Project Title:  EPA Targeted Watersheds Grant DRAFT Final Report
Project Start Date:  November 1, 2004
Project End Date:  October 31, 2007 (extended to October 31, 2008)
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EPA Grant:  WS-97807301
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1.0 INTRODUCTION

This report presents the results of a four year project, funded by the Environmental Protection Agency, to provide essential tools to better manage the Bear River and its watershed. Following a general description of the project itself and the project partners, the report presents the findings for each of the tasks associated with the project objectives. More detailed documents, such as academic reports and model outputs produced as part of this project appear in the appendices of the report. The report also includes a brief discussion of important lessons learned and future recommendations.

The first objective of the project was to develop a Watershed Information System (WIS) for the entire basin. The watershed spans three states, two EPA regions, several National Forests and multiple other jurisdictional entities. Providing spatial and temporal data that crossed these boundaries seamlessly was a significant challenge. The final WIS provides a large array of fully integrated capabilities, including unprecedented access to data and data manipulation, modeling and visualization, and education and outreach to the stakeholders in the watershed and region. It is expected that the watershed information system will promote greater cooperation across state lines and among the different regulatory agencies and stakeholder groups in the basin. Integrated systems such as the Bear River WIS are needed in many watersheds nationwide. For this reason the structure and format of this information system was designed to allow it to be exported to other watersheds.

The second and third objectives of this project were to conduct a detailed feasibility study of the potential for pollutant trading in this watershed. Of particular interest was the possibility of trading across state boundaries and the potential for nonpoint to nonpoint trading. In particular, the study built upon the water quality credit trading frameworks outlined in the EPA’s Water Quality Trading Policy issued in January 2003. Water quality trading can be a cost-effective solution to local pollution discharge problems, and in the case of the Bear River, the credit trading approach is seen to be a tool for lower-cost management for the implementation of the TMDL’s that have been written for the Middle and Lower Bear River reaches. Detailed information about BMP effectiveness, costs, and land uses were compiled. A calibrated, process-based watershed modeling framework was developed and utilized to populate an extensive table of delivered loads to TMDL endpoints (i.e., receptor points) from specific farm fields. Stakeholders within the watershed were educated on the process and specific potential trades were identified, but not yet implemented.

Outreach and public involvement was identified as a fourth objective, but in reality was integrated into all aspects of this project. The public involvement efforts began with a campaign to introduce the project to the stakeholders of the watershed and to identify datasets and other resources with which to populate the WIS. Once the WIS was developed, outreach efforts shifted focus to introducing the functioning WIS to stakeholders and others in the region. This team also populated the WIS with outreach materials and information on pollutant trading specific to the Bear River watershed. The outreach team also provided original educational materials about the watershed and reviewed all materials posted on the WIS to assure that the information system was usable, readable and appropriately targeted for our audience.
2.0 PROJECT PARTNERS

The different components of this project were led by separate teams of researchers. Coordination and oversight was provided by a steering committee.

The following individuals led the different major elements of this project:

Project Management: Jack Barnett
Watershed Information System Development: Jeff Horsburgh and David Stevens
Water Quality Trading Program Development: Terry Glover, Arthur Caplan, and Jason Whitehead
Water Quality Modeling: Bethany Neilson
Education and Outreach: Nancy Mesner and Susan Anderson

A Steering Committee established at the beginning of this project included: Jeff Horsburgh, Terry Glover, Mitch Poulsen, Mike Allred, Lynn Van Every, Jack Smith, Jack Barnett, David Stevens, and Nancy Mesner.

Table 1. All the individuals involved in the project, affiliations and contact information.

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3.0 PROJECT OBJECTIVES AND ACTIVITIES

Specific project objectives are listed below. Each objective was divided into a set of tasks with specific activities and products, which are discussed in Section 3.1.

Objective 1: Develop a dynamic web page (the Bear River Watershed Information System) to include opportunities watershed wide coordination, a comprehensive data and document warehouse, mapping, data visualization and statistical tools, model results, real time monitoring data, and outreach and education components.

Objective 2: Investigate the value and feasibility of a phosphorus trading program for the Bear River Watershed.

Objective 3: Develop a dynamic watershed model to provide important input data for a trading scheme in the watershed and to help predict the effectiveness and value of a given trade.

Objective 4: Include partners throughout the watershed in developing the watershed information system and the trading program, and provide outreach and education on the information system and the pollutant trading program.

3.1 PLANNED AND ACTUAL MILESTONES, PRODUCTS, AND COMPLETION DATES

A brief summary of each objective is provided below, followed by a more detailed description of each of the tasks associated with each objective. The deliverables originally anticipated for each task are listed, followed by the actual deliverables and outcomes of each task. Additional detailed reports associated with some of the tasks are included in the appendices of this document but are specifically referenced in the main report.

Objective 1: Develop a dynamic web page (the Bear River Watershed Information System) to include opportunities watershed wide coordination, a comprehensive data and document warehouse, mapping, data visualization and statistical tools, model results, real time monitoring data, and outreach and education components.

Development of the Watershed Information System (WIS) was guided by the Steering Committee, which provided input and feedback throughout the life of the project. In addition, a significant amount of stakeholder input was solicited to help identify important components of a WIS and to help populate different elements of the information system. Below is a simplified
A Watershed Information System cannot be considered a static product. To retain relevancy to the stakeholders in the watershed, new information, contacts, data and more must be added or updated on an ongoing basis. Some of the functional elements of the WIS will also continue to be modified over time, including a revision in the map server and new data visualization and statistical tools as these are developed. This report focuses on the elements of the WIS developed under this first contract. The WIS will be maintained and updated under a separate funding agreement which is discussed in Section 7.0.

**Figure 1. Overall system architecture for the Bear River WIS.** Third party data sources are consolidated within the WIS Observations Database. The database server provides content for the web server, which serves the WIS applications. Users interact with the WIS using an Internet browser.

**Task 1 – Develop Watershed Wide Coordination Web Pages**

The WIS development team worked closely with the Outreach and Education team to define and develop the components of the WIS related to watershed wide coordination. We divided this functionality into the following components: 1) watershed descriptive profiles – web pages that describe the characteristics of each of the USGS hydrologic units within the Bear River Watershed; 2) experts, organizations, and projects – web pages that present information about
experts and organizations working within the watershed as well as ongoing projects; 3) online
calendar of events – a dynamic calendar that lists current and upcoming events related to water
quality in the Bear River; and 4) news events – a listing of news articles related to water quality
in the Bear River watershed. The experts, organizations, and projects listings, online calendar,
and news events listing are dynamic and searchable, and users can submit new items for
inclusion on the WIS by navigating to the appropriate page on the WIS and filling out an online
form.

**Anticipated Deliverables:**
1. Computer server located at the UWRL to host the Bear River WIS website.
2. Watershed wide coordination web pages integrated with the Bear River WIS website.

**Actual Deliverables and Outcomes:**
- Computer server located at the UWRL to host the Bear River Watershed Information
  System (WIS) website (http://www.bearriverinfo.org).
- Watershed wide coordination web pages integrated with the Bear River WIS website:
  - Watershed descriptive profiles (http://www.bearriverinfo.org/description/)
  - Experts, organizations, and projects (http://www.bearriverinfo.org/guide/)
  - News items (http://bearriverinfo.org/news/)
  - Online calendar of events (http://www.bearriverinfo.org/calendar/)

**Task 2 - Develop Comprehensive Data Warehouse**

The comprehensive data warehouse was intended to be a repository for data and information
related to water quality in the Bear River watershed. It was developed as a database driven
system that houses and distributes historic temporal and spatial datasets, and their associated
metadata. The value added for these data includes both their co-location within the WIS and
their coverage of the entire Bear River watershed, which crosses multiple states and
administrative regions. Datasets in the Bear River WIS comprehensive data warehouse include
time series data (water quality, water quantity, and meteorological) for sampling locations
throughout the Bear River Watershed, GIS data layers (hydrologic, geographic, land use, and
other layers necessary for evaluating and managing water quality in the basin); a geo-referenced
database and evaluation of past and current management activities in the basin, and a geo-
referenced database and evaluation of past and current TMDL related activities in the basin. The
comprehensive data warehouse is used to dynamically populate the data visualization and
analysis tools that are part of the Bear River WIS. Additionally, we have developed tools for
automatically updating the Bear River WIS with real time data being collected by USGS and
Utah State University.

**Anticipated Deliverables:**
1. A collection of raw datasets or links to raw datasets for use in constructing the Bear
   River WIS website.
2. A data index that identifies each dataset/information source compiled and includes
   appropriate metadata.
**Actual Deliverables and Outcomes:**

- A GIS database was constructed for the Bear River WIS. The GIS datasets have been made available for download via the WIS (http://www.bearriverinfo.org/mapping/downloads.aspx) and are also available in the WIS Map Server (http://water.usu.edu/mapviewers/bearrivermap/).
- A time series database was designed and implemented for storing and serving monitoring data via the Bear River WIS. This database has been populated with available datasets from many different data providers including USGS, Utah, Idaho, and Wyoming Environmental Quality departments, NRCS, Pacificorp, Utah State University, and others. These data are available on pages throughout the WIS.
- A database of past and current water quality related projects within the Bear River Basin has been assembled. These projects are accessible at http://www.bearriverinfo.org/guide/.
- A database of past and current TMDL related activities within the Bear River Basin, including associated GIS datasets is available through an Internet map server application (http://water.usu.edu/mapviewers/BearRiverTMDL/) and through the TMDL information viewer available at http://www.bearriverinfo.org/tools/TMDL/.
- A data index that lists the GIS and non-GIS datasets collected by the project and made available via the Bear River WIS has been constructed.
- Windows Services have been developed that automatically ingest all of the real time stream flow data being collected by the USGS and the real time water quality data being collected by USU monitoring projects into the WIS time series database.

**Task 3 – Develop Document Warehouse**

The document warehouse is a database driven system that provides on-line access to an electronic collection of Bear River reports, documents, photographs, and other digital resources. The document warehouse includes documents from the USU Natural Resources Quinney Library collection, many of which were scanned and converted to a digital format for inclusion in the WIS. The WIS document library also provides links to other document collections, including the Bear River Watershed Historic Collection, which is sponsored by Utah State University, and the Western Waters Digital Collection. The WIS Document Warehouse is dynamic in that users can submit new items for inclusion in the WIS database, and it is searchable so that users can find documents that they are interested in. Individuals have used this functionality to post presentations and minutes from water quality related meetings, as well as many other water quality related documents and files.

**Anticipated Deliverables:**

1. The development of a dynamic, Internet-based document warehouse integrated with the Bear River WIS.

**Actual Deliverables and Outcomes:**

- Bear River related documents and digital objects have been collected and added to the WIS Digital Library/Document Warehouse (http://bearriverinfo.org/library/).
- Users can access and upload documents to the warehouse.
Task 4 – Develop Data Visualization and Statistical Tools

The Bear River WIS presents data visualization and statistical tools through an Internet-based map server and through links from data summary tables and lists on the Bear River WIS website. These tools specifically include time series and summary data analysis functions for evaluating and viewing stream flow, water quality, and climate data at user-selected monitoring locations. The time series visualization tools include a variety of plot types, including time series, box and whisker, histogram, and probability plots. The statistical tools can generate simple statistical summaries for sampling locations that include the mean, standard deviation, minimum, maximum, median, percentile values, and other simple statistics. The Internet map server allows visualization of geographic data, and it also links monitoring sites with their geographic context. For example, users can look at terrain, land use, etc. upstream of monitoring sites within the WIS map server and this provides them with context in interpreting the time series data that have been collected at those monitoring sites. The map server also provides point-and-click access to many of the time series datasets included in the WIS by simply clicking on monitoring sites in the map. Users are able download or export both the time series and GIS datasets included in the Bear River WIS.

Anticipated Deliverables:
1. Internet map server populated with GIS datasets for the Bear River Watershed.
2. Internet based time series visualization tools for viewing streamflow, water quality, and climate datasets.
3. Internet based statistical summary tools for generating statistical summaries of time series data.
4. Internet based data download tools for exporting selected time series and GIS data from the WIS.
5. Internet Based watershed characterization tools.

Actual Deliverables and Outcomes:
- An Internet Map Server populated with GIS datasets for the Bear River Watershed (http://water.usu.edu/mapviewers/bearrivermap/).
- An Internet based Time Series Analyst application for plotting, generating statistical summaries of, and exporting time series of stream flow, water quality, and climate data (http://water.usu.edu/analyst/).
- A database query interface that allows users to define and execute custom queries to the Bear River WIS database (http://www.bearriverinfo.org/tools/query_utility/).
- An Internet Map Server for TMDL related information in the Bear River Basin has been created and populated with GIS and related TMDL datasets (http://water.usu.edu/mapviewers/BearRiverTMDL/).
- A TMDL Information Viewer that displays current TMDL related information for 303(d) listed water bodies within the Bear River Basin. It is linked to the TMDL Information Map Server (http://www.bearriverinfo.org/tools/TMDL/).
• A PhotoViewer application that allows viewing digital photographs taken within the Bear River basin (http://www.bearriverinfo.org/photoviewer/default.aspx?watershed=bearriver).
• A variety of watershed characterization data and information are available via the Bear River WIS watershed descriptive profiles (http://www.bearriverinfo.org/description/).

Task 5 - Integration of Virtual Trading Room with WIS

The original intent of the Virtual Trading Room was to provide Internet based infrastructure and support via the WIS for the pollutant trading study of the full Watershed Initiative Project. The Virtual Trading Room was to provide:

1. A public face for the water quality trading program in the form of an introductory page on the WIS that provides information about water quality trading, updates on the success of the program in the Bear River basin, links, etc.
2. An on-line means for identifying those who are interested in possible trading.
3. A water quality model developed to support the water quality trading program for the public to learn about water quality dynamics in the watershed.

Given this, the WIS Development Team worked closely with the Water Quality Trading team to identify the functionality of the Virtual Trading Room. It was determined that the information that would be required for such a system would be sensitive in nature and not necessarily appropriate for the public nature of the WIS. Because of this, the scope of the Virtual Trading Room was defined to be primarily informational in nature, rather than supporting detailed information gathering and potential trading transactions. As a result, the water quality trading section of the WIS that was developed is a public face for the water quality trading program, it provides information on water quality trading in general and in the Bear River Basin, and it provides enough information that individuals interested in trading can get involved. Integration of the water quality model with the WIS is described under Task 8.

Anticipated Deliverables:
1. Internet based Virtual Trading Room that supports the functions of the water quality trading program.

Actual Deliverables and Outcomes:
• A water quality trading section of the WIS that supports the water quality trading program (http://www.bearriverinfo.org/wqtrading/).

Task 6 - Integrate Real Time Monitoring with WIS

Real time water quality, stream flow, and weather data are currently being collected at several locations within the Bear River Watershed. Some of these datasets have been integrated with the WIS and linked to the data visualization and analysis components. Others that are available on external websites from other organizations have been linked to the WIS. Real time datasets that have been incorporated into the WIS database include realtime discharge data at several sites from the USGS, and real time discharge and water quality monitoring in the Logan River.
sponsored by the Utah State University Water Initiative. Other real time data sources that have been linked to the WIS include realtime discharge, water quality, and weather monitoring in the Little Bear River by Utah State University (http://water.usu.edu/littlebearriver/), real time discharge data from Pacificorp (http://www.pacificorp.com/Article/Article40779.html), real time discharge and canal management data for the Upper Bear River (http://www.bearriverbasin.org/), MesoWest weather and climate monitoring data (http://www.met.utah.edu/mesowest/), USDA NRCS SNOTEL (http://www.wcc.nrcs.usda.gov/snotel/), and real time distribution system information from the Utah Division of Water Rights (http://waterrights.utah.gov/distinfo/realtime_info.asp).

It should be noted that this task was funded entirely by matching funds provided by the Utah State University Water Initiative.

**Anticipated Deliverables:**

1. Real time datasets (USU Water Initiative and USGS real time flows at a minimum) integrated with the WIS databases and data visualization components.

**Actual Deliverables and Outcomes:**

- The USU Water Initiative real time datasets for the Logan River have been integrated with the Bear River WIS databases and data visualization components (http://bearriverinfo.org/tools/).

- Links have been provided from the WIS to other sources of real time data within the Bear River Basin (http://bearriverinfo.org/data/).

**Task 7 – Integrate Outreach and Education with the Bear River WIS**

The full USU Watershed Initiative project includes a large outreach and education component addressed by an Outreach and Education Team. The associated effort under this task was focused on both providing a web-presence for the Outreach and Education Team and the materials that they have developed. The Outreach and Education Team also assisted in improving the aesthetic quality, usability, and information content of the WIS. Specifically, this has included: development of informational and training materials; providing links to watershed-wide and sub-watershed water quality outreach efforts; developing on-line help in interpreting data and information about the watershed; and providing links to youth and other outreach programs in the watershed. The WIS Development Team has worked closely with the Education and Outreach team in developing these materials and in incorporating the educational and outreach components with the WIS.

**Anticipated Deliverables:**

1. Web pages with links to outreach efforts and programs.
2. Dynamic Q&A expert system for guiding users through the WIS.
3. Training materials to teach individuals how to use the WIS.
4. Assist the USU Education and Outreach Team with WIS training as specified in Tasks 22 and 23 below.
Actual Deliverables and Outcomes:
- An education and outreach section of the WIS (http://www.bearriverinfo.org/outreach/) that provides information, training materials, and links to additional educational resources.

Task 8 - Integrate Water Quality Modeling with WIS

A dynamic water quality model was developed for the water quality trading focus area by the Water Quality Modeling Team. This model was designed to support the water quality trading program and provides the necessary information to evaluate the environmental equivalence of potential water quality trading scenarios. The model has a complex structure, with components that represent the hydrology of the model focus area, loading of phosphorus from point and nonpoint sources, and in-stream routing of phosphorous loads to receptor points. Because of the complexity and computational requirements of the model, and because it incorporates potentially sensitive information about farm fields and farm ownership, it was impossible to implement it in its native form to run online simulations through the WIS. Instead, we constructed a set of examples that illustrate the results of the water quality model and articulate how they are used in the context of water quality trading. These examples were incorporated into the water quality trading section of the WIS.

Anticipated Deliverables:
1. Executable dynamic model integrated with the WIS.

Actual Deliverables and Outcomes:
- Examples of the results of the water quality model have been integrated with the water quality trading section of the WIS (http://www.bearriverinfo.org/wqtrading/).

Objective 2: Investigate the value and feasibility of a phosphorus trading program for the Bear River Watershed.

The work of this group was closely aligned with the water quality modeling efforts, which provided the necessary water quality loads and delivery ratios. The members of this team were tasked with determining the potential for a water quality trading market in the Bear River basin. One requirement of this effort was an identified water quality target. Sections of the watershed with existing TMDLs or TMDLs in development became the focus of this effort because these TMDLs provided the necessary endpoints.

The Bear River watershed contains a small number of total phosphorus point sources and a much larger number of distributed nonpoint sources. The discussions below and in the appendices, therefore, address the feasibility and necessary elements of trading scenarios between point sources, between point and nonpoint sources, and between nonpoint sources.

Below is a description of the different elements of the Trading Feasibility Study. Detailed reports and compilations of background data are found in Appendices 8.2-8.9, and specifically referenced under each task.
Task 9 – Data and Information Collection

Information is needed in order to determine the conditions and basis for water quality trading as it would apply in the Bear River Watershed. This information includes the potential suitability of total phosphorus (TP) for a market in reduced load credits or allowances tied to a regulated discharge. Information is needed on the loading of TP in a spatial distribution throughout the focus trading area of the watershed which has been designated in this study as Little Bear River and Spring Creek in the southern part of Cache Valley and which streams flow to the Cutler Reservoir, and the main stem of the Bear River, starting from the Oneida Narrows Dam, and including the Cub River drainage as these streams systems flow into the Cutler Reservoir from the north just over the border in Idaho to the Cutler Reservoir. Moreover information on attenuation of the loading of TP is needed to understand the effect of both baseline loads, load reductions and delivery of the same to the main receptor (Cutler Reservoir) has on the level credits or allowances that can be traded. Therefore, delivery ratios have to be developed. Information is also needed on abatement cost conditions and levels of both point source dischargers and projections of possible nonpoint abatement possibilities through the projected installation of best management practices (BMPs). Abatement cost differences amongst discharge sources become a basic driver, as does the load regulation, of trading activity.

Anticipated Deliverables:
1. The development of the Bear River Watershed discharge/loading profile.

Actual Deliverables and Outcomes:
- Determination of total phosphorus suitability for trading:

Trading programs are promoted as a cost-effective approach of reducing most nutrients, including total phosphorus. The potential spatial relocation of nutrient discharges within a river system that may result from trading is less likely to cause localized water problems than is the case for trading in other pollutants (for example pollutants with toxic effects). The ‘commodity’ (total phosphorus) can be measured and traded in the form of tradable load credits which reflect discharge reductions that match the regulated water quality standard written into the TMDL. The ‘commodity’ can also be in the form of allowances whereby the sum of the allowances allocated to source dischargers. Trading programs are also an attractive policy alternative for nutrients such as total phosphorus because extensive conventional programs have not been developed for nutrient discharges.

To evaluate the suitability of trading phosphorus in this particular setting, we conducted a preliminary study using a simplified export coefficient model. A much more detailed process-based model was ultimately used and is described in detail in Tasks 15–21. The preliminary study assumed baseline flow and concentration conditions and relied on literature values for export coefficients. The model, developed in a M.S. Thesis completed in the Department of Economics at Utah State University, was applied to the
Cub River drainage. Appendix 8.4A contains the results of this preliminary modeling study as well as an evaluation of the financial feasibility of phosphorus trading in the larger Bear River watershed.

Nonpoint phosphorus loads were estimated using an export coefficient methodology related to land use types coupled with the use of the PLOAD GIS tool. The study also developed estimates of the point source discharges and loads that would have to be attained in order to meet the Utah point source regulation plan and the Idaho regulation plan since one of the water treatment plant was located in Idaho. Data on alternative farm operations was also developed in the study as well as BMP implementation cost information.

- Development of a loading profile and delivery ratios:

Information regarding loading profiles and delivery ratios were necessary to set up the trading program for the final, process based modeling approach used. These calculations were completed by the water quality modeling team. Details of the approaches and results are included in Appendix 8.2 and Appendix 8.3.

- Compilation of BMP information and Costs:

For the preliminary study the following information was compiled: literature coefficients, BMP cost and effectiveness, point source technology cost and effectiveness, land use distribution. This information was partially used in the final process-based modeling approach.

**Task 10 - Evaluate Financial Attractiveness of Trading**

Information on phosphorus abatement alternatives and the primary drivers of incentives to engage in trading activities is important in order to assess the viability of trades and their effectiveness in reducing effluent discharges. Abatement cost information is necessary since decisions to trade will be based on cost levels and the opportunities afforded the participants in a trade to adopt innovative ways to reduce loads and the costs abatement. The trading activity has to be able to develop incentives in the trading process in order to be economically attractive to potential partners to a trade.

**Anticipated Deliverables:**
1. *The development of an alternative abatement technology database.*
2. *An estimation of the incremental cost of control of the alternative abatement strategies.*
3. *A financial attractiveness assessment of water quality trading with the Bear River Watershed.*

**Actual Deliverables and Outcomes:**
- Summary of cost of abatement levels incurred by point source dischargers and projections of costs associated with the implementation of BMPs by nonpoint source dischargers (refer to Appendix 8.5).
• Development of a manuscript describing a cooperative agreement algorithm that can be used to simulate cost sharing, agreement considerations and project outcomes of agreement and/or conditions that bring about cooperative agreement in trade-like processes (refer to Appendix 8.6).
• Assessment of financial attractiveness for water quality trading in the focus trading area in the Bear River watershed (see Appendix 8.7).

Appendix 8.5 Estimates of Phosphorus Abatement Costs:
A summary of information on the cost of phosphorus abatement was developed in order to determine if there were significant differences in costs of control. Nutrient trading programs have been promoted as cost-effective approaches to achieving water quality control objectives and to specifically reduce discharges in the nation’s waterbodies. Cost effectiveness generally refers to the cost savings achieved by a trade. That is, a low control cost source discharges less effluent in order to for a high cost discharge source to be able to discharge more within the rules of the regulatory reduction mandate. Typically it has been assumed that the nonpoint source, and in specifically the agricultural nonpoint source, is the low cost discharge source. In such cases, the nonpoint source is in the position as the seller when a trade is to be initiated. The cost information derived and reported in this appendix verify that this is the case, but there is considerable variation in the costs of abatement both at the wastewater treatment plant level (the point source) and at the nonpoint source level. We conclude that there is a case for financial attractiveness and viability to water quality trading in the Bear River Watershed.

There is considerable cost variation, for example, even for the implementation of the same type of BMP that might be adopted by the nonpoint source. These costs were derived from different sources of information and location which, of course, introduces considerable variation in cost level. Appendix 8.4A also contains a summary of both point, source costs and the costs of adopting certain BMPs as applied to the Cub River drainage area. BMP effectiveness information is also presented.

Appendix 8.6 Cooperative Surplus Sharing:
A manuscript which develops a solution algorithm for cooperative agreement simulation is contained in this appendix. The solution algorithm follows the concepts of cooperative equilibrium. Now that the cost and load data for the Bear River Watershed are available, simulations of cooperative agreement impacts and the conditions that lead to cooperative agreements, that is the conditions on how discharge sources come together to initiate a trade or that do not provide for cooperative agreement, can be run in order to develop information on the steps that lead up to a negotiation and an agreement. Simulation results are not available at this point but are to come at a future time using the Bear River focus trading area and information as a case study.
Appendix 8.7 Examples of Pollutant Trading:
This appendix reports an example of point source-nonpoint source credit trading that works to reduce phosphorus loading in the Cub River watershed of the focus trading area. An example of a nonpoint-to-nonpoint source trade in credits is worked out using the cost data estimated for the Cub River area, but there is less impact shown by such a trade relative to the point-to-nonpoint source trade. These illustrations of trading show the viability of trading in credits using the information on cost differences between discharge sources. Trading in credits is one mechanism among a set of trading approaches that could be implemented. The trades that are illustrated in this appendix assume that the nonpoint source dischargers have been brought in under the umbrella of the phosphorus reduction regulation under some form of provision or the exercise of state powers to bring them under such regulation. These examples, along with point-nonpoint abatement cost differences shown in appendices 8.4 and 8.5, do show the financial attractiveness of trading at least in the Cub River area which is a significant area of phosphorus load concentrations within the Bear River Watershed. The Cub River drainage, among other drainages, is certainly an area that needs attention in developing a phosphorus reduction program as shown by the projections of the field data loading using the water quality modeling that has been applied in this study.

Task 11 - Assess Market Infrastructure and Strategy for Water Quality Trading

All viable markets, whether trading water pollutant reductions or more familiar commodities, must efficiently create benefits for market participants. Markets are social constructs or results of contracts that facilitate interactions among participants or attract participants who have incentives to trade goods or services. Viable water quality trading, sometimes referred to by the acronym, WQT, or WQT markets, operate like conventional markets with the exception that water quality markets work to exchange nutrient loading reductions that are created by regulations and administrative processes. The loading reductions only derive value because of regulatory mandate. Therefore, water quality markets are responses to regulatory mandate or oversight. To complete this particular task of the study, a review is made of alternative market strategies and their projected impact on phosphorus reductions that could be achieved in the Bear River Watershed.

Anticipated Deliverables:
1. Projection of market operation and frictions.
2. Identification of feasible water quality trading alternatives.

Actual Deliverables and Outcomes:
- Assessment of market structure, alternative trading strategies, and the efficiencies of these alternative strategies in reducing total phosphorus (refer to Appendices 8.8).

Appendix 8.8 Trading Strategies:
This appendix provides a description of the trading strategies that are market-based or market-like and those that are labeled as market-like but are really not
market-like in their initiation and operations. There is a review of the role that the regulator “should” play and the other possible roles that the regulator could take up or that is taken up under certain water quality trading processes. Descriptions of the trading operations of each strategy and the frictions in the market are also provided. The investigation concludes that trading in allowances is the most market-based trading strategy with the role of the regulator solely focused on the water quality standard in effluent discharge. Under this market-like mechanism of control all sources (point and nonpoint) are brought under the regulatory mandate in a fully capped system. The market operation of this system is termed a cap-and-allowance market or CAM as the acronym for such a trading system, see Figure 2.

In this market system, the commodity being traded, that is, an allowance to discharge a limited level of phosphorus is defined in advance of program implementation by the regulating agency. The allowance program can be written into a memorandum of understanding which outlines the trading program and its details and intended operation. Dischargers know exactly how much they own in allowances and how the ownership can be used. The discharge source is given both exchange flexibility and effluent control flexibility which, along with the opportunity to buy and sell creates financial incentives internal to the control process that promote innovation to find lower cost solutions to meet the water quality standard. Exchange flexibility is the permission to transfer discharge to different contract locations and across time periods. Waste control flexibility gives the discharge source discretion to choose the control technology, innovate to find new control technology that matches specific production processes, and lower the cost of control. However, the discharge still has to meet the water quality standard and the sum of the allowances has to equal the standard.

Clean Water Act (CWA) provisions are basically set up as a partially cap system of control through the NPDES permitting system. So ways have to be found to work with this type of system to make trading and control programs more market-like in order to allow trading to work to meet water quality levels and to provide incentives to lower the costs of meeting the discharge reductions that meet the regulatory mandate of the TMDL.

The investigation into alternative trading approaches then derived four basic trading mechanisms that could be structured to operate within CWA provisions within which alternative approaches could be designed.
Trading in credits and allowances appear to be the same trading procedure. However, credit programs present some barriers to achieving exchange flexibility. A new and expanding discharger who is in need of credits cannot know whether there will be any credits to buy at the end of any one accounting period when they enter the market because the number of credits is variable. Under these uncertain conditions the discharge source is less likely to rely on the purchase of credits in a long term control strategy. There can be uncertainty created as well on the supply side of the market because of the uncertainty that there will be buyers. CAM-type programs create a certain number of transferable allowances in advance of the trading which modifies some of the demand and supply uncertainty.

**Task 12 - Evaluate Stakeholder Readiness**

The evaluation of Bear River watershed stakeholder readiness and understanding of the benefits of trading either in allowances or credits is essential for operating water quality trading programs. This evaluation includes the identification and prioritizing of potential participants, including potential coalitions and associations. The task of determining the financial attractiveness of trading is part of this participant identification. The evaluation effort has to also identify advising (legal or otherwise) individuals or agencies that can provide design and contractual information to parties of potential trading activities.
This effort of evaluation and identification has included input from stakeholder meetings and a workshop on water quality trading. It has involved several presentations on alternative trading programs and their effectiveness as discharge control mechanisms to various agencies and public stakeholder meetings to solicit input and to provide explanations on the trading approaches to control and the CWA provisions for control. Presentations on the alternative programs of trading and discharge control have been presented to the Water Quality Board and to other individuals who are involved in water quality standard regulation. The study steering committee members from the three state regulatory agencies have been instrumental in identifying individuals or entities interested in the potential point and nonpoint source trading issue.

The Utah Division of Water Quality (UDWQ) has been engaged in a series of meetings with point source dischargers who are concerned about the alternatives they have for meeting the requirements of completed or draft TMDLs that affect point source discharge control operations in the Utah portion of the Bear River Watershed. Cost impacts on as well as the impacts of alternative forms of trading have been discussed with community officials and waste water treatment plant operators. Discussions have been held with NRCS personnel about alternative BMP implementations and their apparent effectiveness uncertainties and the costs involved in installation by nonpoint source dischargers. The Utah Association of Conservation Districts has been developing cost estimates of potential BMPs for point and nonpoint sources.

**Anticipated Deliverables:**

1. Evaluation of Bear River watershed stakeholder readiness and understanding of the benefits of trading programs.
2. Identification of trading participants, coalitions, and advisors.

**Actual Deliverables and Outcomes:**

- Assessment of stakeholder’s readiness (see discussion above).
- On July 19, 2007, the Bear River Initiative Steering Committee hosted a water quality trading workshop to explore the concepts of pollutant trading and specifics being explored in the Bear River Watershed. Thirty seven representatives from Idaho, Wyoming and Utah, including agencies, educators, and producers attended the workshop. These presentations are available in Power Point format at [http://www.bearriverinfo.org/library/](http://www.bearriverinfo.org/library/).

- Identified potential traders in the Bear River watershed:

  The Cutler Reservoir/Bear River Advisory Group has been meeting for the past four years to assist in the development of a TMDL for dissolved oxygen and nutrients (total phosphorus). The Logan City Waste Water Treatment facility that handles the municipal waste for seven of the largest communities in Cache Valley is a major source of nutrients to the reservoir. The Advisory Committee is currently attempting to develop a Memorandum of Agreement with the stakeholders that would allow a water quality trade via a water quality allowance for the waste water treatment facility. The allowance will be based on the equivalent cost of reduction from nonpoint sources. The exchange rate that is being used is $205 per pound of total phosphorus. The plan on the table now includes an allowance to the WWTP in exchange for a one million dollar a year trade to
address the nonpoint sources. An irrigation project has been identified that would reduce the summertime nutrient loading to the reservoir by thirty-eight percent. If all goes well the framework for the trade will be in place by mid October.

There is also a private contractor working with Lewiston City, Preston City and Franklin City to determine what options are available to them. One of which would be working a trade perhaps with the Richmond WWTP or through NPS trades. In the Cub River Basin in Utah and Idaho there are 6 PS permit holders and a large agricultural component. This scenario makes the potential for trading feasible. Overall the development of TMDL's in the Bear River Basin has raised the level of stakeholder awareness of water quality issues and the potential for pollution trading.

Viable water quality trading for phosphorus in Idaho tends to be complicated as follows. Idaho DEQ does not have NPDES primacy and therefore is somewhat caught in the middle of developing TMDL’s with enforceable waste water treatment plant waste load allocations but DEQ is not in the driver seat for implementing NPDES permit actions. EPA Region 10 has been favoring very stringent phosphorus limits based on what they believe are achievable technologies (both technically and economically) which may likely be an impediment for municipalities to manage a trading scenario with nonpoint sources of phosphorus. Reasonable assurance that a point source to nonpoint source phosphorus trade would achieve the same level of treatment is a much harder burden of proof (the burden of proof would be borne by the municipality) than installing “best available technology” that achieves measureable results at the end of the pipe.

**Task 13 - Initiate Water Quality Trading**

There are several procedures and contractual elements that have to be developed in order to set up a trading program for the focus trading area as part of the Bear River Watershed. Guidelines to meet the TMDL regulation, procedures of engagement, and contractual steps many of which have legal implications have to be identified and worked out with both point and nonpoint source dischargers, the regulator and community waste water treatment officers and operators. All of these functions have to be worked out prior to the initiation of a program and program rules.

**Anticipated Deliverables:**
1. The development of projected outcomes of alternative trading strategies.
2. Set up of the trading format for the Bear River Watershed, if trading is feasible.
3. Determination of trading functions such as paying for total phosphorus reductions, level of abatement and match to TMDL requirements, and allocation of abatement among dischargers in the watershed.

**Actual Deliverables and Outcomes:**
- Projected outcomes of alternative trading programs (see Appendix 8.8).
- A mapping of steps to be taken to progress toward the initiation of two different forms of a trading program for the Bear River Watershed (refer to Appendix 8.7, Appendix 8.8, and Appendix 8.9).
Summary of documentation and rules for trading proposed by other trading programs that have been proposed or initiated (see Appendix 8.8).

Appendices 8.7 and 8.8 – Previously reported under, respectively, Task 10 and Task 11.

Appendix 8.9 Steps to Trading
This appendix reports on steps to be taken by parties of a trade, the regulator, and other stakeholders covering two alternative approaches to trading that can be implemented in the focus trading area of the Bear River Watershed. These two major alternative approaches to trading include the “Cap and Trade” approach which can be instituted with consideration of the usual provisions of the Clean Water Act (CWA) as a partial cap arrangement and the cap-and-allowance market (CAM) approach. There are alternative plans that can be developed within these major program approaches. The steps for trading in credits as well as allowances are also outlined. An actual trade has not been initiated. However, the steps and documentation to go forward to a trade program, either in the form of trading in allowances or in the form of trading credits, are outlined. Reference is also made to documentation, rules of trading, legal implications, and memoranda processes for initiating a trade developed by other efforts within the U.S.

The water pollutant trading workshop held in July 2007, a subsequent summary of the workshop (see Appendix 8.17) was sent to an extensive list of stakeholders. The information section on pollutant trading of the WIS is part of a strategy to increase understanding of trading potential in the Bear River watershed.

Task 14 - Evaluate Operations and Impacts of Water Quality Trading
This task involves the assessment of general economic gains, losses, and tradeoffs that are involved with the initiation of water quality trading programs as a new policy to improve the nation’s water quality and particularly to improve the water quality of the Bear River Watershed which is a special resource of a three-state area in the western U.S.

Anticipated Deliverables:
1. The development of a framework to evaluate the impact of trading activity on total phosphorus reduction and its use in the watershed.
2. The development of an empirical economic welfare evaluation model to evaluate trading program economic impacts.

Actual Deliverables and Outcomes:
• Summary of projected impact of trading by trading/allocation strategy (refer to Appendix 8.6).
• Summary of projected economic impacts of trading programs and the asymmetric information frictions and other market operation influences that limit the viability of water quality trading (Appendices 8.6, 8.7, 8.8, and 8.9).
Objective 3: Develop a dynamic watershed model to provide important input data for a trading scheme in the watershed and to help predict the effectiveness and value of a given trade.

In order to set up a water quality trading framework, the primary informational requirements of the Water Quality Trading Team from the Water Quality Modeling Team were current conditions seasonal total phosphorus loads at a farm or field spatial scale (i.e., seasonal farm/field loads) and seasonal fractions of the total phosphorus farm/field loads that reach a receptor point (i.e., seasonal delivery ratios).

Each of these components is necessary to complete the calculations required for a water quality trading framework. The driving force behind these requirements was that each individual stakeholder in a basin needs to know the amount of phosphorus he or she has available to trade. This quantity is dependent on the amount of a stakeholder’s total phosphorus load delivered to a designated receptor point that can be offset through management actions.

For a watershed model to support a water quality trading program, it must be able to simultaneously capture the physical hydrology at the watershed scale, while representing the spatial variability of loads at the field scale. Generally, watershed models are developed for either broad watershed applications or field specific applications. This led to the development of a modeling framework that coupled a number of models, modeling approaches, and processing tools to provide the necessary information to facilitate water quality trading. The framework includes: TOPNET (Bandaragoda et al., 2004) as the hydrology model; variable source area (VSA) calculations (Lyon et al., 2004) to resolve spatial areas contributing saturation excess flow; a sub-basin Loading Model component based on the VSA calculations, event mean concentrations (EMCs), and land use; and a Water Body Response (WBR) component that incorporates QUAL2E (Brown and Barnwell, 1987) to determine delivery ratios. The most comprehensive explanation of the modeling effort and its role in developing a water quality trading program is included in Appendix 8.11. In order to achieve this end goal of supporting the Water Quality Trading team, there were a number of tasks that had to be completed first.

Task 15: Coordination with the Water Quality Trading Team

The Water Quality Modeling Team worked closely with the Water Quality Trading Team to identify the specific modeling needs, requirements, and objectives of the water quality trading study. Important decisions were made based on the geographic extent of the water quality trading program and the water quality model (hereafter called the Water Quality Trading focus area), the required spatial and temporal resolution of the model, and the required model input and output options.

The water quality model was required to provide sufficient information to enable: 1) evaluation of individual trading viability by incorporating total phosphorus discharges from reach-specific point and nonpoint sources, 2) tracking of the effects of potential trades under different meteorological inputs and flow regimes, 3) examination of the general changes in water quality over time and distance, 4) examination of the effects of timing, river distance between potential seller’s and buyer’s locations, river conditions, and operational activities such as withdrawals.
and diversions, and 5) comparison of the outcomes of different management options.

**Anticipated Deliverables:**
1. To develop a technical memo describing the specific requirements of and objectives for the water quality model.

**Actual Deliverables and Outcomes:**
- The technical memo (Appendix 8.10) describing the specific requirements of and objectives for the water quality model was completed and submitted on 9/8/2005.

**Task 16: Selection of an Appropriate Modeling Approach**

The water quality model was used to assess and project future outcomes of total phosphorus loading and loading distribution within the Water Quality Trading focus area as a result of total phosphorus credit trading. The model was also used to support the evaluation of environmental equivalence of potential trades. In order to facilitate this, an appropriate water quality modeling approach was selected.

The specific requirements for the water quality model identified under Task 15 guided the selection of an appropriate water quality modeling approach for the Water Quality Trading focus area. Due to the number and types of point and nonpoint sources of pollution in the Bear River Basin, the potential diversity in the physical system to be modeled (i.e., small tributary stream reaches, main stem river reaches, reservoirs, etc.), and the anticipated requirements for the water quality model, it was determined that a single model would not be sufficient or appropriate to represent all of the pollutant sources, watershed components, and pathways of interest. A combination of tools working together within a structured framework was needed to capture the spatial and temporal variability in each pollutant source and the interaction among sources and the resulting impacts on water quality. A review of existing, peer reviewed, and public domain water quality models was conducted to identify potential models or model components that could be used within the Water Quality Trading focus area. This review considered simple screening level approaches as well as more sophisticated, mechanistic watershed models. Based on this review and the requirements identified under Task 15, an appropriate modeling approach was selected and described in a technical memo included in Appendix 8.11.

**Anticipated Deliverables:**
1. Technical memo describing the selected water quality modeling approach, including a description of the specific model or models selected and how they will be implemented in the Water Quality Trading focus area.

**Actual Deliverables and Outcomes:**
- The technical memo (Appendix 8.11) describing the selected water quality modeling approach was completed and submitted on 11/7/2005.
Task 17: Development of the Water Quality Model

The water quality modeling approach designed as part of Task 16 was implemented in a portion of the Water Quality Trading focus area (i.e., the Little Bear River watershed and the Bear River watershed between Oneida Narrows and Cutler Reservoir). The Water Quality Modeling Team worked closely with the WIS Development Team to identify and obtain appropriate and available datasets that were used in populating and calibrating the water quality model. Where possible, monitoring data associated with water quality and stream flow monitoring sites were used as model inputs, to estimate model parameters, and to test predicted results. Where no data were available, literature values were used.

Anticipated Deliverables:

1. Executable water quality model that can be used to run water quality trading scenarios, specific to the Bear River Watershed.
2. Technical memo describing the results of the model population, calibration, and sensitivity/uncertainty analysis.

Actual Deliverables and Outcomes:

- Figure 3 shows a simplification of the modeling structure that was developed and implemented to assist in testing the feasibility of water quality trading in a portion of the Water Quality Trading Focus Area. This structure was based primarily on the Task 16 technical memo. However, additional modeling steps were added to meet the modeling needs for the water quality trading structure. This included the implementation of Variable Source Area (VSA) calculations that facilitated the estimation of farm/field loads by season. More information about the modeling structure and details are provided in Appendix 8.3 and Appendix 8.12. As shown in Figure 3, the modeling results include seasonal farm/field total phosphorus loads, seasonal delivery ratios by sub-watershed, seasonal delivered loads to various receptor points, and the ability to calculate seasonal farm/field tradable loads from local knowledge of remediation potential.
Only the Little Bear River watershed and the Bear River watershed from Oneida Reservoir to Cutler Reservoir (including tributaries) were modeled. The Spring Creek watershed was excluded from the modeling effort due to data limitations (including ungauged interbasin transfers) that limited the ability to predict the hydrologic responses in the drainage.

A journal article (see Appendix 8.3) was completed to provide information regarding the connectivity of the modeling structure and its utility in setting up a water quality trading program. Appendix 8.12 provides details about the model structure and the passing of information between components.

**Task 18: Execution of Water Quality Modeling and Trading Scenarios**

The results from the completed water quality model have been used to examine potential Water Quality Trading scenarios as specified by the Water Quality Trading team. The existing TMDL documents have been instrumental in identifying pollutant sources. The data and modeling results provided current conditions upon which future trading scenarios can be based.

**Anticipated Deliverables:**

1. Summarize output from the water quality model for the scenarios specified by the Water Quality Trading Team.
Actual Deliverables and Outcomes:

- The technical memo (Appendix 8.2) describing the integration of the water quality modeling results into the WIS was completed and submitted on 8/18/2008.
- The modeling results were presented to the WIS Development and Water Quality Trading Team as a number of look-up tables that are used to complete the necessary trading scenarios for the Little Bear River and Bear River drainages. As shown in the Figure 3 above, the tables resulting from the modeling effort include seasonal farm/field loads of total phosphorus and seasonal delivery ratios. These tables are the driving forces behind the trading program and the integration of the model results into the WIS.

The ability to determine how certain trading scenarios affect in-stream concentrations has not been implemented into the WIS modeling interface. In addition to the lingering questions concerning how best to implement a trading ’worksheet’ in the WIS, the data included in the final modeling results could reveal information about individual operations that are sensitive and not appropriate for public access. It was therefore determined that each trading scenario assessment would be best carried out by a water quality trading facilitator in response to requests for specific trades. The state TMDL coordinators for the Bear River in Utah and Idaho have agreed to facilitate this process. In Utah, the watershed coordinator for this portion of the watershed will be the primary contact with potential traders.

Task 19: Develop Documentation and Training Materials

Documentation was developed for the water quality model to aid in the understanding of its structure and function. This documentation provides sufficient information to personnel from the other project components (i.e., WIS Development Team, Water Quality Trading Team, Outreach Team) so that they have a basic understanding of the model’s structure and function. The documentation produced has aided the WIS Development Team in implementing results from the water quality model in the WIS and it has aided the Water Quality Trading Team in specifying and understanding the modeling results.

Anticipated Deliverables:

1. Technical memo documenting the water quality model developed for the Water Quality Trading focus area, including model inputs, model outputs, and model parameters that can be changed in developing scenarios.

Actual Deliverables and Outcomes:

- Appendix 8.2 contains a memo that provides detailed documentation of how to use the modeling results to facilitate a water quality trading program.
- Appendix 8.3 is a journal article that provides documentation about the water quality modeling structure and its role in assessing the feasibility for water quality trading.
- Appendix 8.12 is a technical memo that shows detailed flow charts for the water quality modeling framework. These charts were developed to: 1) document the required information for the WIS Development and Water Quality Trading Teams; 2) provide information regarding the inputs and outputs from each component; and 3) to demonstrate intermediate steps or calculations required.
Task 20: Coordination with the Watershed Information System Development Team

This task consisted of coordinating with and providing support to the WIS Development Team in implementing results of the water quality model within the WIS. A straightforward approach to integrating the model results into the WIS was developed that provides for the quantification of the amount of total phosphorus a stakeholder has available for trading. However, we were unable to do this in a way that would protect sensitive land/farm ownership information. Because of this, a fully functional version of the model was not incorporated into the WIS. Instead, we worked to create concrete examples of what the model results are and how they support trading. These examples have been implemented within the trading section of the WIS.

Anticipated Deliverables:
1. Functional water quality modeling component that can be implemented within the WIS.
2. Feedback to the WIS Development Team regarding the functionality of the water quality model within the WIS.

Actual Deliverables and Outcomes:
- The technical memo (Appendix 8.2) describing the proposed approach for integration of the water quality modeling results into the WIS was completed and submitted on 8/18/2008.
- Modeling results have been provided for the calculation of tradable phosphorus loads at a farm/field level. However, due to the sensitivity of the modeling results, data for individual property owners will only be made available by identified facilitators (state TMDL coordinators, working with watershed coordinators when appropriate). The modeling results will provide each farm/field owner with the delivered load from their property. Once the delivered load is calculated, the farm/field owner can work with a local Water Quality Trading Facilitator to determine the amount a farm/field load can be offset by implementing BMPs. This amount is considered to be the “tradable load” or the amount of phosphorus that a farm/field owner has to sell on the market for each season.

Task 21: Investigate the Scalability of the Selected Modeling Approach

Although the bulk of the work associated with this project was focused on providing a detailed model to support the water quality trading program in the Water Quality Trading focus area selected by the Water Quality Trading Team, the Water Quality Modeling Team investigated the ability to scale and expand the model to the entire Bear River basin from its headwaters in the Uinta Mountains to its mouth at the Great Salt Lake. This was primarily tested by first applying the modeling approach to a relatively small watershed, the Little Bear River watershed (~ 286 mi²), and then scaling the effort to a larger watershed, the Bear River Watershed from Onieda Reservoir to Cutler Reservoir (~840 mi²).
Anticipated Deliverables:
1. Technical memo documenting the results of the investigation on the scalability of the selected modeling approach and its usefulness and feasibility on a Bear River Basin Wide scale.

Actual Deliverables and Outcomes:
• Appendix 8.13 contains a memo about the scalability of the water quality trading modeling approach.

Objective 4: Include partners throughout the watershed in developing the watershed information system and the trading program, and provide outreach and education on the information system and the pollutant trading program.

Task 22: Outreach and Coordination with Partners

USU has coordinated with the Bear River Water Quality Committee, the Bear River Water Quality Task Force, Bear Lake Regional Commission, federal stakeholders (NRCS, Forest Service, BLM, and USFWS), state and local stakeholders (conservation districts, watershed groups, municipalities, PacifiCorp, irrigators, and more) in providing information ongoing information for the WIS. These groups are continually informed on the progress of the different components of the project and provide feedback on the different aspects of the project. We have attempted to be responsive to the various needs of the stakeholders and the public.

Anticipated Deliverables:
1. Introductory meetings, conference calls, and mailings (electronic and printed).
2. Ongoing presentations, printed and electronic communications throughout the contract period on progress of the WIS, the water quality trading program, and other technical elements of the Watershed Initiative.
3. To gain input from stakeholders throughout life of project.
4. Support of WIS development, water quality program, and water quality modeling through identification and acquisition of data sources, printed and electronic materials, contact information, and more.
5. To provide training workshops and materials on the WIS and the water quality trading program.

Actual Deliverables and Outcomes:
• Approximately 300 public relations fliers were distributed detailing the development and use of the WIS.
• Over 150 WIS public relations email were sent to state and local stakeholders.
• The team received over 50 emails with detailed feedback for the WIS Resource Guide databases.
• Over 50 phone contacts were made for additional information.
• The WIS Resource Guide houses 100 organizations and 150 individual contacts.
• Water quality data acquisition was completed.
Task 23: Develop Outreach Materials

Bear River WIS outreach materials have been produced and will continue to be generated according to the needs of the stakeholders. These materials have been distributed via mailings, handouts, and emails. Some of the materials were existing components of the USU Water Quality Extension programs (e.g. Journey Through the Bear River Watershed: middle school curriculum based on Project WET materials).

Anticipated Deliverables:
1. To provide a collection of existing printed and electronic outreach materials for the WIS.
2. Develop new printed and electronic materials, including specific Bear River watershed fact sheets, information about the elements of the project (the WIS, the water quality trading program, and the water quality model), information about practices and management approaches, help in interpreting data, and more.
3. To provide a dynamic QA expert system integrated into the WIS.

Actual Deliverables and Outcomes:
- Provided introductory Bear River WIS fliers directing users to the website (www.bearriverinfo.org).
- Six Bear River sub-watershed descriptions were developed and are posted on the WIS, and formatted for a printable copy (http://bearriverinfo.org/description/).
- A middle school curricular material has been developed Bear River watershed (http://extension.usu.edu/waterquality/files/uploads/Part%201%20Part%202_Final.pdf).
- Distributed over 1500 BRWIS bookmarks directing users to the website (Appendix 8.15).
- An electronic newsletter was distributed in August 2007 (Appendix 8.16).
- The BRWIS website (www.bearriverinfo.org) continues to demonstrate significant usage:
  - Average Daily Unique Visitors: 24.5
  - Average Daily Page Views: 121.5
  - Average page Views Per Visitor: 4.94
  - Monthly Total Visits (2008):
    - July: 972
    - August: 609
    - September: 587

Task 24: Public Outreach Activities

We worked with our partners and stakeholders on organizing the Bear River Symposium in September of 2007. This symposium was offered in coordination with the statewide Nonpoint Conference, and was open to the general public as well. Over 150 individuals attended. The symposium included two tours of the watershed and presentations specific to the watershed and the Watershed Information System.

We have also attended public meetings, demonstrations, and other outreach activities throughout the life of the project to highlight activities and solicit input and we will continue to do this after the official end of the project. These types of activities help the public better understand the
issues in the watershed, and help them understand how management changes or efforts such as the water quality trading program can be used to better and more efficiently move toward improved water quality.

Anticipated Deliverables:
1. Informational meetings held throughout the Bear River watershed to inform the public about various elements of the project, to obtain feedback, and to provide updates. Formats of meetings will be dependent on audience needs. Number of meetings: anticipate ~ 12/year for years 1 and 2.
2. Training opportunities to supplement printed and electronic information about the WIS and water quality trading program. Number of trainings anticipated: Up to 6/year in the final year of the project.
3. Public tours throughout the basin. Number of tours anticipated: Up to 3 / year as needed.
4. Assistance with a symposium and other outreach public meetings will be given to the Bear Lake Regional Commission and the Water Quality Committee.

Actual Deliverables and Outcomes:
- Expanded contacts and presentations of project information throughout the watershed and the state. We presented at least 15 water quality meetings discussing the WIS, with an estimate 150 total stakeholders in attendance.
- Initial planning work for the Bear River Symposium began in February 2007.
- On July 19, 2007, the Bear River Initiative Steering Committee hosted a water quality trading workshop to explore the concepts of pollutant trading and specifics being explored in the Bear River watershed. 37 representatives from Idaho, Wyoming, and Utah, including agencies, educators, and producers attended the workshop. These presentations are available in Power Point format at http://www.bearriverinfo.org/library/.
- Distribution of Bear River Water Quality Trading Workshop Summary (Appendix 8.17).

3.2 REFERENCE LIST


4.0 PUBLIC INVOLVEMENT

Public involvement was identified as a separate objective, but in reality was integrated into all aspects of this project. The public involvement efforts began with a campaign to introduce the project to the stakeholders of the watershed. Public meetings were conducted by various members of the outreach team or steering committee. Power point presentations detailed different components of the WIS, and all those present at the meetings were asked to provide input into elements of the WIS that they thought would be most useful for their purposes. During this phase, we also compiled as complete a list of names and contacts as we could for our resources section and our mailing lists. We requested and collected datasets, reports, copies or summaries of completed and ongoing projects, and information about other water related efforts within the watershed. The process of collecting and updating information continued throughout the life of the project.

Once the WIS was developed, the outreach effort shifted focus to introducing the functioning WIS to stakeholders and others in the region. This again involved public meetings as well as a number of presentations at professional meetings. We distributed electronic information sheets and developed revised presentations that demonstrated the functionality of the WIS. At this time, the outreach effort also included soliciting input on modeling efforts and on interest in water pollutant trading. Specifically, we conducted two major public outreach events. We conducted an all day workshop on pollutant trading, attended by 37 stakeholders from the watershed and region. This meeting was extremely helpful in both educating interested stakeholders on pollutant trading possibilities in the basin, but also in soliciting input on some of the strategies being considered. We also organized and ran a Bear River water quality symposium, partnering with the annual Utah NPS water quality meetings. This symposium included research presentations, as well as a general session with a demonstration of the WIS, presentations of modeling efforts, and early results on the trading component of the model.

Originally, we had intended to conduct training on trading options in the watershed, but timing of the final trading models and the completed feasibility study did not allow sufficient time to conduct this effort. Instead, we developed a web outreach page on trading which provides information on pollutant trading concepts, examples of trades that could be conducted in the Bear River watershed, links to trading documents and other materials, and links to the trading facilitators who will work with individual landowners or point sources on initiating actual trades.

The outreach effort also included ongoing review of all materials posted on the WIS to assure that the information system was usable, readable and appropriately targeted for our audience.
We identified broken links and missing information. We wrote outreach materials on the watershed itself, and developed a section of other outreach materials from other sources.

5.0 LONG TERM RESULTS

• Over the course of this project, much was learned about the development of watershed information systems and the presentation of technical data and information to a variety of audiences that range from University researchers to students in local primary and secondary schools. For more information regarding “lessons learned” specifically referencing the Bear River WIS development see Appendix 8.1 The Bear River Watershed Information System, section 5.0.

• Because of enhanced partnerships facilitated through the steering committee of this project, the three states (Utah, Wyoming, and Idaho) have agreed to contract with Utah State University to continue WIS maintenance and improvement.

• Pending trades: Several highly probably trades have been identified, including a trade involving a significant point source and nonpoint sources as part of the Cutler Reservoir TMDL in Utah (in development).

• A mechanism for delivering sensitive model results to potential traders. Throughout the duration of the project, it was suggested that a person or entity become the water quality trading facilitator. The role of this person would be to interpret modeling results, assist in determining the potential to offset nonpoint source loads (i.e., use site specific information to more accurately identify the possible percent reduction due to BMP implementation), and to monitor the impacts of the potential water quality trades on in-stream water quality concentrations.

• Water Quality Trading Modeling framework developed for this project can be used in other future watershed management activities. In particular, it will assist in identifying and prioritizing “critical areas” for BMP implementation. Critical areas are those areas that have the highest potential for nonpoint source loading and have already been identified by season from the modeling results.

• Other groups have made contact with the study team to inquire about water quality trading and how it would be set up. These inquiries have come from conservancy district officers representing conservancy districts in Utah and from landholders such as banks and developers who may be facing compliance with TMDL’s in Utah as a result of the land that they hold in transition to development.
  
  o Officers of the U.S. section of the International Boundary and Water Commission (USIBWC) have inquired about the trading possibilities in the Bear River Watershed. This agency is interested in salinity as well as possible nutrient trading in parts of the Rio Grande River Basin and the Pecos River Basin. This agency operates the Clean Rivers Program under contract with the State of Texas.
- Officers of the Utah Conservation District worked with the study team to develop cost information on BMP implementation in the Bear River Watershed, including cost information on a BMP possibility to handle summer phosphorus reduction for a major regional waste water treatment plant point source.

- Increased public awareness of the potential for water pollutant trades.

- Significant outcomes of the feasibility study of pollutant trading

- The Bear River WIS provides unprecedented access to data and information related to water quality in the Bear River. The WIS contains a collection of over 50 GIS datasets that cover the entire watershed, most of which are available for download via the WIS. The WIS also contains a comprehensive database of environmental observations data (i.e., discharge, water quality, meteorology, snow, etc.) that contains data from 17 different organizations, for nearly 2000 different variables, measured at nearly 2500 different data collection sites, and that has over 7.8 million records.

- The public involvement aspect of the WIS has huge potential in Wyoming. We work under a widespread level of apprehension and suspicion by much of the public concerning non-point source issues in Wyoming even though most of the non-point source pollution comes from voluntary or non-regulated activities. As we spend great pains to inform the public that our non-point source programmatic efforts are voluntary, it remains difficult to reach the broad public in a geographically large state like Wyoming. The ability to provide detailed information in a user-friendly, web-based format has strong application in Wyoming. Many of the Watershed Steering Committees across the state could provide information into a statewide system and use the data within the system in the development of their own locally developed projects.

6.0 ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

It was determined that to implement a “Virtual Trading Room” as originally envision that the information to be required for such a system would be sensitive in nature and not necessarily appropriate for the public nature of the WIS. Because of this, the scope of the Virtual Trading Room was defined to be primarily informational in nature, rather than supporting detailed information gathering and potential trading transactions. As a result, the water quality trading section of the WIS that was developed is a public face for the water quality trading program, it provides information on water quality trading in general and in the Bear River Basin, and it provides enough information that individuals interested in trading can get involved.

Data availability for the modeling effort limited the extent of the application of the water quality and water quality trading models. This was particularly the case for the application of these models in the Idaho portion of the main stem of the Bear River. Field and boundary data used to identify fields and to project phosphorus loads did not become available. This deficit in data
availability limited the study team’s ability to project the impacts of possible water quality trading in a two-state setting.

The confidence in modeling results is very closely related to data availability for both forcing and calibrating the model. In this application, data availability for modeling effort was limited. The lacking data types included in-stream flows, diversion return flows, dam release flows and water quality, in-stream water quality data, and farm/field boundary information in Idaho. With more data, the uncertainty associated with farm/field loads may be reduced and assist in better determining the feasibility of trading.

As mentioned in section 5.0, it was determined that in order to establish a water quality trading program, there is a need for a “neutral moderator” that can facilitate some of the local decisions required to determine the tradable load associated with a farm/field (e.g., ability to offset a farm/field load via BMP implementation). Without this person in place, the ability to set up a point to nonpoint or nonpoint to nonpoint trade is difficult.

In order to determine farm/field loads and the associated delivery ratios, this effort has shown that a large investment of time and expertise is required. If however, the framework developed was automated and streamlined where possible, the time requirements could be substantially reduced.

7.0 FUTURE ACTIVITY AND RECOMMENDATIONS

- The Bear River WIS is a dynamic website. Because of this, and because of the desire from the Steering Committee participants to maintain the WIS as a resource well into the future, updating and continued development of the Bear River WIS will occur on a stakeholder and public needs basis under funding from Utah State University and the water quality divisions from the states of Utah, Idaho, and Wyoming. Contracts for this work are currently being put in place. We will work to maintain the relationships that we have built as part of this project and advance the Bear River WIS so that the databases, software, and application architecture remain current.

- Ongoing Projects that Have been Influenced by the EPA Targeted Watersheds Grant:
  - **Little Bear River Environmental Observatory Test Bed** – USU received funding from the National Science Foundation in 2006 to develop an environmental observatory test bed in the Little Bear River. Much of the proposed work was influenced by the components of the Bear River WIS that we had already developed, including the Bear River WIS comprehensive data warehouse, the Bear River WIS Internet map server, and the Time Series Analyst application.
  - **Development of a Great Salt Lake Information System (GSLIS)** – USU has received funding from the State of Utah to develop an environmental information system for the Great Salt Lake and its surrounding watersheds. The GSLIS will reuse many components of the Bear River WIS, including the comprehensive data
warehouse, the Internet map server, the digital library, the resource guide, and the Time Series Analyst.

- **CUAHSI Hydrologic Information System Project** – On a national scale, the Consortium of Universities for the Advancement of Hydrologic Science, Inc.’s (CUAHSI) Hydrologic Information System (HIS) project has benefitted from our work through the development of an advanced data model for environmental observations data and through the use of the Time Series Analyst application that is part of the WIS.

- **Trinity River IIMS Project** – USU has received funding from the U.S. Bureau of Reclamation to build portions of an Integrated Information Management System (IIMS) for the Trinity River of Northern California. This project has benefitted from our work related to the comprehensive data warehouse and through the reuse of the Time Series Analyst application that was developed for the Bear River WIS.

- A Utah State University Water Initiative Grant was awarded for 2008-2009 titled “Assessing a Variable Effective Source Area (VESA) Modification of TOPMODEL for Predicting Soil Moisture.” This seed grant will assist in addressing some of the concerns associated with the use of the VSA methods applied within this project by collecting data to test the predictive capabilities of the modeling framework. Although, the grant is only $40,884, an extra $35,000 for equipment purchases has been acquired from the Utah Water Research Laboratory.

- Identified potential pollutant trades in the Bear River watershed:

  The Cutler Reservoir/Bear River Advisory Group has been meeting for the past four years to assist in the development of a TMDL for dissolved oxygen and nutrients (total phosphorus). The Logan City Waste Water Treatment facility that handles the municipal waste for seven of the largest communities in Cache Valley is a major source of nutrients to the reservoir. The plan on the table now includes an allowance to the WWTP in exchange for a one million dollar a year trade to address the nonpoint sources. An irrigation project has been identified that would reduce the summertime nutrient loading to the reservoir by thirty-eight percent. If all goes well the framework for the trade will be in place by mid October.

  There is also a private contractor working with Lewiston City, Preston City and Franklin City to determine what options are available to them. One of which would be working a trade perhaps with the Richmond WWTP or through NPS trades. In the Cub River Basin in Utah and Idaho there are 6 PS permit holders and a large agricultural component. This scenario makes the potential for trading feasible. Overall the development of TMDL's in the Bear River Basin has raised the level of stakeholder awareness of water quality issues and the potential for pollution trading.
8.0 APPENDICES

Annotated list:

Appendix 8.1 The Bear River Watershed Information System
This appendix provides a description of the overall system architecture, technical details, and features of the Bear River Watershed Information System (WIS).

Appendix 8.2 Technical Memo: Integration of the Water Quality Modeling Results into the Watershed Information System
This technical memo provides a description of the approach agreed upon by the Water Quality Modeling Team and the Bear River Watershed Information System Team on a straightforward approach to integrating the model results into the WIS.

Appendix 8.3 Assessing the potential for water quality trading in the Bear River watershed
This appendix contains: 1) Appendix 8.3A from Jason Whitehead M.S. Thesis, Dept of Applied Economics, USU, 2006; and 2) Appendix 8.3B, the survey instrument developed for obtaining this information (Survey of Effluent Managers).

Appendix 8.4 Estimates of Phosphorus Abatement Costs

Appendix 8.5 Cooperative Surplus Sharing: Caplan-Sasaki paper submitted to J. of Economic Education
This appendix contains a manuscript by Arthur Caplan and Yuya Sasaki submitted for review to the Journal of Economic Education which develops an algorithm for the sharing of economic surplus generating by exchange opportunities using cooperative game theory concepts.

Appendix 8.6 Examples of Pollutant Trading
This appendix contains an example of a point source to nonpoint source trade and an example of a nonpoint source to nonpoint source trade.

Appendix 8.7 Trading Strategies
This appendix contains an assessment of market structure, alternative trading strategies, and the efficiencies of these alternative strategies in reducing total phosphorus

Appendix 8.8 Steps to Trading
This appendix outlines the trading issues that the regulator needs to consider in order to select a trading strategy for reducing phosphorus loading in the Bear River Watershed and then reviews the steps that need to be taken to initiate the trading program.

Appendix 8.9 Technical Memo: Specific Requirements of and Objectives for the Water Quality Model to Support Water Quality Trading in the Bear River Basin
This technical memo describes the specific requirements of and objectives for the water quality model to be developed as part of the Environmental Protection Agency (EPA) Targeted Watersheds grant in the Bear River Basin.
This technical memo details the water quality modeling approach that has been selected for implementation in the Bear River Basin to support a detailed study of the feasibility for and mechanisms of water quality trading.

Appendix 8.11 Technical Memo: Watershed Modeling for Water Quality Trading (Journal Article, JAWRA)
This memo/paper provides information regarding the modeling framework developed to facilitate trading. Additionally, the application of the modeling results into a trading program is presented.

Appendix 8.12 Technical Memo: Flow Chart of Water Quality Trading Modeling Structure
This memo describes the water quality trading model structure through a series of flow charts.

Appendix 8.13 Technical Memo: Scalability of the Selected Modeling Approach
This appendix discusses the how the selected modeling approach may be scaled for use in different sub-basins.

Appendix 8.14 Bear River Outreach Presentation
This appendix contains a typical outreach presentation given to hundreds of stakeholders in the watershed during the first two years of the project.

Appendix 8.15 Other outreach materials produced
This appendix contains examples of fliers and giveaways produced to get the word out to stakeholders about the Bear River Watershed Information System.

Appendix 8.16 Bear River WIS Newsletter, August 2007
This appendix contains a newsletter sent out to the stakeholders in the Bear River watershed that describes the Watershed Information System and the project in general.

Appendix 8.17 Bear River Water Quality Trading Workshop Summary, August 2007
This appendix contains a factsheet sent out to the stakeholders in the Bear River watershed that describes Water Quality Trading concepts and a summary of the water quality trading workshop that occurred in July 2007.

Appendix 8.18 Bear River Symposium Agenda and photographs, September 2007
This appendix contains Appendix 8.18A) the Bear River Symposium agenda, Appendix 8.18B) abstracts of the symposium poster and oral presentations, and Appendix 8.18C) photographs from the Bear River Symposium.
Appendix 8.1 The Bear River Watershed Information System

The Bear River Watershed Information System

USEPA Targeted Watersheds Grant

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Prepared for:  
Water Quality Committee  
Bear River Commission

8-27-2008

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1.0 Introduction

This Appendix provides a description of the overall system architecture, technical details, and features of the Bear River Watershed Information System (WIS). The overarching goal of the WIS is to provide individuals and agencies in the Bear River watershed with a large array of fully integrated capabilities, including unprecedented access to data and data manipulation, modeling and visualization, and education and outreach. A fully functioning WIS of this scale has been a critical missing component for effective watershed management in the Bear River watershed and in many watersheds nationwide. The development of the WIS has promoted greater cooperation across state lines and among the different regulatory agencies and stakeholder groups in the basin. Key data components of the WIS include realtime and historical water quality and quantity, ecological, economic and cultural information, spatial datasets of land use/land cover, hydrography, terrain, and many others. Key functional elements of the Bear River WIS include watershed-wide coordination web pages, a comprehensive data warehouse, a document warehouse/digital library, data visualization and statistical tools, and outreach and education components that contain information about water quality, pollutant trading, and water quality modeling.

Sections 2 and 3 of this document provide technical details of the overall system architecture for the WIS. Section 4 contains a description of each of the components of the WIS and the functionality that is contained within each one. Finally, Section 5 details some of the larger contributions of the WIS and the lessons learned in its development.

2.0 Overall System Architecture

The Bear River WIS is an integrated information system that is accessed through an Internet website (http://www.bearriverinfo.org). All of the resources provided by the WIS are delivered to users through a standard Internet browser and can be accessed on any computer platform anywhere an Internet connection is available. The functionality of the WIS is split between two separate servers, the application server and the database server. The application server hosts the website application and all of the data visualization and analysis tools. The database server hosts the databases associated with the WIS and applications that load data into those databases. This separation of labor ensures that the WIS is both reliable and efficient in delivering data and information to users.

The main WIS application is driven by two primary underlying databases and a variety of other data resources. The website database contains much of the page content for the website. Most of the web pages within the WIS are generated dynamically from content within this database. The advantage of this approach is that changes can be made to pages within the website by editing information in the database rather than recoding individual pages. The observations database contains all of the environmental observation data that is served by the WIS. The data contained within this database have been assembled from a variety of third party data sources, and some of the data stream into the observations database on a continuous basis (e.g., USGS realtime monitoring data). The observations database is accessed by the data visualization and analysis tools of the WIS. Figure 1 shows the overall system architecture for the Bear River WIS.
Figure 1. Overall system architecture for the Bear River WIS. Third party data sources are consolidated within the WIS Observations Database. The database server provides content for the web server, which serves the WIS applications. Users interact with the WIS using an Internet browser.

3.0 Technical Details

In this section we describe some of the technical implementation details of the Bear River WIS. These details are provided here to illustrate the resource requirements of the WIS and to provide specifics of the technical implementation of the overall system architecture shown in Figure 1. The WIS website and all of its associated tools (except the map server) were developed as a web applications using Microsoft Visual Studio .Net 2003. The WIS uses a technology called ASP.Net, which is a web application framework developed by Microsoft that programmers can use to build dynamic web sites, web applications and web services. The databases that underlie the WIS have been implemented in Microsoft SQL Server 2005 Standard Edition. SQL Server is a relational database management system (RDBMS) produced by Microsoft. Its primary query language is Transact-SQL, an implementation of the ANSI/ISO standard Structured Query Language (SQL). The WIS map server was developed using ArcIMS, which is an Internet Map Server produced by the Environmental Systems Research Institute (ESRI).
As illustrated in Figure 1, the WIS has been implemented on two separate servers, a database server and a web application server. This separation enables both a division of labor and a measure of security for the database server because it is not exposed to outside connections. Both servers are running the Microsoft Windows 2003 Server operating system and are connected to Utah State University’s internal network. The web server is running Microsoft Internet Information Services (IIS), which is a set of Internet-based services for servers using Microsoft Windows operating systems and that is necessary for server web pages over the Internet. The web server also runs ArcIMS. In addition, both servers are running Versions 1.1 and 2.0 of the Microsoft .Net Framework. The .Net Framework is a software technology that enables applications developed in Microsoft Visual Studio .Net to run on Windows computers.

4.0 Features of the Bear River WIS

The Bear River WIS has several different features that were developed with input from the Outreach and Education Team and the Targeted Watersheds Grant Steering Committee so that they meet the needs of the Bear River water quality community. Each of the major features is described below, and screen shots of each of the features are provided where appropriate.

4.1 Watershed Wide Coordination Web Pages

Administrative Functions – Many of the pages within the WIS are dynamic in that users can submit data and information to be included in the WIS. The built in Administrative functionality enables the WIS system administrator to designate moderators for each dynamic section of the WIS. The moderators ensure that all submissions to the WIS are unique and legitimate. All of the moderation functions (i.e., viewing, editing, and approval of new items) are built into the WIS, and notification for newly submitted items is automated via email. Administrators and moderators can log in and perform their designated jobs directly through a web browser and directly within the WIS.

Watershed Descriptive Profiles (http://www.bearriverinfo.org/description/) – The watershed descriptive profiles were designed to provide users with information about each of the major watersheds that make up the overall Bear River basin. The descriptive profiles are organized at the United States Geological Survey Hydrologic Unit Code (HUC) 8 level. They provide a narrative description of each of the HUC 8 watersheds as well as more detailed information about physical characteristics, land and soil, climate, water quantity and quality, and demographics. Figure 2 provides screen shot examples of the information contained within the watershed descriptive profiles.
Resource Guide (http://www.bearriverinfo.org/guide/) – The resource guide is a compilation of information about people and organizations working within the Bear River watershed that have water quality related expertise. This guide is searchable and dynamic in that users can submit new entries to the guide and edit existing entries to update information in the database. The Resource Guide is moderated to ensure that entries are unique and legitimate. The moderator is notified via email when new entries have been added, and approval of new items occurs within the administrative portion of the WIS. The Resource Guide also contains a listing of historical and ongoing projects in the Bear River watershed related to water quality restoration or research. Over the course of the project, approximately 180 different experts, 140 different organizations, and 15 projects have been added to the WIS. Figure 3 provides screen shots of the Resource Guide.
Calendar of Events (http://www.bearriverinfo.org/calendar/) – The calendar of events was created so that users can submit water quality related meetings, conferences, and events to the Bear River WIS. After being approved by a moderator, events are automatically posted to the calendar page and to the front page of the WIS. Each event is automatically assigned a persistent URL that enables users to advertise events by linking others to the WIS. Over the course of the project, approximately 125 events have been submitted to the WIS. Figure 4 shows screen shots of the WIS calendar.
News Events (http://www.bearriverinfo.org/news/) – The News section of the WIS provides users with the ability to search an archive of water quality related news articles for the Bear River watershed and to submit new articles to the WIS. Like the Resource Guide and the Calendar, the News section of the WIS is moderated to ensure that submissions are unique and legitimate. Newer news articles are listed on the front page of the WIS website. Links are provided within the WIS to the original source of the article. Over the course of the project, approximately 45 different news articles have been submitted to the WIS. Figure 5 shows screen shots of the WIS news functionality.
4.2 Comprehensive Data Warehouse

The comprehensive data warehouse is the collection of data that have been assembled within the WIS. The purpose of the data warehouse is to provide users of the WIS with a “one-stop-shop” for Bear River related data rather than being required to navigate through many different agency websites looking for and assembling the data. The data within the data warehouse can be accessed using the data visualization and analysis tools that have been developed for the WIS (described below). The following sections describe the different types of data that have been assembled within the WIS.

GIS Data (http://www.bearriverinfo.org/mapping/downloads.aspx) – GIS datasets have been assembled that provide information about the terrain, land use, land cover distribution, land ownership, hydrography, and many other important characteristics of the watershed. Most of the GIS datasets available via the WIS have been developed at the state level. The value added for the GIS datasets available via the WIS is that they have been stitched together so that they cover the entire watershed, rather than having separate coverages for each of the three states (Utah, Wyoming, and Idaho). GIS datasets are available for download from the WIS, and they are also available via the WIS map server. Over the course of the project, a total of 56 GIS data layers have been assembled, a majority of which are available for download. Figure 6 shows some of the GIS data included in the WIS data warehouse.
Observations Data (http://www.bearriverinfo.org/data/) – The observational datasets assembled within the WIS data warehouse include historical, current, and even realtime time series data collected at streamflow, water quality, and meteorological monitoring sites located throughout the watershed. These data are stored in a relational database and can be accessed and downloaded through the data visualization and analysis tools of the WIS. Examples of observations data included in the WIS include USGS daily and realtime streamflow data, USDA NRCS SNOTEL data, and USEPA STORET data (water quality data from the three state divisions of environmental quality). In total, approximately 7.8 million individual water quality related observations have been assembled from 17 different data collection organization, for over 1500 different water quality related variables, and at over 2400 different monitoring sites. The WIS also provides links to many different organizations that collect observations data within the Bear River watershed. Figure 7 shows the schema of the observations database in which the WIS observational data are stored.
4.3 Digital Library

The WIS Digital Library (http://www.bearriverinfo.org/library/) provides users with a searchable index of Bear River related documents, PowerPoint presentations, meeting minutes, images, and other digital objects. The Digital Library is dynamic, and users can submit new items to the WIS. A moderator must approve all new items. Each Library object is assigned a unique URL within the WIS, ensuring that they are persistent. The value added by this is that once items are added to the WIS they will not disappear or be moved to a new location, which often happens on the variety of source websites from which many of the documents have been extracted. Over the course of this project approximately 150 objects have been added to the Digital Library. Figure 8 shows screen shots of the WIS Digital Library functionality.
4.4 Data Visualization and Analysis Tools

Several data visualization and analysis tools have been developed as part of the WIS that add value to the data that have been assembled in the WIS data warehouse. In general, these tools were developed to increase the availability of the data by providing interfaces for users to find the data that they are interested in, do some simple visualization and analysis of the datasets that they find, and then download the data. The following sections describe the data visualization and analysis tools that are part of the WIS. These tools can be accessed on the Data Tools page of the WIS (http://www.bearriverinfo.org/tools/) or by clicking on the individual links listed below.

Internet Map Server (http://water.usu.edu/mapviewers/bearrivermap/) – The Internet Map Server was developed to provide access to the WIS GIS database over the Internet. This is especially useful for users that do not have any GIS software available to them as all of the functionality of the Map Server is available through a web browser. The Map Server contains many different spatial data layers that characterize the Bear River watershed. These include point layers that show the locations of monitoring sites. Many of these point layers are hyperlinked so that when users click on points on the map they are connected with the data that was collected at that point either through the Time Series Analyst or by linking directly to the data collection agency’s website. Figure 9 shows a screen shot of the WIS Map Server.
Figure 9. Screen shot of the Bear River WIS Map Server.

**Time Series Analyst** ([http://water.usu.edu/analyst/](http://water.usu.edu/analyst/)) – The Time Series Analyst was designed to provide users with the ability to visualize and summarize time series data collected at monitoring sites located throughout the watershed. The Time Series Analyst is connected to the WIS Observations Database and provides a variety of different plot types and descriptive statistics for time series data. Users can export both the plots that they generate with the Time Series Analyst and the data so that they can use it in external software applications like Microsoft Excel. Figure 10 shows a screen shot of the Time Series Analyst.
Figure 10. Screen shot of the WIS Time Series Analyst.

PhotoViewer (http://water.usu.edu/photoviewer/default.aspx?wateshed=bearriver) – The PhotoViewer was developed to provide access to georeferenced photographs taken throughout the Bear River Watershed. Users can select locations at which photos have been taken and then browse through the available photos. Figure 11 shows a screen shot of the PhotoViewer.

Figure 11. Screen shot of the WIS PhotoViewer.
TMDL Information Viewer (http://www.bearriverinfo.org/tools/TMDL/) – The TMDL Information Viewer is made up of two separate components, a map server that displays all of the 303(d) listed waterbodies in the Bear River Watershed, and an information viewer that displays descriptive information about each of the waterbodies. The 303(d) listed waterbodies in the map are linked to their associated attribute information providing users with point and click access to TMDL related information associated with each feature on the map. Attribute information includes the year the waterbody was listed, the water quality constituents of concern, the status of the TMDL for that waterbody, any water quality targets that have been set, and other pertinent information. Figure 12 shows screen shots of the TMDL Information Viewer.

Database Query Utility (http://www.bearriverinfo.org/tools/query_utility/) – The WIS Database Query Utility was designed to enable users to do bulk data downloads from the WIS observations database. It provides a simple interface through with users can specify query criteria (i.e., “get all of the data for dissolved oxygen in the Little Bear River” or “get all of the climate data in the upper Bear River watershed”) and retrieve data that meet those criteria. Data are presented in a simple, delimited text file format for download. Figure 13 shows a screen shot of the WIS Query Utility.
Over the course of the project, the WIS Development Team worked closely with the Outreach and Education team to enhance the usability and aesthetic quality of the WIS. Additionally, some of the outreach and education materials developed as part of this project were incorporated throughout the site to enhance the existing functionality. A specific section of the WIS was devoted to outreach and educational materials and to providing resources for individuals, educators, and students to learn more about water quality in the Bear River. Figure 14 shows a screen shot of the outreach and education page of the Bear River WIS.
5.0 Contributions and Lessons Learned

Over the course of this project, much was learned about the development of watershed information systems and the presentation of technical data and information to a variety of audiences that range from University researchers to students in local primary and secondary schools. The following sections provide details of some of the major lessons learned while developing the WIS for this project.

5.1 General Architecture of a Watershed Information System

The Bear River WIS is a fully integrated web site, providing stakeholders in the watershed with unprecedented access to maps, spatial and temporal datasets, contacts, resource materials pertaining to the watershed, and much more. The Bear River WIS consists of a set of modular components that have been assembled into a single website. Together, these components provide the functionality of the Bear River WIS and demonstrate the general architecture of a watershed information system. The components are transferrable (with a small amount of configuration) and have already been used in information systems for other watersheds.
5.2 Advanced Observations Data Model

Archiving, publishing, and delivering data requires that adequate metadata be developed. Regardless of the source of the data, when data are delivered to end users they must be accompanied by enough metadata so that they can be unambiguously interpreted and used. The simple observations database schema developed for the WIS contains many of the important attributes required to fully qualify observational data when they are delivered to end users, but it does not contain all of the important attributes. Through our experience in developing the WIS, the data model for the Observations Database has grown into a much more robust Observations Data Model (See: Horsburgh, J. S., D. G. Tarboton, D. Maidment, and I. Zaslavsky (2008), A Relational Model for Environmental and Water Resources Data, Water Resources Research, 44, W05406, doi:10.1029/2007WR006392) shown in Figure 15. This data model will be fully integrated with future versions of the WIS to ensure that metadata requirements are met.

Figure 15. The Observations Data Model.

5.2 Spatially Referenced, Point and Click Data Access

The spatially referenced, point-and-click access to observational data that has been implemented within the WIS Map Server is a powerful tool for providing users with data discovery capabilities. In many cases, users don’t know exactly what they are looking for, and the ability to see the layout of the monitoring sites superimposed upon the watershed, streams, terrain, land use, etc. provides them with the spatial context that they need to select the data that they are interested in. This juxtaposition of spatial data and time series of environmental observations
also provides important spatial reference for interpreting the data. Knowing the land use
distribution above a stream monitoring site is important in assessing nutrient concentrations.
Knowing the location of a stream gage in relation to a reservoir release is important in
interpreting measured discharges. The linkage of tools such as the Map Server and the Time
Series Analyst make the data more accessible to individuals who are not familiar with the Bear
River watershed.

5.3 Data Visualization and Summary Tools

The data visualization tools of the WIS, particularly the Time Series Analyst, are powerful tools
that assist users in interpreting available data. Compilation of data into a single location (i.e., the
WIS Data Warehouse) and mediating across the different data formats from different data
collection agencies is important in making data more available to potential users. However, in
many cases, even though a variety of data are available from a single location, users may not
have the technical expertise to extract the data, load it into a data analysis software, and then
develop useful visualizations or statistical summaries of the data. Even though they lack the
technical expertise to do the data analysis on their own, this same class of users is generally very
capable of understanding the information contained within plots of data, statistical summaries,
etc. By providing users with tools that manipulate the data automatically and that do not require
any specialized software expertise other than knowing how to operate an Internet browser, the
WIS extends the reach of the data to less technical users.
Technical Memo

Integration of the Water Quality Modeling Results into the Watershed Information System
(Task 21)

USEPA Targeted Watersheds Grant

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Prepared for:

Water Quality Committee
Bear River Commission

8-15-2008

Utah Water Research Laboratory
Purpose
The Water Quality Modeling Team worked with the Bear River Watershed Information System Team on a regular basis and determined a straightforward approach to integrating the model results into the WIS. This technical memo provides a description of the agreed-upon approach.

Introduction
In order to set up a water quality trading framework, the primary informational requirements of the Water Quality Trading Team from the Water Quality Modeling Team were:

- current conditions seasonal total phosphorus loads at a farm or field spatial scale (i.e., seasonal farm/field loads);
- seasonal fractions of the total phosphorus farm/field loads that reach a receptor point (i.e., seasonal delivery ratios); and
- fractions of a farm/field load that can be offset through BMP implementation (i.e., % BMP reduction).

Each of these components is necessary to complete the calculations required for a water quality trading framework. The driving force behind these requirements was that each individual polluter in a basin needs to know the amount of phosphorus they have available to trade. This quantity is dependent on the amount of a polluter’s total phosphorus load delivered to a designated receptor point that can be offset through management actions. This quantity, designated here as the “tradable load,” is a function of the farm/field load, the associated delivery ratio to a receptor point, and the ability to mitigate the current load.

To calculate the amount of phosphorus a polluter has to trade, a seasonal farm/field delivered load must first be calculated. This seasonal load delivered to a receptor point from each farm/field is calculated by multiplying seasonal farm/field loads by the seasonal delivery ratios (Equation 1).

\[
\text{Farm/Field Delivered Load}_{\text{Season}} = \text{Farm/Field Load}_{\text{Season}} \times \text{Delivery Ratio}_{\text{Season}} \quad \text{Equation 1}
\]

The Farm/Field Tradable Load, or fraction of the Farm/Field Delivered Load that can be offset through the implementation of management practices, can then be determined by multiplying the Farm/Field Delivered Load by a % BMP reduction (Equation 2).

\[
\text{Farm/Field Tradable Load}_{\text{Season}} = \text{Farm/Field Delivered Load}_{\text{Season}} \times \% \text{ BMP Reduction} \quad \text{Equation 2}
\]

Once the Farm/Field Tradable Loads are determined, each farm/field owner knows the total phosphorus credits they own and can sell to another point or nonpoint source trying to offset a portion of their load.
Bear River Modeling Results

Although the modeling effort included both the Little Bear River and Bear River watersheds, for this technical memo, example results will be provided only for the Bear River portion of the water quality trading study focus area (Figure 1). Two tables, which were derived from the detailed modeling results, will be the primary information driving the WIS interface to the water quality model and the trading program. These include: 1) seasonal farm/field total phosphorus loads; and 2) delivery ratios for the stream reaches within each subbasin.

The water quality model, which is discussed in detail in the deliverables from Task 19 and 20, produced results that represented the water quality trading focus area using a regularly spaced grid. Executions of the model resulted in total phosphorus loads that were calculated for each grid pixel (30m x 30m) during each season of the year. These loads were based on the prediction of saturation excess runoff and event mean concentrations which determined the phosphorus load generated. Figure 2 shows an example of the seasonal total phosphorus loads per pixel for the Bear River water quality trading focus area. The red areas represent higher loads, yellow represents medium loads, and the green areas are lower loads. This figure shows that the bulk of the total phosphorus load from this basin originates in the eastern portion of the watershed during winter and spring seasons.

Once the seasonal load calculations had been completed for each pixel, additional steps were taken to aggregate the loads from individual pixels to create farm/field loads by summing the values for all the pixels contained first within the boundary of each field and then each farm (made up of multiple fields). Figure 3 represents the seasonal farm/field loads from the portion of the watershed where farm/field location and ownership information was available. As shown in Figure 3, necessary information for determining farm/field boundaries and ownership was primarily available in the Utah portion of the water quality trading focus area and, therefore, farm/field loads were only calculated where farm/field boundary data was available. Table 1 shows a subset of the detailed information underlying the maps shown in Figure 3.

The last piece of information resulting from the modeling effort was the determination of delivery ratios. The details of how the delivery ratios were calculated are contained in the deliverable from Task 19 and 20, but we have included a simple description here. Total phosphorus seasonal delivery ratios were calculated for each stream reach within the water quality trading focus area by: 1) accounting for losses in the stream due to the fate and transport of total phosphorus using QUAL2E, and 2) accounting for diversions from the river in the instream modeling structure. Each of the subbasins represented in the model contain a single stream reach so the delivery ratio associated with a subbasin is the same as the delivery ratio associated with the reach within the subbasin. Table 2 includes the subbasin seasonal delivery ratio for each reach within the water quality...
trading study area. It is assumed that all farms/fields contained within a subbasin have the same *seasonal subbasin delivery ratio*. The *seasonal delivery*
Figure 1. Bear River Basin subbasin delineations.
ratio for the total phosphorus load from a subbasin to a receptor point can be calculated by multiplying each of the seasonal subbasin delivery ratios leading up to the receptor point of interest.

**Modeling Results and Watershed Information System Integration**

As described above, the primary information resulting from the modeling effort consists of farm/field loads and delivery ratios. Tables of farm/field loads (Table 1) and delivery ratios (Table 2) were presented to the Watershed Information System Team in the form of a relational database. As shown in Figure 4, the common field between the tables is the “Subbasin #.”

From these tables, the necessary calculation of a Seasonal Farm/Field Delivered Load can be completed by:

1.) Querying a specific user identified “Field ID” or “Farm ID”
2.) Determining the Seasonal Farm/Field Load
3.) Determining which subbasin that field is in
Figure 3. Bear River Basin seasonal farm/field total phosphorus loads.

4.) Determining the appropriate delivery ratio for that subbasin based on a user identified receptor point
5.) Completing the calculation shown in Equation 1

Once the Seasonal Delivered Farm/Field Load has been calculated, the Seasonal Tradable Farm/Field Load can be calculated by:

1.) Completing the calculation shown in Equation 2 based on a user identified % BMP Reduction.

The % BMP Reduction will need to be provided by the user of the WIS based on the local knowledge of the farm/field in question. This is necessary due to the large ranges of BMP types and effectiveness given soils, land uses, water quality impairments that are being addressed, etc.
Table 1. Example of total phosphorus farm/field loads per season table.

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<th>Subbasin #</th>
<th>Field ID</th>
<th>Field Area (m²)</th>
<th>Farm ID</th>
<th>Ave Winter TP Load (g/season)</th>
<th>Ave Spring TP Load (g/season)</th>
<th>Ave Summer TP Load (g/season)</th>
<th>Ave Fall TP Load (g/season)</th>
<th>Average Event Mean Concentration</th>
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Table 2. Table of *seasonal subbasin delivery ratios* between each subbasin in the Bear River Basin.

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Example Calculations

As an example of the integration of the modeling results into the WIS, a simple case study using a farm located within the Cub River portion (Figure 5) of the Bear River Basin will be discussed.

In this example, the receptor point of interest will be the outlet of the Cub River (subbasin #24) where it enters the Bear River. We are going to say that we want to know the seasonal tradable load from Field # = 14514 because according to our local contacts, this particular farmer tends to contribute large phosphorus loads and he expressed an interest in participating in trading.

From the “BR FarmFieldsLoads” table in the Bear River relational database (Figure 4), we can quickly find the information for Field # = 14514, shown in Table 3. From this table, we now have the Seasonal Farm/Field Loads of 1306 g in the winter, 798 g in the spring, 272 g in the summer, and 1017 g in the fall. We also now know that this field is located in the subbasin #39.

This subbasin # tells us the location of the field within the entire basin. An already established network of subbasin connectivity (shown in Figure 5) identifies the subbasins that lie between the subbasin containing the farm/field and the receptor point. With this information, the seasonal delivery ratio can be calculated. In our example, we can look at Figure 5 and determine that the load from the farm/field will travel from subbasin #39.
to #38, #31, #30, #29, #28, #27, #26, #25, and then to the receptor point at #24. Since the “BR Delivery Ratios” table in Figure 5 consists of seasonal subbasin delivery ratios, each subsequent subbasin’s value will have to be multiplied to determine the seasonal delivery ratio. Equation 3 details the calculation of the seasonal delivery ratio from each of the seasonal subbasin delivery ratios associated with the subbasins the load will travel through.
Based on seasonal subbasin delivery ratios from Table 2, Table 4 shows the resulting seasonal delivery ratios to the receptor point (subbasin #24) for Field # = 14514 (and all of the other fields within subbasin #39).

The calculated seasonal delivery ratio results (Table 4) show that 100% of the Field # = 14514 load will be delivered to the receptor point during the winter. However, there is some loss during spring (98.4% delivered) and fall (99.4% delivered). In summer, primarily due to diversions, there is a much lower delivery ratio (82.6% delivered) and will result in less phosphorus that will be available for trade.

With the seasonal delivery ratios and the seasonal farm/field loads, the seasonal delivered loads can now be calculated according to Equation 1. The resulting loads are shown in Table 5.

With the seasonal delivery ratios and seasonal delivered loads now determined, the seasonal tradable loads can be calculated. As shown in Equation 2, a % BMP reduction is required to be provided. For this particular field, we will assume that a 50% reduction of total phosphorus can be achieved through the use of a filter strip. The resulting seasonal tradable loads are presented in Table 6.

Once these seasonal tradable loads have been calculated, a farm/field owner now knows the possible amount of total phosphorus credits they have available for sale. In this example, however, a lot of simplifying assumptions were made to illustrate how to take the modeling results, calculate tradable loads, and incorporate them into a water quality trading study. In the real world, participants and facilitators will need to consider how to incorporate TMDL load reduction requirements, safety factors, retirement ratios, etc. into the tradable load calculations.
Table 3. Information from Farm/Field Loads table for Field # = 14514.

<table>
<thead>
<tr>
<th>Subbasin #</th>
<th>Field ID</th>
<th>Field Area (m²)</th>
<th>Farm ID</th>
<th>Ave Winter TP Load (g/season)</th>
<th>Ave Spring TP Load (g/season)</th>
<th>Ave Summer TP Load (g/season)</th>
<th>Ave Fall TP Load (g/season)</th>
<th>Average Event Mean Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>14514</td>
<td>372600</td>
<td>-1</td>
<td>1306</td>
<td>798</td>
<td>272</td>
<td>1017</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Table 4. *Seasonal delivery ratios* for farm/fields in subbasin #39.

<table>
<thead>
<tr>
<th>Subbasin #</th>
<th>Winter Subbasin DR</th>
<th>Spring Subbasin DR</th>
<th>Summer Subbasin DR</th>
<th>Fall Subbasin DR</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.996</td>
</tr>
<tr>
<td>31</td>
<td>1.000</td>
<td>0.986</td>
<td>0.828</td>
<td>1.000</td>
</tr>
<tr>
<td>30</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>29</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>28</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>27</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>26</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>25</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.999</td>
</tr>
<tr>
<td>24</td>
<td>1.000</td>
<td>0.999</td>
<td>0.998</td>
<td>0.999</td>
</tr>
<tr>
<td><strong>Seasonal Delivery Ratio</strong></td>
<td><strong>1.000</strong></td>
<td><strong>0.984</strong></td>
<td><strong>0.826</strong></td>
<td><strong>0.994</strong></td>
</tr>
</tbody>
</table>

Table 5. *Seasonal Delivered Loads* for Field # = 14514 (grams).

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm/Field Loads</td>
<td>1306</td>
<td>798</td>
<td>272</td>
<td>1017</td>
</tr>
<tr>
<td>Delivery Ratio</td>
<td>1.00</td>
<td>0.98</td>
<td>0.83</td>
<td>0.99</td>
</tr>
<tr>
<td>Delivered Loads</td>
<td>1306</td>
<td>786</td>
<td>225</td>
<td>1011</td>
</tr>
</tbody>
</table>

Table 6. Tradable loads for Field # = 14514 (grams).

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tradable Loads</td>
<td>653</td>
<td>393</td>
<td>112</td>
<td>506</td>
</tr>
</tbody>
</table>
Appendix 8.3 Watershed Modeling for Water Quality Trading

Watershed Modeling for Water Quality Trading


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Watershed Modeling for Water Quality Trading


Abstract

Water quality trading has been proposed as a potential solution to assist in addressing water quality impairments in a cost effective manner. In order to determine if a trading program is feasible, key information regarding both loads (point and nonpoint) and the amount of each load reaching a location of interest (or delivery ratio) is necessary. While point source loading estimates are relatively simple to determine, nonpoint source loads are much more difficult. Additionally, delivery ratios, which are primarily dependent on instream processes and withdrawals, can be difficult to estimate. In this paper, a modeling framework is proposed as a means to develop seasonal field loads and the associated delivery ratios required to support a water quality trading program. Example calculations resulting in tradable loads of phosphorus in an agricultural watershed are presented to show how the information resulting from the modeling framework can be utilized to calculate the delivered loads as well as the amount of pollution a field or farm owner could potentially trade. Our results show this approach to be an objective and scientifically based foundation for the development of water quality trading programs that include nonpoint sources of pollution.

KEY TERMS: water quality trading; watershed modeling; watershed management; total phosphorus.
Introduction

The Targeted Watersheds Grant program was designed by the U.S. Environmental Protection Agency (EPA) to develop community-based approaches and management techniques to protect water quality. As part of this effort, the feasibility of water quality trading to assist in meeting instream water quality standards has been a topic of investigation. Water quality trading is a potential cost effective solution to mitigating key sources of pollution. Setting up a water quality trading program, however, requires the quantification of both point and nonpoint sources of pollution and an understanding of how pollutants behave in the system. As stated in guidance provided by the EPA (EPA 2004), the steps required to complete a suitability analysis for trading a particular pollutant include the need to determine watershed loading profiles, understand the effect of load timing, and consider water quality equivalence when trading.

A watershed loading profile is a description of the current pollutant loads within a watershed by source and location. Although simple in concept, creation of a loading profile can be a difficult task. Point source loads are regulated and monitored, which makes them relatively easy to quantify. Nonpoint sources of pollution, however, are not regulated through a permitting process, require voluntarily implementation of management actions, and are difficult to identify, measure, and estimate. For integration and consistency with the Total Maximum Daily Load (TMDL) program, the loading profile must include reductions in point and nonpoint sources set by the TMDL developed for the focus water body. The current loads less the required reduction from
the TMDL result in target loads. The timing of these loads relative to a critical time period for a water body is also an important consideration for both trading and TMDL development. If a water quality management program only considers annual loads from sources, the receiving water body may not meet the instream water quality standard during limiting times throughout the year.

The concept of water quality equivalence is a mechanism to ensure that a load reduction resulting from a trade is the same as the reduction that would have occurred in the absence of a trade relative to a location of interest (or receptor point) (EPA 2004). Delivery ratios must be determined for each pollutant source as a function of a distance from a receptor point, and losses due to diversions, biological uptake, settling, etc. If the current load is multiplied by the corresponding delivery ratio, the result is the delivered load (likewise, the target load multiplied by the delivery ratio results in a delivered load). Many trading applications bypass the explicit determination of time variable loads and delivery ratios and instead estimate more general trading ratios to enforce environmental equivalence (EPA 1999). Equivalence or trading ratios provide a means of determining the number of units of a pollutant a “seller” must clean up to offset a unit of a “buyers” load. For example, a trading ratio of 2:1 requires that 2 units from a seller be traded for 1 of the buyer’s units. Sasaki and Caplan (2008) show how trading ratios themselves are a ratio of buyers and sellers respective delivery ratios. Although the concept of a trading ratio is simple, Scatena et al. (2005) and EPA (1999) have found that the method for establishing these trading ratios and the use in trading programs is highly variable across the nation. Scatena et al. (2005) determined trading ratios are generally based on
economic (difference between the marginal cost of reduction of cost of reduction), environmental, and geographic considerations (spatial location of pollutant source and the potential loss of pollutant). Additionally, the trading ratios may be a function of uncertainty ratios, delivery ratios, retirement ratios, special needs ratios, and site location ratios which are all attempts to ensure water quality equivalence (Chesapeake Bay Program Nutrient Trading Negotiation Team 2000; Scatena et al. 2005). However, the level of incorporation of these considerations is variable and may or may not incorporate the use of a model.

In this project, it was determined that the development of a watershed loading profile and testing the feasibility of a water quality trading program in a highly agricultural area with demonstrated water quality impairments required an objective and scientifically sound method for estimating time variable loads and their associated delivery ratios to key receptor points. Towards this end, a modeling framework has been developed to determine the seasonal current total phosphorus (TP) loads at the spatial scale of specific fields (i.e., seasonal field current loads) and seasonal fractions of the field TP loads that reach a receptor point (i.e., seasonal delivery ratios). With this information, seasonal field delivered loads were calculated. The end goal of the project was to use the modeling results as a means to inform each farm or field owner of the amount of TP they own and can potentially sell in the trading program (i.e., seasonal tradable loads). This paper discusses how the modeling framework can be used to estimate seasonal tradable loads and presents a case study that examines the potential application of the modeling
framework in a water quality trading program for the Bear River watershed in northern Utah.

**Modeling Framework**

A number of existing watershed models have been used in watershed management and TMDL development. Examples include Hydrologic Simulation Program FORTRAN (HSPF) (Bicknell et al. 2000), Soil and Water Assessment Tool (SWAT) (Neitsch et al. 2005), and Generalized Watershed Loading Function model (GWLF) (Haith and Shoemaker 1987). The utility of these and other modeling approaches in water quality trading has been recognized to assist in estimating information that supports trading ratios (e.g., delivery ratios, spatial and temporal loads, uncertainty ratios, etc.). The model selection, modeling approaches, and the application of the results in a trading program, however, have been inconsistent. Examples include the Lower Boise River, where a simple mass balance model is applied to determine delivery ratios that are based on pollutant losses due to diversions, but does not consider other instream removal processes (Idaho Department of Environmental Quality 2003). In the Minnesota River Basin, the Revised Universal Soil Loss Equation (RUSLE) and a field scale water management simulation model (Agricultural Drainage and Pesticide Transport (ADAPT)) have been applied to understand some of the uncertainty in nonpoint source trading (Fang and Easter 2003; Fang et al. 2005). In the Great Miami River Watershed in Ohio, SWAT was used to estimate loads from agricultural areas and estimate the effects of BMP implementation on a watershed scale (Kieser et al. 2005). In the Chesapeake Bay, the
Chesapeake Bay Watershed Model (an application of HSPF) and the USGS Sparrow Model have been applied to determine loading profiles and delivery ratios (Chesapeake Bay Program Nutrient Trading Negotiation Team 2000). Another study in the Susquehanna River Basin used GWLF to estimate nutrient loads associated with trading and calculated delivery ratios by applying a first order decay approximation (Horan et al. 2002).

For a modeling application to more fully support a water quality trading program, it was determined that it must be able to simultaneously capture physical hydrology at the watershed scale, while representing the spatial variability of loads at the field scale. Depending on the goal of a typical watershed management application, watershed models are generally developed for either broad watershed or field specific applications. To more accurately understand and assess water quality trading potential, estimates of field scale loads linked to whole basin behavior is required. Additionally, time variable delivery ratios to receptor points of interest need to be determined. This information could not all be supplied by one model and led to the development of the Water Quality Trading (WQT) modeling framework that coupled a number of models, modeling approaches, and processing tools to provide the necessary information to facilitate water quality trading.

The framework includes: TOPNET (Bandaragoda et al. 2004) as the hydrology model; variable source area (VSA) calculations (Lyon et al. 2004) to resolve spatial areas contributing saturation excess flow; a subbasin Loading Model component based on the
VSA calculations, event mean concentrations (EMCs), spatially distributed landuse information; and a Water Body Response (WBR) component that incorporates QUAL2E (Brown and Barnwell 1987) to determine delivery ratios. Figure 1 shows the components of the framework and the general flow of information between each component.

Figure 1. Water Quality Trading modeling framework.

**TOPNET Component**

TOPNET (Bandaragoda et al., 2004) was selected as the hydrologic model within the modeling framework. TOPNET is a semi-distributed, rainfall-runoff model, which combines TOPMODEL (Beven et al. 1995; Beven and Kirkby 1979) with a kinematic wave channel routing algorithm (Goring 1994) to create a hydrologic model that can be applied over large watersheds using smaller subbasins as model elements. Semi-distributed models can have an advantage over lumped models in variable terrain when
the landscape is subdivided to reduce within-element heterogeneity. This may result in a more accurate representation of the spatial distribution of physical characteristics of the basin. A key contribution of TOPMODEL is the parameterization of the soil moisture deficit, or depth to water table, using a topographic index to identify hydrologically similar areas with respect to saturation excess. TOPNET uses TOPMODEL concepts for the representation of subsurface storage controlling the dynamics of saturated contributing areas and baseflow recession. To form a complete model, potential evapotranspiration, interception, and soil zone components have been added, as well as a terrain-based system for delimiting streams, model catchments, and estimation of model parameters (Bandaragoda et al. 2004).

A number of data types are required to set up and calibrate TOPNET. Inputs for watershed delineation and terrain analysis using TauDEM software (Tarboton 2002) include a digital elevation model and a map of outlet locations (e.g., streamflow gauges or water quality measurement points where predicted streamflow or water quality is of interest). Terrain analysis defined the stream network and the subbasins that function as model elements. Climate data used for model forcing is spatially interpolated for each subbasin using multiple climate stations within or just outside the watershed. Spatially distributed landuse, vegetation and soils information are averaged over each subbasin. Soils data provides model parameters that represent the sensitivity of the subsurface storage zone, surface saturated hydraulic conductivity, drainable porosity, plant available porosity, depth of the soil zone, and wetting front suction. Landuse and vegetation data provides model parameters for canopy capacity, intercepted evaporation enhancement,
and albedo. The three state variables of the model that are tracked for each subbasin include 1) average depth to the water table, 2) soil zone storage, and 3) canopy storage. The model is typically run at a daily timestep.

**Variable Source Area (VSA) Component**

The purpose of the VSA component was to locate the origin of predicted saturation excess flow, and to link surface runoff generation and landuse in the estimation of surface water quality. Using the calibrated results of TOPNET, a combination of parameterized and state variables for each subbasin was used to determine probable nonpoint source pollution locations. Calculations in the VSA component use the following state variables specific to each subbasin: estimates of watershed area, drainable porosity, and the distribution of topographic index values. In addition, this component utilizes time series of effective precipitation, as well as predicted average water table depths and saturation excess runoff estimated by TOPNET. The saturated fraction of subbasin area contributing to runoff was estimated using effective precipitation and average watershed storage following the approach of Steenhuis *et al.* (1995) and Lyon *et al.* (2004). Effective precipitation was derived from interpolated measures of total precipitation and potential evapotranspiration. Following Wang *et al.* (2006), average watershed storage was calculated as the product of drainable porosity and average water table depth in each subbasin. A time series of saturated subbasin fractions was then used to map the origin of predicted saturation excess runoff according to the spatial distribution of topographic index values.
Mapped values of the topographic index were combined with a landuse raster and subbasin boundaries within a Geographic Information System (GIS). The geographic intersection of these inputs was used to create a database of individual topographic index values and their landuse by subbasin. In order to relate saturated watershed fractions to specific mapped locations within a watershed, Lyon et al. (2004) proposed a function relating saturated fractions to a cumulative probability distribution of the topographic index. This approach is valid as long as the difference between the overall storage deficit and each local storage deficit is a function of the average topographic index and each local index value. However, as originally conceived, TOPMODEL assumes that the realized zone of saturation will be small and the overall watershed storage deficit \( S \) is the integral of all local storage deficits \( \int s_i \), when in fact, \( S \) should be the integral of all unsaturated local storage deficits \( \int s_i^* \). Thus, we employed the solution proposed by Saulnier and Daltin (2004) to compensate for this analytical bias in relating saturated watershed fractions and critical values of the topographic index.

A combination of saturated watershed fraction estimates and the topographic index distribution were used to generate a time series of critical topographic index values required for pixel saturation. Assuming that saturated pixels contributed equally to runoff during each TOPNET timestep, predicted saturation excess flow (m\(^3\)/d) was divided by the number of contributing saturated pixels to represent flow per-unit-area. Cumulative yields attributed to each 30-m pixel were tracked by season for the entire time series and converted to seasonal averages for the simulation period.
Loading Model Component

The Loading Model component provides estimates of phosphorus loads from diffuse sources within each modeled subbasin. Two flow components, surface runoff (combination of saturation and infiltration excess) and baseflow, are considered and are provided by TOPNET for individual subbasins each model timestep (1 day). The time series of critical topographic index values provided by the VSA calculations were linked to landuse classes through a database of mapped attributes. From this table it was possible to determine the area and proportional fraction of land uses contributing to runoff at each time step. In the current application, all surface runoff is treated as saturation excess (i.e., infiltration excess is treated as saturation excess).

Average surface runoff phosphorus concentrations are based on the land cover from which the surface flow originates and are assigned using event mean concentrations (EMCs) for phosphorus. Given that an EMC is the average phosphorus concentration in surface runoff generated from a particular land cover, and since this model component simulates phosphorus concentrations at the subbasin outlets (reflecting the combined effects of all land cover within the subbasin), a subbasin average EMC ($EMC_{avg}$) was defined to represent the flow weighted average EMC (across all land cover classes) for phosphorus in each modeled subbasin. The following equation shows how the flow-weighted, average EMC value is defined for each subbasin:
\[
EMC_{avg,i} = \frac{\sum_{x=1}^{n} (Q_{s,x,i} \cdot EMC_{x,i})}{\sum_{x=1}^{n} Q_{s,x,i}}
\]  

(1)

Where:

- \(EMC_{avg,i}\) = Subbasin average phosphorus EMC for subbasin \(i\) (mg/L)
- \(n\) = Number of land cover classes present in subbasin \(i\)
- \(Q_{s,x,i}\) = Total surface flow generated from land cover \(x\) in subbasin \(i\) (m\(^3\)/s)
- \(EMC_{x,i}\) = EMC for land cover \(x\) in subbasin \(i\) (mg/L)

The above equation implies that the amount of surface runoff originating from each land cover is known. In this application, it is assumed that surface runoff is only contributed by saturation excess at a specific location in a subbasin and is predicted using the VSA calculations. The result is an estimate of the area of every land cover class that is saturated for each time step within individual subbasins. Assuming that all saturated areas contribute equally to surface runoff, and given that the saturated areas change over time with changes in soil moisture, the subbasin average EMC values are time variable and were calculated using a saturated land cover area weighted average, simplifying Equation (1) to Equation (2).

\[
EMC_{avg,i,t} = \frac{\sum_{x=1}^{n} (A_{x,i,t} \cdot EMC_{x,i})}{\sum_{x=1}^{n} A_{x,i,t}}
\]  

(2)
Where:

\[ A_{x,i,t} = \text{Saturated area of land cover } x \text{ in subbasin } i \text{ at time } t \text{ (m}^2) \]

The resulting subbasin average EMC values represent the phosphorus concentration in surface runoff generated within a subbasin at each modeled time step.

To quantify the effects of base flow loads, average base flow concentrations \((C_b)\) are input to the loading model component. These values can be estimated using existing groundwater quality observations or results of low flow (base flow conditions) in unimpacted streams. Once the surface runoff and base flow phosphorus concentrations are known, the average subbasin outlet phosphorus concentrations are given by the flow weighted average of the surface runoff concentrations and the base flow concentrations. From the equations above, the average surface flow concentration was given by the subbasin average EMC \((EMC_{avg})\). The average subbasin outlet phosphorus concentrations can be calculated according to Equation (3).

\[
C_{avg,i} = \frac{Q_{s,i}EMC_{avg,i} + Q_{b,i}C_{b,i}}{Q_{s,i} + Q_{b,i}} \tag{3}
\]

Where:

\[ C_{avg,i} = \text{Average subbasin outlet phosphorus concentration for subbasin } i \text{ (mg/L)} \]

\[ Q_{s,i} = \text{Subbasin outlet surface flow for subbasin } i \text{ (m}^3/\text{s}) \]
\[ EMC_{avg,i} = Subbasin \text{ average EMC for subbasin } i \text{ (mg/L)} \]

\[ Q_{b,i} = Subbasin \text{ outlet base flow for subbasin } i \text{ (m}^3/\text{s}) \]

\[ C_{b,i} = Base \text{ flow phosphorus concentration in subbasin } i \text{ (mg/L)} \]

The average subbasin outlet phosphorus concentration and the total flow (surface flow plus base flow) were calculated for each modeled subbasin at each time step. These results were then used as the loads applied at the subbasin outlet in the Water Body Response Component.

**Water Body Response (WBR) Component**

The purpose of the WBR component is to accumulate the total phosphorus loads from the subbasins, and route them downstream to the receptor point while accounting for any intervening point loads, diversions, and chemical and biological processes that might affect the fate of the phosphorus. As an integrated component of the modeling system, the WBR accepts inputs from the subbasins based on the TOPNET, VSA, and Loading Model Components. In addition, the WBR component inputs include external data concerning weather, point loads, diversions, and reservoir releases. The instream routing model component uses the widely-used public domain QUAL2E model (Brown and Barnwell 1987) for steady-state calculation of 15 water quality measures.

To use QUAL2E in this context, the stream network is divided into links that connect junctions where the stream proper intersects a subbasin outlet. Each link, or stream reach
between two tributaries, is represented by a QUAL2E input file that describes the physical setting, the hydraulics of flow, the energy balance for temperature calculations, reaction and mass transfer kinetics, point loads, and diversion flows. The link connections ensure the correct sequence of model calculations: upstream reaches are calculated first, reaches that are part of a branch to the main stem of the river are calculated before the main stem, and river sections composed of several reaches are calculated from upstream to downstream.

This ‘many links’ approach was used to accommodate the hydrologic situation often encountered in highly controlled and heavily allocated western rivers. During the period between mid April and mid October, a large fraction of many rivers are diverted from the natural channel into canals for use in irrigation, a portion of which may return to the natural channel at some downstream point or points. This sometimes occurs a short distance downstream, or it may occur within a separate drainage basin entirely. Although the QUAL2E model was designed for branched networks with diversions into and out of a stream element, diversions into an element are fixed. In cases such as those considered here, the flow and quality of a diversion out of the stream are set by conditions in the stream and will, therefore, differ with changes in boundary conditions and will be unknown until the simulation is complete for that reach. Our approach addresses this problem by shortening the model reaches enough that ‘out’ diversions will never return as ‘in’ diversions within the same reach. In this way, they can be accommodated as point loads in the receiving reach that is assumed to be downstream from the ‘out’ diversion.
The results from the QUAL2E calculations at each link include flows, velocities, water quality measures, and other values as a function of distance downstream through the stream reach. Outputs from an upstream reach are used to first provide the headwater conditions for the next link downstream. To determine these headwater conditions, after completion of the computation for a reach, the conditions at the terminal location of an upstream reach are combined with diversions, point loads and subbasin nonpoint loads that enter at that junction, and a simple mass balance is used to find the upstream terminal conditions for the next downstream reach.

Outputs from QUAL2E also enable computation of the delivery ratio for the reach within a subbasin. The degree to which the load from a particular field influences the constituent concentration at the receptor point depends on what happens to the constituent as it traverses the intervening river reaches. While flowing downstream, the constituent may be subject to a number of processes that act to remove it from the water column. In the case of total phosphorus, this includes uptake into algae, settling of particulate forms, and benthic sources/sinks. Total phosphorus is also removed when water is diverted for agricultural or municipal/industrial use. The significance of these losses are situation dependent in the sense that many of the attenuating processes are nonlinear and the fraction of the total phosphorus that is taken up is dependent on the concentrations of total phosphorus and algae. Point loads must also be factored into the phosphorus balance. The QUAL2E model accounts for these effects.
The attenuation of total phosphorus occurring within a stream reach is calculated as the fraction (from 0 to 1) of the mass flow that remains at the downstream terminus of a reach relative to the mass flow that enters a reach via the upstream reach or any point loads. This fraction, or delivery ratio (DR) is defined as:

$$DR = \frac{Load_{\text{leaving reach}}}{Load_{\text{entering reach}}}$$

(4)

This means that the load leaving a reach is equal to the delivery ratio multiplied by the load entering the reach ($Load_{\text{leaving reach}} = DR \times Load_{\text{entering reach}}$). The individual delivery ratio values are found using the QUAL2E model for the representative reach within a subbasin. In this way, we can estimate the overall delivery ratio as the product of the subbasin-based $DR$ values along the reach path leading from an upstream location to any downstream location as shown in Equation (5).

$$DR_{\text{overall}} = \prod_i DR_{\text{subbasin } i}$$

(5)

**Application of Model Results**

In order to establish a water quality trading program, each individual stakeholder needs to know the amount of pollutant they have available to trade. This quantity, designated here as the tradable load, is a function of: 1) the current load or field load, 2) the target load (based on the TMDL program or other watershed management requirements), 3) the
associated delivery ratio to a receptor point and the delivered load, and 4) the ability to mitigate a load. With the resulting seasonal estimates of loads and delivery ratios that are based on a many year average of daily modeling results, variability over different hydrologic conditions can be accounted for. It is recognized that there are many other factors that may be important in determining tradable loads (e.g., more explicit uncertainty estimates or ratios), however, this section of the paper presents a simplified method to determine tradable loads and illustrates how the information provided by the modeling framework can be used in the context of a water quality trading program in a predominantly agricultural watershed.

Farm/Field Current Loads

Once the results of the cumulative saturation excess runoff per pixel were generated from the hydrologic and VSA components of the modeling framework, appropriate EMCs assigned by landuse in the loading component of the framework were multiplied by the water yields per pixel to determine the seasonal load per pixel. The field loads were then determined by summing the values for all 30-m pixels contained within the boundary of each field. The fields can then be aggregated to determine the farm loads which are made up of multiple fields.

Target and Delivered Loads
To calculate the amount of phosphorus a stakeholder has to trade, a seasonal *delivered load* must first be calculated. In many cases, this calculation will be dependant on the *target load* specified by a TMDL or other watershed management programs. For example, if a TMDL for a watershed specified a need for an overall 20% decrease in agricultural nonpoint source pollution, before a stakeholder knows the amount of a pollutant available for trade, they must account for this prior required reduction according to Equation (6).

\[
\text{Field Target Load}_{\text{Season}} = \text{Field Current Load}_{\text{Season}} - (\% \text{ TMDL Reduction}) \times \text{Field Current Load}_{\text{Season}} \tag{6}
\]

The seasonal load delivered to a receptor point from each field is calculated by multiplying seasonal *target loads* by the overall seasonal delivery ratios (Equation (7)). Where a TMDL reduction is not required, the *current load* or *field load* can be multiplied by the delivery ratio to determine the field *delivered load* (Equation (8)).

\[
\text{Field Delivered Load}_{\text{Season}} = \text{Field Target Load}_{\text{Season}} \times \text{Delivery Ratio}_{\text{Season}} \tag{7}
\]

\[
\text{Field Delivered Load}_{\text{Season}} = \text{Field Load}_{\text{Season}} \times \text{Delivery Ratio}_{\text{Season}} \tag{8}
\]

** Tradable Loads**
With the calculation of the field *delivered loads*, the final step is to determine the amount of the load available to trade. The amount a field owner has to trade is called the field *tradable load* which is defined here as the fraction of the field *delivered load* that can be offset through the implementation of management practices. As shown in Equation (9), this can be determined by multiplying the field *delivered load* by a % *BMP reduction.*

\[ \text{Field Tradable Load}_{\text{Season}} = \text{Field Delivered Load}_{\text{Season}} \times \% \text{ BMP Reduction} \]  

(9)

At this point in the process, the % *BMP reduction* must be determined for a specific BMP and a combination of the resulting anticipated reductions based on literature values and existing conditions of the field (e.g., soils and crop types, prior BMPs implemented). A local trading facilitator would likely be the optimal selection to facilitate the estimation of this % *BMP reduction*. Once the field *tradable loads* are determined, each field or farm owner knows the amount of total phosphorus they own and can sell to another point or nonpoint source trying to offset a portion of their load.

**Case Study Example: Bear River Watershed, Utah**

The Bear River Basin comprises 19,000 square kilometers of mountain and valley lands located in northeastern Utah (44% of watershed), southeastern Idaho (36%), and southwestern Wyoming (20%). The watershed ranges in elevation from 1,283 meters to over 3,962 meters and is unique in that it is entirely enclosed by mountains, thus forming
a huge basin with no external drainage outlets. Agricultural lands throughout the basin, as well as urban areas, are located in valleys along the main stem of the river and its tributaries. Currently, many waterbodies in the basin are on the 303(d) list of impaired waters in all three states. The Cub River and Cutler Reservoir are included in these impaired waterbodies due to dissolved oxygen depletion during summer months. Currently, TMDLs are being updated or developed for each of these waterbodies and the opportunity for water quality trading between point and nonpoint sources is a potential solution for controlling phosphorus, the regulated nutrient.

To assist in testing the feasibility of a potential trading program, the modeling framework was applied to the portion of the Bear River watershed between the Onieda Narrows Reservoir and the Cutler Reservoir, which includes the Cub River (Figure 2). For demonstration purposes, the general model set up and calibration will be explained for the entire study area. However, to show the utility of the modeling results for determining the amount of pollutant per field available for trading, we have focused on a field located in the Cub River. This example was chosen to illustrate the concept associated with multiple receptor points because a field in the Cub River will affect both the impaired reach near the mouth of the Cub River and Cutler Reservoir. In this example, it should be noted that target loads will not be discussed due to pending TMDL requirements.
Figure 2. Portion of the Bear River watershed with the Cub River subbasins highlighted. Delineated subbasins, subbasin outlets, and receptor points of concern are also shown.
Figure 1 shows a generic flow of information between each of the modeling components. Figure 3 shows more details of the steps taken to set up and connect each of the components. In the Bear River application of the modeling framework, TOPNET was populated using SSURGO soils data (Soil Survey Staff 2007), the 30-meter National Elevation Dataset digital elevation model (USGS, http://ned.usgs.gov/), land cover from the National Land Cover Dataset (NLCD 2001), Utah Water Related Landuse (Utah Department of Natural Resources, Water Resources Division, www.water.utah.gov/planning/landuse/), local weather data, diversion data, and reservoir discharges for a simulation time period spanning 10/1/1989 – 9/30/2004. TOPNET calibration used streamflow measurements at multiple locations including the Bear River at the Idaho-Utah State line, the Bear River at Smithfield, and the Cub River near Richmond, UT. The Multi-Objective Shuffled Complex Evolution Metropolis (MOSCEM) (Vrugt et al. 2003) global optimization algorithm was chosen to assist in model calibration due to the ability to optimize multiple objectives (i.e., observed streamflow locations) simultaneously. The calibration time period was limited to the time frame with available daily rainfall, streamflow, and diversion measurements. Streamflow data was simultaneously available for model calibration throughout the six year time period of 1989-1995 at the Idaho-Utah border and Bear River at Smithfield locations. Model validation occurred at the Idaho-Utah border and at the Cub River near Richmond when data was available from 1995-2004.
Once the TOPNET calibration was complete, VSA calculations were performed for each day of the entire simulation period resulting in maps of seasonal water yields across each subbasin (Figure 4).
Figure 4. Cumulative saturation excess runoff per pixel for each season for a portion of the Bear River basin in Utah.
Next, the Loading Model and QUAL2E portion of the WBR were populated and calibrated. Calibration of these components consists of calibrating kinetic parameters within QUAL2E and adjusting EMCs. In this application, kinetic parameters were based on literature, and EMC values for each landuse were initially approximated from the literature. However, the EMCs were adjusted until predicted instream concentrations visually matched observed water quality data.

Once the EMC values for each landuse were set, the loads per pixel (Figure 5) were calculated based on the cumulative saturation excess yields (Figure 4) predicted by the VSA calculations. Given local data about field boundaries, field loads were calculated (Figure 6). Necessary information for determining field boundaries and ownership was only available for a portion of the basin and therefore, field loads were only calculated where boundary data was available. Table 1 shows an example subset of the modeling output used to create the maps in Figure 3. Field ID 14514 is the field we will focus on in this example.
Figure 5. Cumulative total phosphorus loads per pixel for each season for a portion of the Bear River basin in Utah.
Figure 6. Field total phosphorus loads for each season for a portion of the Bear River basin in Utah.
Table 1. Subset of Bear River total phosphorus field loads per season.

<table>
<thead>
<tr>
<th>Subbasin #</th>
<th>Field ID</th>
<th>Field Area (m²)</th>
<th>Farm ID</th>
<th>Ave Winter TP Load (g/season)</th>
<th>Ave Spring TP Load (g/season)</th>
<th>Ave Summer TP Load (g/season)</th>
<th>Ave Fall TP Load (g/season)</th>
<th>Ave EMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11214</td>
<td>900</td>
<td>36971</td>
<td>0.9</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>1</td>
<td>9938</td>
<td>900</td>
<td>36591</td>
<td>0.9</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>…</td>
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<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
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</tr>
<tr>
<td>39</td>
<td>14514</td>
<td>372600</td>
<td>-1</td>
<td>1306</td>
<td>798</td>
<td>272</td>
<td>1017</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>50</td>
<td>13805</td>
<td>900</td>
<td>20782</td>
<td>1.2</td>
<td>1.2</td>
<td>0.3</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>50</td>
<td>13805</td>
<td>900</td>
<td>22305</td>
<td>1.2</td>
<td>1.2</td>
<td>0.3</td>
<td>0.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Next, delivery ratios were calculated within the modeling framework for the reach within each subbasin. Table 2 shows a subset of the delivery ratio results. In this watershed, the dominant factors affecting the amount of a pollutant reaching a receptor point are diversions due to short travel times. Therefore, if a field is located below all major diversions, the associated delivery ratio will be very close to 1.00. Once the delivery ratios were calculated for each subbasin, the overall delivery ratio was calculated for the receptor point of interest. As mentioned earlier, in the Bear River watershed there are two major receptor points of interest. In the Field ID 14514 example, the receptor points of interest are both the mouth of the Cub River where it enters the Bear River (subbasin 24) and Cutler Reservoir (subbasin 1) (see Figure 2).
Table 2. Table of seasonal subbasin delivery ratios between each subbasin in the Bear River Basin.

<table>
<thead>
<tr>
<th>Subbasin #</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>24</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>25</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>26</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>27</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>28</td>
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<td>1.00</td>
<td>1.00</td>
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<tr>
<td>29</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>30</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>31</td>
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<td>0.99</td>
<td>0.83</td>
<td>1.00</td>
</tr>
<tr>
<td>32</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>33</td>
<td>0.93</td>
<td>0.93</td>
<td>0.93</td>
<td>0.99</td>
</tr>
<tr>
<td>34</td>
<td>0.96</td>
<td>0.54</td>
<td>0.02</td>
<td>0.99</td>
</tr>
<tr>
<td>35</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>36</td>
<td>1.00</td>
<td>0.97</td>
<td>0.68</td>
<td>0.99</td>
</tr>
<tr>
<td>37</td>
<td>0.96</td>
<td>0.54</td>
<td>0.02</td>
<td>0.99</td>
</tr>
<tr>
<td>38</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>39</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>49</td>
<td>0.95</td>
<td>0.44</td>
<td>0.03</td>
<td>1.00</td>
</tr>
<tr>
<td>50</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
In this hypothetical example, the seasonal *tradable load* from Field ID 14514 needs to be calculated because, according to the local contact, this particular farmer tends to contribute large phosphorus loads and has expressed an interest in participating in trading. From Table 1, Field ID 14514 has a seasonal *current load* of 1306 g in the winter, 798 g in the spring, 272 g in the summer, and 1017 g in the fall. This table also shows that this field is located in subbasin 39 which provides an understanding of the location of the field within the entire basin. The network of subbasin connectivity (shown in Figure 7) is known, and, therefore, the subbasins that lie between the subbasin containing the field and the receptor point are known. With this information, the *overall* seasonal delivery ratio was calculated for each receptor point. In our example, the load from the field will travel from subbasin 39 to 38, 31, 30, 29, 28, 27, 26, 25, and then to the receptor point at 24 (Figure 7). Table 2 consists of subbasin delivery ratios for each of these subbasins. To determine the *overall* subbasin delivery ratios for the Mouth of the Cub receptor point (subbasin 24), each subbasin delivery ratio will have to be multiplied by all of the downstream subbasin delivery ratios to determine the seasonal delivery ratio according to Equation (5).

Based on seasonal subbasin delivery ratios, Table 3 shows the resulting seasonal *overall* delivery ratios to the Mouth of the Cub River receptor point (subbasin 24) and for the Cutler Reservoir Receptor Point (subbasin 1) much further down in the watershed. These values would be applied to Field ID 14514 (and all of the other fields within subbasin 39) to determine the *delivered load* to these receptor points.
Figure 7. Portion of the Cub River within the Bear River Basin showing subbasin numbering scheme.

Table 3. Seasonal overall delivery ratios for fields in subbasin 39 for both receptor points of interest.
The calculated overall delivery ratio results (Table 3) show that 100% of the Field ID 14514 load will be delivered to the Cub receptor point during the winter. However, there is some loss during spring (98.4% delivered) and fall (99.4% delivered). In summer, primarily due to diversions, there is a much lower delivery ratio (82.6% delivered) and will result in less phosphorus that will be available for trade. If the Cutler River Receptor Point is being considered, the delivery ratios are substantially lower and the field owner will have a much lower delivered load to this receptor point.

With the seasonal delivery ratios and the seasonal field loads, the seasonal delivered loads can now be calculated according to Equation (7). The resulting loads are shown in Table 4.

<table>
<thead>
<tr>
<th>Season</th>
<th>Cub Receptor Point (Subbasin 24)</th>
<th>Cutler Receptor Point (Subbasin 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>1.000</td>
<td>0.885</td>
</tr>
<tr>
<td>Spring</td>
<td>0.985</td>
<td>0.288</td>
</tr>
<tr>
<td>Summer</td>
<td>0.828</td>
<td>0.017</td>
</tr>
<tr>
<td>Fall</td>
<td>0.992</td>
<td>0.940</td>
</tr>
</tbody>
</table>

Table 4. Seasonal Delivered Loads for Field ID 14514 (grams) to Cub River Mouth (Subbasin 24) and Cutler Reservoir (Subbasin 1).
<table>
<thead>
<tr>
<th></th>
<th>Cub (Subbasin 24)</th>
<th>1</th>
<th>0.98</th>
<th>0.83</th>
<th>0.99</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delivered Loads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cub (Subbasin 24)</td>
<td>1306</td>
<td>786</td>
<td>225</td>
<td>1011</td>
<td></td>
</tr>
<tr>
<td>Cutler (Subbasin 1)</td>
<td>0.89</td>
<td>0.29</td>
<td>0.02</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td><strong>Delivered Loads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cub (Subbasin 24)</td>
<td>1156</td>
<td>230</td>
<td>5</td>
<td>956</td>
<td></td>
</tr>
</tbody>
</table>

With the seasonal delivery ratios and seasonal delivered loads now determined, the seasonal tradable loads can be calculated. As shown in Equation (2), a % BMP reduction is required to be provided. For this particular field, we will assume that a 50% reduction of total phosphorus can be achieved through the use of a filter strip. The resulting seasonal tradable loads for the Cub River Receptor Point are winter = 653 g, spring = 393 g, summer = 112 g, fall = 506 g.

Once these seasonal tradable loads have been calculated, a field owner now knows the possible amount of total phosphorus they have available to sell for a particular receptor point. To implement a trading program, participants and facilitators may need to consider how to incorporate TMDL load reduction requirements, safety factors/uncertainty ratios, retirement ratios, etc. into the tradable load calculations. In this example, simplifying assumptions were made to illustrate how to use modeling results to calculate tradable loads.

Limitations of the Water Quality Trading Modeling Framework
Throughout the development of this modeling framework and approach, a number of limitations were identified. Under the current framework, land surface loads are not routed within the subbasin of origin and therefore, no assimilation occurs at the local scale. All assimilation occurs once the load enters the WBR component. Due to loads being handled in this manner, each individual load produced within a subbasin ends up having the same delivery ratio to a receptor point of interest. This means that regardless of a field’s proximity to a small tributary, the delivery ratio within a subbasin will not differ.

Given the current implementation, it is also necessary that this system be applied to watersheds that have relatively short travel times from top to bottom. The QUAL2E portion of the model is steady state with respect to flows, loadings, and most other inputs (temperature and dissolved oxygen can be solved in a ‘quasi-dynamic’ model but this feature is not used in this application). The hydrology and loading models calculate daily average flows and the daily loads at each drainage outlet, and these conditions are used to drive the stream model, so that the stream model is calculating the steady-state response to those daily average loadings. The process is repeated for each time step. In order for this approach to be representative of instream conditions, the effects of one day’s load should clear the stream reach before the next day’s load is applied. Since rivers can be assumed to be advection dominated, the travel time from the top to the bottom of the system is the key characteristic time. Both of these limitations are acceptable in many applications.
Some other limitations that require future research and development include: the need to incorporate infiltration excess flow into the VSA component instead of assuming that saturation excess represents the dominant source of surface runoff; the need to validate the VSA predictions within each subbasin; and the need to enforce hydrologic connectivity of saturated cells to a waterbody in order to transport sediment and phosphorous and contribute to surface loads. Additionally, the implications of using the TOPMODEL representation of the saturated zone in this semi-arid watershed are unclear. It is also not known how the calibration results for the TOPNET modeling would change given additional flow data in the lower portion of the Bear River and an extended record of streamflow data to use in the model fitting. Although not currently available, increased information about agricultural water management, including diversions and return flow, would likely improve the model representation during the irrigation season. Finally, the appropriate subbasin scaling of soil parameters such as drainable porosity and soil moisture deficit remains unknown without field data verification.

**Conclusions**

The growing number of impaired waterbodies in the United States necessitates new approaches and incentives to control pollution. The potential solution of setting up water quality trading programs, however, requires the quantification of both point and nonpoint sources of pollution and an understanding of how pollutants behave in individual hydrologic systems. The modeling framework presented in this paper to assist in estimating field *current loads* and the corresponding overall delivery ratios is an
objective and scientifically based mechanism to support a water quality trading program. Example calculations have additionally shown how the information estimated using this model framework can be utilized to calculate the \textit{delivered loads} and eventually, the amount of pollution a field owner could potentially trade, or \textit{tradable loads}. The results from this effort can also be used to support the determination of whether a water quality trading program is economically feasible in each watershed.

References


Assessing the Potential for Water Quality Trading in the Bear River Watershed

by

Jason R. Whitehead

A thesis submitted in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Applied Economics
(Natural Resource and Environmental Economics)

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Assessing the Potential for Water Quality Trading

In the Bear River Watershed

by

Jason R. Whitehead, Master of Science
Utah State University, 2006

Major Professor: Dr. Arthur Caplan
Department: Economics

The purpose of this thesis is to assess the potential for water quality trading in the Bear River Watershed by following the U.S. Environmental Protection Agency’s water quality trading guidelines (2004). Chapter I of this thesis introduces general issues pertinent to water quality. The chapter summarizes regulatory approaches taken by the United States to address water quality concerns; specifically the United States Clean Water Act and the total maximum daily load management planning process are discussed. The chapter also describes common water quality concerns in the United States, i.e., nutrient pollution from non-point sources that create the need to examine whether economic incentives, i.e., a water quality trading program, can be used to lower pollutant loadings in water bodies and remain financially feasible. Chapter II discusses the economic theory related to water quality trading and explains the U.S. Environmental Protection Agency’s water quality trading guidelines (2004). Chapter III attempts to apply the U.S. Environmental Protection Agency’s guidelines (2004) to the Cub River Watershed. To highlight the feasibility of trading, Chapter IV presents potential trading
scenarios. It is concluded in Chapter V that water quality trading for total phosphorus is financially feasible in the Bear River Watershed based on the given assumptions used in the analysis. Chapter V summarizes the results and discusses future research the author considers necessary.

(117 pages)

Appendix 8.4 B Survey of Effluent Managers

Survey of Effluent Managers

Arthur Caplan
Jason Whitehead

Applied Economics
(Natural Resource and Environmental Economics)
Utah State University
Survey of Effluent Managers

1. Name of company/facility _______________________________________________

2. Please provide an estimate of the amount of dry and wet sludge (in tons or pounds) that your facility currently handles on an average day, as well as an estimate of the % solids of the wet sludge. For your % solids measure, please indicate whether your estimate is based on waste sludge from an aeration tank, if the sludge has been gravity thickened, and if the sludge has been dewatered on a belt filter press.

   Dry Sludge ________________
   Wet Sludge ________________
   % Solids __________________________________________________

3. If you have estimated the cost of implementing new technology to control the discharge of Total Phosphorus (TP) at your facility from (i) your current TP concentration down to 1 mg/L, (ii) 1 mg/L down to 0.5 mg/L, and (iii) 0.5 mg/L down to 0.1 mg/L, or if you have already implemented new technology and have therefore incurred the associated cost, please provide these estimates below (in dollars).

   **Step 1 Technology** (current concentration → 1 mg/L)
   Name of Technology ________________________________
   Cost of Technology ($) ________________________________

   **Step 2 Technology** (1 mg/L → 0.5 mg/L)
   Name of Technology ________________________________
   Cost of Technology ($) ________________________________

   **Step 3 Technology** (0.5 mg/L → 0.1 mg/L)
   Name of Technology ________________________________
   Cost of Technology ($) ________________________________

Thank you!
Appendix 8.5 Estimates of Phosphorus Abatement Costs

Estimates of Phosphorus Abatement Costs

By Terry Glover

Economics and Finance
Jon M. Huntsman
School of Business
Utah State University
1.0 Overview of Costs Information Relative to Phosphorus Abatement

There are several cost components that have to be reviewed in order to understand the cost elements and conditions of phosphorus abatement at the point discharge source and at the nonpoint discharge source. The effectiveness of water quality trading programs for reducing total phosphorus in impaired streams such as those river systems that within the Bear River watershed highly depend on the cost savings achieved by a trade and the ongoing trading process either between a point discharge source and a nonpoint source or even possibly between nonpoint sources. A low control cost source discharges less phosphorus in order for a high cost source to discharge more within the rules of a phosphorus reduction regulation such as imposed by the Total Maximum Daily Load mandated reduction. So there has to be a significant difference in costs to provide incentives for ongoing trading. The important cost difference has to be between a point discharge source and nonpoint discharge sources to drive the point-nonpoint trade. There may be other cost component differences that drive nonpoint-to-nonpoint source trades and there may be several cost components and cost differences associated with phosphorus abatement at the nonpoint discharger level.

In general, further reductions in phosphorus load to meet National Pollution Discharge Elimination System (NPDES) standards set by the states (Idaho, Utah and Wyoming in the case of the Bear River Watershed) at the point source level require Tier 2 and Tier 3 level treatment at waste water treatment plants (the WTTP). Point source animal confinement operations also have to be permitted and adopt manure management plans in order to achieve reductions in phosphorus. Nonpoint sources are exempt from the Clean Water Act (CWA) provisions, but may be brought into compliance through extension of the NPDES permitting system or by various programs to regulate phosphorus discharges if the states exercise their wide latitude of powers under the CWA provisions. In these latter cases, the regulation prescribes best management (BMPs) and reduction technologies that have to be adopted by the nonpoint discharge sources. There are several alternative BMP practices that influence the costs associated with their adoption and management such as riparian restoration, alternative irrigation application, conservation tillage, grass strips, manure management systems, crop rotation alternatives and other production process. The effectiveness of these BMPs is also of concern and alters the cost of adoption and operation considerably.

2.0 Projections of Waste Water Treatment Costs to Reduce Phosphorus Discharge

Whitehead (2004) developed some cost levels for phosphorus reduction for the three waste water treatment plants that are within the Cub River watershed which is a tributary to the Middle Bear River, the latter of which then flows into the Cutler reservoir. These cost estimates were developed from averages of cost estimates for phosphorus reduction using alternative methodologies to develop the reductions and the costs involved. Additional details on the underlying assumptions and estimation methodology are found in the Whitehead M.S. thesis completed under the sponsorship of this Targeted Watershed project in the Department of Economics at Utah State University contained in Appendix
A of this section of the report. Much more detail on cost projection methodology and the resulting estimates is given in the thesis, particularly chapters III and IV where the detail of the analysis is covered. Additionally, a survey sent out to waste water treatment facility officers that was developed for the Whitehead study is contained in Appendix B of this section.

One treatment plant with an average flow of 756,191 gallons per day incurs annualized cost of $168.60 per pound reduction using Tier 2 treatment for the reduction of total phosphorus and has to add Tier 3 treatment to get to the 0.05 mg/L level of Phosphorus discharge. The Tier 3 treatment has a lower estimated cost of $72.45 per pound but greater reduction of phosphorus has to be accomplished with the Tier 3 treatment than the Tier 2 process. Another plant with average flow of 208,350 gallons per day incurs a cost of $152.91 per pound of phosphorus reduction using Tier 2 treatment and $186.90 per pound reduction in phosphorus discharge using Tier 3 treatment to get to the 0.05 mg/L standard. The third plant with an average flow of 25,853 gallons per day has a cost of $1,364.29 per pound for Tier 2 and $4,261 per pound phosphorus reduction for Tier 3 treatment. All of these costs are in 2004 dollars.

Glover (2000) developed some costs of biological phosphorus removal at a treatment plant with discharges that eventually find their way to the East Canyon Reservoir located in the mountains of the Wasatch Front area of Utah. These costs have been indexed to 2007 dollar values. The updated costs of reducing phosphorus from 2 mg/L to a 0.1 mg/L runs $1,850.79 per pound of reduction and $13,993.51 per pound to go from 0.1 mg/L to a Utah standard of 0.05 mg/L. So there is a wide range of costs depending on phosphorus reduction levels and the treatment technology used to meet the lower concentrations of phosphorus in the effluent.

3.0 Costs of BMP Implementations to Reduce Phosphorus Loading

It is cost differences between trading entities that drives the negotiations and initiation of water quality trading. The low cost discharge source is usually assumed to discharge less nutrient effluent in order for a high cost discharge source to buy credits or allowances in order to discharge more if there is an environmentally equivalent condition for such a trade to take place and reduce total nutrient discharge. It is often reported that nonpoint sources, mainly agricultural operations, are the low cost discharge sources and therefore would take the seller position in any trade negotiations (Faeth, 2000; and Ribaudo et al. 2005). So it has been important in this particular study to verify these assumptions as they relate to the Bear River Watershed and the potential nonpoint source costs that are, and would be in the future, lower costs of investment in and operation of best management practices (BMPs) in order to initiate the future reduction in phosphorus discharge in order to meet TMDL regulations using the water quality trading policy tool.

Whitehead (2004) has obtained some cost estimates from various sources and we report these in Table 1 below. Farm units in the Cub River watershed were identified in the Whitehead study using GIS tools, and phosphorus reductions were estimated, mainly using phosphorus load conditions from other than Cub River area conditions and using
PLOAD (a GIS tool) to calculate total phosphorus from fields. This is a different approach to projecting phosphorus loads than was completed in the water quality modeling and field load identification as reported later in this report for the Bear River and the Little Bear River areas. Then estimates of reductions in phosphorus were made with assumptions about export coefficients reflecting the movement of phosphorus to flow lines and to tributaries to the Cub River and actually into the river. The Cub River enters the Middle Bear River section of the Bear River in northern Utah. Then cost estimates associated with these reductions were projected. Four types of BMP controls were considered in the Whitehead study, namely, conservation tillage, nutrient management systems, grass filters, and animal waste system for dairies. The costs are in 2004 dollars.

Table 1. Estimated Costs of Phosphorus Reduction in the Cub River Watershed ($/lb.)

<table>
<thead>
<tr>
<th>BMP Type</th>
<th>Conservation tillage</th>
<th>Nutrient planning management</th>
<th>Grass filter</th>
<th>Animal waste system for dairies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean cost</td>
<td>2.08</td>
<td>7.83</td>
<td>0.85</td>
<td>73.77</td>
</tr>
<tr>
<td>Maximum cost</td>
<td>8.15</td>
<td>30.73</td>
<td>3.36</td>
<td>92.27</td>
</tr>
<tr>
<td>Minimum cost</td>
<td>0.93</td>
<td>3.54</td>
<td>0.39</td>
<td>66.36</td>
</tr>
</tbody>
</table>

The assumptions on the effectiveness of the BMPs listed in Table 1 are that conservation tillage practices can reduce up to 66 percent of the phosphorus load per field. Nutrient planning management effectiveness is less at 45 percent while grass filter practices are estimated to reduce phosphorus field load at 50 percent. Animal waste systems adopted by dairies are assumed to only reduce 30 percent of the phosphorus load of any given dairy. In this latter case there would have to be a combination of BMP implementations to reduce dairy phosphorus loads in order to meet Idaho and Utah standards of target load. So the costs for the animal waste system are only part of the costs that dairies would have to bare in order to meet current water quality standards. There are animal waste systems that are combined with digester complexes in Utah and Idaho, but their effectiveness in converting manure to methane and the costs of such conversion are still being investigated as the systems have only recently been built and are just initiating operation. Capital costs for these systems are running in the $700,000 to $1,000,000 range depending on the collection system and the size of the dairy herd (Glover 2007; Hansen, 2005).

Nonpoint sources and various agencies which provide advice on BMP costs and implementation should recognize that costs become specific to types of BMPs and the conditions under which they are introduced in order to bring about nutrient discharge reductions. Additional information is needed about actual on-farm costs of the implementation of BMPs for the Bear River Watershed. However, these estimates do provide some information on the level of costs for the BMPs considered and which would most likely have to be implemented in the watershed. The costs for the grass filter given in Table 1 may be considerably underestimated since there would be approximately 5
percent of the land of a farm that would be in grass and row crop or alfalfa production would be decreased.

Johansson (2000) provides another set of estimates of the cost of phosphorus reduction by implementing BMPs but the estimates are made for the Lower Minnesota River basin in the upper Midwest. The primary crop production patterns for this area are row crop rotations and continuous row crop with corn and soybeans being the rotation and continuous corn being the continuous crop pattern. Pasture is also included. These reduction and cost estimates are of interest since fertilizer application method and amount applied is included with each tillage practice as part of the BMP implementation. The BMP, percent reduction of phosphorus and cost per pound of phosphorus reduction (in 2000 dollars) are given in Table 2.

Table 2. BMP, Phosphorus Reduction, and Cost per Pound Reduction Estimates for Phosphorus Reduction in the Lower Minnesota River Basin.

<table>
<thead>
<tr>
<th>Cropping Pattern</th>
<th>Tillage</th>
<th>Method of Fertilizer Application</th>
<th>Fertilizer Rate</th>
<th>Percent Phosphorus Reduction</th>
<th>Cost per Pound of Phosphorus Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>Conventional</td>
<td>Broadcast</td>
<td>High</td>
<td>Base case – no reduction</td>
<td>$29.26</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conventional</td>
<td>Broadcast</td>
<td>Medium</td>
<td>17</td>
<td>$29.26</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conventional</td>
<td>Broadcast</td>
<td>Low</td>
<td>26</td>
<td>$50.68</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conventional</td>
<td>Incorporated</td>
<td>High</td>
<td>22</td>
<td>$7.21</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conventional</td>
<td>Incorporated</td>
<td>Medium</td>
<td>24</td>
<td>$34.00</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conventional</td>
<td>Incorporated</td>
<td>Low</td>
<td>26</td>
<td>$48.29</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conservation</td>
<td>Broadcast</td>
<td>High</td>
<td>29</td>
<td>$7.48</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conservation</td>
<td>Broadcast</td>
<td>Medium</td>
<td>40</td>
<td>$16.89</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conservation</td>
<td>Broadcast</td>
<td>Low</td>
<td>52</td>
<td>$27.77</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conservation</td>
<td>Incorporated</td>
<td>High</td>
<td>49</td>
<td>$7.66</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conservation</td>
<td>Incorporated</td>
<td>Medium</td>
<td>49</td>
<td>$19.72</td>
</tr>
<tr>
<td>Rotation</td>
<td>Conservation</td>
<td>Incorporated</td>
<td>Low</td>
<td>52</td>
<td>$26.68</td>
</tr>
<tr>
<td>Pasture</td>
<td>No Tillage</td>
<td>No fertilizer</td>
<td>No fertilizer</td>
<td>62</td>
<td>$295.41</td>
</tr>
<tr>
<td>Continuous</td>
<td>Conventional</td>
<td>Broadcast</td>
<td>High</td>
<td>Increases discharge</td>
<td>$1,095</td>
</tr>
</tbody>
</table>

The costs per pound of phosphorus reduced by implementation of the BMPs are mixed between the conventional tillage and fertilizer application options in this Minnesota case. The other element of influence in these numbers is the reductions of phosphorus that are attained in different soil complexes which exist in the watershed. The percentage reduction attained is what tells the story on abatement when shifting from the conventional tillage practice to conservation tillage and the fertilizer application method and amount applied. Except for the conservation tillage BMP at high application rate, which actually provides a higher percentage than all conventional tillage cases, all the conservation tillage cases yield reduction percentages above 40 percent. The 40 percent
reduction level has been a target for nonpoint source reduction in several proposed uniform reduction plans in extending regulation to the nonpoint sources. There appears to be a jump in effectiveness noted in the above figures for the Minnesota River case from the conventional BMP cases to plus or minus 50 percent for most conservation tillage implementations, and the cost per pound reduced is increasing, in general, as fertilizer application is reduced. The costs are considerably higher than the costs projected by the Whitehead study, but the Whitehead study does not take into account soil conditions and fertilizer application conditions.

Recently Bowcutt and Daugs (2008) attempted to derive estimates of BMP costs that are to be more representative of conditions in the Bear River Watershed using Potomac River Watershed cost data and matching these data with Natural Resource Conservation Service (NRCS) BMP price listing information for BMP project implementation capital and operating costs. The estimates were developed in order to provide information to the Cutler Group and to Logan City (contributor of discharge into the Cutler Reservoir) future waste water treatment planning process. The main target for which this information was intended was for planning purposes for Logan City to develop plans to comply with discharge regulations pertaining to the Cutler Reservoir. However, some interesting BMP cost information comes out of this report both for nonpoint sources and for waste water treatment plant point source discharge planning. The costs per pound of phosphorus removed are significantly higher than both the Whitehead and the Johansson estimates previously reviewed. This may be a related to the use of the Potomac River phosphorus reduction data and also due to the fact that capital costs of implementation were apparently not amortized over the life of the specific BMPs included in the study. However, additional information is contained in the estimates on an expanded set of BMP strategies such as land retirement, fencing, cover crops, and sprinkler irrigation alternatives.

A summary of the BMP, phosphorus reduction, and cost per pound of phosphorus reduction information from this report is given in Table 3. The phosphorus reduction is reported in either pounds/acre for pounds/linear foot except for the animal waste facility for which the reduction is the total reduction of phosphorus estimated for a system. The cost estimates are in current 2008 dollars.

The most interesting of the estimates is the projected phosphorus reduction and the cost per pound of phosphorus reduction that is projected for the introduction of sprinkler irrigation. This reduction alternative is mainly attractive in these estimates because of the phosphorus reduction and this reduction at somewhere around a conventional tillage cost that has little reduction effectiveness. Certainly this alternative is attractive as an approach to discharge reduction and particularly attractive to a point discharge source as an alternative to Tier 2 and Tier 3 treatment at the waste water treatment plant. Of course there are pipeline costs that are involved if a community transports effluent to neighboring nonpoint source sprinkler irrigation operations, but the pipeline investment would also be a part of the capital costs of setting up this BMP as a public agency waste water treatment alternative in addition to treatment at the existing waste water treatment plant facility. Land acquisition costs are probably not included in the Bowcutt-Daug
projections and if included would perhaps increase the cost per pound of phosphorus reduction significantly. Land transaction cost is what is making the land retirement alternative relatively expensive although there is considerable discussion about the

Table 3. Estimated Phosphorus reduction and cost per pound of phosphorus reduction for alternative BMPs possibilities of land retirement as an alternative water quality improvement program at the same time it is a land use preservation alternative.

<table>
<thead>
<tr>
<th>BMP</th>
<th>Pounds of phosphorus reduction per acre (or linear foot)</th>
<th>Cost per pound of phosphorus reduction ($/lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land retirement</td>
<td>1.65/acre</td>
<td>3,342</td>
</tr>
<tr>
<td>Grazing land protection</td>
<td>0.194/acre</td>
<td>108</td>
</tr>
<tr>
<td>Stream fencing</td>
<td>0.016/linear foot</td>
<td>623</td>
</tr>
<tr>
<td>Stream bank stabilization</td>
<td>0.14/linear foot</td>
<td>7</td>
</tr>
<tr>
<td>Cover crops</td>
<td>0.39/acre</td>
<td>306</td>
</tr>
<tr>
<td>Grass filter strips</td>
<td>1.28/acre</td>
<td>187</td>
</tr>
<tr>
<td>Animal waste facility</td>
<td>241.84 per system</td>
<td>331</td>
</tr>
<tr>
<td>Conservation tillage</td>
<td>0.18/acre</td>
<td>153</td>
</tr>
<tr>
<td>Agricultural nutrient management</td>
<td>0.39/acre</td>
<td>76</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td>26/acre</td>
<td>58</td>
</tr>
</tbody>
</table>

The conservation tillage and grass strip options are significantly higher in cost relative to the Johansson and Whitehead costs presented earlier. It is shown in Bowcutt-Daug's projections in Table 3 is that fencing and stream bank stabilization do not yield great reductions in phosphorus movement from the field to the stream relative to the phosphorus reduction costs even though the cost of stream bank stabilization appears to be minimal. The effectiveness of these 10 BMP options is not shown in the table and more information would be needed from the report to develop some estimates of effectiveness percent for each alternative.

4.0 Nonpoint Source-Point Source Cost Comparisons

What is shown by here by the cost comparisons that have been displayed by the three cost projections that have been summarized is that there are significant differences in point source costs relative to nonpoint costs that would provide incentive for point source-to-nonpoint source initiation of trading activity. If one looks at the appendix in the Whitehead study there are some projected differences in costs between nonpoint sources that would make a limited number of nonpoint-to-nonpoint source trades viable. However, for the most part one can conclude that trade viability is for the Bear River Watershed focus trading area is going to be point source trading with the nonpoint source discharges on a basis that the nonpoint sources are brought into regulation via the state’s exercise of broad latitude under regulation of the Clean Water Act provisions or brought into trading negotiations through the extended NPDES process that finances the phosphorus reductions of nonpoint source discharges through the point sources.
References


Hansen, Conly. 2005. Research and Demonstration of an anaerobic system on a large dairy farm. Report of the Center for Profitable Uses of Agricultural Byproducts (CPUAB), Utah State University, Logan, Utah.


Appendix 8.6 Cooperative Surplus Sharing: Interactive Geometry for Surplus Sharing in Cooperative Games

COOPERATIVE
SURPLUS SHARING

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The use of Cooperative Game Theory to model Trading Surplus Allocation

This appendix contains a manuscript by Arthur Caplan and Yuya Sasaki submitted for review to the *Journal of Economic Education* which develops an algorithm for the sharing of economic surplus generating by exchange opportunities using cooperative game theory concepts. The algorithm developed will be used to derive cooperative arrangements in water quality trading strategies. The cooperative game theory model introduces several assumption that are part of the description of the behavior of economic agents as they make agreements among each other to share economic surplus that is generated by trades. The theory incorporates the underlying behavior of economic agents as they respond to incentives and move to negotiate cooperative arrangements with mutual benefit. Economic agents will engage in cooperative arrangements only if such arrangements can improve their economic situation compared with the status quo.

Water quality trading is one such arrangement that can be initiated in a cooperative sharing of surplus that derives from the trading if internal incentives and surplus are generated by the trading activity. The paper contained in this appendix develops an algorithm for comparing incentives and surplus values of agents in order to derive a sharing agreement and solution. The solution concepts used in the algorithm are the Shapley Value, Nucleolus and per capita Nucleolus solution concepts in cooperative game theory. A software algorithm has been developed by Yuya Sasaki which uses trading, incentive, and economic surplus to find these cooperative solutions, if they exist given the data on trading incentives. The algorithm develops the solutions which, in the case of water quality trading, provide information on the viability of certain cooperative agreements that arise out of the initiation of trading between economic agents as parties to the possible trading agreements. This algorithm is being used to sort out viable trades in the Bear River Watershed given cost information, internal incentive structure of costs and the opportunity to derive surplus from mutually beneficial agreements between nonpoint discharge sources and point discharge sources. The use of these concepts is found in other studies of water resource economics and various policymaking setting in natural resource and environmental settings (see, Dinar, et al. 2008).

Interactive Geometry for Surplus Sharing in Cooperative Games

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Abstract: This paper presents interactive geometrical depictions of the Shapley value, nucleolus, and per-capita nucleolus surplus-sharing rules for cooperative games with three players. The program graphically demonstrates how the simplexes corresponding to a host of characteristic functions are "shrunk" to their corresponding cores, calculates allocations using the Shapley Value, nucleolus, and per-capita nucleolus surplus-sharing rules, and graphically depicts the locations of these allocations in the corresponding cores.

Key Words: core, Shapley value, nucleolus, simplex, characteristic function, graphical user interface

JEL Classification: A22, A23, C71
Interactive Geometry for Surplus Sharing in Cooperative Games

1. Introduction
The need to understand surplus- and cost-sharing rules in cooperative game theory is prevalent at both the undergraduate and graduate levels (Moulin, 1988 and 2004). However, the rules are generally depicted as raw mathematical problems that entail the calculation of a vector of allocations. This paper presents interactive geometrical depictions of the rules for games with small numbers of players (the executable program in win32 platform is available at http://cc.usu.edu/~slk1r/teaching/tugames/tugame.htm). The program (i) demonstrates how the simplexes associated with a host of characteristic functions are "shrunk" to their corresponding cores, (ii) calculates the corresponding allocations using the Shapley Value, nucleolus, and per-capita nucleolus surplus-sharing rules, and (iii) graphically depicts the locations of these allocations in the corresponding cores. It is therefore a supplementary tool that can be used to enhance the instruction of surplus-sharing rules in either undergraduate- or graduate-level cooperative game theory courses.

The next section discusses the relevant preliminaries of cooperative game theory, focusing on derivations of the Shapley Value and nucleolus surplus-sharing algorithms. Section 3 discusses the interactive geometry for these rules. Section 4 concludes.

2. Preliminaries of Cooperative Games
Let $N$ be a set of $n$ players with $2^N$ denoting the corresponding power set of $N$ (i.e., the set of all possible coalitions based on $N$, including the empty and grand coalitions) and $v : 2^N \to R$ denoting a characteristic function that allocates some outcome (e.g., coalitional cost or surplus) among each element of $2^N$. An allocation in the grand coalition of the $n$ players is represented by $x = (x_1, \ldots, x_n)$. The core of the game $(N, v)$ is the set of all allocations that induces each of the $n$ players to rationally join in the formation of the grand coalition, i.e.,

$$\text{core}(N, v) = \left\{ x : \sum_{i \in N'} x_i \geq v(N') \text{ for all coalitions } N' \in 2^N \right\}.$$

Provided that \( v \) generates solely positive values (i.e., surplus as opposed to cost), three common types of games are typically considered:

(i) **Additive**: for all disjoint coalitions \( N_1, N_2 \in 2^N \), \( v(N_1 \cup N_2) = v(N_1) + v(N_2) \)

(ii) **Superadditive**: for all disjoint \( N_1, N_2 \in 2^N \), \( v(N_1 \cup N_2) \geq v(N_1) + v(N_2) \)

(iii) **Convex**: for all \( N_1, N_2 \in 2^N \), \( v(N_1 \cup N_2) + v(N_1 \cap N_2) \geq v(N_1) + v(N_2) \)

The core for games of type (i) is a singleton, i.e., \( x_i = v(\{i\}) \) for each player \( i \), corresponding to the Shapley value. Games of type (iii) guarantee a non-empty core that includes the Shapley value. Games of type (ii) are a parent class of types (i) and (iii), but unlike types (i) and (ii) the existence of the Shapley value in the core is not ensured.\(^1\)

We can represent the marginal contribution of agent \( i \) to coalition \( N' \) as \( v(N' \cup \{i\}) - v(N') \) where \( i \notin N' \). We have as many as \( 2^{|N'|-1} \) such values relative to all possible coalitions in \( 2^{N'\setminus\{i\}} \), where \(|N'|\) represents the cardinality of coalition \( N' \). An allocation obtained by a weighted average of these marginal contributions therefore accounts for the "marginality" of this agent. A special set of weights yielding allocations

\[
x_i = \sum_{N' \in 2^{N\setminus\{i\}}} \frac{|N'|!(n-|N'|-1)!}{n!} \left[ v(N' \cup \{i\}) - v(N') \right],
\]

is known as the Shapley value (SV) of game \((N, v)\).

Calculation of the SV is straight-forward, particularly for games with small numbers of players. For example, in the three-player game with coalitional surpluses depicted in Table 1,

\[
x_1 = \frac{2!}{3!} (9 - 6) + \frac{1!}{3!} (5 - 3) + \frac{1!}{3!} (4 - 2) + \frac{0!}{3!} (1 - 0) = 2.
\]

Similar calculations for players 2 and 3 yield allocations \( x_2 = 3 \) and \( x_3 = 4 \), respectively.

The nucleolus provides an alternative method of obtaining an allocation \( x \). Begin by noting that the net benefit, or "excess" for the members of coalition \( N' \) that results from

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\(^1\) See Moulin (1988) for further details on the relationships between additivity, superadditivity, convexity, the core, and the Shapley value. Examples of each of these outcomes for game types (i) – (iii) can be shown using the interactive geometry presented in Section 3.
joining the grand coalition is given by \( \sum_{i \in N'} x_i - v(N') \). Also note that there are \( 2^n \) values of such coalition-wise net benefits associated with forming the grand coalition (including the empty and grand coalitions). The basic concept of the nucleolus is to choose an allocation \( x \) in such a way that the best lexicin ordering of these values is obtained.\(^2\) Here, a lexicin ordering \( \tilde{\mathbf{w}} = (\tilde{w}_1, \ldots, \tilde{w}_m) \) of vector \( \mathbf{w} = (w_1, \ldots, w_m) \) is obtained by sorting \( w_1, \ldots, w_m \) in ascending order, resulting in \( \tilde{w}_1 \leq \ldots \leq \tilde{w}_m \). For example, if \( \mathbf{w} = (3,2,1) \), then \( \tilde{\mathbf{w}} = (1,2,3) \). Vector \( \mathbf{w} \) is "leximin preferred" to \( \mathbf{u} \) if there exists an \( m' \) such that
\[
\tilde{w}_{m'^{n'}} = \tilde{u}_{m'^{n'}} \quad \text{for all} \quad m'^{n'} = 1, \ldots, m'-1 \quad \text{and} \quad \tilde{w}_{m'^{n'}} > \tilde{u}_{m'^{n'}}.
\]
In other words, \( \mathbf{w} \) is lexicin preferred to \( \mathbf{u} \) if the smallest element of \( \mathbf{w} \) is greater than the smallest element of \( \mathbf{u} \), or they are equal but the second smallest element in \( \mathbf{w} \) is greater than the second smallest element in \( \mathbf{u} \), and so on (Maniquet, 2002).

If we set \( \mathbf{e}(\mathbf{x}) = \left( \sum_{i \in N} x_i - v(N) \right)_{(2^n \times 1)} \), which is a \( 2^n \times 1 \) vector accounting for each element (i.e., coalition \( N' \)) in \( 2^N \), then the nucleolus, \( x^* \), is such that \( \mathbf{e}(x^*) \) is lexicin preferred to \( \mathbf{e}(\mathbf{x}) \) for any \( \mathbf{x} \). To see how the nucleolus is determined, consider the three-player game with coalitional surpluses depicted in Table 2 (Serrano, 1999).

[INSERT TABLE 2 HERE]

Following Serrano (1999), begin by considering the "equal-split" vector of surpluses \( \mathbf{x} = (14,14,14) \), where the individual surpluses sum to \( v(N) = 42 \). Thus, \( \mathbf{e}(\mathbf{x}) = (-12,-2,8,14,14,14) \), where the worst-treated coalition is \( \{2,3\} \) with an excess of -12. From an egalitarian perspective, it therefore seems to make sense to transfer some of player 1’s surplus to players 2 or 3. Let the transfer occur from player 1 to player 3, resulting in the surplus vector \( \mathbf{z} = (4,14,24) \) and the corresponding excess vector \( \mathbf{e}(\mathbf{z}) = (-2,-2,-2,4,14,24) \). By (2) we see that \( \mathbf{e}(\mathbf{x}) \) is lexicin preferred to \( \mathbf{e}(\mathbf{z}) \). Through iterative pairwise comparisons of each lexicin-ordered excess vector, it can then be shown that \( \mathbf{z} \) is indeed the nucleolus for this particular game. Hence, the nucleolus provides an egalitarian

\(^2\) See Moulin (1988) and Serrano (1999) for further details on the nucleolus.
solution in terms of the coalition-wise net benefits associated with forming the grand coalition.

The per-capita nucleolus is obtained in the same way as the nucleolus, except that \( \sum_{i \in N'} x_i - v(N') \) is replaced with \( \sum_{i \in N'} (x_i - v(N'))/|N'| \) to account for the cardinality of each coalition. We present the pseudocode used to calculate the nucleolus in Section 3.2. (The actual C++ source code is available upon request from the authors.)

3. The Interactive Geometry

For graphical purposes, our interactive program specializes in three-player games. The interface, depicted in Figure 1 for the SV (using the characteristic function depicted in Table 1), consists of a view which draws a simplex and lines representing coalition-wise values of the characteristic function. The user can set the values for the characteristic function via a dialog box that appears by clicking the "Set" button on the toolbar (discussed further in Section 3.3). The toolbar provides three additional buttons to calculate the corresponding SV, nucleolus, and per-capita nucleolus. In the process of determining these surplus-sharing values, the core is also determined by "shrinking" the simplex according to the constraints on surpluses for each proper coalition. In the case of Figure 1, the core represents 7.4% of the total area of the simplex.

The program is built by C++ with object-oriented capabilities for graphical user interface. Figure 2 describes the overall system relations.

3.1. Construction of the Simplex and Determination of the Core

To see how the simplex is constructed and the core determined in Figure 1, consider its partial construction in Figure 3. In this figure, the simplex is shown from its three-dimensional perspective with the coordinates of each of its vertices normalized by the surplus value of the grand coalition. Recalling from Figure 1 that the allocation for the
singleton coalition \{1\} is \( x_1 = 1 \), or one-ninth of the value of the grand coalition, the area denoted A is effectively "cut away" from the simplex. Similarly, based on the allocation for the coalition \{2,3\} of \( x_2 + x_3 = 6 \), or two-thirds of the value of the grand coalition, the area denoted B is also cut away from the simplex. This cutting away process is performed for each of the proper coalitions listed in Figure 1 until the simplex has shrunk to its core, depicted as the shaded area in Figure 1.

3.2. Computation of the Surplus-Sharing Values

As discussed in Section 2, the interactive program computes and graphically depicts the SV, nucleolus, and per-capita nucleolus allocations. Computation of the SV is performed using (1). With respect to the nucleolus and per-capita nucleolus, recall that both of these surplus-sharing allocations are derived using the same algorithm, except that the latter divides the coalitional net benefits by their respective cardinalities. We therefore focus solely on the computation of the nucleolus.

Although the search for the nucleolus involves finding a maxima, gradient-based approaches (e.g., the Newton method) are not relevant since the values assigned by the lexicmin ordering are in general non-differentiable. We therefore use the following pseudocode to conduct a search in the two-dimensional simplex:

```
precision = 0.1
loop precision \geq 0.001
    loop 0 \leq x_1 \leq v(N)
        loop 0 \leq x_2 \leq v(N) - x_1
            "compare"
            \( x_2 \leftarrow x_2 + \text{precision} \)
        end loop
        \( x_1 \leftarrow x_1 + \text{precision} \)
        \( x_2 \leftarrow 0 \)
    end loop
    precision \leftarrow precision / 10
end loop
```
where the “compare” command initiates comparisons of the leximin orderings. To sort the comparisons, we then employ the following "Bubble Sort" algorithm.\(^3\)

\[
\begin{align*}
\text{loop swapFlag = true} \\
\quad \text{swapFlag = false} \\
\quad \text{loop } 1 \leq m' \leq m - 1 \\
\quad \quad \text{if } w_{m'} > w_{m'+1} \text{ then} \\
\quad \quad \quad \text{swap}(w_{m'}, w_{m'+1}) \\
\quad \quad \quad \text{swapFlag = true} \\
\quad \quad \text{end if} \\
\quad \text{end loop} \\
\end{align*}
\]

The sorting procedure enables a straightforward comparison of the leximin ordered vectors.

### 3.3. Construction and Representation of Characteristic Function

Characteristic functions are represented by an \(n\)-dimensional array of size two for each dimension. This is because the power set \(2^N\) literally contains \(2^n\) elements. If we denote a characteristic function by \(v[i][j][k]\) for three-player case, the representation is given by identifying

\[
\begin{align*}
\nu(\emptyset) & \equiv 0 \quad \text{with} \quad v[0][0][0], \\
\nu(\{i\}) & \quad \text{with} \quad v[1][0][0], \\
\nu(\{i,j\}) & \quad \text{with} \quad v[0][1][1], \\
\nu(\{i,j,k\}) & \quad \text{with} \quad v[1][1][1],
\end{align*}
\]

and so on.

Our program provides two options for specifying the characteristic function. One option is to directly set the values of a characteristic function using the Set button. The corresponding dialogue box is provided in panel (a) of Figure 4. The other option is to select a predetermined characteristic function from the list presented in panel (b) of Figure 4. The three main types of games presented in Section 2 (additive, superadditive, \(^3\)The Bubble Sort algorithm is not the most time efficient algorithm. However, given our fixed dimension of three-player games, this loss in efficiency is a non-issue.)
convex) are provided in both symmetric and asymmetric forms.\textsuperscript{4} The Elongated Core assigns surpluses of 1 to each of the singleton coalitions \{1\}, \{2\}, and \{3\}, surpluses of 2 to coalitions \{1,2\} and \{1,3\}, and a surplus of 7 to coalition \{2,3\}. The Trapezoidal Core also assigns surpluses of 1 to each of the singleton coalitions, but then assigns surpluses of 2 to coalitions \{1,3\} and \{2,3\} and 5 to coalition \{1,2\}. The Wide Core is same as the Elongated Core, except that coalition \{2,3\} is also assigned a surplus of 2. The Boundary-Intersecting Core sets each of the singleton surpluses in the Wide Core to zero.

[INSERT FIGURE 4 HERE]

As an example, Figure 5 presents the core and corresponding Shapley value for the Elongated Core characteristic function.

[INSERT FIGURE 5 HERE]

4. Conclusion
This paper has demonstrated an interactive program that can be used to supplement undergraduate- and graduate-level cooperative game theory courses by graphically demonstrating (i) the construction of the core and (ii) the determination and location of the common Shapley value, nucleolus, and per-capita nucleolus surplus-sharing allocations for games with three players. Because the geometry for the construction of the core is common across all cooperative games, the program can conceivably be augmented with new surplus-sharing rules as they are introduced in the literature. As a result, the program can be thought of as a "one-stop" graphical interface for surplus-sharing games.

\textsuperscript{4} Symmetric(asymmetric) in this context means that individual surpluses assigned to the singleton coalitions are equal(unequal). For example, the asymmetric convex characteristic function depicted in panel (a) of Figure 4 assigns surpluses of 1, 2, and 3 to the singleton coalitions \{1\}, \{2\}, and \{3\}, respectively.
References


Table 1. Coalitional Surpluses for Calculating the Shapley Value.

<table>
<thead>
<tr>
<th>Coalition</th>
<th>Coalitional Surplus</th>
</tr>
</thead>
<tbody>
<tr>
<td>{1}</td>
<td>1</td>
</tr>
<tr>
<td>{2}</td>
<td>2</td>
</tr>
<tr>
<td>{3}</td>
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</tr>
<tr>
<td>{1,2}</td>
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</tr>
<tr>
<td>{1,2,3}</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 2. Coalitional Surpluses for Calculating the Nucleolus.

<table>
<thead>
<tr>
<th>Coalition</th>
<th>Coalitional Surplus</th>
</tr>
</thead>
<tbody>
<tr>
<td>{1}</td>
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</tr>
<tr>
<td>{2}</td>
<td>0</td>
</tr>
<tr>
<td>{3}</td>
<td>0</td>
</tr>
<tr>
<td>{1,2}</td>
<td>20</td>
</tr>
<tr>
<td>{1,3}</td>
<td>30</td>
</tr>
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<td>{2,3}</td>
<td>40</td>
</tr>
<tr>
<td>{1,2,3}</td>
<td>42</td>
</tr>
</tbody>
</table>
Figure 1. The graphical interface.

Figure 2. The overall systems relations.
Figure 3. Partial construction of the core in Figure 1.
(a) Defining a characteristic function.

(b) Loading predetermined example for characteristic functions

Figure 4. Interface for the characteristic functions.
Figure 5. The Elongated Core Characteristic Function.
Appendix 8.7  Examples of Pollutant Trading

Examples of Pollutant Trading

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Example of point source to nonpoint source trade:

Note: This is an example where the potential seller of credits is a non-point source located in the Cub River sub-watershed.

The seller is matched with two separate receptor points - the one at the mouth of the Cub River, the other at the Cutler Reservoir - and therefore must participate in two separate trading markets.

The buyer - a point source - is, for sake of the example, also matched at the Cub and Cutler receptor points.

**Potential Seller**: Farmer 34391 in sub-basin 45 has totals of 16,419.72 and 10,251.10 credits (measured in grams of TP per year) to sell from his six fields (Nos. 4705, 12280, 12286, 14766, 14767, 14822) Cub River and Cutler Reservoir receptor points, respectively. The farmer's field-specific credits and corresponding average control costs are presented in the following table (Table 1).

<table>
<thead>
<tr>
<th>Field</th>
<th>Cub Credits (grams)</th>
<th>Average Cost of Cub Credits ($/gram)</th>
<th>Cutler Credits (grams)</th>
<th>Average Cost of Cutler Credits ($/gram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4705</td>
<td>57.66</td>
<td>0.08</td>
<td>32.47</td>
<td>0.14</td>
</tr>
<tr>
<td>12280</td>
<td>5751.46</td>
<td>0.01</td>
<td>3927.10</td>
<td>0.01</td>
</tr>
<tr>
<td>12286</td>
<td>3132.51</td>
<td>0.01</td>
<td>2115.97</td>
<td>0.01</td>
</tr>
<tr>
<td>14766</td>
<td>6985.81</td>
<td>0.05</td>
<td>3900.02</td>
<td>0.09</td>
</tr>
<tr>
<td>14767</td>
<td>462.72</td>
<td>0.05</td>
<td>259.03</td>
<td>0.09</td>
</tr>
<tr>
<td>14822</td>
<td>29.56</td>
<td>0.05</td>
<td>16.50</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>16419.72</td>
<td></td>
<td>10251.10</td>
<td></td>
</tr>
</tbody>
</table>

**Potential Buyer**: The Preston WWTF located in subbasin 39 has necessary reductions (to meet its TMDL commitments) of 1,283,970.61 and 560,930.88 grams per year at the Cub and Cutler receptors, respectively.

Preston WWTF's average costs of control for meeting its TMDL commitments at the Cub and Cutler receptors are $0.39 and $0.90 per credit, respectively.

Since both of these average costs are larger than the largest average control cost for Farmer 34391 ($0.14 per credit), there seems to be potential for trade.

**Trade Calculation**: To calculate the effective number of credits Farmer 34391 has to sell to the Preston WWTF, we divide Farmer 34391's Cub and Cutler credits by the average of Preston WWTF's seasonal delivery ratios for the Cub and Cutler receptors, which are 0.95 and 0.53, respectively.
This results in Farmer 34391's effective credits (potentially available for sale to the Preston WWTF) being increased up to 17,283.92 (16,419.72/0.95) and 19,341.70 (10,251.10/0.53) credits for the Cub and Cutler receptors, respectively. In terms of the expected effective prices of Cub and Cutler credits from Farmer 34391, first consider the credits from fields 12280 and 12286 (the lowest-cost fields at $0.01 per credit per field).

If the Preston WWTF purchases all of the Cub and Cutler credits from these fields (5,751.46 + 3,132.51 = 8,883.97 Cub credits and 3,927.10 + 2,115.92 = 6,043.02 Cutler Credits, respectively) for totals of $88.84 ($0.01 * 8,883.97) and $60.43 (0.01*6,043.02), respectively, the Preston WWTF receives the equivalent of 9,351.55 (8,883.97/0.95) Cub credits and 11,401.92 (6,043.02/0.53) Cutler Credits.

This translates into expected effective per-credit prices for the Preston WWTF of $0.01 per gram ($88.84/9,351.55) for its Cub credits and $0.005 per gram ($60.43/11,401.92) for its Cutler credits. The Preston WWTF's expected effective per-credit prices corresponding to each of Farmer 34391's fields is presented in the following table (Table 2).

**Table 2: Preston WWTF's Effective Credit and Per-Gram Price Information**

<table>
<thead>
<tr>
<th>Field</th>
<th>Effective Cub Credits (grams)</th>
<th>Effective Cub Credit Price ($/gram)</th>
<th>Effective Cutler Credits (grams)</th>
<th>Effective Cutler Credit Price ($/gram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4705</td>
<td>60.70</td>
<td>0.073</td>
<td>61.27</td>
<td>0.072</td>
</tr>
<tr>
<td>12280</td>
<td>6054.17</td>
<td>0.005</td>
<td>7409.62</td>
<td>0.004</td>
</tr>
<tr>
<td>12286</td>
<td>3297.37</td>
<td>0.008</td>
<td>3992.40</td>
<td>0.007</td>
</tr>
<tr>
<td>14766</td>
<td>7353.48</td>
<td>0.049</td>
<td>7358.54</td>
<td>0.049</td>
</tr>
<tr>
<td>14767</td>
<td>487.08</td>
<td>0.048</td>
<td>488.74</td>
<td>0.048</td>
</tr>
<tr>
<td>14822</td>
<td>31.12</td>
<td>0.047</td>
<td>31.14</td>
<td>0.047</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>17283.92</strong></td>
<td></td>
<td><strong>19341.70</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Final Note:** The Effective Cub and Cutler Credit Prices calculated in Table 2 are based on the
assumption that the Preston WWTF is able to pay Farmer 34391 its minimum willingness to accept (WTA) for each respective field's credits (e.g., through a bargaining process), which are the respective Average Costs presented in Table 1 (see Caplan (2008) for a discussion on the relationship between WTA and Average Cost). Obviously, to the extent that the Preston WWTF is unable to bargain as successfully, its effective credit prices will be higher (and Farmer 34391's per-credit payments will thus be higher as well).

Example of Nonpoint Source to Nonpoint Source Trade

Note: This is an example where the potential seller of credits is a non-point source that is matched solely with the Cutler receptor. The buyer is another non-point source that is also matched solely with the Cutler receptor point.

Potential Seller: Farmer 18567 in sub-basin 50 has a total of 45.94 credits (measured in grams of TP per year) to sell from his three fields (Nos. 6312, 6314, and 14860). The average cost of control for 17.01 credits from field 6312 and 20.29 credits from field 6314 is $0.43 per credit (i.e., per gram of TP). The average cost of control for 8.64 credits from field 14860 is $0.68 per credit.

Potential Buyer: Farmer 30365 in sub-basin 5 has a necessary reduction (to meet his TMDL commitment) of 11.30 grams per year (0.31 grams from field 3626 and 10.99 grams from field 15013). The average cost of control for field 3626 is $5.12 per gram per year and for field 15013 it is $0.92 per gram per year. Since both of these average costs are larger than the largest average control cost for Farmer 18567 ($0.68 per credit), there seems to be potential for trade.

Trade Calculation: To calculate the effective number of credits Farmer 18567 has to sell to Farmer 30365, we divide Farmer 18567's credits by the average of Farmer 30365's seasonal delivery ratios, which is 0.5825. This results in Farmer 18567's effective credits (potentially available for sale to Farmer 30365) being increased up to 78.87 credits (45.94/0.5825). In terms of the expected effective price of a credit from Farmer 18567, first consider the credits from field 6312. If Farmer 30365 purchases all of the 17.01 credits from this field for a total of $7.31 ($0.43 * 17.01), he receives the equivalent of 29.20 credits (17.01/0.5825).
This result is driven by the fact that Farmer 30365's (average) delivery ratio is smaller than Farmer 18567's (i.e., Farmer 30365 is located upstream of Farmer 18567 vis-à-vis the Cutler receptor point). This translates into an expected effective per-credit price for Farmer 30365 of $0.25 per gram ($7.31/29.20).

In the end, farmer 30365 only needs to purchase 6.58 credits from Farmer 18567 to meet his TMDL commitment of 11.30 grams (17.01/29.20 = x/11.30, solve for x). Farmer 30365 therefore pays Farmer 18567 at total of $2.83 ($0.43 * 6.58) for what is effectively 11.30 credits, which results in Farmer 30365 paying the equivalent of $0.25 per credit.

**Final Note:** After Farmer 18567 sells the 6.58 credits to Farmer 30365, he has a total of 45.94 - 6.58 = 39.36 credits still available for sale. He can sell these credits to any potential buying source that is matched with the Cutler receptor point, including those sources located in the Cub River sub-watershed that are matched with both the Cub River and Cutler receptor points (as in Example Trade 1 - Cub Seller).
Appendix 8.8 Trading Strategies

Trading Strategies

By Terry Glover

Economics and Finance
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Utah State University
1.0 The Focus Area for Water Quality Trading in the Bear River Watershed

The Bear River watershed covers a territory starting in eastern Utah and extending into western Wyoming, southeastern Idaho, and then back into northern Utah where the Bear River runs prior to entering the Great Salt Lake. The primary focus area on the study of the possibility of water quality trading within this watershed was centered around the Total Maximum Daily Loads (TMDL’s) being developed and implemented in the watershed and the availability of data as input to water quality modeling and the investigation of trading mechanisms. The extent of the trading area considered is mapped and illustrated in Figure 1. From the north the territory considered covers the Bear River system from the Oneida Narrows Reservoir in southeastern Idaho to the Cutler Reservoir. This portion of the area considered for trading possibilities includes the Cub River drainage area since the Cub River enters the Bear River. The drainage area of the Little Bear River is also included in the trading focus area. The Little Bear River flows mostly northward into Hyrum Reservoir, and continues to the Cutler Reservoir. The Logan River drains from the east through the Logan Canyon and enters the Cutler Reservoir and at that point is considered to be in the trading area at the Cutler Reservoir. Spring Creek is another tributary into Cutler reservoir and is also within the focus territory.

The Cutler Reservoir is then considered as a major receptor point of the flow from the Bear River, the Cub River, the Little Bear River, Spring Creek and the Logan River. As such the Cutler Reservoir becomes the major water quality measurement and control point to which the control of nutrients is targeted. The major nutrient being considered in developing the strategies for trading is total phosphorus (TP) which is the main nutrient on the 303(d) listing for the Bear River system and its contributing streams. Other receptor points can be considered since the study has developed data on TP concentrations and deliver ratios for various sub-basins within this defined trading focus territory. The TMDL’s for the area are mainly linked to the control of TP in Cutler Reservoir.

2.0 Overview of Trading

The theoretical benefits of markets created by regulatory policy for water and air pollution discharge authorizations have certainly been recognized for some time (Dales, 1968; Crocker, 1966). Ideally, a limited number of discharge authorizations (or rights) are issued and these are linked to the amount of pollution reduction dictated by regulatory mandate. Those parties holding such rights can discharge no more than the rights they are issued and then have incentives to seek out and implement the most efficient abatement methods to meet the regulated emission targets given their operation/emission conditions. Again, ideally the dischargers can exchange these permitted authorizations to pollute as long as the regulatory control of emissions is met. There is no increase in discharge allowed beyond the issued permits. If one discharger avoids more expensive control while another discharger implements equivalent, but less expensive control, the same environmental result is achieved but at lower overall cost. Hence, the claim that
permit trading is a discharge control mechanism that achieves the desired emission control at lower cost relative to other control mechanisms such as taxes on emissions or command-and-control regulation. In this market framework, the regulatory authority’s responsibility is to assure that each unit of discharge is authorized and the total discharge by authorized parties meets the water quality standard measured at some receptor point. The regulator has to insure compliance with the mandated reduction in the particular pollutant in question.

Support for market-based emission control policy such as trading in permits is widespread and several emission trading programs have been proposed or documented\(^1\). The process of trading is now thought to be a key force in implementing the U.S. Clean Water Act and received renewed governmental emphasis from the U.S. Environmental Protection Agency in 2003 (\textit{Water Quality Trading Policy}, Office of Water, 2003; and \url{http://www.epa.gov/owow/watershed/trading/finalpolicy2003.pfd}). However, point/nonpoint trading involving agriculture has been slow and difficult to initiate. Nonpoint load reductions have to be brought into the control mix.

In principle, the establishment of an emission trading program depends on the following:

- the basic action taken to establish clear reductions that need to be achieved (the total maximum daily load – TMDL)

- the establishment of clear and enforceable regulations complemented with a market-based process to provide incentives to arrive at emission reduction solutions

- the establishment of an overall cap on pollution discharges and in the case at hand the establishment of a cap on total phosphorus for the Bear River system

- the allocation of the cap to individual discharge sources

- allowing each source to meet its allowance by reducing discharge or by purchasing allowance/credits from other sources that reduce discharge to levels below their allocation and do so at low cost and with minimal transactions costs

Market-based solutions to water quality problems, if initiated, need to be coupled with the regulatory solution. There has to be limits set on the emissions into water bodies. Market solutions are not substitutes for the regulation of the emissions. They may be used to lower the cost of meeting the standards set and enforced in order to reduce pollution in the nation’s streams and more particularly in the Bear River watershed.

\(^{1}\) Connecticut Long Island Sound (Bennett, et al 2000); the Neuse and Tar-Pamlico programs in North Carolina (North Carolina Division of Water Quality, 2003); the Minnesota River system (Fang et al. 2005) and proposals in Idaho (Idaho Department of Environmental Quality, 2005, and Ross & Associates Environmental Consulting, Ltd, 2005 ) and Pennsylvania (Pennsylvania Department of Environmental Protection, 2007).
Figure 1. Water quality trading area.
The objective of the Targeted Watershed study of the Bear River system has been to explore some ways to introduce market-based functions that can be incorporated into nutrient trading programs to comply with TMDL-defined nutrient reductions, particularly total phosphorus reduction. The application of trading processes in the nutrients control arena appears to be an attractive alternative if incentives to initiate trades can clearly be understood by the potential parties that could participate in such processes. Moreover, the potential spatial relocation of nutrient discharges within a river system such as the Bear River that may be a result of trading is less likely than other pollutants to cause localized water quality problems. Still another favorable feature is that it is often reported that nonpoint sources are presumed to be the low cost dischargers (Butt and Brown, 2000; Ribaudo et al. 2005) placing the nonpoint sources in the position as seller in a market mechanism process and supposedly a basic incentive for nonpoint sources to enter into favorable contractual arrangements with existing permitted point sources who are under the NPDES regulation. However, most nonpoint sources remain outside the regulatory scope of the Clean Water Act. Most nonpoint sources are unregulated or do not anticipate that violating TMDL regulations will be very costly. This is particularly the case if subsidies for implementations to reduce emissions are available even if the intent of subsidies is to induce the financing of water quality improvements to be supplied by the nonpoint sources which supply considerable amounts of the phosphorus pollutant. So the incentives to attract nonpoint sources into nutrient reduction processes seem to be at best confused if not at odds with market based solutions coupled with perhaps weak regulatory enforcement of reductions.

2.1 The Elements of a Trade

Let us suppose that a TMDL is written and uses the latitude that a specific state has under the regulatory specifications of the Clean Water Act to bring nonpoint sources into a total phosphorus (TP) reduction arrangement in a particular watershed. Further assume that the TMDL specifies an allowable watershed load and also indicates that identified nonpoint sources riparian to the streams are to reduce TP at a uniform rate of 50 percent. The major point sources, such as local waste water treatment plants (WWTP’s) who are regulated under a National Pollution Discharge Elimination System (NPDES) permit are found to be needing considerable pounds of TP credits per month during the irrigation season to meet the stated NPDES discharge. Also assume the nonpoint sources are in the seller position in the watershed so that implementation of Best Management Practices (BMP’s) to reduce TP loads can and are made at lower cost relative to the incremental cost of reducing TP at the WWTP’s given the latter’s reduction technology and outflow into the streams of interest. So one of the major problems facing the nonpoint source is finding a buyer is solved. So the action on the part of any nonpoint source within the watershed is driven by the need for information and calculations to arrive possible BMP removal of TP, regulated removal, and TP reduction eligible for trading.

The steps for the nonpoint source in this particular case, and a case that would not be far from typical, are:
**Step 1:** The nonpoint source needs information on TP emission given current management practice to determine current load. This is key information needed by the nonpoint source in order to initiate trading.

[This is one of the pieces of information that has been developed on a field basis from the water quality modeling and the cooperative analytical developments of the water quality modeling, GIS, and water quality trading groups completed for the trading focus area in the Bear River watershed]

**Step 2:** The nonpoint source needs information on the effectiveness of certain BMP’s that could be adopted in order to reduce the current TP load calculated in step 1.

[There is currently considerable uncertainty about the effectiveness of BMP’s as they would be applied in fields and areas that border the Bear River, the Cub River and the Little Bear River. With this uncertainty in mind, there are some discounts and/or margins of safety that can be considered both in implementing BMP’s and in mandating the TP reductions in implementing the mandate to reduce TP in the Bear River Watershed. Considerably more investigation of BMP effectiveness needs to take place]

**Step 3:** Computation of the TP reduction that can be expected by the adoption of a particularly suitable BMP or set of candidate BMP’s that are suitable for the particular operations in which the nonpoint source is engaged. In the latter case, BMP cost and effectiveness levels need to be evaluated. If a BMP is already in place, then consideration has to be made of the practice effectiveness relative to its cost and incremental changes that could be made to enhance effectiveness at certain incremental costs.

\[
\text{BMP TP reduction} = \text{current TP load} \times (\% \text{ BMP effectiveness adjusted for any discount})
\]

**Step 4:** Compute the required TP reduction imposed by the regulation which, in the assumed case conditions is 50% reduction.

\[
\text{Required TP reduction} = \text{Current TP Load (step 1)} \times (\% \text{ required reduction})
\]

[The required TP reduction becomes the baseline requirement in TP reduction]

**Step 5:** Compute the TP reduction eligible for trading.

\[
\text{TP reduction eligible for trading} = \text{BMP TP reduction} - \text{Required TP reduction}
\]

or

\[
\text{TP reduction eligible for trading} = \text{BMP TP reduction} - \text{Baseline requirement}
\]
Step 6: Compute TP reduction eligible for trading relative to delivery of TP concentration at a regulation receptor point where measure of TP and its control is monitored.

TP reduction eligible for trade adjusting for delivery to a receptor point
= TP reduction eligible for trading (step 5) X Delivery Ratio

[Delivery ratios have been derived by the water quality modeling team from the output of the water quality modeling effort for the Middle Bear River for any subbasin outlet from Oneida Reservoir down to the major receptor, the Cutler Reservoir for the northern subbasins of the focus trading area and for outlets of subbasins in the Cub River watershed to the mouth of the Cub River (entry of the Cub into the Middle Bear) as a possible receptor and to the Cutler Reservoir. Additionally delivery ratios have been derived for any outlet in any subbasin of the Little Bear River (the southern part of the trading focus area) to the Cutler Reservoir.]

These same computations would have to be followed in order to develop information on trades that might take place between nonpoint sources or associations of nonpoint sources. But such trades would be made between such sources if there is significant cost differences in the particular reductions in TP that could be accomplished. So costs of such reductions do have to be evaluated as a precursor computation before there is incentive to trade as a strategy to bring about required reductions in nutrient discharges and entry in the nations streams to comply with the main driver of the market-based process that is embodied in the enforcing the regulation dictated by the TMDL.

3.0 Alternative Trading Strategies

Several forms of trading strategies have been either proposed or initial experiences of such have been reported in the literature (Malik et al., 1993; Hoag and Hughes-Popp, 1997; Fossett et al. 1999; Butt and Brown, 2000; Horan et al., 2001; Horan et al., 2002; Woodward and Kaiser, 2003; King, 2005; Woodward, 2005; Horan and Shortle, 2005; Rabotyagov et al. 2006; Shabman and Stevenson, 2007; and Hennessy and Feng, 2008 to identify but a few and trace some history in the literature on trading). There is a mixed report card on both the initiation and initial experience in trading nutrient permits or nutrient reduction credits written into credits. Most of the trading forms have been labeled as market-based water quality trading. The encouragement of water quality management programs and their implementation have been coined as applications of market-based environmental policy. There are considerable differences in the proposed and actual operations of these water quality management proposals and initial implementations and one is actually hesitant to actually label a lot of them as being market based. Indeed Shabman and Stevenson (2001), Fang et al.(2005) in reporting on the Minnesota River experience, and Shabman and Stevenson (2007) report that many of the water quality management proposals and plan adoptions do not have the market design basis and in fact may not be set up to actually complement the regulation of nutrient reduction that is mandated in the TMDL. Of course, what is termed lack of
market-based design may actually be the problem of a weakly designed TMDL or weak enforcement of the TMDL in the implementation of the particular management program.

In order to shed some light on the alternative forms of trading that could be operated in the Bear River watershed, an attempt is made here to provide a summary of some proposed programs to initiate water quality trading and to remark on what they may or may not offer. A sketch of alternative trading mechanism is outlined in Figure 2.

Figure 2. Alternative Trading approaches
3.1 The Regulator Model Approach: A Form of Cap and Trade

Some forms of this approach have been alluded to by Bennett et al. (2000), Woodward et al. (2002) and Ribaudo et al. (2005) in their descriptions of various approaches that suggest the regulator take initiative in gathering data, developing control cost and effectiveness level estimates, deciding trading ratios amongst participants, and deciding permit allocations. An information data base is developed by the regulator. A computer model is then set up to compute the cost effective combination of controls and in the case of the Bear River system the emphasis of the data base and modeling would be placed on total phosphorus (TP) reduction. Based on this information the regulator then issues permits to each source and requires that the cost effective controls identified be followed by the sources issued the permits. In order to lower the costs of TP reduction the regulator, using the computer model, allocates permits to the lower cost and most effective sources and inventories the trades that are made in order to assure that the allocation reduces TP and meets the desired cap on TP.

The regulator could also allocate funding to investigate the effectiveness of new technology to reduce the nutrient load and if more effective technology is found at lower cost. Based on this new information, the regulator would then reallocate control responsibilities within the system, again through some allocation system to insure that the cost of TP reduction decreased. The regulator could also use funds to match funding of the sources that would be invested to obtain permits or to improve TP reduction capabilities. The regulator could work with other agencies in order to obtain funds to match the sources’ investments in the TP reduction practices in order to receive allocations. In general, in this type of mechanism, the regulator also specifies the technologies that can be adopted in order to meet the regulated reductions mandated by the TMDL if there is a serious effort to enforce the limits placed on nutrient control written into the TMDL. In this case there is generally more sure understanding of the effectiveness of the management practices on nutrient reduction.

This approach is sometimes referred to as a “trade mandating mechanism” for getting the desired reduction in nutrient pollution out of trading activity amongst a mixture of sources. This type of approach clearly focuses the regulator on the control and the control technology.

This type of regulatory mechanism would not, however, be classified as a market-based approach. However, these types of control mechanisms are frequently used to justify trading. They are usually set up as an “exchange of water quality improvement for dollars” approach as summarized in Figure 1 below.
Market-based approaches are more than just the offer of financial assistance for sources to reduce nutrients. Offering financial payments arranged by the regulator in order to induce sources to adopt a specified technology does not define a market. Markets create financial incentives internal to the market for the sources to reduce nutrient discharges. Strictly speaking, the design of rules for market implemented programs probably should not be based solely on trades nor should they be based on financial compensation to dischargers who voluntarily adopt regulator specified nutrient control practices.

### 3.2 Cap and Trade Approach

Many control programs are labeled “cap and trade” control programs including the regulator model approach suggested above. Often specific market oriented programs are labeled as cap and trade operations. Cap and trade programs emphasize trading but do not generally imply that a set of rules has been developed to institute a market or to clearly be market oriented. Many of the features offered in the more centralized information base and regulator controlled operation that emphasizes trading as the solution to the reduction of nutrients are incorporated into alternative forms of cap and trade mechanisms. These programs rely on regulators, rather than the nutrient discharging sources, to specify the nutrient control technologies that are to be used to reduce nutrient discharge to the stream in compliance with mandated reduction. It is generally assumed in these cases that the regulator has more information on the control effectiveness or adjustments that need to be made in order to bring about the desired reductions.
Specific concentration limits are established based on the management practices and permits are then issued under the National Pollution Discharge Elimination System (NPDES) to point sources since discharge can be measured. Nonpoint sources may or may not be brought into the system. However, in most situations there is need for the nonpoint sources to be brought into the control framework such as through the financing of the implementation of specific regulator approved BMP’s to be implemented by the nonpoint sources or including certain percent reductions of nonpoint sources in the TMDL control mandate. It appears that the states, as regulators under the Clean Water Act (CWA), do have considerable latitude in bringing nonpoint sources under the regulatory umbrella if the TMDL mandate is clear on the total reduction that needs to take place to recover the impaired waters of concern but there are some hard choices that the regulator has to make in such cases to conform with the TMDL when there is no teeth to the regulatory process to include nonpoint sources. Generally a new set of permits and control technology requirements have to be drawn up for the presumed exempt nonpoint sources. If that cannot be politically implemented, then the regulator has to implement zero discharge from point sources and has to join with other government agencies to prohibit growth in certain areas.

Several forms of trading fit into the cap and trade mode and general descriptions of these control-through-trading programs have been summarized by Langley (2001) and Dunn and Bacon (2005) among others. Another feature of these trading programs is that the regulator, who generally specifies the control technology both for the point and nonpoint sources, periodically, reviews the effectiveness of the control technologies and practices to revise standards downward. This action is sometimes referred to as forcing or ratcheting down. This type of action is the reason that regulators issue permits on a cycle basis. That is, an emission permit may only be issued for a period of five years and then it is reviewed against additional knowledge of the reduction technology and effectiveness of this technology in reducing pollutants. So dischargers only have some degree of consistent pollutant level targets for short periods of time and have to anticipate the ratcheting down as new control technologies enter on the horizon with promise to allow lower levels of discharge at lower cost. The initiative of control is with the regulator not the point discharge source. Incentives for control on the part of the point source is somewhat weakened in this type of approach to control with trading.

3.4 Market-Based Approach (CAM)

Although many programs of nutrient discharge control are labeled as being market oriented since common reference to trading in control is associated with market mechanisms some do not have the underlying design which drives markets. In a market-like operation the commodity that is exchanged is a discharge allowance. A limited number of allowances are issued and the limit is called a cap. The limit is related to the mandated reduction of nutrient discharge that is written into the TMDL. This form of control is referred to as a cap-and-allowance market (CAM)².

² The cap-and-allowance market term is from Shabman and Stephenson (2007) but others currently refer to this term in describing market-like control programs.
The main features of this approach that distinguish it as a market-based control mechanism are:

- Ownership of the allowance to be traded

- Discharge sources have substantial discretion to decide how the nutrients should be controlled and choose minimum cost control within the rules designed to achieve the mandated reductions – waste control flexibility

- Discharge sources have discretion on whether to buy or sell allowances – exchange flexibility

- Allowances are time-limited permission to discharge a fixed quantity of a nutrient under regulation such as total phosphorus (TP) in the case of the Bear River regulation. These permissions would have to be written into any contract and may vary by season the contract may allow provisions for weighted permission by season over the year.

- Allowances are to be accompanied with requirements on the measurement of the total amount of nutrients such as TP discharged

- A discharge source must own or lease allowances in order to legally discharge in the regulated water body

- Expanded allowances are not granted – buyers or lessors could be discharge sources who experience growth, or experience unexpected control problems, or they could be new discharge sources, but none of these sources are granted expanded allowances

- Allowances can be sold, bought, leased, retired or banked for future use – which admits growth issue concerns

The regulator’s responsibilities in such a control program are indeed important to the control process. Attention has to be centered on the water quality standard and not focused solely on developing trades or providing financial compensation to dischargers who voluntarily adopt approved nutrient control practices. Indeed the trading focus of the regulator has been criticized in the literature as the reason why we only see minimal trading taking place to control nutrient discharges (King and Kuch, 2003). The concept of allowances focuses on the water quality mandate and the market for allowances is a regulator created market. The operation of the market forces the discharge source to seek low cost control to meet the standard.
The role of the regulator in this type of control program is to:

- Create the mandated water quality regulation and to assure that the TMDL specifies the reduction in nutrient discharge that needs to be accomplished at the key receptor points where measure of water quality improvement can be made

- Translate the regulatory standard into total amount of nutrient and in the case of the Bear River watershed trading area focus this would be a translation to the total amount of TP

- Issue the allowances commensurate with the reductions that are to be met by the discharge sources. The regulator issues a cap on allowances and does not issue extended allowance to compensate growth or control emergencies. The sum of the allowances issued is to be equal to the permissible discharge into the water body or is related to a mass load cap.

- Issue the total load of nutrient discharge and reduction thereof to a broad category of discharge sources such as both point and nonpoint sources. Finer breakouts of the load can be initiated as well based on discharge and control cost information.

- Charge penalties for failure to hold the number of allowances equal to nutrient discharge

- Work toward a fully capped control mechanism via the market. Every discharger is required to hold allowances before being allowed to discharge. Enforcement of a fully capped program ensures that actual discharge does not exceed the total maximum load target.

- Maintain flexibility in prohibitions such that a zero discharge case does not result. Some amount of discharge can be allowed within the rules of meeting the water quality standard to keep away from the regulatory problems of forcing zero discharge while still achieving the water quality standard.

- Maintain focus on the water quality standard and allow exchange flexibility to work its course. Within the cap, exchange flexibility can be exercised by the dischargers and discharge can be transferred, by permission, to different locations and across time periods via buying and selling. The mechanism to maintain exchange flexibility while achieving the set standard is through the delivery ratio rather than narrowing the geographic scope of trades. The delivery ratio contains the information on attenuation of the load across watershed segments. However, exchange flexibility must have spatial limits since water quality results depend on location and timing of nutrient discharges. Moreover, monitoring of the stream should be set up to detect
possible hot spots that could occur between discharge locations and the water
quality measuring point (receptor point)

- Certify that exchange of allowances result in equivalent water quality
outcomes in the watershed.

Emission control discretion is the key to developing incentives to reduce pollution
discharge into streams and meet the water quality standards. The discretion to choose the
discharge reduction technology relates to the opportunity to buy and sell allowances. If
these two forces are allowed to come together then financial incentives for discharge
control are created. The presence of these incentives is critical to maintaining control of
water quality over the long term in the face of growth pressures within a watershed. In
the cap-and-allowance program nutrient discharge reduction does not occur when the
regulator prescribes additional control requirements. Financial incentives to control
nutrient discharge do not emanate from subsidy programs to induce control. Instead, it is
the opportunity to buy and sell allowances that motivates innovation and reductions in
cost in order to meet the nutrient reduction mandate. Discharge sources that reduce their
nutrient discharges below allowance holdings earn revenue from the sale of their
allowances. Other sources that need to expand nutrient discharge for whatever reason
avoid having to buy allowances by innovating and finding ways to lower their discharges
and lower their costs if allowance prices become inflated because of increased need for
allowances. So just the opportunity to trade creates both seller and buyer incentives to
lower nutrient discharges.

If the emphasis of the regulator is solely on initiating trades rather than on the regulatory
mandate with exchange and control flexibility, actual trading activity may not get started.
Moreover, the opportunity to trade and discretion to choose control technology may
actually reduce the trading activity at least in the initial stages of the CAM operation.
Markets without intense trading activity may in fact be a signal of successful control
program design. That is, the discharge sources find that they respond to the new and
forthcoming incentives by aggressively reducing nutrient discharge below actual
allowance allocations and hopefully at a much reduced cost. It may be the case that the
sources favor innovation and cost reduction rather than pay others to meet the water
quality standard. However, area economic growth and expansion tends to have the effect
of increasing trading activity as more buyers enter the market to buy up allowances in
order to meet the standard. This activity increases the price of the allowances.

The opportunity to choose discharge control technology also provides incentives for
finding or developing production/condition specific nutrient discharge technology and
implementation at reduced costs than perhaps general best management practices. This
opportunity can also force closer evaluation of production processes that cause pollution
and investigation of its reduction. Financial returns, created by either not having to
purchase allowances or by being able to sell or lease allowances, provides incentives for
the discharge sources to apply specialized knowledge of production processes that reduce
nutrient discharge. Such a program may also work to cause reductions in actual output
form certain operations or elimination of the production activity altogether because of the
imposition of costs that have to be internalized with the enforcement of the water quality standard.

A cap on allowances program can induce discharge source self-reporting of actual discharges. Under such a program the allowances are limited because of the cap and the allowances can be traded. This limited issue concept and the fact that the allowances can be purchased, leased, or sold allows the creation an asset and asset value that derives financial value. All discharge sources then have interest in protecting the asset value. The value of allowance asset holdings is diminished if one source discharges over the amount of allowance associated with a given nutrient discharge. The value reduction results from the violator’s action of reducing the number of customers in the market to the sellers of allowances. Market existence does not rely solely on self enforcement but incentives for self enforcement certainly help to sustain the operations of a market. The CAM type process actually relies heavily on the regulator enforcing the water quality standard so the operation of such a market is highly dependent on regulator attention to and enforcement of the standard.

Obviously, there is fear that sources will attempt to game the system when exchange and effluent control flexibility is allowed and encouraged. But the record of trading under proposed and implemented pseudo-market or non-market-like approaches has not been sterling. Noncompliance under the existing permit system is reported to be a frequent occurrence (U.S. General Accounting Office, 1996) but one may notice that there is really no specified market-like control program in place that strictly follows the market-like principles and regulatory duties and oversight as outlined just immediately above. There appears to be little demand for credits that allow certain levels of discharge and, as a result, there is a lack of incentive to supply credits. For some discharge sources there is relatively little or even zero marginal cost of not complying with water quality standards, so there is little price to pay. The noncompliance of a discharge source with the water quality regulation imposes no negative consequence for other dischargers. So the usual setting of demand being equated with supply does not exist and the cost of not complying is relatively cheap or perhaps even nonexistent. So we see no basis for trade and no incentives that exist to drive buying and selling. A market-like plan for water quality control probably has not been put in place. Therefore, what could be interpreted as the gaming of the regulatory system is merely that there is no basis for a market and not the case that markets fail to produce the desired control results.

4.0 The Provisions for Trading in the Clean Water Act

Under the Clean Water Act (CWA) regulatory authorities are given a charge to develop TMDL standards for the nation’s impaired streams. There is heavy reliance on the regulator for several control roles. The role of the regulator extends from focus on water quality into the initiation and concentration on trading as a tool to be implemented in order to encourage nutrient reduction in effluent discharge. This latter emphasis has been accelerated since the U.S. Environmental Protection Agency’s 1996 Draft Framework for Watershed Based Trading and the January 2003 announcement on the focus on trading as a process to heighten increased cleanup of the nation’s impaired waters. However, the
initial guidelines for this water quality management tool contained little emphasis on exchange and waste control flexibility that underlie a basic market-like control process where incentives to reduce the discharge of nutrients are derived from the operation of the market, that is, the opportunity to buy and sell and to decide on innovation to lower the cost of nutrient reductions. The role of the regulator seems to have expanded focus into the areas of promoting trading of any kind and brokering the possibilities of financial subsidization to dischargers to volunteer to meet water quality standards as outlined in TMDL limits developed for the impaired watersheds in addition to enforcing the control arrangements of the National Pollution Discharge Elimination System (NPDES).

In summary, under CWA provisions, the role of the regulator includes:

- Development and oversight of the Total Maximum Daily Load (TMDL) regulation and standards for nutrient reduction
- Direct the reallocation of allowed discharges among sources. Nonpoint sources are exempt from provisions of CWA making water quality trading arrangements “partial cap” control tools rather than “fully capped” tools for control. However, the states have latitude to improvise to bring nonpoint discharge sources under the control umbrella, and particularly to use the NPDES process to finance nonpoint source nutrient discharge reductions.
- The specification of the best control technology and consideration of the costs of the implementation of the technology
- Specification of the performance standards (concentration limits) that are established based on the designated control technologies
- Negotiation with dischargers to establish an NPDES permit on permissible nutrient concentration discharge
- Periodic review of technologies to revise standards – the establishment of a regulatory and concentration limit cycle
- Encourage and broker water quality trading as a water quality control tool

Concentration on water quality standards is a key and dominant role of the regulator. Central focus should be placed on the attainment of improved water quality at set standards for water quality. The NPDES permit system does focus on effluent reduction. However, individual NPDES permits do not offer dischargers flexibility which is needed in a market-based water quality control system. Point source dischargers face “anti-backsliding” rules that may prevent a point source from buying allowances to increase discharges if a cap-and-allowance (CAM) market-based program is set up as the water quality improvement tool. These rules certainly focus on the water quality standard but
they diminish discharger flexibility, hence weaken incentives, in a market-like control mechanism.

As discussed earlier, the CAM (cap-and-allowance market control mechanism) focuses on the establishment of mandatory mass load caps for existing and new sources. The implementation of CAM-like control tools under CWA provisions would be an important step forward in working toward a fully capped program to promote improved water quality. The fully capped process ensures that actual discharge does not exceed total maximum load which is established to achieve a water quality standard. Currently, under CWA regulation provisions, once a TMDL is established then only a subset of sources are regulated. This subset consists of only the point source dischargers that are regulated under the NPDES permit system. The role of redirecting the allocation of allowed discharges seems to be weakened by the actual CWA regulatory provisions. However, as described below there may be some improvising that can be done in order to restore some of the regulatory teeth within the CWA regulatory guidelines.

In the occasion that water quality standards cannot be met by the point sources, then the regulator has the difficult choice of requiring the permitted point discharge source to maximize effluent control technologies. These limits that are imposed cannot generally be transferred or enter into trade, but are incorporated in the new NPDES permit cycle. In some cases zero discharge has to be imposed. If these tight limitations cannot achieve the water quality standard the regulator may require the point source to finance nutrient reductions from other unregulated discharge sources such as a set of nonpoint source dischargers. Then regulator approved nonpoint source control technologies are designated to be implemented to extend the reductions of the pollutant needed to meet the water quality control standard. The controls that are implemented become new conditions in the new cycle of the point source’s NPDES permit. There is no trade control responsibility.

This permitting program is a partial cap arrangement without exchange and control technology flexibility. Payments from the point source are not voluntary and the payments actually do not result in the point source investing in less expensive control technology. The regulators have primary responsibility to oversee what are commonly termed trades, but such transfers are really not trades. Moreover, additional controls are needed to conform to the mandated reduction in nutrients that are discharged into the impaired water bodies. There may be merits in this type of system as it evolves out of CWA regulatory authority but the process of control is not market-based.

Of course, the current regulatory territory is dictated by the provisions of the CWA and changes to that control format do not appear to be on the immediate horizon. Therefore programs for trading and discharge control need to be designed within the CWA statutory and regulatory constraints. There are some challenges in setting up market-like control programs and some incentives cannot be captured in these trading programs but some of the rigidities can be worked out.
4.1 Possible CAM-Like Programs under Current CWA Provisions

A possible permit mechanism that might work under CWA regulatory provisions is the so-called “ASSOCIATION COMPLAINCE PERMIT” (sometimes referred to as the “group compliance permit” system). One can refer to the U.S. Environmental Protection Agency, *Watershed-Based National Pollution Discharge Elimination System Permitting Implementation Guidance* document 833-B-03-004 (2003) for more detailed guidelines on the association compliance permit.3

The summarized steps in the association compliance permit approach to mimic a CAM-like program are as follows:

Step 1: Assign individual discharge source limits in NPDES permits in order to develop a group cap

Step 2: The NPDES-based limits are then waived and converted into allowances if the discharge sources agree to participate in a “discharger association”

Step 3: The association is covered by a group compliance permit --- this forms a partial cap on the discharge sources that form the association

Step 4: Allowances that sum to the cap are then allocated to the discharge sources in the association

Step 5: Trading can then occur under the group permit

Step 6: The permit requires individual monitoring and measurement provisions to identify the load of nutrients actually being discharged

Step 7: The permit has to establish immediate enforcement provisions in the event that total discharges exceed the established cap --- penalties or fees on sources would have to be established for noncompliance--- failure to follow association bylaws pertaining to the cap and discharge control activates the individual NPDES permit and its enforcement which is a forced incentive to comply with association discharge rules under the cap

Dischargers are free to make choices about the control technologies and forms of control that can be specific to production processes so waste control flexibility exists in this type of system. The control flexibility is key to generating incentives derived from buying and selling and for promoting innovation in control technology which seeks to lower the cost of the implementation of such controls that meet the water quality standard. The group compliance permit allows individual dischargers to choose the efficient control

3 A form of this association compliance permit which is a group cap has been initiated in the case of the Neuse River water quality control provisions in North Carolina (North Carolina Division of Water Quality (2003a). This program was initiated to control nitrogen discharges.
technology suitable to their specific production processes and discharge conditions as long as the control of discharges is matched with the allowances allocated and is equal to the cap. The approach generates both exchange flexibility and waste control flexibility within the association. Existing discharge sources as well as new discharge sources that enter the association are not required to use specific control practices as a condition to discharge. New discharge sources would have to purchase allowances from existing sources within the association. There are no extended allowances issued.

Another approach that can be used and which is linked to the exercise of wide latitude by the states on managing nonpoint source discharges is to **EXPAND THE CAP**. This approach is a direct approach to bringing in the nonpoint discharge problem under pseudo-market approaches to control. Mass load limits can be placed on nonpoint sources and examples have been summarized by Stephenson et al. (1998) and the Neuse River example is described by the North Carolina Division of Water Quality (2003b). The cap can be expanded by writing a uniform nonpoint discharge reduction level or percentage in the TMDL. The steps to initiating such an expansion would involve the TMDL and the steps suggested for the Association Compliance Permit system outlined above.

This expanded cap approach may not be particularly efficient unless details of field concentrations of nutrients have been estimated via water quality and transport modeling. The key purpose of the water quality modeling completed in this current Environmental Protection Agency Targeted Watershed study, however, was to project total phosphorus (TP) load using field data. The results of this modeling and projection work as well as links to delivery ratios are reported in a later section of this study report. Furthermore, a spreadsheet system has been developed by Caplan, et al. (2008) which summarizes field data information that could be used by the regulator, an association of nonpoint discharge sources, or representative advisors to agricultural nonpoint sources (such as the Natural Resource Conservation Service of the U.S. Department of Agriculture) in order to arrive at field and farm TP estimates by season. This system can be used to identify nonpoint source discharges that are both riparian to the streams, those that are located at distance from the stream and, in addition pinpoint the production processes or types of vacant land or septic tank systems of the nonpoint sources.

One approach to expanding the cap is to reward point discharge sources that come under a partial cap regulation for expanding the cap to nonpoint source control either through their own financing of nonpoint management practices or by bringing in the nonpoint dischargers into an Association Compliance Permit system. The reward could be a grant of additional allowances for the point source dischargers or an association of point source dischargers. Woodward (2003) discusses some of these strategies for expanding the cap from a partial point source regulation to nonpoint sources. If the financing of discharge controls by the nonpoint sources was cheaper than buying additional allowance capacity from other point sources, then the expansion of the cap is motivated by incentives. Of course, measurement and verification of the improvement would have to be included in any contract to finance nonpoint effluent reductions and fees served for noncompliance of the measurement activity would have to be imposed.
Yet another approach to bring nonpoint source dischargers into conformance with water quality regulations is to introduce **TRADING BEYOND THE CAP**. This involves **TRADING IN CREDITS** rather than in allowances and poses some problems that are associated with the uncertainty of credits by season or over the span of the trading contract. If the nonpoint source dischargers remain outside a cap, a point source-nonpoint source trading program could be established. Trading beyond the cap takes place. This type of trading is different than the CAM (cap-and-allowance market trading) approach since the nonpoint source seller of credits does not have a legal requirement to control nutrient discharges. Allowances are not issued to the nonpoint source. The nonpoint source trades in credits where a credit is a documented nutrient discharge reduction below a required baseline level of reduction with the baseline requirement being generally established by the TMDL load reduction. Of course the documentation of the credit is a particular problem in and of itself since credit creation is uncertain from year to year, and from season to season, depending on conditions such as weather, irrigation efficiency and production processes.

Credit documentation is essential but problematic. One approach to documentation is to model the nutrient yield by field (or aggregated to the farm level) prior to the implementation of any mandated reduction to establish load under existing management and production conditions. This establishes a baseline load and reductions that could be achieved. Credits could be calculated by estimating the actual load and subtracting the baseline. The spreadsheet system developed by Caplan et al. (2008) for the subbasins of the Middle Bear and the Little Bear river systems within the Bear River watershed could be applied to obtain the credit measurement and documentation of the measurement.
References


Pennsylvania Department of Environmental Protection. 2007. Nutrient and sediment reduction credit trading interim final policy and guidelines. [http://www.dep.state.pa.us/river/Nutrient%20trading.htm](http://www.dep.state.pa.us/river/Nutrient%20trading.htm).


Appendix 8.9 Steps to Trading

Steps to Trading

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1.0 Overview

The investigation into alternative trading approaches reported previously in Appendix 8.7 (Trading Strategies) concluded that there are four basic trading mechanisms that could be structured to operate within CWA provisions and for which alternative plans for setting up and operating trading in allowances or credits could be achieved. These basic approaches are given in Figure 1 below.

Figure 1. Four Basic Trading Arrangements.
These trading approaches scope the possibilities but there are alternative plans to the trading that could be developed within these approaches in order to achieve phosphorus reduction in the focus area of the Bear River Watershed included in the Targeted Watershed study.

1.1  Cap-and-Allowance Markets

As indicated in Figure 2 the most market-like general approach is the “cap-and-allowance market” operation. The reason for this conclusion is that incentives internal to the operation of the trading are created under such an approach that induce dischargers to find lower cost and perhaps more focused effluent control methods in order to reduce phosphorus below the discharge allowance that is allocated. Discretion is given to the discharge source to implement phosphorus reduction technology that may be more specific to control given production processes that are being used. The incentive is derived from what could be termed waste control or abatement flexibility given to the dischargers.

Exchange flexibility is the opportunity to buy and sell, and in this case discharge allowances are exchanged. However, new buyers, who for various reasons need allowances, have to purchase or rent allowances from those dischargers who have been allocated such allowances with the total of the allowances meeting the TMDL reduction requirement. There are no extended allowances for such reason as growth, emergency discharge conditions, or for switches in abatement technology. So this is a fully capped system that creates value in the allowances in the trading process.

1.2  Cap-and-Trade Approach

The “cap-and-trade” system is a partially capped system dependent on the permitting under the National Pollution Discharge Elimination System (NPDES). This approach is the most commonly suggested trading approach offered in the literature and for trading initiatives that have been undertaken in recent years and conforms to Clean Water Act (CWA) nutrient reduction specifications and provisions (see the U.S. Environmental Protection Agency, Water Quality Trading Toolkit for Permit Users, EPA-833-R-07-004, 2007 and http://www.epa.gov/waterqualitytrading/WQTToolkit.html). CWA provisions suggest that the regulator determine the abatement technology in line with the reductions that are to be achieved but there is latitude in working out the adoption of the technology that can be permitted under NPDES. Regulators are to periodically review the abatement technologies in order to revise standards over time. This procedure puts the point source discharger on a standards and technology cycle which can introduce uncertainty into the abatement decision without the desired incentive to lower the cost of control. There is some suggestion in the literature that such an operation induces the point source discharger to just move to expensive abatement technology for control (Shabman and Stephenson, 2007; King, 2006).
There are alternative trading initiative plans that can be followed using the general cap-and-trade approach. One such approach could be a modeling approach that either initiated by the regulator or actually carried out by the regulator. For lack of a better title this is termed the “regulator model approach” (see Appendix 8.7). The regulator or their designate assembles phosphorus reduction cost and effectiveness information and uses a computer model to arrive at the cost effective approach to control and allocation of permits. The regulator allocates credits and controls under permitting, using the modeling approach, to the low cost abatement dischargers subject to the constraint that the total phosphorus discharged by all sources is limited to the cap. This allocation scheme is usually extended to the point source dischargers.

In this study, the research team has essentially performed the data collection and some of the modeling needed to initiate a trade, and some of the allocation processes have been searched out and discussed in this current report (see Appendices 8.1, 8.2, 8.4, 8.5, 8.9 and 8.10). Certain best management practices (BMPs) have been identified by both the regulator and the research team which could be implemented by point source dischargers in the watershed and also nonpoint sources. Baseline credit and target loads and credits based on projections of field level phosphorus yield have been projected. Water quality modeling has been completed as a base modeling effort in order to derive the field phosphorus loads and delivery ratios from outlet points of the subbasins in the Cub River, the Middle Bear River of the Main stem the Bear River, and the Little Bear River. So a great deal of modeling has been completed as part of regulator model and control approach to trading, and particularly trading in credits.

Another plan or approach under this cap-and-trade trading process is to bring nonpoint sources under the phosphorus regulatory umbrella. These discharge sources can be brought in under the permitting system by requiring the point sources to finance the phosphorus reductions of nonpoint sources needed in addition to the point source control to meet the TMDL discharge limits. In fact, these discussion and some estimates of the cost of this type of extension and regulator specification of the control technology by both point source and nonpoint source have been going on with administrators of waste water treatment operations within the Bear River Watershed. Other forms of financing BMP implementation by nonpoint sources have been discussed and or proposed by the regulator to agency groups as reported in Appendix 8.4.

1.3 Extension of the CAM approach

Extensions of the CAM-type approach can be implemented in trading programs which follow more closely programs encouraged by the CWA provisions. These may be attractive alternatives under conditions where the nonpoint sources need to be brought under regulation. However, these CAM-like plans usually work to lesson the waste control flexibility and to some degree exchange flexibility to actually allow these programs to operated in a market-like trading process. There are considerable monitoring/measuring costs that are incurred in these programs in addition to documentation and credit validation costs.
A direct way to include nonpoint sources into a CAM-type program is to include them under a mandatory mass load cap. To be implemented in the focus trading area of the Bear River Watershed, there would probably have to be monitoring of the phosphorus at certain junctures (within subbasins) of drainage areas such as in the Cub River drainage, other areas in the Middle Bear and the Little Bear rivers in addition to the assumed receptor point at the Cutler reservoir. However, if such measurements are taken, they can be applied with the estimated delivery ratios in order to get information on conveyance of the phosphorus loads to any set of receptor points in any of the drainages considered in this current study. Of course there is monitoring cost and strategy that needs to be considered in implementing such CAM trading strategy and particularly the initiation of trading given projected base loads and target loads. Such a plan is not without precedent. There is a mandatory selenium cap program implemented in the San Joaquin Valley of California where selenium caps are imposed and loads have been directly measured for some of the irrigation districts in the area (Austin, 2001). All discharge sources are apparently under the cap in the Neuse River project as well (North Carolina Division of Water Quality, 2003). Trading in these types of plans is in allowances. Some number or a single point source can be granted additional allowances if the point source agreed to either finance or bring into control a set of nonpoint sources under such a cap. Of course the incentive for this action on the part of the point source is provided if this encompassing/financing approach is cheaper than purchasing allowances from another point source. Again, measurement would have to be required of the point source under these conditions of such a plan.

Still another CAM-like option is to set up trading beyond the cap, that is, credit trading between the point source and the nonpoint source. The problem with this plan is that the nonpoint source, under current provisions, faces no legal requirement to control its discharges since allowances would not be issued to the nonpoint discharge sources. So the trade, in such case, would be a trade in credits. There are costs to validation in this case, but baseline and target loads developed from the models to develop field phosphorus loads along with assumed BMP effectiveness information developed in this study would help in the documentation of the credits that could be traded in this plan.

1.4 Association under a Group Permit

An interesting form of trading that has established precedence in the Neuse River project is the “group compliance permit” and is apparently accepted under the NPDES permitting process of CWA. Individual source limits in NPDES permits are assigned which establishes a group cap. The NPDES-based discharge limits are then waived and converted into allowances so long as the source agrees to participate in a “discharger association” covered by the group compliance permit. This plan is sometimes designated as an “association group permit” system. This plan would actually be a partial cap system on the group sources that are in the association. Allowances summing to the partial cap are allocated to the association sources. Trading of allowances then takes place under the regulation of the group permit and the dischargers have discretion on control technology. However, failure to participate in the group and comply with meeting the cap, which is equated with the overall discharge limit, activates the NPDES
permit. If control technology is left to the discretion of the dischargers in the group and inadequate control results then the discharger’s cost increase as switches in control processes have to be made in order meet the phosphorus limitations mandated under the group cap. The permit has to require accurate individual monitoring and measurement as a condition for being in the association which imposes costs, but there is an incentive to work to lower monitoring costs in order to enhance the allowance value in any exchange of allowances that takes place to comply with the phosphorus reduction mandate.

The U.S. Environmental Protection Agency *Water Quality Trading Toolkit* (U. S. Environmental Protection Agency, 2007) actually classifies trading scenarios into only two categories, namely, point source-point source trading and point source-nonpoint source trading. The reason for this general classification is that the rules and guidelines are tied to the development of the NPDES permit in order to show state regulators and other parties interested in nutrient control how to incorporate trading into that process. The toolkit also provides some examples by certain cases of the permit writing and alternative trading plans within the point-point and point-nonpoint trading plans. Additionally, the toolkit suggests the language and concepts that need to be in the permit in order to steer the actual application of the permit in reducing pollutants that pertains to these broad categories of contracting which permit the trades. Here, the purpose is to expose some of the alternative plans for exchange that could be developed given the phosphorus discharge conditions and potential parties to trades in the Bear River Watershed and which also fit within the EPA’s broad trading outline and National Water Quality Trading Policy (2003).

### 2.0 Summary of the Steps to be taken To Initiate Trading

In this section the general information needs and processes that make up the steps to any particular trading regime are outlined. There are several pieces of information that are needed in order to develop the processes in order to initiate viable trading activity that actually works to reduce phosphorus loading. Since trading has not been initiated in Utah and under Utah DEQ regulations there are investigations into legal, control process, TMDL regulation, and trading processes that will have to be made. There is also the consideration of the three states and their application of the CWA provisions and particularly TMDL enforcement that have to be considered when dealing with control of phosphorus in the Bear River Watershed. A serious question that looms large in attempting to bring phosphorus control in line with the TMDL’s that are being written for the water bodies is whether the nonpoint source dischargers are to brought into the phosphorus reduction process within the watershed and how such a move will direct control and what it will cost. Point source treatment facility administrators in the watershed are currently investigating alternative that can be implemented to bring phosphorus loads into compliance with TMDL limits on phosphorus loads. The options include the nonpoint dischargers and they also include alternative control technologies that might include BMP installations to augment treatment plant technology usually thought to be nonpoint source discharge control implementations.
Figure 2. General Information Needs and Processes of setting up Trading.
There are serious questions as well on how the Utah DEQ takes the lead to enforce the regulatory mandate of the completed TMDLs within the Bear River Watershed which may or may not involve trading processes. Discussion on the role of the regulator is taken up in Appendix 8.7 of this report and this role varies or changes focus depending on the control process adopted for the watershed. It was suggested there that the regulator needs to concentrate on the water quality standard and its enforcement and perhaps limit focus on developing financing for bringing in the nonpoint sources into compliance in partnership with point source dischargers and concentrating on trades. Yet, the regulator also has interest in getting all discharge sources to be willing to come into compliance to clean up the nations water bodies and to understand the benefits of nutrient load reduction. This process takes time and effort to educate the populous about the benefits of clean water and what it will mean in the Bear River Watershed as well as other watersheds in the three-state area of Wyoming, Idaho and Utah through which the Bear River and its tributaries run.

Figure 2 provides a summary of the information needs and processes that are projected to have to come together in order to seriously consider water quality trading as a viable alternative for reducing phosphorus. The many and varied decisions that have to be made are only abbreviated in the figure and need further explanation. The Targeted Watershed study reported on in this document can and has dealt with the information needs, the investigation of alternative trading plans to bring about compliance, and the projected decisions that have to be made using the information. However, there are legal considerations, regulatory action on the part of the regulator, and actual permitting that have to be done by others, including the legal and regulatory agencies, in order to produce tradable instruments that document either discharge allowance limits or credits beyond baseline control that can be traded in the market place.

3.0 The Information needs: Target loads and Credits

In order to develop target load and credit information to initiate water quality trading there has to be an information base indicating phosphorus loads in the watershed, delivery ratio information indicating the conveyance of the loads to receptor points and projected target loads and credit information. This is one of the important and major information bases that has been developed from the research effort of this study. As a result of the development of a water quality modeling effort reported in Appendix 8.10 coupled with identification of field level phosphorus loads by season using GIS tools, a Bear River database has been developed (Neilson and Baker, 2008; Caplan, et al. 2008) from which total phosphorus loads (and seasonal loads) and delivery ratios to any receptor from subbasin outlets and farm field locations can be developed.

This database can now be used by regulator personnel or other interested stakeholders to develop the needed phosphorus load and conveyance information in order to derive “target loads” at certain receptor points as well as credits that would be available as certain BMPs and point source technologies are used for the control of phosphorus discharge in the focus trading area of the Bear River Watershed. This database that has been developed provides the basis for developing measures of discharge allowances if a CAM-type trading program is to go forward as the trading procedure or if some form of trading in credits is to be initiated as the policy for phosphorus reduction in the watershed.
Using the database that has been developed it is recommended as step 1 to development of a water quality trading program for the Bear River and its major tributaries.

**Step 1: Determine the basis of and derive target loads and credits.**

It is recommended that the regulator appoint an agency person or team to go into the field and work with point source dischargers and nonpoint source dischargers to:

a) develop field and waste water treatment plant information on projected existing loads of phosphorus that need to be reduced to be in compliance with the TMDL load limitations that have been established or are in process of being established;

b) Identify target loads (baseline loads) that can be used to establish the level of loads meeting the TMDL regulatory mandates. The database includes all fields that could be identified within the focus trading area of the Bear River Watershed but there needs to be an identification of fields that are actually within the discharge set that when under control by the TMDL mandate would produce the desired reductions. Control of other fields may have no affect. We have found in the present investigation to develop the database that there is considerable concentration of phosphorus loads in the Cub River drainage area subbasins, but there needs to be further investigation of the actual load reductions that could be made in order to improve compliance with the TMDL specified limits.

c) Work with other agencies and nonpoint source representatives/advisors ((NRCS, municipalities, regional agencies) to derive information on the implementation, operation, effectiveness and costs of alternative BMP systems that can be used by either nonpoint or point source dischargers to reduce existing loads and to come into compliance with the needed water cleanup limitations; and

d) To derive information on credits and/or discharge allowances relative to different original loads, delivery ratio information, control technology (treatment plant technology and BMP implementation) capability and effectiveness and required discharge reductions.

The Bear River database has been developed as a tool to aid this effort and provides the information base for such an effort. The research team of the Bear River Targeted Watershed Study can also provide aid and support in this effort. Some of this work by the Utah DEQ has already been initiated in discussions with point source dischargers who are moving to implement strategies to control phosphorus discharge in order to comply with the TMDL regulations within the watershed. There has been discussion within this agency that this investigation be extended to determine nonpoint load levels and the type of BMP implementations that could be introduced to reduce such loads and minimum cost. This investigation probably should be made with partnering agency personnel to derive the information on BMP effectiveness and cost as well as load levels that could be efficiently reduced. The Bear River database could also be used in this process since it can incorporate BMP information and use such information along with delivered load and targeted load information.

The Bear River database contains the following base information:

- field data on seasonal phosphorus loads and total loads over the seasons
- projected total field phosphorus loads for a field or subbasin configuration
• identification of phosphorus comparative subbasin loads within the focus trading area

• capability of identifying collections of field phosphorus load at the farm level

• total delivery ratios by subbasin outlet to the Cutler Reservoir and end-of-Cub River receptor points --- the delivery ratio data base can be used to develop delivery ratios dependent on other receptor points in order to develop information on possible “hot spot” locations.

• limited BMP effectiveness and cost information. Additional data needs to be derived and incorporated into the database.

• capability for alternative computation (ACCESS and EXCEL based database)

The subbasin delineation for the focus trading area is given in Figure 3 below.
Figure 3. Subbasins of the Bear River Part of the Focus Trading Area by location and number including the Cutler Reservoir Receptor point in Subbasin 1.
Phosphorus loads for the Bear River are mainly located in the Eastern areas of the watershed which is the Cub River drainage area. A magnification of the subbasin locations within the Cub River drainage area (part of the Bear River set of subbasins) are given in Figure 4 above along with the identification of the receptor point subbasin that was assumed in developing phosphorus conveyance information and delivery ratios for the Cub River subbasins. The receptor point location is subbasin 24 which is the location of the mouth of the Cub River where the Cub River flows into the Main Stem of the Bear River in the Middle Bear area of the Bear River.
There are several computations that can be made using the database. For example, to calculate the delivered load of any field by season to a receptor point such as the Cub River mouth, then one can use the existing information in the database to compute:

**Delivered Load to Cub River Mouth (by season) =**

\[
\text{Delivery Ratio (by season) X Average Load (by season)}.
\]

Similarly, the delivered load by season to the Cutler Reservoir is computed as:

**Delivered Load to Cutler Reservoir (by season) =**

\[
\text{Delivery Ratio (by season) X Average Load (by season)}.
\]

The database can incorporate alternative information on BMPs including cost per pound (or gram) to implement and operate, and the percentage effectiveness. Again, using the database information, BMP adjusted delivered loads by field within subbasin can be computed as:

**BMP Adjusted Delivered Load to Cub River Mouth (total) =**

\[
\text{Total Delivered Load to Cub River Mouth} \times (1- \% \text{BMP Effectiveness})
\]

using average total load from any field within a subbasin in the above computation. Similarly, the BMP adjusted delivered load to the Cutler Reservoir is computed as:

**BMP Adjusted Delivered Load to Cutler Reservoir =**

\[
\text{Total Delivered Load Cutler Reservoir} \times (1 - \% \text{BMP Effectiveness}).
\]

In these last two example computations, the delivered load to the respective receptor points are derived by applying the delivery ratio to the average total load over all the seasons from any given field as for example using the Cutler Reservoir as the receptor,

**Total Delivered Load to Cutler Reservoir =**

\[
\text{Delivery Ratio X Average Total Load},
\]

and the computation would be similar for the Cub River mouth computation by using the average total load over the seasons and applying the respective delivery ratio. One uses the appropriate subbasin delivery ration in all of the above examples since delivery ratios have been developed for all of the subbasins included in the database.

Further computation using the database leads to the target delivered load or what could be termed the proposed annual load. This particular load level is the percent reduction required by the TMDL regulatory mandate. This computation can also be developed on a field basis within each subbasin. Using the Cub River subbasins (and Cub River mouth as the receptor) and field data as an example, then,

\[
\% \text{Reduction Required by TMDL} = \text{Target Delivered Load to Cub River Mouth} =
\]
Total Load – (Target Delivered Load to Cutler Reservoir/100) X 
Total Load to Cub River mouth),

using,

Target Delivered Load to Cutler Reservoir = Delivered Total Load to Cutler Reservoir - (Proposed Annual Load To Cutler /100) X 
Total Delivered Load to Cutler Reservoir.

Trading credits are computed as annual load reductions and are dependent on the particular receptor point used as the point of measure of the TMDL limitation. Therefore trading credits as related to the Cutler Reservoir receptor point are computed as:

Cutler Reservoir Trading Credits = (Targeted Delivered Load to Cutler Reservoir) - 
(BMP Adjusted Delivered Load to Cutler Reservoir 

= Annual Load Reduction.

Similarly, the trading credits for annual load reductions that are dependent on the Cub River mouth as the receptor point are computed as,

Cub River Mouth Trading Credits = 
(Targeted Delivered Load to Cub River Mouth) - 
(BMP Adjusted Delivered load to Cub River Mouth) 

= Annual Load Reduction.

Therefore the database developed using the water quality modeling and GIS field identification tools enables one to derive the credits that are available for trading, given the TMDL regulation on proposed load. The proposed load can also be used to derive discharge allowances. So the database tool can be used to develop a field information base for two major directions of trading and alternative plans for trading within these two trading frameworks. It can also be used for developing the nonpoint discharger information should an association with a group permit under the NPDES system be proposed to be implemented within the focus trading area, or any other form of cap-and – trade framework.
4.0 Determining Possible Trade Patterns within and among subbasins

Step 2: Identify possible trade patterns.

The next step in the process of initiating a viable trading framework is to identify possible trading patterns that are present in the computed deliver ration, targeted delivered load, and load reduction information in using the Bear River data base. To date some limited investigation of the patterns has been completed, particularly for the subbasins within the Cub River drainage area which is reported earlier in Appendices 8.3 and 8.6. The results of the identification process reported to date in these appendices suggests that both potential point-point source and point-nonpoint source trading opportunities exist. There are cost differences between discharge sources depending on the particular BMP that is adopted by nonpoint discharge sources and the effectiveness of the BMPs. There certainly is a rather large cost difference between treatment plant technology used to reduce point source phosphorus loads and the costs of control of nonpoint discharge sources. These results suggest that trading certainly could be viable in the trading of credits if one could assume the credits are stable from year to year. Furthermore, if trading in credits appears to be feasible then the trading in allowances is as well, since the allowance is the proposed load limitation that is used in eventually computing the annual reduced load or credit.

Certainly further investigation of possible trade patterns using the information from the Bear River Database is merited. As pointed out above the information in the database needs to be used to develop further calculation using actual field phosphorus loads that have been derived in a more detailed coverage of the subbasins within the focus trading area and identification of favorable trading conditions. Currently the data are now being used in an empirical version of the cooperative sharing model approach developed by Caplan and Sasaki (see Appendix 8.5) to derive incentive-based coalitions that exist and that are derived out of the field load information. Alternative BMP effectiveness information is also being investigated along with this approach to determining if there are viable coalitions that result from the field load data that has been produced to this point. There is considerable uncertainty about certain BMPs and there effectiveness in reducing phosphorus loads as pointed out earlier in Appendix 8.4.

Trading patterns between parties within the Little Bear River subbasins and the Main Stem of the Bear River and/or the Cub River drainage area have yet to be identified using the information from the Bear River database. Ongoing investigation of the feasibility of these types of trading patterns and whether they could be viable in either an action to incorporate them in a permitted system whereby a trading area point source finances the BMP implementation or general inclusion of nonpoint source dischargers in a trading program is still in process.
5.0 The Process of Determining the Trading Strategy

Step 3: Identify the viable trading strategy

A comparison of trading strategies was completed and reported in Appendix 8.7. The pros and cons were also reviewed in an earlier summary introduction to this appendix. The serious question that needs to be asked by the regulator and other stakeholders that have interest in water quality in the Bear River Watershed is, “will the nonpoint source dischargers be incorporated into the phosphorus reduction process and at what cost? How do the stakeholders answer that question? They need information and information has been generated in this study to help in determining the strategy to go forward. There is more information on possible trading coalitions that is forthcoming as explained above. Limited water quality trading is in existence with the possible exceptions of then nitrogen reduction program in the Neuse River project in North Carolina (cited earlier in Appendix 8.7), some one-time exchange arrangements in the Lower Minnesota area (cited earlier), and the nitrogen credit exchange program in Connecticut (Connecticut Department of Environmental Protection, 2001, 2005).

One has to ask the question of why such limited trading in order to reduce nutrient loads. What is apparently being observed in many startup trading initiatives is that there is no basis of demand for the credits that can be shown to exist and preliminarily credits equating to computed annual reductions in phosphorus in the Bear River Watershed have been shown in this present study have been shown to exist. But what is being observed in most initiatives is that weak and rarely enforced discharge restrictions prevail and there is little cost for noncompliance. So there is little interest in purchasing the credits and thus little incentive to supply the credits.

Strategies to restore incentives then have to focus on these demand and supply issues and the internal incentives that are derived within trading systems that induce supply and attention on the part of dischargers in lowering the costs of the phosphorus reductions that need to be made. Interest also has to be turned to the cost of not complying in order to get the attention and focus of particularly nonpoint dischargers into finding low cost means of phosphorus reduction to get the reductions needed to be in compliance with the TMDL mandate. This would seem to suggest that nonpoint sources be somehow brought into the regulatory picture and there are a couple of approaches that can be used to do just that and work with the CWA provisions as reported in Appendix 8.7 which covered alternative trading strategies. One way is to bring these sources in under the permitting umbrella through the TMDL, and financing by the point sources, and another approach is to bring them into the TMDL and permitting system through an association and group permit operation. It also appears that trading in allowances may put teeth into the regulations and allow for source discretion on control technology/BMP implementation which provides incentives to comply and at the same time seek lower cost nutrient control that is targeted to specific production processes as long as certain effectiveness levels are attained.
It is suggested that the regulator be put in charge of the water quality regulation that is imposed by the TMDL. Then establishing a phosphorus trading framework should be viewed as a step process involving the following:

- The establishment of an overall cap on phosphorus discharges and this would seem to imply, with the exception of working with CWA exemptions which in fact can be changed using the broad latitude of regulatory powers of the states, that a fully capped system should be applied.

- The allocation of at least a portion of the cap as allowances to a set of dischargers if not the implementations of a complete allowance trading framework.

- Make use of the differences in discharge reduction costs. This involves allowing each source to meet their allowance by reducing discharge or by purchasing allowances (or in the case of partial allowance programs, purchase of credits from suppliers of credits who derive the credits by reducing discharges below allowances).

Typically, the terms that actually govern a trading program are developed outside the NPDES process and they can be reflected in the permit at the permitting juncture. The Environmental Protection Agency water quality trading policy actually does describe several mechanisms for implementing trading through the NPDES permits. One such framework implies the discharger association under a group permit where the NPDES is converted to the group discharge limit under which the association has to comply with the mandated nutrient discharge limitations imposed by the TMDL. The regulator, or combination of state regulators in the case of the Bear River Watershed, should make agreements that sufficiently incorporate details that lead with some detail of certainty that agreements provide incentive to meet the overall water quality standard. The information developed in the Bear River Database should be of help in developing these agreements or indicating the loop-holes associated with certain rather loosely enforceable agreements.

Obviously, there should be a thorough review of the Environmental Protection Agency’s Water Quality Trading Toolkit for Permit Writers which can viewed along with its many appendices at [http://www.epa.gov/waterqualitytrading/WQTToolkit.html](http://www.epa.gov/waterqualitytrading/WQTToolkit.html). This is an August, 2007 publication as well under the EPA number of EPA-833-R-07-004. Appendix B to this toolkit should also be reviewed and it contains the Environmental Protection Agency 2003 National Water Quality Trading Policy. All state permitting and trading documents should be reviewed as well.
6.0 The Permitting Process

Step 4: Write the permits that initiate trading depending on trading strategy adopted.

This section does not go into the detail of the permit writing. This process is better understood by the regulating agency. What is covered here, however, are some of the elements that need to be considered in the process of writing in the trading of credits or allowances into permits, and the documentation that describes the trading agreement which structures the particular trading strategy.

A review of the Water Quality Fact Sheet is an important initial action that needs to take place prior to setting up the permitting system and writing trading agreements which put in place the structure of the trading strategy. There are important reviews of information for alternative trading initiatives that are provided. For example, one can find the review of the information needed for the trading agreements associated with the Neuse River trading project which may turn out to be a model to follow if nonpoint sources are brought into the regulatory structure in the Bear River case. There are other discussions of information and the idea of actually developing a fact sheet that is a document of the basic information guiding the trade agreement and it language is an important guidance piece that probably should coupled with any agreement. Such a fact sheet becomes the basis for permitting and drawing up trading agreements. The outline and components of the fact sheet are found in Appendix B of the Water Quality Trading Toolkit for Permit Writers and it can be found online at [http://www.epa.gov/npdes/pubs/wqtradingtoolkit_app_a_case_studies.pdf](http://www.epa.gov/npdes/pubs/wqtradingtoolkit_app_a_case_studies.pdf). Of course, the state regulators may have a similar document that backs up and provides the basis for any permitting that is contracted. These documents provide the information on “what it is that you need to know” for all parties to any agreement, including the regulator.

Short summaries of what needs to be considered in the permit writing and trading agreements are given below for basic alternative cases of trading. More detailed coverage of these processes are given in state regulation documents and by reviewing the Water Quality Trading Toolkit and the National Water Quality Policy guidelines.

6.1 Point-to-Point source Agreements

The written trading agreement in this case should contain sufficient detail to allow the permitting authority to determine with some degree of certainty that the terms of the agreement will in fact result in the loading reductions proposed. If credits are to be traded, then there has to be sufficient information given that would indicate the credits will be generated to satisfy the water quality requirements. Here again, the computational tool and information from the Bear River Database could be useful in both the permitting and trading agreement writing process for agreements developed for the Bear River Watershed.
As indicated previously, the terms of the trading agreement are typically developed outside the NPDES permit process and then can be incorporated into the permit. The Water Quality Trading Policy document describes the mechanisms for implementing trading through the NPDES system. State permitting systems are similar in procedure but incorporate any broader latitude that the state regulator decides to assume in developing the permit and its application to water quality trading. Special provisions can be written into the agreement as well. Importantly, provisions for monitoring and responsibility for monitoring can and should be written into any agreement. There should be particular detail written into the agreement under permitting that shares the responsibility for monitoring and reporting of the monitoring. All parties to the agreement and their role in the agreement and carrying out the trading strategy should be written into the trading agreement.

There should be definitions included in any fact sheet that documents the basis for the trading strategy and the agreements that carry out the strategy. These definitions include the TMDL mandates of load reduction and where they are to be measured (receptor points), water quality–based discharge limitations, the existing technology–based effluent limitations, current and proposed flows at waste water treatment facilities, wasteload allocation and other important definitions that will be referred to as the permit and effluent reductions are enforced.

NPDES permits that authorize water quality trading do not differ in great extent from the typical NPDES permit. These agreements require the same structure, analysis, basis and justification for the permitting to meet the water quality standard as the typical permit. The permits have the same components such as the cover page, effluent limitations, monitoring and reporting requirements and schedule, any special conditions or provisions, and the provisions of the standard. Each NPDES permit is coupled with a permit fact sheet. At a minimum, the fact sheet is to explain any trading provisions in the permit and explains the strategy of the trading. Explanations of the minimum control level and trading limit should be in the fact sheet. Detailed specifications and division of monitoring procedures and accountability may be written into the agreement under the permit that is written and issued. This may be of great importance in initiating any trading activity in the Bear River Watershed. A review of the such detail that could be written into the permit and trading provisions associated with the permit can be found by reviewing the TOOLKIT.

In this particular trading case and where credits are to be traded, permits for credit buyers should include both the baseline (the proposed load target or what is generally defined as the water quality base effluent limitations or WQBEL). This would be the case for trading in allowances as well but may include other information that focuses on net allowance provisions and the fact that extended allowances would not be issued in cases involving emergencies or planning for growth. There have to be definitions of the discharge limits that the buyer would have to meet through treatment when not trading and a minimum control level that must be achieved through treatment when actually trading. The permit should also include the load level to be offset through credit purchases when trading takes place. This latter could be the technology-based effluent
limit (or TBEL). There is language that could be used to specify these identified limits above in the TOOLKIT.

When a credit seller is able to reduce its discharge below its most stringent effluent limitation, credits are generated. The quantity of credits that any given seller actually can sell depends on the forces the market to equate sellers with demand from buyers and the treatment requirements placed on the buyers. A seller’s permit will include both the most stringent discharge limitation that would apply without trading and then a trading limit. The seller then chooses the control level using a treatment technology or even the implementation of a BMP. Discretion over the choice of treatment technology or BMP is advised if the trading strategy is to allow waste control flexibility and provide incentives to find lower abatement costs that may also be specific to the point source’s influent load complex and production processes that cause the specific influent load.

The identification of the nutrient form, units of measure, flow and timing considerations should all be identified in the permit along with the trading specifications listed above. The regulator should ensure that the trading program and agreement are consistent in terms of the form. Equivalent ratios may have to be worked out if the form that moves into trades changes or gets mixed. This investigation has only been targeting the total phosphorus form, but in actuality there could be mixed forms of effluent regulation and permitting.

Consistent reconciliation periods are also essential in trading between point sources. In trading in credits, the buyer’s permit limits for the traded nutrient and the credit seller’s permit limits should have the same units and averaging period. Since both sets of limits are designed to address the same water quality problem, both should use the averaging period and units that bring about efficiency in producing the needed phosphorus reductions. This consistency also simplifies the reconciliation of credit purchases and sales.

Anti-backsliding refers to a CWA provision that prohibits the removal, reissuance, or modification of an existing NPDES permit that contains WQBEL’s, permit conditions, or standards that are less stringent than those established in the previous permit cycle. Exceptions to this general provision are provided in the CWA provision through the interpretation of section 402(o)(1) to allow for less stringent effluent limitations if either an exception under section 402(o)(2), or, for WQBEL’s, the requirements of section 303(d)(4) are met. If these exceptions come to play in the permitting system, then the “ratcheting down” rulings can develop into dis incentives to innovation in phosphorus reduction when applied to the discharge sources, either point sources being presently discussed or to nonpoint sources that need incentives to implement BMPs that are continually being more efficient at reducing phosphorus loading. This kind of exception interpretation works the same negative incentive effects if in the case of trading allowances, extended allowances are offered in the trading strategy and written into the permit and trading agreement of the permit.
There are special considerations that have to be considered in the case of trading between a multiplicity of point sources such as in an association or agreements between treatment plant facility operators. The agreements and ground rules have to be carefully crafted. A review of the general provisions and detailed specifics can be made of the TOOLKIT to get a sense of the ground rules in these cases.

6.2 Point Source-Nonpoint Source Trading

If the answer as to whether the nonpoint source dischargers should be brought in under the regulation umbrella is affirmative, then there are certain specifics that need to be written into permits and trading agreements associated with the permits that extend to nonpoint source commitments. The big issue in permitting and extending to the nonpoint sources is the quantification of nonpoint source loads and then developing measures of the credits. This issue was anticipated in the Targeted Watershed Study and is the reason that extensive water quality modeling, GIS identification of field level data including location by subbasin and then the derivation of the field level total phosphorus loading. These data have now been generated and are included in the Bear River database.

The issue that remains is the uncertainty in the effectiveness of BMPs that can be used to reduce the nonpoint phosphorus loads that have been derived to this point. The effectiveness and effectiveness uncertainty will be the drivers of the potential credits that the nonpoint sources, as sellers, can generate as well as the drivers of the targeted load that reaches any specified receptor point. Therefore the nonpoint sources need information on BMP implementation, the potential of certain BMPs, and the costs of the installation and operation of the BMPs that could be used in the case of the Bear River setting.

Earlier (Appendices 8.3, 8.4, 8.7 and introductory discussion in this present appendix) it was suggested that personnel from the regulating agency and/or other stakeholder work with the nonpoint sources that have been identified to provide BMP effectiveness information, operation and cost information. The Bear River database information can be used to run several BMP effectiveness and cost situations and conditions to provide information to the nonpoint sources. NRCS information on BMPs can also be shared with these dischargers and coupled with the computational tools developed in this study various cases and conditions can be analyzed. Some of this effort has already been started by the regulating agency in Utah and the Utah Agricultural Conservation District representatives in the watershed area. It is recommended that the effort receive greater attention and intensity so that trading can be initiated.

Some of the potential issues that have to be considered that are dependent on BMP use include the lag time between BMP installation and phosphorus reduction efficiency, when and whether a BMPs credit-generating or target load generating capacity expires, adjustment or accounting for BMP effectiveness uncertainty, and monitoring of BMP performance. The Environmental Protection Agency’s (EPA) trading policy recommends that states establish methods to account for greater uncertainties in estimates of nonpoint source loads and reduction. A review of Appendix B of the trading policy guidelines
will provide an outline of these concerns and some approaches that can be used in monitoring and testing effectiveness. Similarly, the EPA’s *Monitoring Guidance for Determining Effectiveness of Nonpoint Source Controls* provides guidance on the design of water quality monitoring programs to assess both impacts from nonpoint sources and effectiveness of control practices and management measures. NRCS information can also be used to test management practices and BMP effectiveness.

Uncertainty ratios (uncertainty ratio being a type of trading ratio) can be incorporated with the use of the Bear River Database in order to assess the impact of nonpoint load uncertainty on the operation of a point source-nonpoint source market in the Bear River region. Uncertainty ratios that have been applied in other trading initiatives have ranged from 2:1 upwards to 5:1. Application of an uncertainty ratio of 2:1 means that a point source purchases up to 2 units of phosphorus reduction from a nonpoint source in order to ensure that the point source’s single unit of discharge is covered. The main impact of the application of an uncertainty ratio in the trading process is that the effective price of nonpoint credits that are generated is increased thus decreasing the incentive for the point source to rely on nonpoint credits to cover discharge. The work of Hennessy and Feng (2008) and Horan and Shortle (2005) reflect this uncertainty concern as it is related to weather variability and particularly rainfall variability and nitrogen discharge, but not phosphorus loading.

The delivery ratios and the field loads in the study have been developed by season and used a 15-year data series from which the ratios were developed. This is particularly the case for the data generated in the Cub River and Main Stem of the Bear River. These ratios then reflect the wet and dry weather patterns over those years and correct some of the uncertainty that may be embedded in the management practices as applied to the identified fields and the loads that reflect the influence of weather variability over those years. Of course more could be done to describe and project the distribution of the loads and the delivery ratios such as Monte Carlo analysis and this type of analysis may be undertaking in future research. Field load data and delivery ratios for the Little Bear Rivers reflects less history of weather patterns and mainly is related to three rather dry years in the watershed. So uncertainty is more of an issue in the use of these data. There is still uncertainty in the management practice of the operation of BMPs that is inherent in the BMP effectiveness assumptions applied to derive targeted (baseline) loads and credits from annual load reductions.

The nonpoint source, as supplier of credits, has to meet the specified baseline before trading in credits can occur. Baseline is defined as the pollutant control requirements that apply to a buyer and seller in the absence of trading. Upon meeting the baseline load, the seller can then generate credits. There may be margin of safety that apply to the baseline as applied to the nonpoint source discharger that require a nonpoint seller to implement controls beyond the baseline before generating credits. These baseline and credit generation issues have to be incorporated into the trading agreements and be part of permitting. There are difficulties that are encountered in the establishment of baseline or proposed loads for the nonpoint dischargers. Furthermore, the permitting authority may not have part in establishing the baseline loads of the many nonpoint sources, the permit
writer should be aware of the issues associated with nonpoint load considerations and how they impact the trading provisions in permits and how the permits are used to initiate trading between the permitted point source entities and the nonpoint sources. To be reliable, the trading program that carries out the control strategy should use the maximum amount of verifiable information on the loads in the watershed, such as the information in the TMDL, and in particular the loading analysis and projection that is now part of the Bear River database using the field data in this database.

The load allocation mandated under TMDL provisions defines the nonpoint source load reductions necessary to achieve the water quality standard. In fact the TMDL may specify a load allocation for an individual nonpoint source or for a category of nonpoint source dischargers in a watershed. This specification is a good way to bring the nonpoint dischargers under water quality regulation to meet a standard. If the TMDL establishes an aggregate load allocation for a category of nonpoint sources in a watershed or particular tributary to a watershed, the watershed stakeholders, including the permitting authority (the regulating agency), need to make decisions on how to distribute the aggregate load allocation. Again, information is needed on the set of loads generated from the Bear River database that can efficiently be brought into the trading program in order to make the necessary phosphorus reductions to meet the TMDL load allocation. Referring back to previous suggestion, this is the basis for recommending that the regulator or some form of stakeholder agency using the database information and go out the nonpoint dischargers and determine those loads that can be reduced with minimal cost in order to meet the TMDL provisions.

The EPA’s trading policy indicates that where a TMDL is in place, the load allocation of the TMDL serves as the threshold for nonpoint sources to generate credits. This does not mean that EPA requires all nonpoint sources in a watershed to meet an aggregate load allocation for a single nonpoint source to participate in the trading program chosen. The requirement is that all nonpoint sources participating in trading under TMDL provisions make Phosphorus reductions consistent with the load allocation specified in the TMDL prior to being able to generate credits. This ensures that phosphorus reductions advance in order to meet the standard. The states, however, have flexibility to set other appropriate baseline levels, and in fact can require all nonpoint sources to meet the baseline before participating in any trading program that is initiated.

In Idaho for example, the DEQ apparently designates the nonpoint source baseline year which, in the Lower Boise River Basin, is 1996, but waiting further information on a pending TMDL. Each nonpoint source then is to calculate the baseline load for the baseline year and then uses the baseline so calculated to determine the eligibility of reductions which are to serve as credits for trading. So this pattern of action shows that in the Lower Boise case if a nonpoint source adopts a BMP in a year after 1996, then the source has generated eligible credits. A BMP adopted in a year prior to 1996 would not be eligible in generating credits. Nonpoint sources in Idaho are required to use a list estimating equation for particular BMPs to calculate baseline loads. This equation used incorporates the U.S. Department of Agriculture Surface Irrigation Soil Loss equation.
It is not feasible for a nonpoint source to achieve 100 percent control of its runoff into a water body. So some analysis has to be completed to estimate the maximum amount of runoff that can actually be controlled. The difference between this estimate and the baseline equals the maximum load reduction that the nonpoint source can achieve. These calculations have to be considered in the initiation of a watershed trading program. The calculations indicate that credits being purchased actually result in phosphorus reductions. The trading program can calculate the maximum tradable nonpoint source load reduction for a trading area or watershed. The trading area’s maximum tradable nonpoint source load reduction is calculated by:

- first determining the maximum feasible implementation of BMPs (uniform or mixed in application and management);
- then estimation of the reduction from that level of BMP adoption on the basis of watershed modeling, published BMP effectiveness information or professional judgment; and
- then finding the difference between the maximum loadings reduction and the aggregate baseline for all generated credits (for all sellers).

The calculation can be done for the individual farm as well. The information and data developed in the Bear River Database will be of help in these calculations since field data and farm identifications can be made for the most part from the data contained in the database.

6.3 Credit Exchanges

The point source may buy nonpoint source credits either by directly contracting with the nonpoint source discharger or many such dischargers or by buying from an association of nonpoint discharges organized nonpoint source credit exchange. The exchange holds credits which represents approved reductions by the nonpoint sources who have implemented effective BMPs. These exchanges can be a broker-facilitated exchange whereby a broker the broker brings the point and nonpoint sources together in the trading program that is adopted, or they can be organized as a central exchange where the point sources deal with a central agency or board such as an nonpoint association board in order to buy credits. The central credit exchange model could also be organized by a third party who buys credits from nonpoint sources to sell to point sources.

There can be considerable transactions costs involved in getting the trading partners together and, as a result, there is need for some form of a credit exchange, particularly if there is some distance between the point sources and the nonpoint dischargers. The administration of such exchanges can be by a state agency, and local government entity, soil and water conservation districts or private third parties. The credit exchange can...
assume other functions in addition to the facilitation of the exchange of credits depending on the needs of the stakeholders it is designed to serve. These additional functions may include the advancing of water quality standards, credit approval and determination of eligibility of sources for creating credits and buying credits, establishing credit prices and the basis behind the prices, verification functions and other functions.

Many of the same issues in establishing trading in the point source-nonpoint context summarized in section 6.2 above are similar issues in the operation of an exchange. However, other responsibilities and accountability functions can be assigned to the exchange and of course there would be administration costs. The advantage of handing off some or all of the administration of the point-nonpoint trading program is that primary responsibility for resolving credit generation issues and perhaps the monitoring issues. If the trading program involves allowances, then a more streamlined functioning of the trading program is likely to occur, and the issues that remain in verification of are the measurement of what the nonpoint source targeted or allocated load will be and how that varies over the watershed amongst nonpoint sources particularly but also how this varies over point sources.
References


Technical Memo

Specific Requirements of and Objectives for the Water Quality Model to Support Water Quality Trading in the Bear River Basin

USEPA Targeted Watersheds Grant

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8-5-2005

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1.0 Introduction

This technical memo describes the specific requirements of and objectives for the water quality model to be developed as part of the Environmental Protection Agency (EPA) Targeted Watersheds grant in the Bear River Basin. The water quality model will be developed to specifically meet the needs of the water quality trading study that is also part of the Targeted Watersheds Grant. The information in the memo was arrived upon after coordination between the model development team and the water quality trading team. The requirements set forth in this document will govern the selection of an appropriate water quality modeling approach and its application in the Bear River Basin.

The focus of the water quality modeling work will be on establishing the environmental equivalence of potential trades of total phosphorus in the Bear River Basin. In the context of the model, this includes estimating equivalence ratios that account for pollutant load delivery from sources on the land to active stream reaches, and, subsequently, from stream reaches to downstream receptor points within the watershed. These equivalence ratios are essentially defined by the amount of phosphorus loading (or load reduction) from a particular source that reaches a downstream receptor point, and as such can be directly tied to the output from the water quality model.

Other ratios may be considered in the water quality trading study. These include uncertainty ratios, which attempt to account for the uncertainty present in the estimates of loads and potential load reductions (i.e., credits available to be traded). In addition, the concept of retirement ratios may be considered at the discretion of the water quality trading team. Retirement ratios have been used to ensure an overall reduction in pollutant loading by requiring that a certain percentage of all pollutant credits available to be traded are put into a credit bank and removed from the market. Uncertainty and retirement ratios are not directly tied to the output of the water quality model (i.e., they are not based on changes in loads or concentrations); however, at least in the case of uncertainty ratios, they are tied to the uncertainty of the model predictions and as such will be evaluated as necessary with the water quality trading team.

2.0 Water Quality Modeling Objectives

The selection of an appropriate model depends on the application needs or objectives. The definition of these needs or objectives is an essential first step in the development of a modeling approach (Shoemaker et al., 1997). The following objectives have been identified for the water quality modeling effort, and the water quality model that will be developed will be required to provide sufficient information to enable the following objectives to be met:

1. Evaluation of individual trading viability by incorporating total phosphorus discharges from reach-specific point and nonpoint sources.

The viability of potential trades is affected by the ability of one particular source to reduce loading to a point at which they have something to sell, the financial incentive for them to do so, and by the location of the source in relationship to the buyer. The viability of a potential trade generally decreases as the distance between the buyer and seller increases, depending
on the river conditions and operational activities that occur between potential buyers and sellers. These factors will be specifically accounted for in the water quality model, and so the results of the water quality model will provide the means by which viability of trades can be examined with respect to the physical characteristics of the system.

2. **Tracking of the effects of potential trades under different meteorological inputs and flow regimes**

The water quality benefit that results from potential trades must be viable under a variety of seasonal (spring runoff vs. late fall low flows) and climatic (wet year vs. dry year) conditions. Potential trades will be evaluated by running the water quality model using a variety of forcing data as input so that the variability in the resulting water quality caused by differences in season or climate can be considered.

3. **Examination of the general changes in water quality over time and distance**

The water quality model will provide the framework within which proposed trades can be evaluated. However, in a more general sense, the model can also be used to evaluate changes in water quality that may be associated with other, exogenous factors, such as changes in point source loading associated with population growth, or changes in nonpoint source loading associated with land use change. The resulting water quality associated with different scenarios can be evaluated over time (i.e., now vs. 20 years from now) and space (upstream vs. downstream conditions). In addition to its primary purpose, which is to support the water quality trading study, the water quality model could be used as a general tool for evaluating and managing nutrient-related water quality in the Bear River Basin.

4. **Examination of the effects of timing, river distance between potential seller’s and buyer’s locations, river conditions, and operational activities such as withdrawals and diversions**

The environmental equivalence of potential trades is determined by several factors, including the distance between buyers and sellers, timing, river conditions, and operational activities. Within the water quality model, pollutant sources will be located with the greatest degree of spatial resolution available, allowing the environmental equivalence of potential trades to be established in the context of distance, river conditions, and operational activities such as withdrawals and diversions. Timing is also critical as load reductions sold as credits must correspond in time with additional discharges from buyers (i.e., credits generated from reductions in spring runoff loading from nonpoint sources are likely not equivalent to increased loading from a point source in fall or winter).

5. **Comparison of the water quality outcomes of different management options**

The water quality model will provide a framework in which the outcomes of different management options can be evaluated in terms of the resulting water quality. Management includes any potential trades, but it can also include land management practices, or other management practices that may or may not be part of the trading program (i.e., the implementation of BMPs through public cost share programs).
6. *Establishment of environmental equivalence between potential trades*

The model will provide the ‘physical’ information needed to evaluate the environmental equivalence of potential trades. In context, this means that the model output will allow us to evaluate the equivalence of loads and load reductions at buyer’s and seller’s locations (i.e., if the load is reduced at a seller’s location, what is the equivalent load reduction at buyer’s location). As stated above, environmental equivalence is affected by timing, distance, river conditions, and operational activities, and these processes can be specifically accounted for in the model.

7. *Assessment of nonpoint source load reduction potential*

In addition to the model component that routes pollutant loads through the stream network, it may also be necessary to employ a variety of methods to assess the load reduction potential for point and nonpoint sources. It is important to assess each source to determine what the current loading is and what it could be reduced to after implementation of management alternatives. This can range from estimating pollutant loads from point sources after implementation of best available technology (BAT) to simulation of load reduction from nonpoint sources following BMP implementation. In some cases this can be accomplished by simply applying information obtained from the literature and without specifically simulating the processes by which the load is reduced.

3.0 Spatial Extent

In order to perform a detailed study of the feasibility for and potential mechanisms of water quality trading in the Bear River Basin, a focus area has been chosen. Several factors contributed to the selection of an appropriate water quality trading and modeling focus area. These include:

1. The existence of TMDLs that have been developed and are driving total phosphorus load reduction
2. The existence of a significant number and mix of point and nonpoint sources of phosphorus that could be potential participants in a water quality trading program
3. The availability of existing water quality and streamflow data
4. The ability to select, develop, and adequately run a water quality model of sufficient spatial and temporal resolution to support the evaluation of potential trades

The spatial extent of the water quality model has been defined as the mainstem of the Bear River from Oneida Narrows Dam downstream to Cutler Reservoir, including the Cub River drainage. In addition, the model will cover the Little Bear River and Spring Creek Drainages at the south end of Cache Valley. Although they are located outside of the selected area, the Logan City Lagoons may be included, but will be modeled as a direct point source to Cutler Reservoir. Figure 1 shows the water quality trading and modeling focus area that has been selected.
Figure 1. Water quality trading and modeling focus area.
The spatial extent of the water quality model is important because it defines the area in which detailed information regarding the environmental equivalence of potential trades will be available. The model provides the mechanism by which potential trades between two sources are evaluated in terms of distance between buyer and seller, timing, river conditions, climate conditions, and operational activities such as diversions. This detailed information for sources outside of the water quality trading and modeling focus area will not be available.

The modeling approach to be implemented in the focus will be designed so that it is scalable or expandable. The detailed model output required to provide the necessary information for establishing the environmental equivalence of potential trades constrains the spatial resolution of the selected modeling approach (the level of detail associated with the model segmentation into watersheds, river reaches, etc.), but for practical purposes, the spatial extent of the model (the area within which the model is applied) has been limited to fit the purposes of the Trading study. As additional TMDLs are developed in the Bear River Basin and the feasibility for trading increases in other areas of the watershed, water quality managers may wish to increase the spatial extent of the model to included additional areas.

### 4.0 Spatial and Temporal Resolution

The spatial and temporal resolution of the water quality model are driven by several factors that are described in more detail in the sections below. It is important that the model be capable of providing enough spatial resolution to evaluate potential trades among a variety of sources, both point and nonpoint, and enough temporal resolution to ensure that potential trades are viable throughout the year and over time.

#### 4.1 Spatial Resolution

The spatial resolution of the model controls the level of detail at which important processes can be evaluated and the type and number of locations at which model output is available. In general, the water quality model must have sufficient spatial resolution that the effects of potential trades between both point and nonpoint sources of pollution can be evaluated. It is important that the effects of changes in loading from individual sources (such as a single point source or a group of farms) can be evaluated in terms of changes in water quality that result at critical downstream receptor locations. These critical locations may include water quality sampling/compliance stations, stream confluences with major receptors such as Cutler Reservoir, or locations of potential pollution credit buyers and sellers.

The issue of spatial resolution is mainly one of model segmentation, which is the mathematical division of space and matter into segments or compartments (Chapra, 1997). In a model, the natural system is divided up into segments or compartments, each representing one component of the physical system. For example, a stream network may be divided up into a series of stream reaches, and each reach may be divided up into a series of computational elements or control volumes. Similarly, land segments may be divided up into watersheds, subwatersheds, hillslopes, patches, etc., all with the goal of creating a level of spatial granularity that is consistent with the process that is being described and that allows us to apply a series of
mathematical equations describing the mass balance and interaction between compartments. The final goal is to simulate the movement of constituents through the natural system, which, in the context of the model, means simulating the movement of constituents from one compartment or segment to the next.

In some cases, the properties of the constituent determine the required spatial resolution of the model. For example, enteric bacteria die rapidly after being discharged to a water body. Because of this, these bacteria are typically at high levels near a sewage discharge, but they tend to decrease rapidly as the distance from the source increases. Therefore, a model designed to simulate bacterial pollution would require relatively fine spatial segmentation around the source or outfall. In other cases, the physical characteristics of the system can dictate the required level of segmentation. This is the case where the natural system is complicated, such as a lake that has many embayments or is thermally stratified. In such cases, it is unrealistic to treat the system as a single compartment or segment, and, in general, the number of compartments increases as the complexity of the natural system increases. Regardless of whether the segmentation is controlled by the constituent being modeled or the complexity of the natural system, segmentation is fundamental to the application of mass conservation to water-quality problems (Chapra, 1997).

It is anticipated that the segmentation of the water quality model to be developed in the Bear River Basin will be controlled principally by the physical characteristics of the system to be modeled rather than the properties of the constituent to be modeled (total phosphorus). One of the most important requirements of the model is that it must enable the Water Quality Trading team to examine changes in water quality at specific receptor points resulting from management applied to specific sources. For example, what happens to phosphorus concentrations at a specific water quality monitoring location as a result of a reduction in loading from an upstream point source? The level of spatial detail required to adequately represent all of the potential sources and receptors will likely be more than adequate for the representation of important physical and chemical processes that control phosphorus concentrations in a stream system.

The water quality model will require that the spatial location of phosphorus sources and potential receptors be known and represented in the model with some certainty. Unfortunately, it is anticipated that information available to adequately characterize the spatial locations of pollutant sources and loads within the model will vary by source. Point source locations are known with a relatively high degree of certainty, but available information on nonpoint sources such as animal feeding operations may be inadequate to define exact spatial locations. In cases such as this, sources may have to be summarized at a subwatershed or stream reach level, depending on available information.

In order to address this issue, the selected model or group of models must be capable of representing loads from point sources added to the stream network at a point, and nonpoint source loads generated in a subwatershed and added incrementally along the length of a stream reach. Land areas represented by the model will be divided up into subwatersheds and the stream network will be segmented into a series of stream reaches. Specifically, the USGS 12 digit hydrologic units will be used as the primary watershed units. All subwatersheds represented in the model will be subsets of the USGS 12 digit HUCs – the 12 digit HUCs may be subdivided to satisfy the needs of the model, but they will not be aggregated (i.e., the largest
potential spatial element representing the land surface will be a single USGS 12 digit HUC. The medium resolution National Hydrography Dataset (1:100,000 scale) will be used to define the stream reaches in the model. Subwatersheds and stream reaches will be segmented within the model such that adequate representation of pollutant source and receptor locations can be maintained. In addition, stream reaches will be divided into computational elements, allowing model output (phosphorus concentrations and flows) to be generated along the length of the stream network.

4.2 Temporal Resolution

Similar to spatial resolution, the temporal resolution required to adequately describe a process can be affected by the properties of the constituent and the characteristics of the natural system. Because both point and nonpoint source loads vary from time to time, the water quality model will need to be able to simulate or incorporate major load variations that occur over the course of the year. Potential traders must meet TMDL timing requirements (which may be seasonal or annual), and the water quality model must have sufficient temporal resolution that the effects of changes in the seasonal and climatic driving forces within the model (streamflow, precipitation, etc.) can be evaluated along with the timing of the loading from each of the sources.

Point source loads are generally pretty constant over time, but nonpoint source loads can be the result of episodic events that may occur over time periods of days or even hours. Both point and nonpoint source loads can be influenced by seasonal or climatic driving forces such as precipitation, runoff, streamflow, etc. It is also important to consider that variability in loading may be due to seasonal management. For example, a point source may choose not to discharge during the summer because they can move to land application during these months, or downstream effects of a nonpoint source may not be realized because a large portion of the water is diverted prior to reaching a downstream receptor.

Given the above considerations, it is likely that a daily time step will be required for the water quality model. Daily model output can be summarized monthly, seasonally, or annually and should provide the necessary temporal resolution to evaluate potential trades in the water quality trading focus area. Using a daily time step, the water quality model will be capable of simulating a variety of streamflow conditions (i.e., wet year, drought year, etc.) and a variety of seasonal conditions (i.e., late fall/winter base flow vs. spring runoff conditions) to ensure that load reductions that result in potential trades are viable year-round (under a variety of seasonal conditions) and that they are viable regardless of climatic conditions that vary from year to year.

5.0 Required Model Input and Output Options

The most important output of the water quality model will be estimates of phosphorus concentrations at locations throughout the trading focus area. These concentrations, coupled with estimates of streamflow will enable the examination of changes in loads, while still maintaining the ability to evaluate instream concentrations against water quality criteria, which are expressed in terms of concentrations and not loads.
The water quality model will supply the water quality trading team with information needed to accomplish the goals outlined in Section 2.0 above. It is important to note, however, that the trading team may incorporate the water quality model output or information derived from the water quality model output into a number of economic models designed to evaluate the potential for and mechanisms of a water quality trading program in the Bear River Basin. Figure 2 shows a simplified schematic of the anticipated flow of information associated with the water quality model and the water quality trading program.

Figure 2. Schematic depicting the potential flow of data and information between the water quality model and the water quality trading economic model(s).
References


Technical Memo

Review and Summary of Water Quality Modeling Approach to Support Water Quality Trading in the Bear River Basin

USEPA Targeted Watersheds Grant

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Bear River Commission

11-3-2005

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1.0 Introduction

This technical memo details the water quality modeling approach that has been selected for implementation in the Bear River Basin to support a detailed study of the feasibility for and mechanisms of water quality trading. The focus of the water quality modeling work will be on establishing the environmental equivalence of potential trades of total phosphorus in the Bear River Basin and to provide the Water Quality Trading Team with the information needed to complete the evaluation of the potential for water quality trading in the Bear River Basin. This includes estimating equivalence ratios that account for pollutant load delivery from sources on the land to active stream reaches, and, subsequently, from stream reaches to downstream receptor points within the watershed. These equivalence ratios are essentially defined by the amount of phosphorus loading (or load reduction) from a particular source that reaches a downstream receptor point, and as such can be directly tied to the output from the water quality model.

When selecting a modeling approach, it is important to consider existing water quality conditions and the potentially unique physical, chemical, and biological aspects of the system to be modeled so that an appropriate approach can be chosen. To this end, a brief discussion on the availability of existing water quality and streamflow data and water quality issues within the water quality trading focus area is provided. In addition, a review of current streamflow and water quality modeling efforts ongoing within the focus area and a review of currently available water quality models are presented as appendices. These reviews were undertaken to facilitate the selection of an appropriate water quality modeling approach to support the water quality trading study.

2.0 Water Quality Trading Focus Area

In order to perform a detailed study of the feasibility for and potential mechanisms of water quality trading in the Bear River Basin, a focus area has been chosen. The spatial extent of the water quality trading focus area, and, therefore, the water quality model has been defined as the mainstem of the Bear River from Oneida Narrows Dam downstream to Cutler Reservoir, including the Cub River drainage. In addition, the model will cover the Little Bear River and Spring Creek Drainages at the south end of Cache Valley. Although located outside of the focus area, the Logan City Lagoons may also be included in the trading study, but will be modeled as a direct point source to Cutler Reservoir. Figure 1 shows the water quality trading and modeling focus area that has been selected.

The spatial extent of the water quality model is important because it defines the area in which detailed information regarding the environmental equivalence of potential trades will be available. The model provides the mechanism by which potential trades between two sources are evaluated in terms of distance between buyer and seller, timing, river conditions, climate conditions, and operational activities such as diversions. This detailed information for sources outside of the water quality trading and modeling focus area will not be available.
Figure 1. Water quality trading and modeling focus area.
3.0 **Summary of Water Quality Issues in the Trading Focus Area**

3.1 **Major Pollutant Sources and Water Quality Issues**

Within the Bear River watershed, streams, lakes, and reservoirs are primarily designated for agricultural use, recreational contact, and cold-water fish habitat. As the water bodies fail to meet these designations, they are listed as impaired for a particular pollutant (303(d) listing). Water quality impairments within the Bear River watershed include sediment, nutrients, fecal coliform bacteria, low dissolved oxygen, and elevated temperatures. Within the area designated as the spatial scope of the modeling and trading program, those water bodies that have received a 303(d) listing and their associated pollutants are given in Table 1.

<table>
<thead>
<tr>
<th>Water body</th>
<th>Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weston Creek</td>
<td>TP, Sediment</td>
</tr>
<tr>
<td>Newton Reservoir</td>
<td>TP, DO, Temperature</td>
</tr>
<tr>
<td>Clarkston Creek</td>
<td>TP</td>
</tr>
<tr>
<td>Cub River</td>
<td>TP, Sediment</td>
</tr>
<tr>
<td>Porcupine Reservoir</td>
<td>Temperature</td>
</tr>
<tr>
<td>Hyrum Reservoir</td>
<td>TP, DO</td>
</tr>
<tr>
<td>Spring Creek</td>
<td>TP, DO, Ammonia, Temperature, Fecal Coliform</td>
</tr>
<tr>
<td>Little Bear River</td>
<td>TP</td>
</tr>
</tbody>
</table>

TP = Total Phosphorus, DO = Dissolved oxygen

As shown in Table 1, the pollutants of concern common to the majority of impaired water bodies are total phosphorus and dissolved oxygen. As total phosphorus is a pollutant of high priority and considering that phosphorus pollutant credits could feasibly be traded, the modeling effort will focus on nutrient loading and processes. Additionally, dissolved oxygen concentrations are associated with phosphorus loadings. Excessive nutrient enrichment can degrade the water quality of rivers and lakes. Phosphorus is a leading nutrient causing eutrophication of surface water bodies. Specifically, high nutrient levels increase biological productivity resulting in growth of undesirable algae and other aquatic plant species. The presence of algae depletes dissolved oxygen resulting in concentrations too low for many fish and aquatic invertebrate species. Additionally, undesirable odors and scum can be produced, compromising the aesthetic quality of the water.

Phosphorus is also an important nutrient to agricultural production. Just as the presence of phosphorus increases biological productivity in streams, it also increases the productivity of crops. As a result, phosphorus is commonly applied to crops as fertilizer. Phosphorus is also found in livestock manure, which can enter streams after being applied to crops or through runoff generated at animal feeding operations and grazed pastures near existing streams. In agricultural watersheds, phosphorus reaches the stream by various means including surface runoff, interflow, and soil erosion. Phosphorus can be strongly held by soil particles and then released as particles separate. As a result, phosphorus concentrations can be related to suspended sediment concentrations in a stream. When phosphorus is bound to sediment, it can have effects further downstream than the initial point of entry as it is released over time.
In reviewing the TMDL documents that have been developed to date, specific sources of phosphorus loadings to the water bodies in question have been identified. The loadings from point sources were generally known while the loadings from nonpoint sources were estimated using methods that varied from TMDL to TMDL. In order to compare relative loadings between the different TMDLs, these sources were grouped into the following categories: point sources, agricultural nonpoint, urban nonpoint, AFO/CAFO nonpoint, and other nonpoint sources. Other nonpoint sources might include on-site wastewater treatment operations, groundwater background, or any other unidentified nonpoint source. The loading distributions are summarized in Table 2. Figure 2 summarizes the loading in each category across all of the TMDLs that were considered by percent contribution to the total loading.

Table 2. Annual phosphorus loadings summarized from each of the existing TMDL documents for 303(d) listed water bodies within or bordering the modeling focus area.

<table>
<thead>
<tr>
<th>Phosphorus Source</th>
<th>Spring Creek</th>
<th>Hyrum Reservoir</th>
<th>Little Bear River</th>
<th>Newton Reservoir</th>
<th>Newton Creek</th>
<th>Cub River^4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point sources</td>
<td>33,050</td>
<td>882</td>
<td>1,050</td>
<td>0</td>
<td>0</td>
<td>1,660</td>
</tr>
<tr>
<td>Agriculture nonpoint</td>
<td>1,390</td>
<td>3,503</td>
<td>3,503</td>
<td>2,872</td>
<td>1,311</td>
<td>0</td>
</tr>
<tr>
<td>Urban nonpoint</td>
<td>1,990</td>
<td>167</td>
<td>167</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AFO/CAFO nonpoint</td>
<td>600</td>
<td>1,550</td>
<td>1,550</td>
<td>556</td>
<td>3,218</td>
<td>0</td>
</tr>
<tr>
<td>Other nonpoint</td>
<td>1,300</td>
<td>2,405</td>
<td>2,405</td>
<td>207</td>
<td>74</td>
<td>18,396</td>
</tr>
</tbody>
</table>

^4These numbers are for the Idaho portion of the Cub River. No specific breakdown for nonpoint source loading was given and so it was all lumped into one category.

Figure 2. Annual phosphorus loadings summarized by percentage contribution for all of the existing TMDLs within or bordering the modeling focus area.

Table 2 shows that within the model focus area there are some streams where the phosphorus loadings are dominated by point sources, as is the overwhelming case in Spring Creek, and there are some streams that are dominated by nonpoint sources. In all of these streams, animal feeding operations are a significant source of loading, and, in general, urban nonpoint sources are relatively small. In all cases, agricultural nonpoint sources are a very significant portion of the total loading. The loading profile shown in Table 2 is, in general, characteristic of the Bear River Basin. Water quality problems are generally most severe in valley locations impacted by
surrounding agriculture. The model focus area excludes the largest urban area within the Bear River watershed (Logan City), and as such, urban impacts on water quality are mainly associated with the wastewater treatment facilities in towns such as Hyrum, Richmond, Franklin, and Preston.

The information in Table 2 has some implications on the selected modeling approach. First, since there are areas within the model focus area that are point source dominated and some areas that are nonpoint source dominated, the selected approach must be capable of representing both. This will be challenging, since many existing water quality models are designed specifically for systems that are point source dominated or systems that are nonpoint source dominated – few models do both well. Second, in all of the existing TMDLs animal feeding operations and agricultural nonpoint sources are both significant components of the total loading. While this holds promise for the water quality trading program because there is a significant amount of loading within categories that should have relatively low pollution abatement costs, it will be challenging to develop a model capable of distinguishing between individual sources within these categories for the purposes of the water quality trading study.

3.2 Availability of Existing Data for Modeling

The availability of existing data for model population, calibration, and validation is an important consideration in the selection of a streamflow and water quality modeling approach. The following sections provide a brief description of the data available for modeling in the focus area.

3.2.1 Streamflow Data

The main source of streamflow data for the modeling effort will be USGS daily streamflow records at gages located throughout the model focus area. In addition, we will explore data available from the Utah Division of Water Rights regarding diversion flows and from Pacificorp regarding river flows and release data. Streamflow and diversion data will be used to calibrated and validate the hydrologic portion of the model that will be developed.

There are several USGS gages on the main stem of the Bear River between Oneida Narrows Reservoir and Cutler Reservoir, only one of which is currently active. In addition, there are several gages on tributaries to this section of the Bear River, but again only one of these gages is currently operating (the USGS has recently reactivated station 10093000 – Cub River Near Preston Idaho as a real time gage). Table 3 lists the available streamflow gages and the period of record and number of observations associated with each. Figures 3 and 4 show the number of observations at each gage and the time distribution of the observations.
Table 3. USGS streamflow gages in the Bear River portion of the model focus area.

<table>
<thead>
<tr>
<th>Gage ID</th>
<th>Site Name</th>
<th>Begin Date</th>
<th>End Date</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>10087500</td>
<td>Mink Creek Below Dry Fork, Near Mink Creek, Id</td>
<td>4/1/1947</td>
<td>9/30/1962</td>
<td>4,567</td>
</tr>
<tr>
<td>10090500</td>
<td>Bear River Near Preston, Idaho</td>
<td>10/1/1944</td>
<td>9/30/1986</td>
<td>2,191</td>
</tr>
<tr>
<td>10092700</td>
<td>Bear River At Idaho-Utah State Line</td>
<td>10/1/1970</td>
<td>9/30/2004</td>
<td>12,419</td>
</tr>
<tr>
<td>10093000</td>
<td>Cub River Near Preston, Id</td>
<td>3/1/1940</td>
<td>9/30/1986</td>
<td>15,920</td>
</tr>
<tr>
<td>10099000</td>
<td>High Creek Near Richmond, Utah</td>
<td>4/1/1944</td>
<td>9/30/1989</td>
<td>7,367</td>
</tr>
<tr>
<td>10102200</td>
<td>Cub R. Nr. Richmond Utah</td>
<td>6/1/1962</td>
<td>9/30/2000</td>
<td>1,294</td>
</tr>
<tr>
<td>10102250</td>
<td>Bear River Near Smithfield, Ut</td>
<td>4/1/1964</td>
<td>9/30/1995</td>
<td>7,493</td>
</tr>
<tr>
<td>10102300</td>
<td>Summit Creek Abv. Diversions Nr. Smithfield, Utah</td>
<td>10/1/1961</td>
<td>10/25/1979</td>
<td>6,599</td>
</tr>
</tbody>
</table>

The USGS data available below Oneida Narrows Dam is likely insufficient to adequately specify a boundary condition at that location. However, PacifiCorp has collected historical data on releases from Oneida Narrows Reservoir, and these data (daily average releases) have already been made available to us for use in the modeling effort.

Figure 3. Data density plot for streamflow gages located between Oneida Narrows Reservoir and Cutler Reservoir.
Figure 4. Time distribution of streamflow observations for streamflow gages located between Oneida Narrows and Cutler Reservoir.

Table 4 lists the USGS streamflow gages in the Little Bear River watershed and the period of record for each. Figures 5 and 6 show the number of observations at each gage and the time distribution of the data. There is currently only one active gage within the Little Bear River watershed near Paradise (station 10105900). No continuous streamflow monitoring has been conducted by the USGS within the Spring Creek drainage. Streamflow estimates in Spring Creek are limited to those collected at the same time as water quality samples by the State of Utah Division of Water Quality.

Table 4. USGS streamflow gages in the Little Bear River watershed.

<table>
<thead>
<tr>
<th>USGS Gage ID</th>
<th>Site Name</th>
<th>Begin Date</th>
<th>End Date</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>10104600</td>
<td>South Fork Little Bear River Near Avon, Utah</td>
<td>7/1/1966</td>
<td>9/30/1974</td>
<td>3,014</td>
</tr>
<tr>
<td>10105000</td>
<td>East Fork Little Bear River Near Avon Utah</td>
<td>1/1/1938</td>
<td>1/2/1951</td>
<td>4,689</td>
</tr>
<tr>
<td>10105900</td>
<td>Little Bear River At Paradise, Utah</td>
<td>10/1/1991</td>
<td>9/30/2004</td>
<td>4,385</td>
</tr>
<tr>
<td>10106000</td>
<td>Little Bear River Near Paradise, Utah</td>
<td>10/1/1938</td>
<td>9/30/1986</td>
<td>17,532</td>
</tr>
<tr>
<td>10107500</td>
<td>Little Bear River Near Hyrum, Utah</td>
<td>10/1/1942</td>
<td>3/1/1974</td>
<td>11,475</td>
</tr>
<tr>
<td>10107600</td>
<td>Little Bear River At Wellesville Utah</td>
<td>7/1/1966</td>
<td>9/30/1968</td>
<td>823</td>
</tr>
</tbody>
</table>
3.2.2 Water Quality Data

Water quality data will also be required to calibrate and validate the water quality portion of the model. It is anticipated that the main sources of water quality data will be the state of Utah Division of Water Quality and the state of Idaho Department of Environmental Quality. Other sources will be incorporated as they are identified. The most critical datasets will be those collected at the boundaries of the system being modeled – the outlets of the Little Bear River and
Spring Creek where they enter Cutler Reservoir on the south end of Cache Valley, the Bear River where it enters Cutler Reservoir, the Cub River above its confluence with the Bear, and the Bear River where it comes out of Oneida Narrows Reservoir (the upstream boundary condition for that portion of the model). Additionally, data will be needed at intermediate points within the model focus area to ensure that the model is capturing spatial differences in water quality.

The following plots show data density and data distribution plots for two of the major downstream boundary conditions that will be included in the model. Figure 7 summarizes some of the water quality data collected by Utah DWQ for the Little Bear River just upstream of its confluence with Cutler Reservoir, and Figure 8 summarizes some of the water quality parameters for Spring Creek near the same location (Mendon Road). At both of these locations it looks like there is a reasonable water quality dataset – for example, there are over 100 observations of total phosphorus in Spring Creek and over 200 observations of total phosphorus in the Little Bear River at the locations shown in the figures.

Figure 7. Data density (a) and distribution (b) plots for the Little Bear River at Mendon Road (UDWQ 4905000).
Figure 8. Data density (a) and distribution (b) plots for Spring Creek at Mendon Road (UDWQ 4904900).

These two figures are shown as examples of stations with a relatively large number of water quality observations. There are a limited number of such stations within the model focus area, and it is anticipated that most water quality stations will have fewer observations than are shown in the figures above. It is beyond the scope of this memo to review the water quality data at each potential model calibration location; however, the Model Development Technical Memo that will be written as the model is developed will describe the sampling locations and water quality datasets used in calibrating the model.

3.2.3 Climate Data

The water quality model will require climate data as forcing functions to drive the hydrology and water quality of the system. Required parameters include air temperature, solar radiation, precipitation, relative humidity, wind speed, and barometric pressure. Data for these parameters will be required on at least a daily basis for the time period to be simulated using the model.
After a preliminary review of available climate data in Cache Valley, it is apparent that there is a general lack of good climate data (especially precipitation data). It is anticipated that this will be somewhat limiting to the modeling effort. Both spatial and temporal coverage of precipitation data within the model focus area is generally poor, although relatively good datasets exist associated with Utah State University and stations associated with Logan City. Climate data collected at two SNOTEL sites in the upper portions of the Little Bear River will be useful, as will the data collected at USU’s campus, but few data are available in the lower elevations of the model focus area, especially in the Bear River portion from Oneida Narrows to Cutler Reservoir.

The few climate stations available will be of limited utility to the modeling effort because of the scale of the area covered by the model. It is not uncommon for summer or winter storms to pass through Cache Valley with significant precipitation occurring at one end of the valley but missing the other. One or two stations with relatively good coverage is not going to be enough to drive the model due to the spatial extent of the model focus area. Due to the lack of good climate data within the model focus area, we will explore the use of simulated meteorological information from a source such as those created by the Surface Water Modeling Group at the University of Washington (Hamlet and Lettenmaier, 2005). These datasets represent a reconstruction of daily climate variables, including daily precipitation, maximum and minimum temperature, and wind speed at a four kilometer grid cell resolution for the entire United States. Although the information from sources such as the one referenced above represents model simulation results (i.e., estimated rather than measured), they may prove to be invaluable to the modeling effort in the absence of detailed observations.

### 3.2.3 Physical Data

In addition to streamflow and water quality data, the modeling effort will require physical data to describe the morphometry of the streams and reservoirs that are to be modeled. We will need information to characterize the width and depth of the stream reaches to be modeled at different flow rates. For the stream reaches, we will capitalize on work that has already been done where possible. It is anticipated that several groups at USU, including individuals from the College of Natural Resources, the College of Engineering, and the Utah Water Research Laboratory, have done stream cross section measurements within the modeling area. In addition, the USGS maintains stage discharge relationships at gage locations. Where no information is available, we may extrapolate from other similar sites, or we may send field crews to the sites to make cross section, stage, and flow measurements.

For reservoirs that will be represented in the model, we will require a relatively detailed description of the bathymetry. This is likely to be an issue only for Hyrum and Porcupine reservoirs in the Little Bear River watershed. For these reservoirs, we can construct the bathymetry from as-built contour maps, which almost certainly exist, or we can construct it from bathymetric survey data if available. It is not known at this time what the availability of bathymetric data is for these reservoirs.
4.0 Proposed Water Quality Modeling Approach

The proposed modeling approach involves combining several sub-models or components, each of which serves a particular function, within a single, connected modeling framework. The model components will include a hydrologic model for simulating streamflow, a watershed loading model for estimating nonpoint source loading from the landscape, a stream response model that will route constituents through the system, and an accounting model component that will superimpose management such as diversions and inter-basin transfers of water on the system. The watershed loading model handles the generation of loads and their delivery to the stream, and the stream response model handles the transport of the loads as they move through the stream network. Additional components may be necessary to simulate loading from sources not directly tied to the landscape such as point sources.

In order to simulate the natural system, the model components will be required to interact (i.e., the output of the watershed loading component becomes the input for the stream response component). Each of the model components will be tied together within a single modeling framework that will manage the interaction between the model components. An interface will be created that will allow users to input or change scenario options and then execute each of the model components. The interface will execute each of the model components without additional interaction from the user (i.e., the interface will take care of the interaction between the sub-models).

4.1 Model Segmentation

The segmentation used by the water quality model will consist of subwatershed areas, stream reaches, and control points. The model focus area will be divided up into a series of terrain based subwatershed areas, each representing the area contributing flow to a downstream control point. Control points will be located strategically at important locations within the focus area, including major tributary confluences, major diversion locations, and streamflow and water quality monitoring sites. Control points will be connected by stream reaches that will be represented in the model. The modeling framework will then provide the connection between the different segments of the model. The hydrologic model component will simulate the amount of flow generated within each subwatershed, the watershed loading model component will simulate the amount of loading generated within each subwatershed, the stream response model component will route the flow and loading generated within each subwatershed through the modeled stream reaches, and the accounting model component will ensure that diversions and inter-basin transfers are accounted for. Figure 9 shows a simplified schematic of the segmentation for a single subwatershed and stream reach.
The subwatersheds will be the fundamental modeling units, and, in general, the model will be lumped at the subwatershed scale. A single stream reach will be modeled within each subwatershed, except for those subwatersheds that are headwaters (subwatersheds with no upstream subwatershed or control point) in which no stream reach will be represented in the model. The stream network will be broken at the inflow and outflow of all reservoirs, and a separate subwatershed will be included within the model for each reservoir. The reservoir will then effectively become the stream reach within a reservoir subwatershed. Control points will be placed at the outlet of each subwatershed, at the intersection of the subwatershed boundary and the stream reach, representing the pour points for the subwatersheds. The following figure shows the subwatersheds, stream reaches, and control points for the Little Bear River portion of the model focus area as an example of this concept.
4.2 Hydrologic Model Component

The purpose of the hydrologic model component is to simulate the amount of flow generated within each of the subwatersheds in the model focus area. We will use TOPNET as the base hydrologic model to generate flows in the model focus area. TOPNET is an enhanced version of the rainfall runoff model TOPMODEL (Bevan and Kirkby, 1979; Bevan et al., 1995). Enhancements include calculation of reference evapotranspiration using the Penman-Monteith method, and snowmelt using the Utah Energy Balance Snowmelt model (Tarboton et al., 1995). The model has also been modified to include plumbing and options for diversion and storage of water under different management options. The model is capable of partitioning model elements (subwatersheds) into separate components representing irrigated and non-irrigated area. Components to calculate water use and implement water rights rules are also included.

Driving inputs to TOPNET are primarily precipitation and potential evapotranspiration, as well as other climate parameters needed to model the energy balance required for snowmelt. Climate variables are taken from nearby climate monitoring stations and are interpolated to each subwatershed. TOPNET also takes as inputs many physical characteristics of the landscape, including topographic parameters derived from a digital elevation model, soil characteristics, land cover information, and other GIS derived information. The following figure illustrates the major processes accounted for in the TOPNET model.

![Figure 11. TopNet model schematic. Source: Bandaragoda et al., 2004.](image-url)
4.3 Watershed Loading Model Component

The watershed loading model will provide estimates of the pollutant loads generated within each subwatershed. The existing TMDL documents generally provide at least annual estimates of total phosphorus loading from important sources within the modeling focus area. However, these documents do not contain load estimates that are time variable, and the spatial resolution of the load estimates in the TMDL documents is inadequate for the purposes of the water quality trading study. In some cases, seasonal or even monthly loads are presented, but this information is not sufficient to drive a dynamic water quality model. Because of this, a watershed loading model that provides dynamic (time varying) estimates of loading to streams and water bodies from the landscape will be required. Although insufficient to drive the water quality model, the load estimates in the TMDL documents will be used as checks of the load estimates provided by the watershed loading model to ensure that the model is sufficiently capturing existing conditions prior to running management scenarios.

The loads output by the watershed loading model component will be lumped at a subwatershed scale. This means that the output from the watershed loading model for a particular subwatershed will represent the total loading in the subwatershed from each source. For example, the simulated loading from animal feeding operations within a subwatershed will represent the combined loading from all animal feeding operations within that subwatershed. Loads from individual animal feeding operations will be accounted for if information is available, but the model output will be the sum of loading from all animal feeding operations within the subwatershed.

The watershed loading model will be made up of several subcomponents. One subcomponent will calculate the diffuse loading from each land use within the subwatershed using an export coefficient based approach. Another subcomponent will simulate loading from animal feeding operations based on available information on number of animals, proximity to existing streams, etc. Point source loads will be estimated using existing sampling data. Each of these subcomponents will be designed taking into consideration the magnitude of the loading from each source, the complexity of the loading mechanism, and the information available to characterize each source.

The loads simulated by the watershed loading model for a particular subwatershed will be added to the modeled stream reach within that subwatershed as a distributed load along the length of the reach or as a point load at the outlet of the subwatershed, whichever is more appropriate. Point source loads will be added to the stream network as close to the actual location of the point source discharge as possible. Within the model segmentation, the reach network will be broken at the location of point source discharges so that a subwatershed outlet (control point) is located as close to each point source discharge as possible.

4.4 Stream Response Model Component

Generally, phosphorus is not conservative within aquatic systems. Various physical, chemical, and biological processes affect phosphorus concentrations within stream reaches, and so a model that simulates changes in phosphorus concentrations within each stream reach, or from control
point to control point, will be required. This model component will simulate the major processes affecting total phosphorus concentrations within the stream, including advection, dispersion, algae uptake, and sediment interactions.

Due to the complexity of modeling phosphorus interactions within a stream environment, an existing, public domain, peer reviewed model, QUAL2K, has been selected for this component. QUAL2K is a one dimensional river and stream water quality model that assumes that the stream channel is well-mixed vertically and laterally. QUAL2K simulates steady-state hydraulics, and contains a diurnal heat budget and water quality kinetics. The heat budget and temperature are simulated as a function of the meteorology on a diurnal time scale, and all water quality variables are also simulated on a diurnal time scale. QUAL2K can be used to simulate the effects of both point and nonpoint source loads on instream water quality. Figures 12 and 13 show the segmentation of the QUAL2K model.

QUAL2K can be run in steady-state mode, where time is frozen and the results represent a snapshot of the spatial variability in water quality throughout the system given a set of input conditions. We will also run QUAL2K in a time varying mode – essentially the model is executed in steady-state mode for each day over a relatively long simulation period that may be months or even years long. This ability to run the model in both steady-state or dynamic modes will allow us to either zero in on critical conditions (such as summer low flow) or look at changes in water quality over a simulation period that is representative of the variability in local hydrologic conditions.

![Figure 12. QUAL2K longitudinal segmentation – streams are divided into reaches, with point sources and abstractions added and subtracted along the length of the stream.](image)

Source: Chapra and Pelletier (2003).
For those subwatersheds in which the representative stream reach is actually a reservoir, QUAL2K would be inappropriate. Instead, a reservoir response model will be used to represent these water bodies. The reservoir response model that we will use is called RESENTIME, and is a dynamic version of the reservoir water quality model RESEN that was originally developed at Utah State University (Messer et al., 1982). The proposed modeling approach is relatively simple and can be considered as a lower-resolution complement to the high resolution, 2-dimensional, CE-QUAL-W2 model. The model includes the major water quality-related processes present in CE-QUAL-W2 – an energy balance for the vertical temperature distribution, mass balances for nutrients, organic matter, dissolved oxygen, and the growth, decay, and settling rates of algae. The model can be described as a 2-dimensional laterally averaged but vertically and longitudinally distributed compartment model with exchange between compartments. Figure 14 shows a schematic view of the box model approach. The top view in Figure 14 is a plan view representation of a reservoir with 3 theoretical basins shown from left to right. Adjacent to each basin is one or more smaller compartments into which contributing streams flow and exchange with the body of the lake. The bottom portion of this figure shows the potential vertical segmentation of the model. Energy and mass balance equations are solved for each compartment within the reservoir for the water quality constituents. The volume of each of the compartments in the model is determined by the morphometry of the reservoir and can be determined from bathymetry data.
4.5 Accounting Model Component

The control points will be used within a water and pollutant accounting model that will account for diversions, interbasin transfers, and flow accumulation within the model focus area. Each control point, which represents the pour point of a subwatershed, will accumulate flow and loading from any control points immediately upstream of the subwatershed. The control point will also accumulate any flow and loading generated within the subwatershed for which the control point is the outlet. Diversion flows will be subtracted or added as necessary, as will flows from point sources. The following figure and equations illustrate these concepts:

Figure 14. Schematic diagram of RESENTIME reservoir model segmentation.

Figure 15. Accounting model schematic. The greenish blue area represents a subwatershed, the blue line represents a modeled stream reach, and the pink points represent control points.
\[ Q_i = Q_u + Q_w + Q_{in} + Q_p - Q_{out} \]  

(1)

Where:  
\( Q_i \) = Flow at the downstream control point  
\( Q_u \) = Flow at the upstream control point  
\( Q_w \) = Flow generated within the subwatershed  
\( Q_{in} \) = Diversion flows into the subwatershed  
\( Q_p \) = Point source flows into the subwatershed  
\( Q_{out} \) = Diversion flows out of the subwatershed  

\[ L_i = C(Q_u C_u + Q_w C_w + Q_{in} C_{in} + Q_p C_p - Q_{out} C_{out}) - L_r \]  

(2)

Where:  
\( L_i \) = Pollutant load at the downstream control point  
\( C \) = Units conversion constant  
\( C_u \) = Concentration at the upstream control point  
\( C_w \) = Concentration of flow generated with the subwatershed  
\( C_{in} \) = Concentration of diversion flows into the subwatershed  
\( C_p \) = Concentration of point source flows into the subwatershed  
\( C_{out} \) = Concentration of the subwatershed outflow  
\( L_r \) = Loading lost to reactions along the length of the reach

Loading lost to reactions along the length of the stream reaches will be estimated by the stream response model component.

### 5.0 Constituents to be Modeled

The focus of the water quality trading study is total phosphorus, and because of this, total phosphorous will be the primary constituent that is modeled. However, since phosphorus is not conservative in an aquatic system, several other constituents will be simulated because they interact with total phosphorus. Water temperature will be simulated because it controls rates of chemical and biological reactions. Nitrogen concentrations will be simulated because the growth of algae is dependent on both nitrogen and phosphorus. Algae will be simulated because algae growth is one mechanism of phosphorus uptake. In addition, dissolved oxygen concentrations will be simulated because some chemical and biological reactions are dependent on oxygen concentrations. Biochemical oxygen demand (a measure of organic matter) must be simulated to get dissolved oxygen concentrations. Last, the model will be capable of simulating pH and concentration of a generic, inert tracer. Simulation of inert tracers can help in resolving problems with the hydrology model.

### 6.0 Model Resolution

#### 6.1 Spatial Resolution

The water quality model must have sufficient spatial resolution that the effects of potential trades between both point and nonpoint sources of pollution can be evaluated. It is important that the
effects of changes in loading from individual sources (such as a single point source or a group of farms) can be evaluated in terms of changes in water quality that result at critical downstream receptor locations. These critical locations may include water quality sampling/compliance stations, stream confluences with major receptors such as Cutler Reservoir, or locations of potential pollution credit buyers and sellers.

Because the proposed watershed loading model will be lumped at the subwatershed scale, it is important that enough resolution be present in the delineation of subwatersheds so that the pollutant sources can be adequately represented and evaluated. All subwatersheds represented in the model will be subsets of the USGS 12 digit HUCs – the 12 digit HUCs may be subdivided to satisfy the needs of the model, but they will not be aggregated (i.e., the largest potential spatial element representing the land surface will be a single USGS 12 digit HUC). A single stream reach will be modeled within each subwatershed, and stream reaches may be divided into sub-reaches within the QUAL2K model if necessary. The medium resolution National Hydrography Dataset (1:100,000 scale) will be used to define the stream reaches in the model. Subwatersheds and stream reaches will be segmented within the model such that adequate representation of pollutant source and receptor locations can be maintained.

Primary model output (flow and total phosphorus concentrations) will be available at control points that represent the outlets of each subwatershed. Care will be taken in the model setup process to ensure that control points are collocated with water quality and streamflow monitoring sites so that output from the model can be compared to actual data for calibration and validation purposes. This is also important because the primary receptor points for the trading study are likely to be water quality monitoring locations. Output will be available, if necessary, at locations between control points in the case that an important phosphorus source (i.e., a potential buyer of seller of phosphorus credits) is located between model control points.

6.2 Temporal Resolution and Simulation Time Step

Because both point and nonpoint source loads vary from time to time, the water quality model will need to be able to simulate or incorporate major load variations that occur over the course of the year. Potential traders must meet TMDL timing requirements (which may be seasonal or annual), and the water quality model must have sufficient temporal resolution that the effects of changes in the seasonal and climatic driving forces within the model (streamflow, precipitation, etc.) can be evaluated along with the timing of the loading from each of the sources.

Point source loads are generally pretty constant over time, but nonpoint source loads can be the result of episodic events that may occur over time periods of days or even hours. Both point and nonpoint source loads can be influenced by seasonal or climatic driving forces such as precipitation, runoff, streamflow, etc. It is also important also to consider that variability in loading may be due to seasonal management. For example, a point source may choose not to discharge during the summer because they can move to land application during these months, or downstream effects of a nonpoint source may not be realized because a large portion of the water is diverted prior to reaching a downstream receptor.
Given the above considerations, a daily time step will be used for the water quality model. Daily model output can be summarized monthly, seasonally, or annually and should provide the necessary temporal resolution to evaluate potential trades in the water quality trading focus area. Using a daily time step, the water quality model will be capable of simulating a variety of streamflow conditions (i.e., wet year, drought year, etc.) and a variety of seasonal conditions (i.e., late fall/winter base flow vs. spring runoff conditions) to ensure that load reductions that result in potential trades are viable year-round (under a variety of seasonal conditions) and that they are viable regardless of climatic conditions that vary from year to year.

7.0 Limitations of the Selected Modeling Approach

7.1 Availability of Existing Data and Information

It is anticipated that the sparseness of the available water quality, streamflow, and climate data available for modeling will be a significant limitation to the model that we will develop. Calibration of the water quality model will likely be difficult due to the lack of water quality stations with an adequate number of water quality observations. The same is likely true of the effort to calibrate the hydrologic model component. There are streamflow gages within the model focus area with long periods of record for streamflow. However, the periods of record for gages located throughout the model focus area generally do not overlap and may not correspond with the time period of climate inputs available as inputs to drive the model.

At this point, little is known about the physical characteristics of the stream reaches that will be modeled. These characteristics include hydraulic characteristics for the stream channels and morphometry information for any reservoirs that will be simulated. To some extent, this data gap can be overcome by sending technicians into the field to make some rudimentary measurements. However, this will be a last resort as we have allocated very little for field work in this modeling effort.

7.2 Model Limitations

The spatial resolution of the model may limit our ability to evaluate the effects of some management scenarios. This limitation is imposed on the model by the potential lack in spatial resolution of loading inputs. For example, if the spatial location of animal feeding operations is unknown, this will introduce some uncertainty into the modeling effort. Of course, the old adage is true – garbage in does usually equal garbage out. The model that we develop will only be as good as the inputs that we have available to us to drive the model.

8.0 Scalability of the Selected Modeling Approach

The proposed modeling approach to be implemented in the focus area has been designed so that it is expandable. The modeling framework is generic in that it is independent of the geographical area in which it is applied. For practical purposes, the spatial extent of the model (the area within which the model is applied) has been limited to fit the purposes of the Trading study. As additional TMDLs are developed in the Bear River Basin and the feasibility for trading increases in other areas of the watershed, water quality managers may wish to increase the spatial extent of...
the model to included additional areas, or they may wish to apply the modeling framework independently in other areas of the watershed. Both are possible with the proposed modeling framework. The proposed framework can be extended to additional parts of the Bear River Basin as the need arises, as the data become available, and as funding becomes available to do so.

9.0 Model Calibration and Validation

After the model components are developed and populated, calibration is required to ensure that the model is truly representing the system. Calibration consists of varying the model parameters to obtain optimal agreement between the model simulation output and a set of observed water quality conditions (Chapra, 1997). Physical parameters and other known inputs are not varied in calibration activities. Kinetic parameters such as oxygen and nutrient uptake rate constants and mass transfer coefficients, which vary greatly and are not well understood without intensive data collection efforts, will be the primary calibration parameters. In the calibration process, ranges for the calibration parameters will be developed from historical literature, and the values of the parameters will be varied within those ranges until the model agrees with monitoring data. If agreement between the model and data cannot be achieved within these ranges, errors or incompleteness in the model are suggested and the model will be modified. After calibration is complete and the model is satisfactorily representing the system, validation, or testing the models ability to predict outside of the calibration data set, will be carried out.
References


**Technical Memo Appendix A**

**Glossary of Modeling Terms**

**Deterministic model** – Mathematical models designed to produce system responses or outputs (i.e., runoff) from temporal or spatial inputs (i.e., precipitation).

**Dynamic model** – Model that is time variable.

**Empirical model** – Empirical models are built directly from data and data only. There is no ‘theoretical’ basis for the model – so it is curve fitting in the purest sense. Examples are simple trend analysis and response surface analysis.

**Hydrodynamic model** – Mathematical formulation used in describing circulation, transport, and deposition processes in receiving water.

**Loading model** – Model of the drainages and grid segments that respond to precipitation events based on land use/land cover and constituent loading predictions from export coefficients.

**Mechanistic model** – Mechanistic models are based on a theoretical description of the physical, chemical, and biologic processes deemed by the modeler to be important. This approach explores relationships between model processes. At best, mechanistic models for surface water quality are semi-mechanistic because many process rates are essentially empirical (e.g., oxygen uptake rate by bacteria) in that their description is based primarily on data. As ‘science’ advances, these models tend to become more theoretical because they are developed to test our understanding of the process that make up a system.

**Receiving water model** – Model of a lake and/or stream system for constituent routing driven by loadings from the landscape.

**Steady state model** – Model that is not time variable.

**Stochastic model** – Stochastic models can be strictly empirical or mechanistic. They have in common the inherent uncertainty and variability in data, processes, and process rates.
This appendix summarizes the review of existing water quality models. Many of the models discussed below have been recognized by the USEPA and have been included in the Compendium of Tools for Watershed Assessment and TMDL Development (USEPA, 1997). Most are well documented, and various applications of each can be found in literature. Although there is a large number of existing streamflow and water quality models, many of which were reviewed as part of the model approach selection process, this summary presents only the subset of models considered relevant to the water quality modeling and trading study in the Bear River basin.

In general, the models have been placed into two groups - loading models and receiving water models. Loading models include techniques primarily designed to predict pollutant movement from the land surface to waterbodies. Loading models can range in complexity from simple loading rate assessments in which loads are a function of land use type to complex simulation techniques that more explicitly describe the processes of rainfall, runoff, sediment detachment, and transport to receiving waters (Shoemaker et al., 1997). This review was limited to loading models that can be applied at a watershed scale (i.e., field scale models were excluded), and only those models with a strong agricultural component were considered.

Receiving water models are those that simulate constituent routing through a lake and/or stream system and are driven by loadings from the landscape (i.e., they simulate water quality within a stream network or reservoir with loadings as inputs). Similar to loading models, receiving water models encompass a range of complexity from simple empirical formulations to deterministic models. In some cases models contain both a loading model component and a receiving water model component.

Tables A-1 and A-2 provide summary descriptions of a subset of the water quality models evaluated as part of this model review. These tables summarize each of the models in terms of the waterbody types that can be simulated, the processes included within each model, the pollutants simulated, and several other distinguishing characteristics. In addition, the following sections provide a very brief summary of each of the models included in this review. Many of the model descriptions in the following sections have been adapted from Fitzpatrick et al. (2001).

**Loading Models**

HSPF – Primarily a watershed hydrodynamic and water quality model, but also has one of the better stream routing codes. Simultaneously determines watershed loading and stream routing (i.e., it has a loading component and a receiving water component) but is ‘lumped’ in the sense that the physical location of land uses is not explicit and produces water quality estimates only at the watershed outlet. HSPF is moderate to difficult to use and requires considerable input data.

SWAT – Similar in many ways to HSPF, including difficulty of use. Developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields on
complex watersheds. Primarily used for runoff generation for non-urban catchments because its stream routing component is limited to transport (no fate/transformation is simulated). SWAT is similar to HSPF in that it has a loading component and a receiving water component, but as mentioned the receiving water component is weak.

WARMF – WARMF is actually a set of models that are integrated into a single modeling framework. WARMF represents a river basin by land catchments, river segments, and lakes. Meteorological data is accepted to simulate runoff, nonpoint load, river hydrology, and river water quality. For stratified lakes or reservoirs, WARMF provides two options: 1D (vertically stratified, horizontally mixed) or 2D (CE-QUAL-W2). The scientific basis of WARMF is mass balance, heat balance, reaction kinetics, and chemical equilibriums. Both flow and water quality constituents are simulated dynamically as they actually occur in the real system.

GWLF – The Generalized Watershed Loading Functions (GWLF) model was developed at Cornell University to assess the point and nonpoint loadings of nitrogen and phosphorus from a relatively large, agricultural and urban watershed and to evaluate the effectiveness of certain land use management practices. One advantage of this model is that it was written with the express purpose of requiring no calibration, making extensive use of default parameters. The GWLF model includes rainfall/runoff and erosion and sediment generation components, as well as total and dissolved nitrogen and phosphorus loadings. This model uses daily time steps and allows analysis of annual and seasonal time series. The model also uses simple transport routing, based on the delivery ratio concept. In addition, simulation results can be used to identify and rank pollution sources and evaluate basinwide management programs and land use changes. The model also includes several reporting and graphical representations of simulation output to aid in interpretation of the results.

Receiving Water Models

QUAL2E – The Enhanced Stream Water Quality Model (QUAL2E) is applicable to well mixed, dendritic streams. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It can predict up to fifteen water quality constituent concentrations. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. By operating the model dynamically, the user can study diurnal dissolved oxygen variations and algal growth. However, the effects of dynamic forcing functions, such as headwater flows or point source loads, cannot be modeled with QUAL2E. QUAL2EU is an enhancement allowing users to perform three types of uncertainty analyses: sensitivity analysis, first order error analysis, and Monte Carlo simulation. The QUAL2E Windows interface was developed to make the model more user friendly. It provides input screens to facilitate preparing model inputs and executing the model. It also has help screens and provides graphical viewing of input data and model results.

QUAL2K – QUAL2K is an updated version of QUAL2E. New components include a Windows interface, user-defined model segmentation, carbonaceous BOD speciation, anoxia simulation, sediment water interactions, bottom algae, light extinction, pH, and pathogen removal.
EUTROMOD – Eutromod is a spreadsheet-based model that is used for the prediction of nutrient runoff and lake eutrophication for individual lakes in the US. With the model, phosphorus and nitrogen runoff may be predicted using either nutrient loading functions or nutrient export coefficients. The nutrient loading functions are based on the rational formula for dissolved nutrients, and the universal soil loss equation for sediment-attached nutrients. The sediment delivery ratio is addressed with user-defined trapping zones. Lake eutrophication response is predicted based on a set of regional statistical models. Response variables include: total phosphorus concentration, total nitrogen concentration, chlorophyll a level, secchi disk depth and in some cases - probability of hypolimnetic anoxia and probability of blue-green algal dominance.

PHOSMOD – PHOSMOD uses a modeling framework for assessing the impact of phosphorus loading on stratified lakes. A total phosphorus budget for the water layer is developed with inputs from external loading, and recycling from the sediments, and considering losses from flushing and settling. The sediment-to-water recycling depends on the levels of sediment total phosphorus and hypolimnetic oxygen concentration, the latter estimated with a semi-empirical model. PHOSMOD can be used to make daily or seasonal analyses and was developed to assess long-term dynamic trends. Output includes tabular and graphical output of lake total phosphorus, percentage of total phosphorus in sediment, hypolimnetic dissolved oxygen concentrations, and days of anoxia.

BATHTUB – Three interrelated programs (FLUX, PROFILE, and BATHTUB) simplify assessments of eutrophication-related processes and effects. FLUX is a program that allows estimation of tributary mass discharges (loadings) for sample concentration data and continuous (e.g., daily) flow records. Five estimation methods are available and potential errors in estimates are quantified. PROFILE is a program that facilitates analysis and reduction of in-lake water quality data. Algorithms are included for calculation of hypolimnetic oxygen depletion rates and estimation of area-weighted, surface-layer mean concentrations of nutrients and other eutrophication response variables. BATHTUB applies a series of empirical eutrophication models to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network, which accounts for advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (total phosphorus, total nitrogen, chlorophyll-a, transparency, and hypolimnetic oxygen depletion) are predicted using empirical relationships derived from assessments of reservoir data.

WASP5 – WASP5 is the acronym for Water Quality Analysis Simulation Program, Version 5, developed for the EPA. WASP5 is essentially a current version of WASP with flexible eutrophication and chemical fate and transport. WASP was originally developed in the early 1970's as a propriety water quality model. It was designed to be a flexible tool for simulating a variety of relatively complex time variable water quality problems, and in particular, eutrophication. This model helps users interpret and predict water quality responses to natural phenomena and man made pollution for various pollution management decisions. WASP5 is a dynamic compartment modeling program for aquatic systems, including both the water column
and the underlying benthos. The time varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program.

CE-QUAL-RIV1 – CE-QUAL-RIV1 is a one-dimensional (cross-sectionally averaged) hydrodynamic and water quality model, meaning that the model resolves longitudinal variations in hydraulic and quality characteristics and is applicable where lateral and vertical variations are small. CE-QUAL-RIV1 consists of two parts, hydrodynamic and water quality. Each of these parts is a separate computer code (RIV1H, the Hydrodynamic code and RIV1Q, the water Quality code). The hydrodynamic code is applied first to predict water transport and its results are written to a file, which is then read by the quality model. It can be used to predict one-dimensional hydraulic and water quality variations in streams and rivers with highly unsteady flows, although it can also be used for prediction under steady flow conditions. RIV1Q can predict variations in each of twelve state variables: temperature, carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, dissolved oxygen, organic phosphorus, dissolved phosphates, algae, dissolved iron, dissolved manganese, and coliform bacteria. In addition, the impacts of macrophytes can be simulated. Numerical accuracy for the advection of sharp gradients is preserved in the water quality code through the use of the explicit two-point, fourth-order accurate, Holly-Preissman scheme.

CE-QUAL-W2 – Sophisticated 2-dimensional, longitudinal/vertical general purpose hydrodynamic and water quality model geared primarily toward lake and reservoir eutrophication. The model is based upon a finite difference solution of the laterally and layer averaged equations of fluid motion. The philosophy behind model development has been to provide an accurate solution to the original governing equations, include capabilities to model all the important hydrodynamic processes known to occur in the prototype. Additionally, the model was developed with the philosophy that the user should have the ability to make the representation of the prototype as simple or as complicated as the available data and questions to be addressed require. Iron cycling is included for phosphorus model. CE-QUAL-W2 was designed for lakes and reservoirs, but may be used in streams and other water bodies where a 2-d representation is required. A drawback of this model for general use is the technical skill required for users.

CE-QUAL-ICM – The CE-QUAL-ICM water quality model was initially developed as one component of a model package employed to study eutrophication processes in Chesapeake Bay. Subsequent to employment in the Bay study, the model code was generalized and minor corrections and improvements were installed. ICM stands for "integrated compartment model," which is analogous to the finite volume numerical method. The model computes constituent concentrations resulting from transport and transformations in well-mixed cells that can be arranged in arbitrary one-, two-, or three-dimensional configurations. The model does not compute hydrodynamics. Flows, diffusion coefficients, and volumes must be specified externally and read into the model. There are two distinctly different development pathways to ICM: a eutrophication model (ICM), and an organic chemical model (ICM/TOXI). The release version of the eutrophication model computes 22 state variables including physical properties; multiple forms of algae, carbon, nitrogen, phosphorus, and silica; and dissolved oxygen. Each state variable may be individually activated or deactivated.
Table A-1. Comparison of water quality models – loading models.

<table>
<thead>
<tr>
<th></th>
<th>HSPF</th>
<th>SWAT</th>
<th>WARMF</th>
<th>GWLF</th>
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<td>X</td>
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<tr>
<td>Lakes/Resevoirs</td>
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<td>X</td>
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<tr>
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<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td><strong>Chemical Fate</strong></td>
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<td>X</td>
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<td>X</td>
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<tr>
<td><strong>External Loading-Dynamic (point sources)</strong></td>
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<td>X</td>
<td>X</td>
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<tr>
<td><strong>User Interface</strong></td>
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<td>X</td>
<td></td>
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</tr>
<tr>
<td><strong>Documentation</strong></td>
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<td><strong>Internally Calculated NPS Loading</strong></td>
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<td>X</td>
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<td>Temperature</td>
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<tr>
<td>Alkalinity</td>
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<tr>
<td>(Coliform) Bacteria</td>
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<td>X</td>
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<tr>
<td>Algae</td>
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Table A-2. Comparison of water quality models – receiving water models.

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<th>PHOSMOD</th>
<th>BATHTUB</th>
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**Sediment analysis vary in these models. The following is a short explanation of the classifications:**

Low = Models sediment as a conservative constituent, considers only nutrient sedimentation, or sediment processes may be input.

Medium = Models local sediment mixing, etc.

High = Settling velocity, burial velocity, resuspension, etc. is incorporated into the model.
Table A-2 (continued). Comparison of water quality models – receiving water models.

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<td>Nonconservative Constituent</td>
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</tbody>
</table>

** Sediment analysis vary in these models. The following is a short explanation of the classifications:
Low = Models sediment as a conservative constituent, considers only nutrient sedimentation, or sediment processes may be input.
Medium = Models local sediment mixing, etc.
High = Settling velocity, burial velocity, resuspension, etc. is incorporated into the model.
Technical Memo Appendix C
Review of Existing Streamflow and Water Quality Modeling Efforts in the Bear River Basin

Utah Division of Water Rights Accounting Model

The Utah Division of Water Rights maintains a model that accounts for the water flowing from Bear Lake to the Bear River Migratory Bird Refuge at the terminus of the Bear River. The model is not a hydrologic model (i.e., it does not simulate runoff as a function of rainfall and other driving forces), but it is an accounting model that accounts for diversions from the river. The model is built within a framework known as WATmodel developed by the Division of Water Rights. The model runs within FORTRAN. Idaho has a similar model that runs on a different operating system.

Between Bear Lake and the Refuge, there are 25 diversions in Idaho as well as 2 major canals and approximately 100 pumps in Utah. The pumps are automated, and the model receives daily data from each pump during the irrigation season, so the accounting is after the fact. As water is removed from the system, the model makes that water unavailable, and then storage water is taken from Bear Lake, which must be paid for. The inputs to the model are the files of each pump, a storage file of the water from Bear Lake, and a natural flow file for the stream. As far as output is concerned, many combinations of desired parameters can be printed out. As the water rights can be contested, the Division holds conference calls twice a week with water users and with PacifiCorp who manages the releases from Bear Lake.

This model may be useful to our modeling effort as it essentially contains the plumping of the Bear River system from Bear Lake to the Migratory Bird Refuge. We will continue to work with the information provided to us by the Division of Water Rights in order to ensure that our model adequately represents the management of flow within the model focus area. It should be noted that this model will likely be of little use to the southern part of the model focus area because, to our knowledge, the Little Bear River and Spring Creek are not represented in the accounting model.

Bear River and Cutler Reservoir TMDL Modeling

Under contract from the Utah Department of Environmental Quality, SWCA Environmental Consultants is conducting a TMDL on Cutler Reservoir, including modeling of the reservoir. The following is as reported by Tonya Dombrowski, a consultant heading up the model effort. Various models were examined in the model selection process including CE-QUAL-W2; QUAL2E/2K; BASINS; FLUX, PROFILE, and BATHTUB; PREWET; and WiLMS. Originally, BASINS was the model approach of choice, but the necessary data resolution is not available. Instead, the BATHTUB, PROFILE, FLUX modeling package was selected for modeling Cutler Reservoir. BATHTUB models the system as an open-water reservoir. Output can be sent to a spreadsheet or a graph, and the capability to view output as a contour algorithm with a visual of the pollutant moving down the reservoir is being examined.
The advantages of using the BATHTUB model include its ability to account for advective and diffusive transport, nutrient transport, and predict eutrophication-related characteristics. The model can also be segmented, and Cutler Reservoir will likely be broken into five reservoir segments with the output of one being the input of the next. The primary limitation of the BATHTUB model is its poor handling of stratification. The tributaries, Spring Creek, the Little Bear River, the Swift Slough, the Logan River, and the Bear River, will be modeled as inputs to the reservoir while the Cub River will be modeled as a point source to the Bear River. In addition to the BATHTUB model of the reservoir, PREWET will be added as another layer to the model to adjust the upper part of the reservoir to make it more like a marsh than a lake. This should permit examination of reactions with plankton and plants.

The modeling work being done by SWCA, especially their efforts to develop a model of Cutler Reservoir, could be a potential aid to our modeling and water quality trading study. Our scope of work does not include modeling Cutler Reservoir, so it would be difficult to understand whether water quality trading can occur between entities on the Bear River above Cutler Reservoir and the Little Bear before it reaches Cutler, or whether the trading will be restricted to two separate markets, one in the Bear River and one in the Little Bear River and Spring Creek. In addition, our work in modeling the Bear River may be of use to the TMDL study because as of our last meeting, SWCA had not picked a modeling approach for the Bear River. We will continue to collaborate with Tonya Dombrowski and SWCA as we progress in the modeling work to ensure that our results are as consistent as possible with the work being done for the TMDL.

Technical Memo

Flow Charts of the Water Quality Trading Modeling Framework

USEPA Targeted Watersheds Grant

Bethany T. Neilson  
David K. Stevens  
Matthew Baker  
Christina Bandaragoda  
Jeffery S. Horsburgh

Prepared for:

Water Quality Committee  
Bear River Commission

9-9-2008

Utah Water Research Laboratory  
Utah State University
The ability to test the feasibility of a water quality trading program in a highly agricultural area requires each individual polluter to know the amount of pollutant they have available to trade. This quantity, designated as the *tradable load*, is a function of the *current load* or *farm/field load*, the *target load* (based on the TMDL program or other watershed management requirements), the associated delivery ratio to a receptor point and the *delivered load*, and the ability to mitigate a load.

A water quality trading modeling framework has been developed to support the requirements of farm/field loads and delivery ratios for calculation of the *delivered* and *tradable loads* and is described further in Task 20 and 22 Technical Memo: Watershed Modeling for Water Quality Trading. As additional documentation of this effort, detailed flow charts for the modeling framework have been developed to assist the WIS Development and Water Quality Trading Teams. These flow charts provide information regarding the inputs and outputs from each component. Additionally, the information passed between the components is provided to assist in understanding the connectivity.

As shown in Figure 1, the water quality trading modeling framework couples a number of models, modeling approaches, and processing tools to provide the necessary information to facilitate water quality trading. The framework includes: TOPNET (Bandaragoda et al. 2004) as the hydrology model; variable source area (VSA) calculations (Lyon et al. 2004) that resolves spatial areas contributing saturation excess flow; a subbasin Loading Model component based on the VSA calculations, event mean concentrations (EMCs), and landuse; and a Water Body Response (WBR) component that incorporates QUAL2E (Brown and Barnwell 1987) to determine delivery ratios.

Figure 1. Overall modeling framework information flow.

Figure 2 shows more detail regarding the steps taken to setup and connect the each of the components. Figures 3-5 are provided to further understand information flow between framework components. Figure 3 shows the details of data, passing of information, and steps required to populate and calibrate the TOPNET portion of the framework. Figure 4 shows how some of the data was used within both TOPNET and the VSA calculations. Additionally, it shows how these components are connected. In this portion of the modeling framework, seasonal farm/field loads are generated as a function of seasonal saturation excess and EMC
values that are calibrated within the Loading Model component. Figure 4 also demonstrates information flow between the VSA component and the Loading Model component which leads into the Water Body Response component. Figure 5 details the inputs and different modules within the Water Body Response component. The end result of this component is the subbasin delivery ratios.

Figure 2. Detailed outline of steps and information flow within trading modeling framework.
Figure 3. Hydrologic Component Workflow Diagram
Variable Source Area and Loading Model Component Workflow Diagram

Figure 4. Variable Source Area and Loading Model Component Workflow Diagram.
Figure 5. Water Body Response Component Workflow Diagram.
Technical Memo

Scalability of the Selected Modeling Approach
(Task 20)

USEPA Targeted Watersheds Grant

Bethany T. Neilson
David K. Stevens
Matthew Baker
Christina Bandaragoda
Jeffery S. Horsburgh

Prepared for:

Water Quality Committee
Bear River Commission

8-15-2008

Utah Water Research Laboratory
Utah State University
The modeling structure developed to assist the Water Quality Trading and WIS Teams has been tested on the Little Bear River watershed (~ 286 mi²) and the Bear River Watershed from Onieda Reservoir to Cutler Reservoir (~840 mi²). The area associated with these watersheds is highly variable and the number of subwatersheds that were delineated within these watersheds ranged from 18 in the Little Bear River Basin (Figure 1) to 49 in the Bear River Basin (Figure 2). The average subbasin size, however, was similar (Little Bear average subbasin size ~15.6 mi² and Bear River average subbasin size ~16.2 mi²).

Figure 1. Little Bear River Watershed Delineation
In addition to having more subwatersheds, the portion of the Bear River Basin modeled also includes hundreds of diversions and many point sources that had to be accounted for. The Little Bear River basin only had four diversions and one point source. The success in applying this model to simple and complicated watershed networks shows the model structures’ ability to scale up to larger watersheds that typically contain large numbers of inflows and outflows.

Data availability is another important consideration associated with scalability due to larger, more complicated watersheds requiring more data to represent the system. Adequate data is particularly a critical component of the modeling effort because it affects: 1) the accuracy of predictions due to the model requiring forcing and calibration data, and 2.) the ability to ensure that the processes represented in the model line up with those occurring in the basin. The data availability within the Little Bear River and Bear River modeling efforts ranged between very few in the Little Bear River and much more in the Bear River (discussed in more detail in the Task 19 technical memo). The Little Bear River model simulation only covered 1/1/2001-
12/31/2003 while the Bear River model simulation covered 10/1/1989-9/30/2004. The simulation time periods were dictated by data availability. This included boundary condition information (e.g., dam releases), diversion data, weather data, flow data, and water quality data. The Little Bear River application only had a few years of data over which to calibrate both the hydrology and the loading model. Although not preferable, it was enough information to get a reasonable estimate of the loads from farm/fields and their associated delivery ratios during low flow years. In the Bear River basin, a longer simulation time period was possible and therefore, better estimates of loads and delivery ratios were able to be calculated.

The additional only concern regarding the ability to use this approach in different watersheds or the larger Bear River basin is inability to capture the effects of impoundments and/or dams on transport of nutrients. Although the Little Bear River application considered the effects of Hyrum Dam on nutrient fate and transport through the use of a previous reservoir modeling effort, a reservoir model is currently not implemented into the modeling structure and would limit the expansion of the current application to the larger Bear River basin. Given the flexibility of the modeling structure, however, a reservoir model could be integrated. Even with the current reservoir modeling limitation, however, based on the successful application of the water quality trading modeling structure to the Little Bear River and the portion of the Bear River, the modeling structure developed has proven to be applicable to a broad spatial scale, various temporal scales, and additionally can facilitate complexities in terms of diversions and point sources.
Appendix 8.14 Typical Bear River Watershed Outreach Presentation

Typical Bear River Watershed Outreach Presentation

by Nancy Mesner
Watershed Sciences
Utah State University
USEPA’s Targeted Watersheds Grant Program

- To encourage successful community-based approaches and management techniques to protect and restore the nation’s waters
- Focus on partnerships with a wide variety of support
- Creative, socio-economic approaches to water restoration and protection
- Explicit monitoring and environmentally-based performance measures

Common water quality problems throughout the basin

Difficulties in managing at a watershed scale because of multiple jurisdictions

Bear River Project Objectives

Develop and demonstrate:
1. An integrated, Internet-based Watershed Information System (WIS)
2. A water quality trading program
3. Dynamic water quality model to support the water quality trading program
Bear River Watershed Information System

- Provide a community resource
  - Data and information available at a variety of technical levels
  - Education and outreach
- Support both science and management questions
- Create a system with transparent state and political boundaries

WIS Components

- Watershed-wide coordination web pages
- A comprehensive data warehouse
- A document warehouse
- Data visualization and statistical tools
- Integration of other project components
  - Water quality trading program
  - Water quality modeling
  - Real time monitoring
  - Outreach and education

Existing Bear River WIS
http://www.bearriverinfo.org

Watershed Descriptive Profiles
http://www.bearriverinfo.org/descriptions/

- Based on USGS 8-Digit HUC Boundaries
- Summaries of land uses, water quality and hydrology, other physical features, population characteristics
- Linked to other parts of the site (i.e., projects, events, etc.)

Online Resource Guide
http://www.bearriverinfo.org/guide/

- Searchable index of experts, organizations, and projects
- Users can submit experts, organizations, or projects

Online Calendar of Events
http://www.bearriverinfo.org/calendar/

- Searchable database of water quality related events
- Events are linked to front page
- Can view either calendar or list
- Users can submit events
Document Warehouse/Digital Library
http://www.beaverinfo.org/library/
- Database of Bear River related documents, reports, maps, images, etc.
- Searchable bibliographies
- Users can submit digital objects

Comprehensive Data Warehouse
GIS Data
- Includes:
  - Administrative Boundaries
  - Environmental Monitoring Locations
  - Climate Monitoring Locations
  - Hydrology
  - Land Use/Land Cover
  - Geology
  - Terrain
  - Transportation
  - Watershed Boundaries

Comprehensive Data Warehouse
Time Series Data
- Datasets:
  - USGS published water quality data
  - USGS published water quality data
  - USGS groundwater data
  - STORET water quality data
  - NRC SNOTEL Data
- Additional data that will be included:
  - Additional water quality data
  - NCDC climate data

Data Analysis and Visualization Tools
- Time Series Analyst for streamflow, water quality, climate, etc.

Data Analysis and Visualization Tools
- Internet Map Server for GIS Information

Data Analysis and Visualization Tools
- Internet Map Server for GIS Information
**Integration of Real Time Monitoring Data**
- Real time monitoring efforts in the basin
  - UNR
  - USU
  - Pacificco
  - Utah Water Rights
- Include as many others as possible

**Integration of Water Quality Trading Program**
- Create "Virtual Trading Room"
  - Informational component - describes and explains the trading process
  - Presentation of results
- Ensure that sensitive information is protected and DEQ's role is maintained
- Integrate the Water Quality Model so that users could do "what if" scenarios

**Integration of Outreach and Education**
- Watershed wide coordination
- Present information to technical and non-technical users
- Dynamic "question and answer" expert system
- WIS training

http://www.beaiverinfo.org

Questions or comments?

Contact:
Nancy Mesner
435-797-2465
nancym@ext.usu.edu
Other Outreach Materials Produced

by USU Water Quality Extension
Utah State University
The Bear River Watershed Information System

http://www.bearriverinfo.org

The Bear River Watershed Information System is a web site that provides users with a single location to access local data, information, maps, documents, photos, resources and more. The site is designed for watershed managers and resource specialists, agricultural producers, educators, scientists, and all other citizens in the watershed.

This project arose from comments and feedback from citizens, educators and resource managers concerning the need for better, easier access to Bear River information, and is a collaborative effort between the following partners:

Bear River Commission * Utah State University * UT, ID, and WY DEQ’s * The Bear River Water Quality Task Force * EPA

Advertisement for the Bear River Symposium:

BEAR RIVER SYMPOSIUM &
NONPOINT SOURCE POLLUTION WATER QUALITY CONFERENCE

Date: September 5-7, 2007
Location: Utah State University, Logan, Utah

The Bear River Symposium / Nonpoint Source Pollution Water Quality Conference is a joint conference sponsored by the EPA Bear River Targeted Watershed Initiative and the Utah Nonpoint Source Pollution Task Force. This annual conference covers nonpoint source and other water quality issues throughout the state and region, but this year will have a special focus on the Bear River Watershed.

Conference sessions will cover a range of topics in watershed science and management including special sessions on the Bear River Watershed and the on-line Bear River Watershed Information System.

All those in the water resource field are encouraged to attend, including scientists, researchers,
Bear River WIS Newsletter,
August 2007

by USU Water Quality Extension
Utah State University
An element of the Bear River Watershed Initiative is to explore the feasibility of pollutant trading as a means of reducing point and non-point source phosphorous inputs to the watershed in the most cost effective manner. On July 19, 2007, the Bear River Initiative Steering Committee hosted a water quality trading workshop to explore the concepts of pollutant trading and specifics being explored in the Bear River watershed. 37 representatives from Idaho, Wyoming, and Utah, including agencies, educators, and producers attended the workshop.

The following is a summary of the workshop presentations. These presentations are available in Power Point format at http://www.bearriverinfo.org/library/.

- Dr. Terry Glover of Utah State University, introduced pollutant trading as established by the EPA to support market based programs for improving water quality. Water quality trading is a market-based mechanism that allows a source facing relatively high pollution-reduction costs to compensate another source to achieve a less-costly reduction with the same or higher water-quality benefit. The Bear River watershed is being assessed by the initiative for the feasibility of trading assuming pre-fixed pollution targets (e.g. TMDL process).

- Utah and Idaho DEQ TMDL coordinators, Mike Allred and Lynn Van Every presented an agency overview to water quality trading. The TMDL process determines the amount of pollution the water body is capable of assimilating while maintaining its intended beneficial uses. While the TMDL methods are not self-implementing, they do set the stage for implementing water quality trading programs by evaluating the potential for local impacts and proposing remedies.

- Marti Bridges of the Idaho DEQ presented a water quality trading framework established for the lower Boise River watershed. Before a trading program was established for the Boise watershed, factors including the market driver, cost differential, ability, and opportunity were defined.

- Darcy Sharp of Idaho DEQ gave a brief synopsis of BMP monitoring programs and their effectiveness as a stepping-stone for water quality programs.

- Dr. Bethany Neilson of Utah State University presented the approach to trading in the Bear River watershed using a water quality model. The model can help simulate physical, chemical, and biological processes that affect pollutant concentrations by calculating delivery ratios to determine the environmental equivalence of load reductions and potential trades.

- Tom Solon of Aqua Capital Management gave a brief overview of 3rd party private roles potential in trading programs. In a unique watershed such as the Bear River where the watershed lies within 3 states, 3rd party brokers could help mitigate high transaction costs in pollutant trading.
What's next?

- Continue to obtain stakeholder feedback
  - Contact USU Water Quality Extension to express questions, concerns, or comments regarding pollutant trading in the Bear River watershed at (435)797-2580 or email susana@ext.usu.edu.
  - USU Water Quality Extension will create a dynamic blog on the Bear River WIS website (www.bearriverinfo.org) for trading feedback.
  - USU Water Quality Extension will continue to post trading resources on the Bear River WIS website (www.bearriverinfo.org).
- The Bear River Initiative team is available to speak concerning trading within the watershed, please contact Nancy Mesner at (435)797-7541 for further information.
- If you are interested in participating in an ongoing citizen/stakeholder advisory committee regarding pollutant trading in the Bear River watershed contact USU Water Quality Extension at (435)797-2580 or email susana@ext.usu.edu.
- The project leaders and stakeholders will work to resolve the following issues:
  - Pollutant runoff and delivery ratios
  - Differentiating between NPS sources
  - Collecting water quality data
  - Employing BMP implementations
  - Utilizing TMDL allocations for pollutant trading
  - Enforcing trading agreements

To remove your name from our distribution list, please send a request to the email below.
Questions or comments? E-mail us at susana@ext.usu.edu or call 435-797-2580.
Bear River Water Quality Trading Workshop Summary, August 2007

by USU Water Quality Extension
Utah State University
An important element of the Bear River Watershed Initiative is to explore the feasibility of pollutant trading as a means of reducing point and non-point source phosphorus inputs to the watershed in the most cost effective manner.

The Bear River Watershed Initiative is an EPA funded project which is improving water quality coordination and management for the entire Bear River Watershed. The Bear River Watershed Information System (www.bearriverinfo.org) provides one place to get basic information about the different regions of the watershed, to find or create maps, to access real time and historic data, to find contact information for resources across the watershed, to locate documents, and much much more.

The Bear River Water Pollutant Trading Feasibility Study will focus on total phosphorus in areas with existing TMDLs:

- Cub River – Middle Bear
- Bear River from Oneida Narrows Reservoir to Cutler Reservoir
- Little Bear River
- Spring Creek

On July 19, 2007, the Bear River Initiative Steering Committee hosted a water quality trading workshop to explore the concepts of pollutant trading and specifics being explored in the Bear River watershed. 37 representatives from Idaho, Wyoming, and Utah, including agencies, educators, and producers attended the workshop. The presentations made at this workshop are available at www.bearriverinfo.org/library/.

WHAT IS WATER QUALITY TRADING?

A market-based mechanism that allows a source facing relatively high pollution-reduction costs to compensate another source to achieve a less-costly reduction with the same or higher water-quality benefit. Water Quality Trading can provide an opportunity for nonpoint sources to receive compensation for implementing conservation practices on their lands.

For Example:

Suppose Source A is required to reduce a unit of total phosphorus (TP) from the river. This reduction will costs Source A $100.

Source B, however, can reduce an additional unit for $80.

Under WQT, there is room for Source A to pay Source B something less than $100 but more than $80 for Source B to clean up that unit of TP.
What’s Next?

The Bear River Watershed Initiative Project is developing a water quality model to help determine the pollution coming from different land uses before and after the implementation of best management practices. The model will also predict the amount of phosphorus that moves through the river from one point to another.

To complete the feasibility study, a number of issues remain. For example:
- How much uncertainty is there in our ability to calculate pollutant runoff and delivery ratios?
- TMDLs allocate pollutant loads between different general groups of sources, not for each nonpoint source. How will different nonpoint sources in one area of a watershed be differentiated?
- Who will monitor whether best management practices are implemented?
- What is the life span of negotiated trades?
- Questions regarding contractual, payment and default issues will also need to be resolved.

The Bear River Watershed Initiative Project will continue to look for feedback. If you want to be involved or if you have questions:
- Contact USU Water Quality Extension regarding pollutant trading in the Bear River watershed at (435)797-2580 or email susana@ext.usu.edu.
- USU Water Quality Extension will post trading resources on the Bear River WIS website (www.bearriverinfo.org).
- If you are interested in participating in an ongoing citizen/stakeholder advisory committee or in having a presentation about trading, contact USU Water Quality Extension at (435)797-2580 or email susana@ext.usu.edu.

For more information visit:

www.bearriverinfo.org
Appendix 8.18 A Bear River Symposium Agenda

Bear River Symposium Agenda

by USU Water Quality Extension
Utah State University
BEAR RIVER SYMPOSIUM &
NONPOINT SOURCE POLLUTION WATER QUALITY CONFERENCE

Agenda

Wednesday, September 5, 2007: USU Eccles Conference Center, Utah State University

7:30 – 8:45 a.m.  Registration and Continental Breakfast

8:45 – 9:00 a.m.  Load Busses at Utah State University, University Inn

9:00 – 3:30 p.m.  Tours

5:30 – 7:00 p.m.  BBQ at Willow Park, 419 West 700 South Logan, UT
The Rain Dogs (local band) will play at 5:30 p.m.
Dinner to be served at 6:00 p.m.

Thursday, September 6, 2007: USU Eccles Conference Center, Utah State University

7:00 – 8:00 a.m.  Registration and Breakfast

8:00 a.m.  General Session I:
Welcome given by Jack Barnett, Bear River Commission

8:15 a.m.  General Address:  Rick Sprott, Utah Department of Environmental Quality

8:45 a.m.  Keynote Address: Ed Marston, previous publisher of High Country News

9:30 a.m.  General Address: Troy Forrest, UACD

10:00 a.m.  Break

Concurrent Presentations Session I (10:30 a.m. – 12:00 p.m.)

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<thead>
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<th>Track IA: Room 201 &amp; 203</th>
<th>Track IB: Room 205 &amp; 207</th>
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<tr>
<td>Mediator: Bethany Neilson, USU</td>
<td>Mediator: Mike Allred, Utah DEQ</td>
</tr>
<tr>
<td><strong>Title:</strong> Recent NAWQA publications and data collection activities in the Great Salt Lake Basins</td>
<td><strong>Title:</strong> What’s the Value of Private Match – Federal dollars and ECC funds provided by PacifiCorp and an overview of projects in the Bear River</td>
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<tr>
<td><strong>Presenter:</strong> Susan Thiros, USGS</td>
<td><strong>Presenter:</strong> Mark Stenberg, PacifiCorp Energy</td>
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<tr>
<td><strong>Title:</strong> The Bear River/Cutler Reservoir Advisory Committee’s Involvement in the TMDL Process for Cutler Reservoir</td>
<td><strong>Title:</strong> Fish passage restoration to benefit Bear River Bonneville cutthroat trout</td>
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<tr>
<td><strong>Presenter:</strong> Candace Hutchinson, UACD</td>
<td><strong>Presenter:</strong> Warren Colyer, Trout Unlimited</td>
</tr>
<tr>
<td><strong>Title:</strong> Implementation and Maintenance of WQ BMPs: A sociological study of cooperator behavior in the Little Bear River watershed</td>
<td><strong>Title:</strong> Elwood City Field Drain Identification Project</td>
</tr>
<tr>
<td><strong>Presenter:</strong> Doug Jackson-Smith, USU</td>
<td><strong>Presenter:</strong> Thayne Mickelson, UACD</td>
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### Concurrent Presentations Session II (1:30 – 3:00 p.m.)

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<th>Track IIA: Room 201 &amp; 203</th>
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<tr>
<td><strong>Mediator:</strong> Nancy Mesner, USU</td>
<td><strong>Mediator:</strong> Don Barnett, Bear River Commission</td>
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<tr>
<td><strong>Title:</strong> Promoting Watershed Stewardship with the Utah Master Naturalist Program Utah Botanical Center</td>
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<tr>
<td><strong>Presenter:</strong> Mark Larese-Casanova, USU Extension</td>
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<tr>
<td><strong>Title:</strong> Stormwater runoff and export changes with development in a traditional and low impact subdivision</td>
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</tr>
<tr>
<td><strong>Presenter:</strong> Michael Dietz, USU</td>
<td><strong>Panel Discussion</strong></td>
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<tr>
<td><strong>Title:</strong> Knowledge as a niche: independent retail garden centers and the market for waterwise plants and landscaping</td>
<td></td>
</tr>
<tr>
<td><strong>Presenter:</strong> Joanna Endter-Wada, USU</td>
<td><strong>Title:</strong> Occurrence, loading, and distribution of potential pollution products in the Great Salt Lake</td>
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<td><strong>Presenter:</strong> David Naftz, USGS</td>
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### Concurrent Presentations Session III (3:30 - 5:00 p.m.)

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<thead>
<tr>
<th>Track IIIA: Room 201 &amp; 203</th>
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<tbody>
<tr>
<td><strong>Mediator:</strong> David Stevens, USU</td>
<td><strong>Mediator:</strong> Lynn Van Every, Idaho DEQ</td>
</tr>
<tr>
<td><strong>Title:</strong> Responding to Drought in the Bear River Basin of Idaho, Utah, and Wyoming</td>
<td><strong>Title:</strong> Tri-State Water Quality Monitoring in the Bear River Watershed: The First Year</td>
</tr>
<tr>
<td><strong>Presenter:</strong> Joanna Endter-Wada, USU</td>
<td><strong>Presenter:</strong> Melissa Thompson, Idaho DEQ</td>
</tr>
<tr>
<td><strong>Title:</strong> Implementing Utah's AFO-CAFO Strategy – Emphasis on the Bear River</td>
<td><strong>Title:</strong> Bear River Tributaries - Water Quality Assessment in Idaho, Utah and Wyoming Western Watersheds Project</td>
</tr>
<tr>
<td><strong>Presenter:</strong> Ray Loveless, UACD and Dr. Howard Thomas, Utah Farm Bureau</td>
<td><strong>Presenter:</strong> John Carter, Western Watersheds Project</td>
</tr>
<tr>
<td><strong>Title:</strong> Regarding new approaches in DEQ Water Quality monitoring programs</td>
<td><strong>Title:</strong> Temperature Data Collection for Dynamic Stream Modeling in the Bear River Basin</td>
</tr>
<tr>
<td><strong>Presenter:</strong> Jeff Ostermiller, UDWR</td>
<td><strong>Presenter:</strong> Jonathan Bingham, USU</td>
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### Other Sessions

- **5:00 p.m. Break**
- **5:30 p.m. Poster Session Social & NPS Awards (Room 307 & 309)**
Friday, September 7, 2007: USU Eccles Conference Center, Utah State University

7:00 – 8:00 a.m.  Breakfast

8:00 - 9:30 a.m.  General Session

EPA Targeted Watershed Project on the Bear River
  • Bear River Watershed Information System
  • Modeling
  • Bear River Water Quality Trading
  • Outreach

9:30 a.m.  Break

Concurrent Presentations Session IV (10:00 a.m. - 12:00 p.m.)

<table>
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<tr>
<th>Track IVA: Room 201 &amp; 203 Mediator: Jack Barnett, Bear River Commission</th>
<th>Track IVB: Room 205 &amp; 207 Mediator: Jeff Horsburgh, USU</th>
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</table>
| **Title:** Watershed-scale statistical assessment of salinity loads in the Upper Colorado River Basin  
*Presenter:* Terry Kenney, USGS | **Title:** Surrogate measures for providing high frequency estimates of total suspended solids and phosphorus concentrations in the Little Bear River  
*Presenter:* Amber Spackman, USU |
| **Title:** Salt loading to surface water from non-point sources in the natural landscape, Muddy Creek basin, Utah.  
*Presenter:* Steven Gerner, USGS | **Title:** Bayesian network analysis of Total Phosphorus loading in the Little Bear River  
*Presenter:* David Stevens, USU |
| **Title:** Discontinuities in sediment transport caused by flow disruption at stream flow diversions  
*Presenter:* Paul Grams, USU | **Title:** Comparison of Water Quality Monitoring Techniques: Detecting change in a variable environment  
*Presenter:* Nancy Mesner, USU |

12:00 p.m.  Lunch and Closing Conference Wrap Up given by Terry Glover, USU  *(Room 205 & 207)*
Appendix 8.18 B Bear River Symposium Abstracts

Bear River Symposium Abstracts

Collected by USU Water Quality Extension
Utah State University
**POSTER Presentations:**

Robert L. Newhall  
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Utah State University  
Logan UT 84322-4820  

Non-student  

**Student Monitoring of Shoreline Erosion along Cutler Reservoir**  

In the fall of 2004, students at Utah State University (Soils 4000 class) established permanent benchmark locations for monitoring shoreline erosion along a stretch of Cutler Reservoir near Cache Junction, Utah. Students have been collecting data twice a year from 2004 – 2007 for analysis. Shoreline retreat, by a process of both soil sloughing and bank toe erosion, has been calculated to be over 30.4 cm per year. The banks along this portion of Cutler Reservoir are over 2.1 meters high. Data calculations have estimated a yearly loss, directly into the reservoir, of over 28 cubic meters (55.5 metric tons) of eroded soil, along the 36.6 m monitoring bank. The negative impacts on both land and water of such enormous soil loss, over similar eroded banks along the extended reservoir shoreline, are a major concern. Continued soil stabilization efforts are warranted to protect both resources from further degradation.

Brendan Waterman  
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Heber City UT 84032  

Non-Student  

**East Canyon Creek Restoration at Swaner Nature Preserve**  

I will prepare a poster/booth that will highlight the ongoing stream restoration project along East Canyon Creek at the Swaner Nature Preserve in Park City, UT. This is a 319 funded project. We have relied heavily on a volunteer workforce. To date, 1100 feet of eroding streambanks have been protected with brush revetments (more will be completed this summer), approximately 3000 willows cuttings have been planted, and 760 trees and shrubs have been planted. Upper Weber River Watershed Coordinator - UACD
Multi-Use Planning for Stormwater at the Utah Botanical Center Utah Botanical Center

The ponds at the Utah Botanical Center were first used to detain stormwater from the City of Kaysville, Utah, in or around the 1950’s. In the following decades, the quality of the ponds became so degraded that they ceased to function. Upon acquiring the land in 1994 to develop the Utah Botanical Center, Utah State University began the process of planning pond reconstruction to serve multiple uses:

1. Stormwater detention and treatment - The pond system not only improves the overall quality of storm water, but also increases the capability for flood control.
2. Fisheries and wildlife habitat - The fish and waterfowl populations are diverse and sustaining.
3. Recreation - Anglers and birding groups often visit the ponds, and the existing and planned trail systems provide opportunities for walking and jogging.
4. Education - The ponds are invaluable resources for teaching about wetland ecology, and will be the site of the Wetland Discovery Lab.
5. Open space - The 200-acre Utah Botanical Center is surrounded on all sides by suburban development.

While planning for multiple uses of stormwater ponds often has its challenges, the benefits of increased cumulative use are of great consequence.

Spotlight on the Past: the Bear River Watershed Historical Digital Collection

Come see what’s new in the Merrill-Cazier Library’s digital collection on the Bear River Watershed. Take a virtual tour of historical images, maps, papers, and reports from the 19th and 20th century on the watershed’s water conditions, geography, history, and development. Funded by grants from the Utah State University Water Initiative, this project digitizes selected materials from Utah State University Libraries’ Special Collections and Archives.

Talk to University Archivist and Photograph Curator about the many documents and
images tucked away in the University’s archives. See the digital collection’s zoom and pan map features demonstrated. Tell us what other materials from the Bear River Watershed Historical Bibliography you would like to see added to this collection.

The Bear River Watershed digital collection is part of a collaborative regional digital project called Western Waters Digital Library. Consisting of digital collections hosted by academic research libraries in six western states, the WWDL offers centralized searching of materials related to water in the Western U.S.

Kirk Dahle
Utah State University
435-797-3524
kirkdahle@hotmail.com

Student

Predicting the growth potential of a warm water sport fishery: a spatially explicit bioenergetics approach

Spatial delineation of bioenergetic model inputs is necessary in order to accurately predict the non linear growth and consumption responses of game fish in large, heterogeneous reservoirs. Cutler Reservoir located in northern UT, demonstrates a wide range of physical conditions and potential water quality problems that include high summertime water temperature, low dissolved oxygen, and high nutrient loading. In order to quantify the interaction that these water quality parameters have on fish growth potential we measured a suite of biotic and abiotic variables across six sites during 2005-2006. We combined measurements of water temperature, fish distribution, diet, and growth into a bioenergetic-based model; and then used a GIS framework to spatially delineate the growth potential of the predominant species throughout the reservoir. The predicted growth potential of these fish varied according to spatial differences in temperature and food availability, acting in combination with species–specific physiological tolerances and habitat preferences. The majority of the reservoir demonstrates optimal growth potential for carp, catfish, and crappie however walleye display a temperature and dissolved oxygen habitat "squeeze" that occurs on a longitudinal profile rather than the more commonly observed vertical profile. Walleye are particularly sensitive to warm water temperatures and low dissolved oxygen content, as such their distribution may provide managers with a valuable index of water quality. Ultimately this model will provide a tool for identifying the factors potentially limiting fish populations in Cutler Reservoir as well as illustrating the role of water quality in structuring the fish community of the system.
ORAL Presentations

Michael Dietz
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Haddam CT 06438

Non-student

Stormwater runoff and export changes with development in a traditional and low impact subdivision.

Development continues at a rapid pace throughout the country. Runoff from the impervious surfaces in these watersheds continues to be a major cause of degradation to freshwater bodies and estuaries. Low Impact Development techniques have been recommended to reduce these impacts. In this study, stormwater runoff and pollutant concentrations were measured as development progressed in both a traditional development, and a development that used low impact development techniques. Increases in total impervious area in each watershed were also measured. Regression relationships were developed between total impervious area and stormwater runoff/pollutant export. Significant, logarithmic increases in stormwater runoff and nitrogen and phosphorus export were found as development occurred in the traditional subdivision. The increases in stormwater runoff and pollutant export were more than 2 orders of magnitude. TN and TP export after development was 10 and 1 kg/ha/yr, respectively, which was consistent with export from other urban/developed areas. In contrast, stormwater runoff and pollutant export from the low impact subdivision remained unchanged from pre-development levels. TN and TP export from the low impact subdivision were consistent with export values from forested watersheds. The results of this study indicate that the use of low impact development techniques on a watershed scale can greatly reduce the impacts of development on local waterways.

Univ. of CT, Nonpoint Education for Municipal Officials program
Measures of temperature, pathogens and sediment have been collected in tributaries of the Bear River in National Forests and BLM lands in Idaho, Utah and Wyoming during 2004 – 2006. Results show that temperature and sediment impair habitat for species of cutthroat trout and other native aquatic organisms. Fecal pathogens exceed water quality criteria. Forest Service and BLM land management practices leading to these conditions are discussed and restoration strategies described.
Salt loading to surface water from nonpoint sources in the natural landscape, Muddy Creek basin, Utah.

The natural landscape in much of Utah is a rich source of dissolved solids (salts), which, when transported to surface or ground water, may degrade the suitability of that water for certain uses. Salts derived from nonpoint sources in the Utah portion of the Upper Colorado River Basin, including the Muddy Creek basin, affect the suitability of water in basin streams for municipal, industrial, and agricultural uses, and adversely affect downstream water users. To understand salt transport by surface waters in the Muddy Creek basin, the U.S. Geological Survey conducted an investigation of dissolved-solids transport in Muddy Creek and its tributaries during 2004-06. The study determined updated estimates for annual dissolved-solid loads transported in Muddy Creek, identified important dissolved-solid sources and transport mechanisms, and determined the trend in dissolved-solids concentration in Muddy Creek. An important component of the study was the quantification of dissolved solids transported by Muddy Creek in direct runoff from rain events, which was poorly understood.

Estimates of dissolved solids transported annually in streamflow from the Muddy Creek basin ranged from about 11,000 tons to more than 142,000 tons during 1975-2006. As much as 43 percent of the annual total was from direct runoff. About 30,000 tons of dissolved solids may have been transported out of the Muddy Creek basin by runoff from a single storm in October 2006. These and other results from this study will provide land managers with updated information to help guide decisions relative to salinity control in the Muddy Creek basin and possibly in other basins with similar land use and topography.
Promoting Watershed Stewardship with the Utah Master Naturalist Program Utah Botanical Center

The Utah Master Naturalist Program will develop a corps of well-informed professional and volunteer naturalists who will provide education, outreach, and service to promote citizen stewardship of natural and cultural resources within their communities. By connecting Utah citizens with the local natural resources within their communities, the UMNP will educate an increasingly urbanized population to positively affect the public’s awareness and involvement in natural resources conservation.

The Aquatic and Wetlands Systems module will be developed and first offered in 2007, followed by the Arid Lands module in 2008 and Alpine and Montane Systems module in 2009. As a result of using a watershed system approach in designing the Aquatic and Wetland Systems module, it can be taught and applied throughout Utah, regardless of region.
Occurrence, loading, and distribution of trace metals, nutrients, hormones, food additives, detergents, pharmaceuticals, and combustion products in water and bottom sediments, Great Salt Lake, Utah U.S. Geological Survey

Great Salt Lake (GSL), in the western United States, is a terminal lake with a surface area that can exceed 5,100 km\(^2\). The open water and adjacent wetlands of the GSL ecosystem support millions of migratory waterfowl and shorebirds from throughout the Western Hemisphere. The GSL ecosystem receives industrial, urban, mining, and agricultural discharge from a 37,500 km\(^2\) watershed that includes over 1.7 million people. Beginning in 2000, the USGS in cooperation with the State of Utah began to quantify current and historical contaminant loadings to the GSL ecosystem. Lake sediment cores collected from GSL exhibit measurable increases in cadmium, copper, lead, nitrogen (N), phosphorus (P), polycyclic aromatic hydrocarbons (PAHs), selenium, and zinc in suspended material entering the lake since the mid-1950s. Discharge and water-quality data from stream gages installed on the perimeter of GSL were used in combination with the LOADEST software to provide a preliminary model of P and N loads. From May through December, 2006, the combined cumulative N loads from the tributaries to the south arm of GSL, were 1.2 grams per square meter (g/m\(^2\)), with 45% contributed from Farmington Bay (FB) efflux and 55% from Bear River Bay (BRB) efflux. Total P loading from the two sources was 0.9 g/m\(^2\), with 47% contributed from FB and 53% from BRB. In 2006, both N and P loads from FB outflow exceeded N loads from BRB outflow between July through November, 2006. The loading of the limiting nutrient (N) from FB + BRB efflux approaches what is considered dangerous levels (2 g/m\(^2\)) for freshwater lakes. Consequently, Gilbert Bay is eutrophic (Chlorophyll a \(>>\) 15 mg/m\(^3\)) except during summer when top-down control by \textit{Artemia} grazing can depress chlorophyll concentration to oligotrophic levels. Over 25 emerging contaminants (ECs), including hormones, food additives, detergents, and pharmaceuticals, were detected in effluent discharging from FB to GSL. Compounds detected included coprostanol (fecal steroid), cotinine (nicotine byproduct), and benzo[a]pyrene (PAH). Lake bottom sediments collected from GSL contained similar EC compounds and were enriched by over 7,000 times relative to their concentration in water discharge from FB. \textit{Artemia} samples are currently (2007) being analyzed for EC compounds to evaluate potential bioaccumulation and biomagnification processes. Methyl mercury (Hg) concentrations in water from GSL can exceed 30 nanograms per liter, triggering human consumption warnings by the State of Utah for three duck species harvested from GSL. A program to monitor and model riverine Hg loadings to the GSL ecosystem was initiated in early 2007 by the UDEQ and USGS.
Watershed-scale statistical assessment of salinity loads in the Upper Colorado River Basin U.S. Geological Survey

The economic effects of increased salinity in the Colorado River have prompted a number of water-quality related legislative actions. Salinity in streams of the Upper Colorado River Basin, as measured by total dissolved-solids concentration and load, is variable. Geologic and vegetation characteristics, land-use practices, and precipitation are some of the sources and controlling mechanisms in the production and delivery of waters high in total dissolved-solids to rivers and streams. Streamflow discharge, total dissolved-solids concentration, and specific conductance have been measured at more than 200 U.S. Geological Survey stream-monitoring sites in the Upper Colorado River Basin. River discharge and chemistry is controlled by the geology, land cover, land use, and precipitation characteristics of the contributing drainage basin. The U.S. Geological Survey Spatially Referenced Regressions On Watershed attributes (SPARROW) model relates measured transport at monitoring stations to upland catchment attributes including contributing upstream reaches. A SPARROW model was developed for the Upper Colorado River Basin in an effort to enhance the understanding of the sources, transport, and sinks of total dissolved-solids throughout the Upper Colorado River Basin. A variety of geo spatial datasets for the Upper Colorado River Basin including geology, land cover, land use, climate, and irrigation practices were examined for statistical significance in predicting total dissolved-solids loads.
Recent NAWQA publications and data collection activities in the Great Salt Lake Basins

The water quality in the Great Salt Lake Basins was studied intensively by the U.S. Geological Survey’s National Water-Quality Assessment Program (NAWQA) from 1998-2001. The Great Salt Lake Basins study unit is made up of the Bear River, the Weber River, and the Utah Lake-Jordan River Basins. The major findings from this phase of the study are available in published reports on the internet and in print. Studies are currently underway to utilize the data collected from the Great Salt Lake Basins in a regional context to better understand the factors and processes affecting water quality. Since 2001, monitoring has been ongoing at selected sites to determine trends in the quality of surface water, ground water, and ecological indicators. Two new reports were recently published from the initial study-unit assessment. The report ‘Water quality in the Bear River Basin of Utah, Idaho, and Wyoming prior to and following snowmelt runoff in 2001’ describes the concentrations and loads of dissolved solids, suspended sediment, and nutrients in water from sites on the Bear River and selected tributaries. Samples were collected at 57 sites in March 2001, during base-flow conditions before spring snowmelt runoff, and at 63 sites in July and August 2001, during the flow-regulated irrigation season. The study found that the magnitude and timing in transport of sediment, nutrients, and other contaminants is affected by the amount of water in a stream. The report ‘Characterization of habitat and biological communities at fixed sites in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, water years 1999-2001’ provides a comprehensive summary of biological and physical habitat data collected from 10 streams, including 4 sites in the Bear River drainage basin, representing a range of environmental conditions. Findings highlight the strong influence of natural landscape-scale gradients such as temperature, slope, elevation, and basin size on species composition. Three sites are currently monitored for trends in stream water quality: Little Cottonwood Creek at the Jordan River near Salt Lake City (an urban site), Red Butte Creek near Salt Lake City (an undeveloped site), and the Jordan River at 1700 South in Salt Lake City (a mixed/urban site). Aquatic ecological conditions also are monitored at Little Cottonwood Creek and Red Butte Creek. U.S. Geological Survey
Warren Colyer  
Trout Unlimited  
wcolyer@tu.org  
249 South 100 West  
Providence UT 84332

Non-student

**Fish passage restoration to benefit Bear River Bonneville cutthroat trout**

Several recent radio telemetry studies have documented that Bear River Bonneville cutthroat trout exhibit a fluvial life history strategy, spending winters in lower elevation mainstem river habitats and traveling large distances to spawn in tributaries each spring. Those studies also have shown that full-spanning irrigation diversions on several critical spawning tributaries block upstream spawning migrations some years and entrain downstream outmigrants in irrigation canals most years. Trout Unlimited, in partnership with multiple state and federal agencies and private landowners and irrigators, began in 2004 to restore upstream and downstream fish passage at several of these irrigation diversions. In 2006 we retrofitted four diversion structures with fish ladder bypasses and fish screens, bringing our total number of completed projects to six. As part of this fish passage restoration effort we use fish traps to monitor movements of adult and juvenile BCT at restoration sites and at control sites (i.e. spawning tributaries without upstream migration barriers). Monitoring during 2007 documented increased numbers of BCT outmigrants in one restored tributary and over 150 BCT in another tributary using a newly installed fish ladder to move upstream past an irrigation dam for the first time in over 20 years. TU and partners continue to use thermal imagery data, telemetry, and aerial photography to identify spawning habitats and important migration barriers and to work with interested landowners and irrigators to restore fish passage along critical migration corridors.
Discontinuities in sediment transport caused by flow disruption at stream flow diversions Utah State University

Individual stream flow diversions extract water from streams and have the potential to disrupt sediment flux by altering transport capacity and by extracting a portion of the sediment load. The cumulative impact of many diversions over a period of many decades has the potential to cause channel change associated with either sediment deficit or surplus conditions and decreased magnitude of floods. In 2006, we initiated a program of stream flow, sediment transport, and channel morphology measurements in the Cub River watershed in southeastern Idaho where three large diversions have been operating for more than 100 years. Highest flows and highest rates of transport in the lower part of the watershed occurred earlier in spring than runoff in the upper watershed. During the peak of the snowmelt pulse, flow and sediment transport rates were greatest in the upper watershed and decreased downstream as flow was extracted by diversions. This indicates that the flux of sediment from the upper to the lower watershed is not continuous and that some segments of the stream may have a sediment surplus while other segments may have a sediment deficit. Estimates of total sediment flux for the 2006 runoff suggest that surplus conditions might exist where the channel is affected by only one or two diversions and that deficit conditions might exist further downstream where the channel is affected by a third diversion. The impacts of these patterns of flow and transport on channel morphology are under continued investigation.
Neilson (2006) published results from a study in the Virgin River, UT where a data collection methodology was developed to assist in modeling the separate effects of hyporheic and dead zones on heat and solute transport. This study was unique in that temperature and tracer data were collected in the main channel, hyporheic zone, and dead zones to help estimate parameters associated with a two zone modeling approach rather than previous one zone modeling approaches that lump the effects of hyporheic and dead zones (transient storage). Research in the Bear River basin proposes to investigate whether the data collection methodology and modeling approach developed by Neilson in the Virgin River will transfer to a mountain stream. The Virgin River has minimal shading, sand/gravel substrate, and lower average channel slope than most mountain streams. In comparison, the mountain streams of northern Utah have gravel/cobble substrate, extensive shading, and generally steeper bottom slopes. If it is determined that the variables measured previously (i.e., temperature, tracer studies) are found to be inapplicable to the mountain stream scenario, new approaches will be developed to collect data that better describe the system. Preliminary data collection strategies and results from Bear River basin will be presented.
Elwood City Field Drain Identification Project

Elwood City Field Drain Identification Project by Thayne R. Mickelson Utah State University, 2007 Utah Association of Conservation Districts Major Professor: Dr. Bruce Miller Department: Agricultural Systems Technology

Poorly drained soils prevent proper plant growth. Farmers in Elwood City, Utah realized they could increase crop production by installing underground field drains. In the late 1800’s farmers began digging trenches and placing drain lines throughout the area as a way to transport water from the soil profile. This was slow tedious work. The industrial revolution introduced machinery that was capable of installing the drains much faster and more efficient. In 1923, the Sumner G. Margetts and Company finished a major drainage project in Elwood City and provided them with a map indicating the placement of the drains they installed. Some lines were not identified on the original map which became confusing. Many problems have reduced the flow potential of the drain lines since the original installation. In places that were open on the surface, sediment entered the systems which plugged lines. Trees placed above lines also began to penetrate the lines creating sediment traps. In some cases, debris caused complete closure of the pipes. Most recently, lines have been severed during the excavation of new homes. Conflicts have risen due to the lack of an accurately marked system. Some of the valuable information and history of the drainage systems reside only in the minds of a passing generation. The Northern Utah Soil Conservation District realized that something needed to be done. As the problem was identified at a local board meeting, I presented a proposal for electronically identifying the Elwood City drainage which would add pertinent information to improve management. We gathered information from historical data, filed with the University of Utah Historical Archives, interviewed landowners, took aerial photography, used GPS/GIS technology to create an electronic file, and created management zones according to drainage areas. A presentation was made to landowners and city officials showing concerns and a report of all systems located updated on an electronic database. This project could be adapted very easily to other locations by using the same technology, realizing that each area may have a variety of available information. An important item to remember is the value of working with the local landowners and ground truthing the data to more accurately pinpoint the existing systems. (117 pages).
Comparison of Water Quality Monitoring Techniques: Detecting change in a variable environment

Best management practices for nonpoint source reduction have been implemented nationwide, with the goal of improving or protecting water quality in threatened or impaired water bodies. Agencies such as EPA and USDA increasingly require that the impacts of their funding programs be measured or otherwise demonstrated quantitatively. Detecting change using traditional water quality monitoring approaches has proven to be a challenge, however. Monitoring programs designed for other purposes may not be sufficient to detect reductions in pollutant loads resulting from implementation of individual practices, especially given the wide range of natural or anthropogenic variability in pollutant concentrations. As part of the national Conservation Effectiveness Assessment Program, our team is working to compare traditional monitoring efforts with alternative methods. This presentation will focus on evaluating the strengths and weaknesses of different approaches. In particular, this talk focuses on results of high frequency, continuous water quality monitoring in the Little Bear River of Northern Utah, which we have paired with periodic and storm event sampling using automated ISCO samplers. Pollutant load estimates from these data are compared with traditional monitoring data, and with alternative approaches such as macroinvertebrate monitoring or simple sediment yield modeling. The high frequency monitoring allows us to more accurately characterize variability in the system, leading to the development of more effective monitoring programs in the future.
**Surrogate measures for providing high frequency estimates of total suspended solids and phosphorus concentrations in the Little Bear River**

Within the Bear River basin, phosphorus enrichment has been and continues to be a water quality concern. Total Maximum Daily Loads have been developed for impaired streams and reservoirs, however, little is known about the transport of nutrients in these water bodies due to limited spatial and temporal resolution in the available phosphorus sampling data. Traditional water quality monitoring involves the collection and analysis of grab samples which typically are not collected with enough frequency to accurately characterize the concentrations of water quality constituents over time. Additionally, routine sampling does not often occur during storm events, which may represent the most important periods for quantifying the transport of sediment and nutrients. Because of these limitations, we are investigating the use of surrogate measurements (e.g., turbidity) in generating high frequency estimates of total suspended solids and phosphorus concentrations.

Three types of sampling equipment (in-situ water quality sensors, automated water samplers, and weather stations) are currently being installed in the Little Bear River watershed. A network of instream water quality sensors will provide real time measurements of constituents that can readily be measured in situ and that may have value as surrogates for total suspended solids and phosphorus concentrations. Automated samplers will collect samples which will subsequently be analyzed for total suspended solids and phosphorus concentrations. Finally, weather stations will record data (e.g., precipitation) that will trigger collection by the automated samplers during storm events. All of the sampling equipment will be telemetered to a central server to allow the two way transfer of data. Relationships between continuous surrogate measurements and the results of the wet chemistry analysis of periodic and storm event samples will be used to construct continuous time series of total suspended solids and phosphorus concentrations. The methodology used for site selection and telemetry of the various sampling equipment, along with data collected and preliminary analysis will be presented.
Shelly Quick  
Environmental Scientist  
Utah Division of Water Quality

Non-student

**Abstract for Non-Point Source Conference Presentation: Statewide Nonpoint Source Pollution/SRF Hardship Grant Funds**

New legislation was passed during the 2007 session that affects available funding for non-point source pollution projects. Utah Code Annotated 73-10c-2 and 73-10c-4 defines new ways that State Revolving Fund Hardship Grants can be used. The law enables individuals, businesses and municipality’s to utilize hardship grant funds for non-point source pollution projects that have a water quality improvement component. Grant funds are not required to be paid back to the State.

A presentation of the SRF Hardship Grant program will be initiated and questions will be encouraged from the audience. The discussion points will include the following topics:

1. Project Solicitation Factors
2. Project Evaluation Criteria
3. Project Prioritization
4. Changes in applications or proposals

The process for SRF Hardship grant solicitation, evaluation and distribution is currently being developed. The preliminary direction is to target high priority watersheds to receive the majority of grant funds based on the following criteria: projects that achieve improved water quality conditions and reduce pollutant loading within the highest priority watershed(s); critical needs including waters that have approved TMDLs or 303(d) listed waters; special resource waters or waters with high value for fisheries, endangered species and associated habitat; and natural resource damage areas such as fires or flood areas.

SRF Hardship Grant funds may be combined with EPA 319 Grant funds, State Revolving Fund (SRF) loans, and potentially, NRCS Salinity Control Funds, Farm Bill Program funds, and other funding sources.

A Utah Division of Water Quality web site will be developed that will identify non-point source projects that have been completed or are ongoing. The web site will be demonstrated if it is developed prior to September 2007.

Successful EPA 319 Grant project before and after pictures will be shown.
"Implementing Utah's AFO-CAFO Strategy – Emphasis on the Bear River"

A Utah Strategy to Address Water Pollution from Animal Feeding Operations (AFO) was prepared by the Utah AFO/CAFO committee in August 2001. An AFO is defined as an agricultural enterprise where animals are kept and raised in a confined situation for 45 days or more during the year, and no vegetative forage grows during the normal growing season. A Concentrated Animal Feeding Operation (CAFO) is defined as an animal feeding operation where more than 1,000 “animal units” are confined at the facility. An AFO with less that 1,000 animal units can also be declared a CAFO if there is a direct discharge into the waters of the State. All CAFOs are considered to be “point sources” and require a regulatory permit. AFOs have a window of opportunity to participate in a voluntary incentive-based program to correct unacceptable conditions related to water quality.

An on-site inventory and assessment of AFOs in Utah identified a total of 2,927 facilities. Of those, 59 are CAFOs and 398 are AFOs that have the potential to impair water quality. All others were determined to be in compliance with the Utah Strategy. In the Bear River drainage, there are 11 CAFOs, and 101 AFOs with the potential to impair water quality. This presentation will discuss progress made after five years of planning and implementation. The presentation will talk about technical resources that are being used to prepare individual nutrient management plans and discuss financial resources available to correct the unacceptable conditions.
Water Quality Stewardship Plan (WaQSP) Presentation

In 2006, the Public Works Department of Salt Lake County began a collaborative effort to develop the Salt Lake Countywide Watershed, Water Quality Stewardship Plan (WaQSP). The WaQSP will serve as an update to the existing Area-Wide Water Quality Management Plan and will allow Salt Lake County to accommodate the rapidly changing characteristics of Utah’s most densely populated urban area while assuring the health of local waterways in a sustainable manner.

Watershed planning is no longer isolated to in-stream water quality. The interrelationship between social, physical, chemical, and biological factors is now seen as an essential component in the promotion of long-term sustainability and stewardship. The WaQSP will therefore instigate a holistic approach—incorporating riparian health, aquatic habitat, in-stream water quality, and public outreach—in order to assure the ecological health of Salt Lake County’s waterways in the future.

Salt Lake County has identified the following as targets for the WaQSP: 1) Improve water quality in streams; 2) Develop regional wastewater planning procedures; 3) Evaluate the effects of Utah Lake and irrigation canals on water quality; 4) Restore and protect stream channels and banks; 5) Increase preservation of stream corridors and ground water recharge areas, and 6) Develop strategies to evaluate instream flows. The recommendations from the WaQSP will guide efforts to achieve these targets.

In order to offer an example of local watershed planning in Utah, we will present an overview of the WaQSP effort, key findings, and implementation recommendations.
Tri-State Water Quality Monitoring in the Bear River Watershed: The First Year

The 550 miles of mainstem Bear River meanders across Utah’s, Wyoming’s and Idaho’s state boundary five times before it drains to the Great Salt Lake. Over the years each state has conducted water quality monitoring to varying degrees, however, due to the trans-boundary nature of the Bear River, each state’s water quality monitoring efforts have generally been conducted independent of each other. Integrating and coordinating water quality monitoring efforts among Idaho, Utah, and Wyoming is as an essential component of integrated watershed management.

In summer 2006 Utah, Idaho, and Wyoming joined forces and began a coordinated monitoring effort in the watershed. Twenty-one monitoring locations were selected along the entire length of the Bear River. Over the past year water quality has been examined at each of the 21 mainstem sites, totaling five events, one for each of the four hydrologic seasons and a single watershed-wide bacterial event in mid-summer. Aspects of this coordinated effort and results of this first year’s water quality monitoring will be discussed.
The Bear River/ Cutler Reservoir Advisory Committee’s involvement in the TMDL process for Cutler Reservoir

The Bear River / Cutler Reservoir Advisory Committee purpose is to provide input to the Division of Water Quality in the policy roles applicable to creating a Total Maximum Daily Load document and for the procedures for effectively analyzing the water quality and its impairment. Committee members represent local governments or interest groups who have expressed concern or have an interest in the TMDL. Motivation for participating in the committee stems from the desire to shape the TMDL policies in a fashion most beneficial to all parties invested in the water quality and regulations imposed on Cutler Reservoir. Suggestions or actions of this committee are intended to insure that all science included into the TMDL document will be scientifically sound and that all possible concerns are addressed. Committee members have influenced what types of research have been conducted on Cutler Reservoir to establish a baseline data set in order to draft a TMDL document and what direction the TMDL document should head in.
Bear Lake, a Giant Carbonate Factory

Sediments deposited over the last 225,000 years in Bear Lake, Utah and Idaho are predominantly calcareous silty clay, with calcite as the dominant carbonate mineral. The abundance of siliciclastic sediment indicates that the Bear River usually was connected to Bear Lake for most of the last 225,000 years. However, three intervals containing more than 50% CaCO$_3$ were deposited during the Holocene (last 10,000 years) and the last two interglacial intervals, back to 225,000 years ago, and indicate times when the Bear River was not connected to the lake. Aragonite is the dominant CaCO$_3$ mineral in two of these three high-carbonate intervals, which indicates saline conditions. These high carbonate, aragonitic intervals coincide with warm, dry interglacial continental climates and warm Pacific sea-surface temperatures. Aragonite also is the dominant mineral in a carbonate-cemented microbialite mound, the “Rock Pile”, which formed in the southwestern part of the lake over the last several thousand years. The history of carbonate sedimentation in Bear Lake is documented through the study of isotopic ratios of oxygen, carbon, and strontium, organic carbon content, CaCO$_3$ content, X-ray diffraction mineralogy, and HCl-leach chemistry on samples from sediment traps, gravity cores, piston cores, drill cores, and the “Rock Pile.

Sediment-trap studies show that the carbonate mineral that precipitates in the surface waters of the lake today is high-Mg calcite. The lake began to precipitate high-Mg calcite sometime in the mid-20$^{th}$ century after the artificial diversion of Bear River into Bear Lake that began in 1911. This diversion drastically reduced the salinity and Mg$^{2+}$/Ca$^{2+}$ of the lake water, and changed the primary carbonate precipitate from aragonite to high-Mg calcite. However, sediment-trap and core studies show that aragonite is still the dominant mineral accumulating on the lake floor today, even though it is not precipitating in surface waters. The isotopic studies show that this aragonite is derived from reworking and redistribution of shallow-water sediment that is at least 50 years old, and probably older. Apparently, the “Rock Pile” also stopped forming aragonite cement sometime after Bear River diversion. Because of reworking of old aragonite, the bulk mineralogy of carbonate of bottom sediments did not change very much after the diversion. However, the diversion is marked by very distinct changes in the chemical and isotopic composition of the bulk carbonate.

At the end of the last glacial interval (LGI, about 15,000 years ago), a large amount of endogenic carbonate began to precipitate in Bear Lake when the Pacific moisture that filled the large pluvial lakes of the Great Basin (Lakes Bonneville and Lahontan) during the LGI diminished, and Bear River apparently abandoned Bear Lake. At first, the carbonate that formed was low-Mg calcite, but as the salinity, and presumably Mg$^{2+}$/Ca$^{2+}$, increased, aragonite began to form. Aragonite is the dominant carbonate mineral that has
accumulated in the lake for the last 7000 years, with the addition of high-Mg calcite after the diversion of Bear River into the lake in the beginning of the 20th century.

The present elevation of the lake when full is 1805 meters above sea level (masl; 5922 feet), but this level has varied considerably during the Holocene, and even over the last 100 years, mainly in response to drought conditions. Flow volumes of the Green and Colorado Rivers are low when Bear Lake level is low, indicating that fluctuations of the elevation of Bear Lake are due to regional and not local conditions. The low levels of Bear Lake during the drought years of the 1990s and 2000s approached the low levels of the 1930s. When Bear River was not connected to Bear Lake, a situation that existed for most of the last 7000 years, evaporation greatly exceeded precipitation. The precipitation of aragonite indicates that Bear Lake became saline, but the salinity of the lake never increased to the point that evaporite minerals, such as gypsum and halite, formed. This implies that in the past as well as today there must be a large, continuous supply of ground water, ultimately derived from snow melt. Such a supply of ground water could be supplied by fracture flow along major faults in the highly faulted Bear Lake Valley, and through the cavernous carbonate rocks in the Bear River Range.

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Bayesian network analysis of Total Phosphorus loading in the Little Bear River
Appendix 8.18 C Bear River Symposium Photographs, taken by Jack Wilbur (UDAF)

Bear River Symposium Photographs

by Jack Wilbur (UDAF)
Cutler Reservoir Tour – water treatment facilities

Cutler Reservoir Tour

Identifying macroinvertebrates

Evening barbeque
Keynote address: Ed Marston

Utah Master Naturalist presentation

Poster session

Nonpoint Source Water Quality Awards