Water Resources Planning and Management Curriculum Incorporating RiverWare™

By Elizabeth A. Eschenbach[1], Member ASCE, Edith Zagona[2], Member ASCE, Katrina Grantz[3]

Abstract

Multiple reservoir management requires the consideration of competing demands for the water for irrigation, domestic consumption, hydroelectric generation, recreation, transportation, and ecosystem management. Such management requires sophisticated tools along with well educated personnel. Many point to the need for universities and professional societies to partner to assure that newly educated professionals will be available. This paper described water resources planning and management curriculum that incorporates the river basin modeling package RiverWare™. RiverWare is a flexible general river basin modeling tool that allows water resources engineers to both simulate and optimize the management of multipurpose reservoir systems for daily operations as well as for planning studies. The curriculum was developed by faculty and staff at Humboldt State University and University Colorado Boulder. In the fall of 2005, ten Environmental Resources Engineering seniors at Humboldt State University experienced the RiverWare curriculum in ENGR 445, Water Resources Planning and Management. RiverWare assignments were developed for the following topics: storage yield analysis, firm yield/firm water, storage allocation zones, rule curves, operation rules, operation of multi-purpose reservoirs, and hydropower concepts. These assignments are further described as well as students' responses to the RiverWare tutorials and assignments. By the end of the semester, students had enough expertise to develop their own models. One student developed a rule curves model of the Shasta and Keswick reservoirs in Northern California. Finally, the paper describes further planned curricular developments. This curriculum is available at no cost for faculty that want to teach Water Resources Planning and Management using RiverWare. The authors anticipate receiving valuable feedback on the content of this curriculum from conference attendees.

---

1 Professor and Chair, Environmental Resources Engineering, Humboldt State University, Arcata CA, 95521, PH: 707-826-4348; FAX: 707-826-3616; email: eae1@humboldt.edu.

2 Director, Center for Advanced Decision Support for Water and Environmental Systems - CADSWES, University of Colorado, Boulder, CO 80309, email: zagona@colorado.edu

3 Professional Research Assistant / Water Resource Engineer, Center for Advanced Decision Support for Water and Environmental Systems - CADSWES, University of Colorado, Boulder, CO 80309 email: Katrina.Grantz@colorado.edu.

Introduction

Given future trends in both increasing demand for water resources and an aging population of professionals, there is great need for the training and development of future water resources planning and management professionals. Many, including the Renewable Natural Resources Foundation[4] in its report *"Federal Natural Resources Agencies Confront an Aging Workforce and Challenges to Their Future Roles"* point to the need for universities and federal agencies to re-partner to assure that newly educated professionals with appropriate skill sets will be available to replace retiring personnel. University of Colorado Center for Advanced Decision Support for Water and Environmental Systems CU-CADSWES, developers of the river basin management software RiverWare™ (CADSWES 2006) are frequently contacted by federal agencies and consultants requesting to hire engineers with expertise in RiverWare. This paper describes the incorporation of RiverWare into the curriculum of an undergraduate water resources management and planning course. The authors anticipate the presentation of this work will provide an opportunity to solicit input on the further development of this course curriculum in order to meet federal and state agencies and consulting firm's needs.

ENGR 445 Water Resources Planning and Management

Before graduating, Environmental Resources Engineering (ERE) students at Humboldt State University in Arcata, California must choose three design electives from the areas of Water Resources, Water Quality, Energy Resources, Air Quality or Geoenvironmental Resources. ENGR 445 Water Resources Planning and Management is a design elective within the undergraduate curriculum of the ABET accredited ERE program at Humboldt State University. The catalog description for ENGR 445 is

> *"Engineering applications of economics, risk analysis, and mathematical simulation and optimization models to water resource planning; multiobjective and sequential decision problems in reservoir operation and water quality management. Engineering design applications".*

The course prerequisites include engineering economics, statistics, systems analysis, numerical methods, and hydrology. The course consists of 15 weeks of instruction. Each week consists of two 50-minute lecture periods and one 3-hour laboratory period. Typically between 10 and 25 students take the course and the course is offered once every two years.

The course objectives of ENGR 445 Water Resources Planning and Management are:

- Students will effectively apply a systems approach to formulate and solve water resources design problems.
- Students will learn about the different types of water resources problems.

---

4 Renewable Natural Resources Foundation member organizations include the American Geophysical Union, American Society of Civil Engineers, American Water Resources Association, and the Universities Council on Water Resources.

- Students will become familiar with the different approaches used to solve water resources problems and they will be able to articulate the strengths and weaknesses of each approach.
- Students will be prepared for graduate studies in water resources by completing a literature review in a current research topic and leading a discussion on that topic as well as completing a design project of their own choosing.
- Students will become skilled users of RiverWare, able to build, run and modify river basin models for planning and operations.

The students were required to buy Jain and Singh (2003) and other texts (Mays and Tung 1992; Loucks, Stedinger and Haith 1981; Littleworth and Garner 1993; Reisner 1993) were on reserve in the library.

Students participated in a two day field trip, where they toured numerous water projects in Northern California as well as met with water resources professionals with the US Bureau of Reclamation (BOR) and the California Department of Water Resources (DWR) in Joint Operations Center in Sacramento California.

The final course grade was based on the following proportions:

- 30% Final Design Project
- 20% Literature Review
- 25% Homework/Lab Assignments (mostly RiverWare)
- 25% Quizzes (5 over the semester).

RiverWare

RiverWare is a general, multi-objective river and reservoir modeling tool used for scheduling, forecasting and planning operations, policy evaluation, and other operational analysis and decision processes (Zagona et al., 2005; Zagona et al., 2001; CADSWES 2006). RiverWare models the hydrologic processes of river and reservoirs systems, including reservoir storage, flow routing, gains and losses, diversions, distribution canals, consumptive uses, shallow groundwater interaction and conjunctive use. Additionally, it models hydropower and hydropower economics, water rights, water ownership, and water accounting transactions. Operating policies and objectives are expressed as prioritized rules or goals, expressed in the RiverWare Policy Language (RPL). The logic of the multi-objective policies interacts with the hydrology by means of a solution algorithm to produce resulting operations and hydrologic states.

RiverWare's object-oriented, data-centered approach enables the modeler to represent site-specific conditions by creating a network of simulation objects, populating each with data, and selecting physical process algorithms on each object that are appropriate to the purposes of the object and its representation in the overall model. RiverWare has three solution algorithms. Data-driven simulations solve the hydrologic variables by propagating solutions of flows and stage through the network.

For multi-objective operational analysis and decision-making, RiverWare provides an interface for expression of operational policies as well as both descriptive and prescription solution algorithms driven by these policies. Rulebased simulation allows the specification of prioritized "if-then" operating policy statements to drive the simulation instead of input data values. The optimization solution is a linear goal programming solution (Eschenbach et al. 2001) that solves the system for each prioritized goal in order. Among possible objectives are maximizing the economic benefits of the hydropower produced. For both rulebased simulation and optimization, the policies are expressed by the modeler in a language provided through the syntax-directed editor. The policies are interpreted and executed as part of the solution algorithm. Thus the policies are represented as dynamic data, which can be viewed and modified outside the compiled code.

RiverWare is developed in C++, uses several third-party libraries, and currently runs on Unix and Windows platforms.

Research and development take place at the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CU-CADSWES) under sponsorship by the Tennessee Valley Authority (TVA), the US Bureau of Reclamation (BOR) and the U.S Army Corps of Engineers (USACE). RiverWare is available to the public through the CU Office of Technology Transfer and CADSWES provides training and user support

RiverWare Assignments

RiverWare assignments were developed for the following topics: storage yield analysis, firm yield/firm water, storage allocation zones, rule curves, operation rules, operation of multi-purpose reservoirs, hydropower concepts.

Before any assignments in RiverWare could be completed, students needed to become familiar with the software. CADSWES training manuals that are used to teach water resources professionals were modified for the student audience. Below is the list of topics in the student training manuals:

- Running and Viewing Simulation Models
- Analyzing Simulation Run Results
- Rule Based Simulation Introduction
- Output Tools
- Accounting Simulation
- Scenario Manager
- Rule Set Design
- Debugging Rule Sets

Note that the students did not receive any hands-on instruction of the use of optimization within RiverWare, as currently, optimization requires an additional CPLEX software license.

PowerPoint presentations explaining different aspects of RiverWare were provided to the students on the following topics:

- Overview of RiverWare
- Simulation in RiverWare
- Rule Simulation in RiverWare
- Power Calculation Methods in RiverWare
- Optimization in RiverWare

Table 1 describes the RiverWare assignments completed by the students, along with an estimated time on task. The early assignments familiarized the students with RiverWare while later assignments utilized the software to teach water resources engineering topics such as firm yield analysis, storage allocation zones, rule curves and operation rules as well as power calculation methods. The students found the hands-on exercises for learning RiverWare straightforward, however not all were sure they were learning enough about how RiverWare works.

Student Response

Students were able to choose their own design projects that were completed the last 8 weeks of the semester. Two of the nine students that completed the class chose RiverWare projects. One student project examined the operation of the Shasta and Keswick reservoirs in Northern California by developing a RiverWare model of the two reservoir system and designing an operation policy using rule based simulation. The rule based simulation policy included operating within flood guide curves and meeting established minimum flows. The model was developed and validated using data obtained from the BOR and the DWR. The second project examined the impacts of recently established minimum fish flow requirements on the daily releases and reservoir storage of Trinity Dam in Northern California. This model was also developed using data from BOR and DWR.

Students appreciated learning a real tool, but some were not confident enough to use RiverWare for completing a final project. One or two students did not find the tutorials in depth enough, however, all students felt it was important to keep RiverWare part of the course. One student commented that *"I think it [RiverWare] helped me to understand better how water resources are managed.... the importance and significance modeling has on the allocation of resources"*.

Table 1: RiverWare assignments for ENGR 445 Water Resources Planning and Management

Task	Description	Approximate Time on Task	Comments
RiverWare Introduction to Simulation	Students completed tutorials on Running and Viewing Simulation Models and Analyzing Simulation Run Results	Two hours in lab and two hours independently	Students found the tutorials straight forward, but were not sure they were learning enough about how RiverWare works.
RiverWare Introduction to Rule based Simulation	Students completed tutorials on Rule Based Simulation and Output tools	One hour in lab and three hours independently	Students found the tutorials straight forward, but were not sure they were learning enough about how RiverWare works.
Firm Yield Analysis with RiverWare	After learning how the USACE uses RiverWare to determine Firm Yield, students used RiverWare to determine the firm yield proportion for two different scenarios. The first scenario did not consider minimum fish flows and the second scenario did.	1.5 hours in lab.	This task required students to use RiverWare tools to calculate appropriate amounts, turn rules on and off and view output graphically. The students varied in their ability to reflect upon the meaning of the results of the assignment. Some just "pushed buttons" until they "found an answer".
Policy Rules Development – Including Storage Allocation Zones, Rule Curves And Operation Rules	Students are provided a set of policies (as text) for two reservoirs in series. They then translate those policies into a ruleset for RiverWare.	This task was completed over two lab periods, for a total of 5 hours.	The exercise of translating the verbal policy into a set of RiverWare rules was very educational. The students came away with a deeper understanding of the multiobjective nature of reservoir management.

Task	Description	Approximate Time on Task	Comments
Debugging Errors in RiverWare	Students were provided existing RiverWare models with increasingly complex errors.	Students were told to spend no more than two hours on the entire exercise as the final model error was very complex .	Many students were not able to stop debugging after two hours. Some expressed frustration at the last problem, although they had been told the same problem had challenged RiverWare experts.
Exploring Power Calculation Methods	Students were provided a model and then asked to change the input for Energy as well as explore using Best Efficiency or Max Capacity or Peak Power to determine energy	One hour in lab, with one to 5 hours outside of class (highly variable).	This exercise required that students to apply power calculation methods they had read about and learned about in class. In addition, they learned more about the System Control Table – a utility that provides a spread sheet like view of the data. The students were required to compare and contrast their results. The assignment was too open ended for some students.

Future Curriculum Development

This RiverWare curriculum project is not complete. Further curriculum will be developed in the coming year and piloted in the Fall 2007 ENGR 445 Water Resources Planning and Management course. The following topics will be addressed in the curriculum.

Impact of Uncertainty – Students come into ENGR 445 well versed in probability, statistics and hydrology and thus are prepared to examine the impact of uncertainty on operating policy and planning studies. RiverWare's multiple run management utility facilitates the study of multiple hydrologic inputs that would be required in a Monte Carlo study.

Multi-Objective Reservoir Management – Further RiverWare assignments will be designed to encourage students to explore policies for operating multiple reservoirs in series and in parallel, while considering multiple objectives as described by Lund and Guzman (1999) and further discussed in Jain and Singh (2003).

Optimization – ERE students come to ENGR 445 well versed in linear and nonlinear programming methods. RiverWare does include an optimization solution which uses a linear, pre-emptive goal programming algorithm incorporating a set of prioritized objectives input by the user (Eschenbach et al. 2001). Currently, the optimization solution requires a third party optimization software license (CPLEX) that is prohibitively expensive. However, RiverWare will soon incorporate an open-source optimization package. Further RiverWare assignments will be developed for students to learn how to use optimization in multi-objective reservoir management.

Conclusion

The RiverWare curriculum was well received by the students, although the exercises could be improved to increase student confidence in their ability to use the software. The curriculum will be further developed including the topics listed above as well as topics that are provided by practitioners. Students in the ENGR 445 Fall 2007 class will pilot test the new and refined RiverWare curriculum.

Those that are interested in using the curriculum at no cost or providing input on topics for future curriculum should contact the authors.

References

CADSWES (2006) *RiverWare* The Center for Advanced Decision Support in Water and Environmental Systems, University of Colorado Boulder <http://www.riverware.org/riverware/> (May 15, 2006).

Eschenbach, E., Magee, T., Zagona, E., Goranflo, H., and Shane, R., (2001). "Goal programming decision support system for multiobjective operation of reservoir systems", *Journal of Water Resources Planning and Management*, ASCE 127(2), 108.

Jain, S.K. and Singh V.P. (2003). *Developments in Water Science 51*: *Water Resources Systems Planning and Management* Elsevier.

Littleworth, A. L. and Garner E. L. (1993). *California Water* Solano Press.

Loucks, D. P., Stedinger, J. R. and Haith D. A. (1981). *Water Resource Systems Planning and Analysis*, Prentice Hall.

Lund, J.R. and Guzman J. (1999). "Some Derived Operating Rules for Reservoirs in Series or in Parallel," *Journal of Water Resources Planning and Management*, ASCE, Vol. 125, No. 3, pp. 143-153, May/June.

Mays, L. W. and Tung Y.-K. (1992). *Hydrosystems Engineering and Management*, McGraw-Hill, Inc.

Reisner, M. (1993). *Cadillac Desert: The American West and Its Disappearing Water* Penguin USA.

Renewable Natural Resources Foundation (2003). *Federal Natural Resources Agencies Confront an Aging Workforce and Challenges to Their Future Roles Conference on Personnel Trends, Education Policy, and Evolving Roles of Federal and State Natural Resources Agencies* Presented at the Conference on Personnel Trends, Education Policy, and Evolving Roles of Federal and State

Natural Resources Agencies, AAAS, Washington DC October 28 - 29, 2003. Renewable Resources Journal Volume 21 Number 4 Winter 2003-2004. <http://www.rnrf.org/2003conf/03report.pdf> (May 15, 2006).

Zagona, E., Fulp, T., Shane, R., Magee, T., and Goranflo, H. (2001). "RiverWare: a generalized tool for complex reservoir systems modeling", *JAWRA* 37(4), 913.

Zagona, E., Magee, T., Frevert, D., Fulp, T., Goranflo M. and Cotter J. (2005). "RiverWare:. In: V. Singh & D. Frevert (Eds.), *Watershed Models*, Taylor & Francis/CRC Press: Boca Raton, FL, 680pp.

