FY2015 Annual Report
October 1, 2014 – September 30, 2015

CADSWES, founded in 1986, is a Research Center within the College of Engineering and the Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder. Cadswes.colorado.edu.

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1. Overview

CADSWES research focuses on natural resource management, particularly the sustainable management of multi-objective water resource systems for planning and operations, climate change adaptation, policy analysis, improved short and long term forecasting under hydrologic variability, and hydropower optimization. Almost without exception the research aims to develop techniques that can be applied by water management agencies.

CADSWES continued its research and development activities with its three major sponsors – Bureau of Reclamation, U.S. Army Corps of Engineers, and Tennessee Valley Authority - on multiple decision support software products, research projects and applications. Enhancements to, and applications of the RiverWare modeling system are the primary focus of CADSWES R&D. As the use of the tools expands, the need for more advanced capabilities evolves. The RiverWare software has become a widely used tool in the U.S. and has a growing number of users abroad. With increasing number of users, technology transfer continued to be a major part of the activities at CADSWES in FY2015.

In FY2015 a major new application for the Bonneville Power Administration was developed for operations and hydropower optimization of the Columbia River, to be tested and deployed in FY2016. Research funded by Oak Ridge National Labs developed a new optimization approach to modeling total dissolved gases in hydro systems where spill-induced TDG is an environmental constraint on operations.

The Center's research and development emphasis continued to be a strong platform for graduate student education – building the next generation of sustainability focused natural resource researchers and practitioners. Projects in decadal scale projections in the Colorado River Basin and development of a Reservoir Model for Lake Powell provided graduate student research.

CADSWES faculty, as part of the Department of Civil, Environmental and Architectural Engineering, participate in collaborative research and teaching within the Department and College.

2. Research and Development of Decision Support Software

A major activity of CADSWES is research and development of decision support software, funded by water management agencies, and used widely by the water management community. RiverWare is the flagship product. RiverSMART, the Graphical Policy Analysis Tool and the Demand Input Tool are designed to be used in conjunction with RiverWare.

RiverWare

RiverWare®, a river and reservoir modeling tool for operational scheduling and forecasting, basin planning, policy evaluation and other operational analysis and decision processes, has been developed at CADSWES since 1993, funded by the Bureau of Reclamation, the Tennessee Valley Authority and the U.S. Army Corps of Engineers. Each year, sponsors fund new enhancements. RiverWare is licensed through the CU Technology Transfer Office. Additional software upgrades, releases and maintenance are supported through the license revenues. See also riverware.org.

Releases

Two major RiverWare releases (6.6, 6.7) and 9 patch releases were issued in FY2015.

Enhancements

Major RiverWare R&D efforts during FY 2015 include the following new features:

Columbia River Models for BPA. CADSWES developed operations models of the Columbia River for use by the Bonneville Power Administration as part of their new Hydro Regulation Model System (HERMES). The hourly timestep optimization and rulebased simulation models will be used by the Real Time (RT) and Short Term (ST) schedulers at BPA to operate the Big 10 Federal Projects and numerous smaller projects on the Columbia and its tributaries. The ST planning group creates forecasts up to 30 days to guide hydro operations and marketing activities. RT makes operational decisions on an hourly basis, to meet generation and reserve requirements, physical and legal constraints including environmental regulations. The models were developed based on extensive user requirements and iteration with BPA schedulers on the operating policies and solution. CADSWES researchers and developers also provided training classes for BPA on the use of RiverWare and the BPA models. In addition to the models, the RiverWare software was enhanced to provide data exchange with FEWS. New optimization methods were developed: the power surface approximation method and the plant power coefficient method extend hydropower modeling in optimization; also, the ability to generate and save a "seed" to jump-start the optimization solution was developed. At the end of FY2015 the models were tested. Completion of the project including deployment in the BPA production system is planned for FY 2016.

FEWS Adapter. BPA will use RiverWare through the Deltares FEWS system that integrates models, data, analysis and graphical user interface. The RiverWare adapter for FEWS was developed and tested and enhancements to RiverWare software make it possible to communicate with FEWS, including exporting solution path information for both rules and optimization solutions.   FEWS is also being adopted at TVA where schedulers will continue to use RiverWare with the native user interface. CADSWES provided additional FEWS adapter enhancements specific to the TVA implementation.

Reservoir Salinity Model. A 2-layer segmented reservoir salinity model was developed and calibrated for modeling Lake Powell at a monthly timestep.
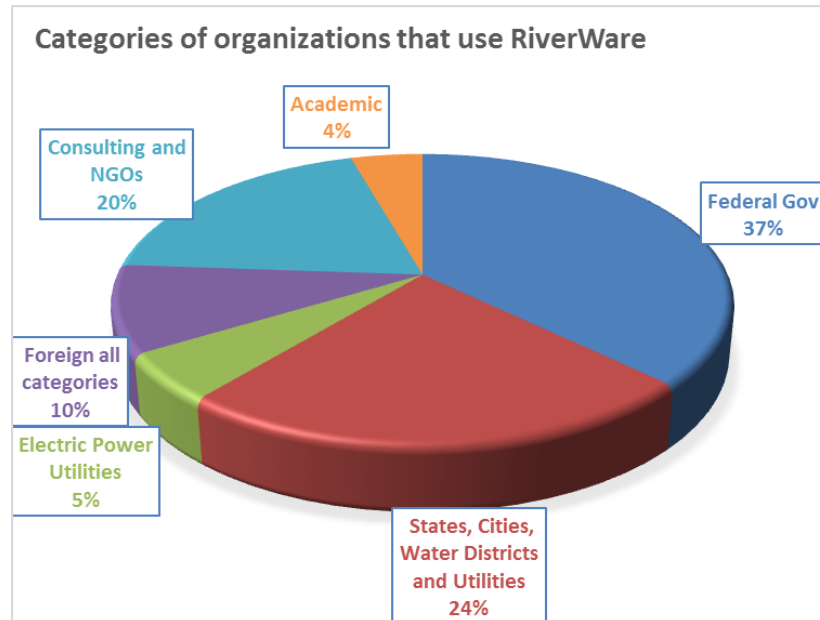
Usability Features. Enhancements that provide more powerful model building, analysis and visualization capabilities were developed including detailed model run analysis for water quality, access to the scripted policy language function library from the editor, extension of model reports to include images and support rich text, completion of Object Attributes metadata on simulation objects, extension of the output canvas with animated teacup representation of storage in reservoirs and flow magnitudes in routing reaches, and enhancement to the multiple run manager to directly handle ensemble data from Reclamation's Hydrologic Database (HDB). Numerous other enhancements are described in the release notes for RiverWare 6.6 and 6.7 at riverware.org.

Scenario Explorer. Requirements and design were completed for a new feature, the **Scenario Explorer**, which will allow stakeholders to explore alternative scenarios within constraints specified by the model developer. The Scenario Explorer will be executed with a different limited-use version of RiverWare that will be freely available.

CWMS Integration. The task to closely integrate RiverWare into the new version of the Corps Water Management Systems (CWMS) continued and is expected to be complete in FY2016.

RiverWare User Community

RiverWare is used by TVA River Operations in Knoxville, TN, by 23 offices of the Bureau of Reclamation, 12 offices of the Army Corps of Engineers, and 77 (as of September 2015) other entities including federal agencies, states, cities, water districts, utilities, NGOs, academic institutions, consulting companies and foreign entities including Mexico and Canada. Ten new entities acquired the RiverWare software in FY2015. The figure shows the number of entities in various categories that have RiverWare, including the sponsors. Total number of organizations is 113.

Categories of organizations that use RiverWare

- Academic 4%
- Federal Gov 37%
- Consulting and NGOs 20%
- Foreign all categories 10%
- Electric Power Utilities 5%
- States, Cities, Water Districts and Utilities 24%

RiverSMART

Developed under the Department of Interior's WaterSMART initiative, The RiverWare Study Manager and Research Tools (RiverSMART) is a software framework to facilitate the creation, execution, and archiving of RiverWare planning studies that compares the results of several scenarios representing differing hydrologic ensembles, demands, and strategies, such as operating policies and infrastructure alternatives. It manages the execution of the simulations to multiple processors, and keeps track of the output files for analysis. It can serve as an archiving structure to save the results of an entire study. The tool was designed and developed to address the needs of complex modeling studies that often explore options for meeting projected imbalances of future supplies and demands due to changing climate, water uses, and operating policies. In 2015 numerous major and minor enhancements to the RiverSMART tools were made including the CSV combiner plugin (for Tableau output), and NetCDF output; study validation, diagnostics, navigation and GUI improvements and online help enhancements.

Graphical Policy Analysis Tool

The Graphical Policy Analysis Tool (GPAT) is an Excel-based tool that provides statistical analysis and comparison of policy alternatives that have been simulated in RiverWare with the Multiple Run Manager to simulate ensembles of hydrologic traces. GPAT provides the ability to effectively visualize and analyze RiverWare model outputs as well as other data set, allowing statistical comparisons and graphing of multiple modeling runs

3. Research Projects

Multi-Decadal Stochastic Streamflow Projections and Application to Water Resources Decision Making in the Colorado River Basin.
PhD research by Solomon Erkyihun, Directed by Professors Edith Zagona and Balaji Rajagopalan. Funded by the Bureau of Reclamation, Lower Colorado Regional Office.

In basins such as the Colorado River Basin (CRB), streamflow exhibits variability that reflects teleconnections with climate indices such as Atlantic Multi-decadal Oscillation (AMO) & Pacific Decadal Oscillation (PDO). This research addresses this problem with four main contributions: It develops a conditional stochastic streamflow simulation model and decadal scale streamflow projections based on these climate indices, compares this with recently developed models, identifies and quantifies periods of unpredictability, and demonstrates the value of adding decadal projections to existing decision criteria in the CRB Supply and Demand Study.

Total Dissolved Gases Research
Funded by Oak Ridge National Laboratory, UT-Battelle.
Principal Investigators: E. Zagona, Technical lead: T. Magee; D. Neumann implemented the algorithms in RiverWare.

Total dissolved gases (TDGs) are a significant issue in the Pacific Northwest and are present to a lesser extent in other areas. This project improves the products produced in a 2012 project by improving and generalizing the TDG optimization solution within RiverWare. The project will be completed in FY2016.

4. Presentations and Outreach

CEAE Classes: Dr. Zagona and David Neumann assisted Professor Kasprzyk in teaching CVEN 5393 Water Resources Development and Management in Spring 2015, including providing support and guidance to students on class projects using RiverWare.

Seminars and Presentations:

- Dr. Zagona gave keynote address "Sustainability through collaborative use of data and analysis tools" at the 4th Nile Basin Development Forum, October 6, 2014, Nairobi, Kenya.
- Solomon Erkyihun presented "Wavelet-based Time Series Bootstrap Model for Multi-decadal Streamflow Simulation Using Climate Indicators" at AGU Hydrology Days, March 23, 2015.
- David Neumann gave a presentation and RiverWare demonstrations at the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-21, 2015, Reno, Nevada.
- Tim Magee moderated a session and gave a talk on Total Dissolved Gas Modeling at the Hydrovision Conference in Portland, OR July 14-17, 2015.

The 2015 RiverWare User Group meeting on February 3 – 4 was attended by over 80 RiverWare users from federal, state and local water management agencies, hydropower utilities, consulting firms and research institutes. Users presented their Riverware applications and CADSWES R&D team demonstrated new and upcoming software features. Attendees and agenda are available at riverware.org.

CADSWES participated in a project with Reclamation, Rand and Lawrence Livermore National Lab to execute the Colorado River Basin Study simulations on the LLNL supercomputer with a group of stakeholders to experiment with the decision-making response to a quick turnaround of results that normally require many weeks and thousands of simulations.

CADSWES hosted a weekly meeting of about a dozen Water Resources graduate students with Professors Zagona, Balaji and Kasprzyk throughout the year.

5. Technology Transfer

CADSWES held 5 three day RiverWare Simulation and Rulebased Simulation training classes in FY2015. Additional dedicated classes were given at BPA and at CADSWES for the TDG model solution. The classes were attended by 54 people, 19 from sponsoring agencies, 6 from academic institutions, and 29 from commercial entities. Attendees from the following organizations attended:

Bonneville Power Administration, Portland OR	National Park Service, Denver, CO
Chelan County PUD, Wanatchee WA	National Renewable Energy Lab, Golden CO
CO River Board of CA, Glendale CA	Natural Resources Consulting Eng., Ft. Collins
DiNatale Water Consultants, Boulder CO	NM Interstate Stream Com. Santa Fe NM
East Bay Municipal Utility Dist., Oakland CA	Precision Water Resources Eng., Loveland CO
Freese and Nichols, Ft. Worth TX	Pyramid Lake Paiute Tribe, Nixon NV
Hazen and Sawyer Environ. Eng., New York, NY	State of WY Engineers Office, Cheyenne WY
Idaho Power Company, Boise ID	Tetra Tech, Sana Fe and Austin Offices
Lower CO River Authority, Austin TX	Oak Ridge National Laboratory
Academic/Research Institutions	**Sponsoring Agencies**
CO State University, Ft. Collins CO	Bureau of Reclamation sent people from:
Texas A & M, El Paso TX	Albuquerque NM, Boise ID, Boulder City NV,
Universidad Autonoma de Chihuahua, Mexico	Denver CO, Heyburn ID, Provo UT and Yuma AZ
CU, Boulder CO	U.S Corps of Engineers, Albuquerque NM
University of Nevada, Reno NV	

CADSWES hosted the following RiverWare users for one-on-one tech transfer and modeling support
- Rohan Chaterjee of Grant County PUD visited CADSWES for 2 days Oct 2,3. Mitch Clement provide support for developing a rules version of the Mid-Columbia hydropower optimization model.
- Susan Behery, Reclamation Durango Area Office, and Todd Vandegrift, Reclamation Denver Technical Services Center for 3 days October 21 to 23, 2014, working with David Neumann to gain modeling expertise needed to continue modeling for the San Juan River Basin Recovery Implementation Program.
- Jessica Mason of Lotic Hydrologic visited CADSWES for 2 days in October 2014. David Neumann provided RiverWare Water Accounting training and helped her set up a model of the Crystal River.
- Greg Mueller from TVA visited CADSWES February 6-13 to work with Tim Magee and Mitch Clement to gain expertise in RiverWare optimization modeling.

6. Publications

Journal Articles

Brown, C. M., J. R. Lund, X. Cai, P. M. Reed, E. A. Zagona, A. Ostfeld, J. Hall, G. W. Characklis, W. Yu, & L. Brekke (2015). The Future of Water Resources Systems Analysis: Toward a Scientific Framework for Sustainable Water Management, *Water Resour. Res.*, 51, DOI 10.1002/2015WR017114.

Smith, R., J. Kasprzyk, and E. Zagona (2015). Many-Objective Analysis to Optimize Pumping and Releases in Multireservoir Water Supply Network, *J. Water Resour. Plann. Manage.*, 04015049-1—04015049-14, DOI 10.1061/(ASCE)WR.1943-5452.0000576.

Conference Papers

Butler, A., Jerla, C, Nowak, K., Prairie, J, Oakley, B., Wilson, N., Zagona, E. (2015). "The Colorado River Basin Water Supply and Demand Study: Modeling to Support a Robust Planning Framework." In *Proc 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling*, April 19-21, Reno, NV

Daylor, J., Neumann, D., Zagona, E., and Steffen, J., (2015). "Multi-objective Modeling in RiverWare for USACE-SWD." In *Proc 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling*, April 19-21, Reno, NV.

Steffen, J., Stringer, J., Daylor, J, Neumann, D. and Zagona, E. (2015). "TAPER – A Real-time Decision Support Tool for Balanced Flood Operation of the Arkansas River in Tulsa District." In *Proc 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling*, April 19-21, Reno, NV

7. Personnel

The CADSWES R&D team includes:

Director: Edie Zagona, Research Professor, CEAE
Affiliated Faculty: CEAE Professor Balaji Rajagopalan and Assistant Professor Joe Kasprzyk
Research Associate: Tim Magee, Operations Research Analyst
Senior Research Assistant: David Neumann, Water Resources Engineer
Research Assistants:
    Mitch Clement – Water Resources Engineer
    Jessica Lee – Software configuration
    Patrick Lynn, PhD. – software developer
    Bill Oakley – software developer
    Jim Pasquotto – IT and documentation support
    Phil Weinstein – software developer
    Neil Wilson – software developer
Graduate Students:
    Solomon Erkyihun, Ph.D. student, CEAE
    Sarah Baker, M.S. Student, CEAE
Exempt Professional Staff:
    Kathryn Baack – Financial Coordinator
    Gwen Miller – Tech Transfer Coordinator

The Bureau of Reclamation Boulder Duty Station shares space with CADSWES. Reclamation employees at this duty station are Alan Butler, Carly Jerla, Ken Nowak of the LC Region, and Jim Prairie of the UC Region, and Student Engineer Jessica Shirey.

8. Financials

CADSWES receives most of its funding through contracts and grants. Additional revenues are from the Technology Transfer Office as distributions for RiverWare software licenses, from payments for training classes provided to the users of our software tools, and from indirect cost return. CADSWES receives its share of the ICR return directly from the College of Engineering and Applied Science.

The funds from contracts and grants are spent on R&D staff, project management, support staff that provide direct assistance to the technical staff, travel, tuition, direct operating expense are described below, and F&A.
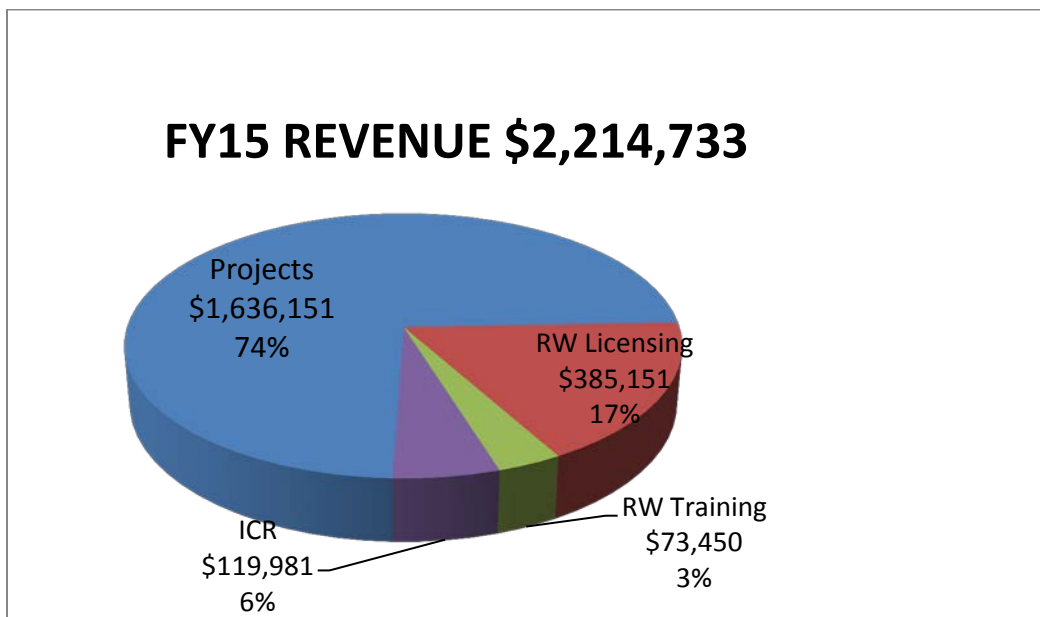
The TTO revenues are used for releases and maintenance of the software and installation processes, and for personnel and other expenses of keeping track of licenses, collecting payments, maintaining the databases, IT support and other direct expenses of the licensing and distribution activity.

Training revenues are spent on direct cost of training classes including personnel to organize, schedule, prepare and teach the classes, training materials, IT equipment used for the training classes, and IT personnel support.
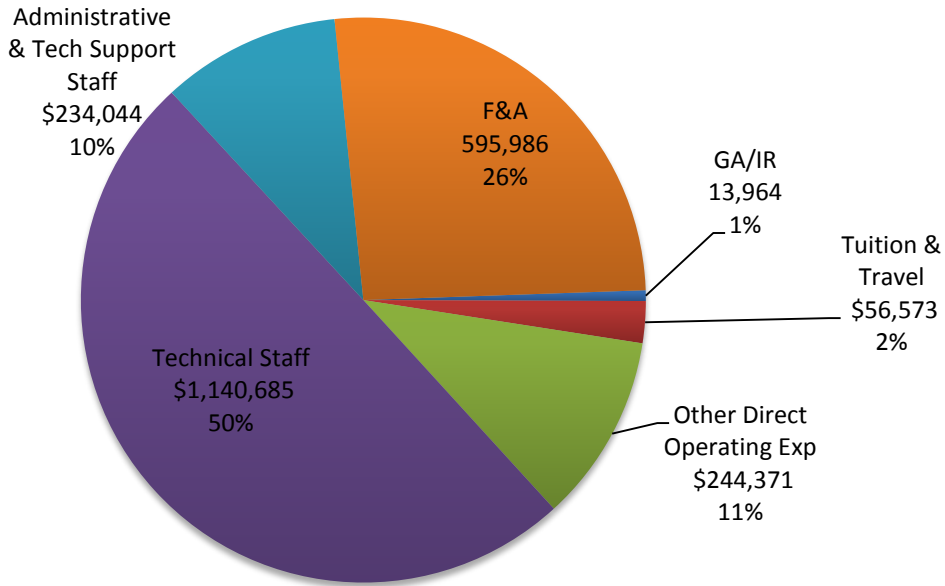
Indirect Cost Return is used for general Center expenses that cannot be applied to contract and grants, including rent, furniture, office supplies, and administrative staff time that is not specific to particular projects. It is also used for a portion of the Director's salary for Center administration, and for other personnel costs that are not covered by specific project, e.g., writing proposals and papers, outreach, conferences, and special development that can be strategically leveraged for winning future funding.

Direct operating expenses are expenses that are project specific or general center expenses that are not covered by the University. They include hardware, software, IT supplies and services, office equipment, office supplies, official functions, shipping and mailing, credit card fees, printing, furniture and rent.

The following figures show the sources of revenues in FY2015, total expenses and details of expenses.

FY15 REVENUE $2,214,733

Projects $1,636,151 74%

RW Licensing $385,151 17%

RW Training $73,450 3%

ICR $119,981 6%

FY15 Total Expenses $2,285,625

Administrative & Tech Support Staff
$234,044
10%

F&A
595,986
26%

GA/IR
13,964
1%

Tuition & Travel
$56,573
2%

Technical Staff
$1,140,685
50%

Other Direct Operating Exp
$244,371
11%

FY15 Total Other Direct Operating Expense Categories $244,371

- Software $154,278
- Systems Admin $31,473
- IT Hardware $13,827
- CINC Rent $13,040
- Official Functions $11,008
- IT Services/Telecom $5,528
- IT Supplies $5,286
- Credit Card Fees $4,301
- Office Supplies $2,845
- Xerox Copier $1,388
- Shipping/Memberships/Other $1,396