



River System Operations and Planning with RiverWare

Edith Zagona, Research Professor and Director
University of Colorado Boulder

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Integrating River Planning for Energy and Environment Technical Workshop
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River System Operations and Planning with RiverWare A River and Reservoir Decision Support Toolset

Developed at CADSWES 1993 to present through
collaborative research and development with

Tennessee Valley Authority
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

RiverWare R&D Team: water resources scientists and engineers, operations research
analysts, professional software developers, IT security and performance specialists,
configuration management specialist, documentation specialist



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CADSWES

The Center for Advanced Decision Support for Water and Environmental Systems

Education

Research & Development

Technology Transfer

Mission of CADSWES...

Develop **Decision Support Tools** for the Global Water Management Community
 Bridge the gap between science and decision-making
Technology Transfer and Outreach to agencies, Utilities, Universities, others
Education - for next generation of water resources engineers and scientists

www.cadswes.colorado.edu

















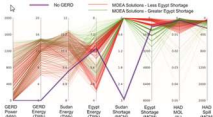

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R&D Decision Support Tools:

River/reservoir/hydropower modeling and analysis for planning, real time operations, policy analysis and development, transboundary negotiations, hydropower optimization



Research Areas:



Multi-objective decision making with uncertainty
 Collaborate with Prof. Kasprzyk



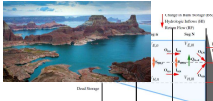
Climate variability/change for adaptive basin management
 Collaborate with Prof Balaji; Reclamation



Adaptive realtime reservoir operations with uncertain forecasts



Value of hydropower in the grid as balancing reserve for variable renewables
 Oak Ridge National Lab, NREL, Hydro Research Foundation

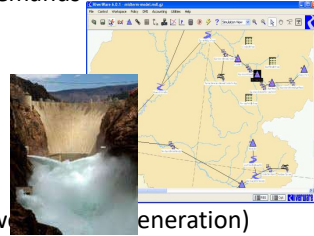


Basin Scale Physical process modeling for long term planning

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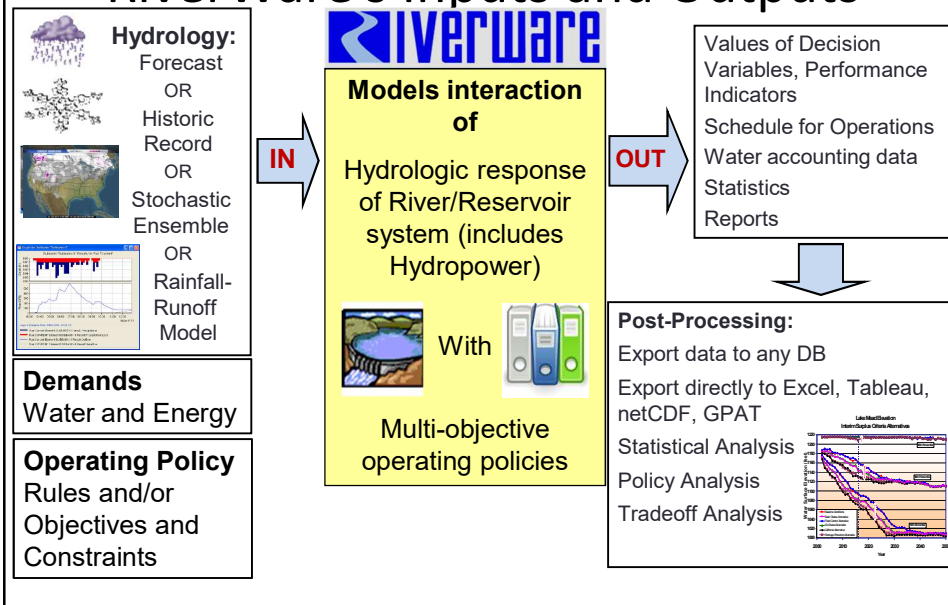
Uses of RiverWare

- **Planning**, reliability assessment and decision-making for
 - New infrastructure development or new demands
 - Policy development and evaluation
 - Environmental impact assessment
 - Climate change studies
 - Compact or treaty negotiations
- **Scheduling of Operations**
(reservoir releases, diversions, transfers, hydropower generation)
- **Water accounting**, priority water rights allocation
- Facilitate **stakeholder** participation and collaborative decision-making including **transboundary negotiations**
- **Computational Timestep: 5 min, 15 min, 1 hr, 6 hr, 1 day, 1 mo, 1 year**



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RiverWare's Inputs and Outputs



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OO Model of river system features

Objects contain data, physical process methods

Method selection per object

Reaches → Routing

No Routing, Time Lag,
Impulse Response, Muskingum,
Muskingum Cunge, Kinematic

MuddyInflow

File Edit View TimeStep I/O Adjust

Inflow

Value: 21.28997015 cfs

Jan 4, 2012

	Total	cfs
01-02-2012 Mon	16.9	I 0
01-03-2012 Tue	15.8	I 0
01-04-2012 Wed	21.3	I 0
01-05-2012 Thu	24.6	I 0
01-06-2012 Fri	18.7	I 0
01-07-2012 Sat	22.2	I 0
01-08-2012 Sun	26.2	I 0
01-09-2012 Mon	32.3	I 0

Show: ☐ Description

Open Object - Bartlett

File Edit View Slot Account

Object Name: Bartlett

Level Power Reservoir Object

Slots	Methods	Accounts	Accounting Methods	Description
	Selected Method:	Plant Power Coefficient		
	Category	None		
		No Power Turbine Flow		
		Plant Power Coefficient		
	Power	Plant Efficiency Curve		
	Power Release	Plant Power Equation		
	Energy in Stor	Unit Generator Power		
	Tailwater	Peak and Base		
	Spill	Peak Power		
		Unregulated Spill Peak Power Equation		
		Regulated Spill Peak Power Equation with Off Peak Spill		
	Input Outflow Adjustment	None		
	Future Value	None		
	Ramping	None		

Object Palette

Close

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Data Management Interface



Import or export data from/to any external source (files, databases, spreadsheets, Corps of Engineers DSS)

Extend or redefine start/stop time of the runs

Group DMIs together for operational updates

Batch Mode

Automate runs without GUI

Control start/stop times; DMIs; policy sets(rules, constraints, objectives)

Save outputs, diagnostics, other run information



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Multiple objective modeling

River systems are operated for a variety of objectives



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RiverWare's Solvers

1. Simulation

models physical processes for a variety of input/output combinations
(upstream/downstream; forward/backward in time)

2. Rulebased Simulation

simulation driven by user-specified operating rules (policy) expressed through an interpreted language. Solves each timestep completely then moves to next.

3. Optimization

linear goal programming solution. Solves all timesteps and all objects at once.

4. Water Accounting (with or without rules)

Models ownership, water type and water rights; can be coupled with rules

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Multiple Operating Policies and Objectives:

Rulebased Simulation

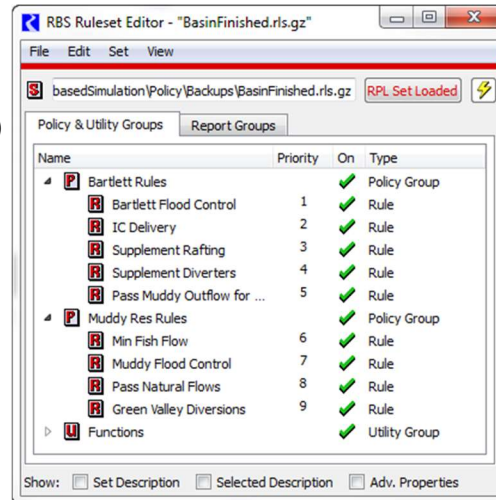
Operating policies are prioritized rules

IF (state of system)
THEN (set decision variables)

Rules assign values to decision variables to drive solution.

Execute entire policy set at every timestep.

Decision variables are reservoir releases, storage level, hydro generation, diversions, etc.

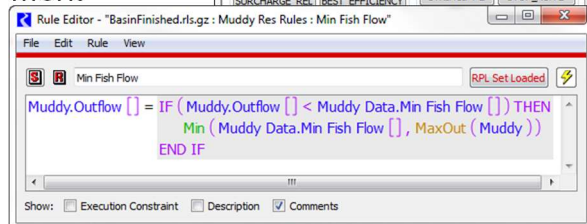
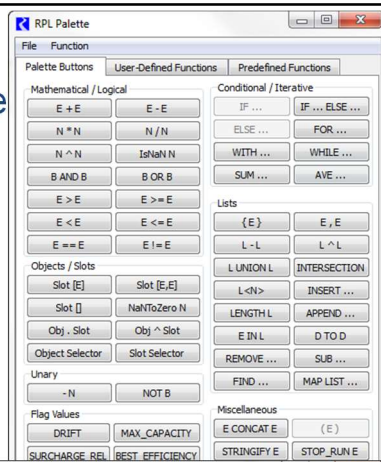


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Operating Policies – detailed and transparent:

RPL RiverWare Policy Language

- Rich scripting language
- Structure allows complex logic
- As a functional language, transparency is guaranteed
- Syntax directed editor
- Automatic Unit Management
- Function Libraries
 - user-defined
 - pre-defined



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Colorado River

New Era of Collaborative Transboundary Decision Making

Shortage Criteria 2007 negotiated among 7 basin states – interim guidelines to 2026



After 2 years of negotiations

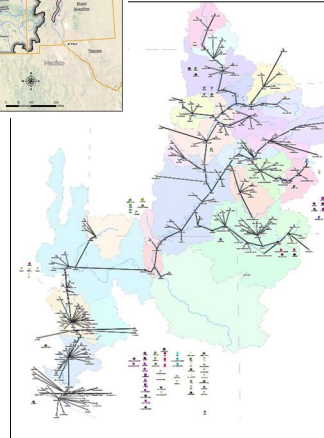
Mexico Minute 323

Negotiated 2016 – Mexico shares in shortages and surpluses; gets environmental flows to the Delta



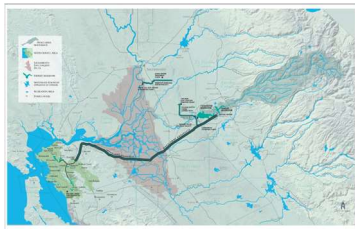
CRSS – Colorado River Simulation System

Long term planning, Complex “Law of the River”



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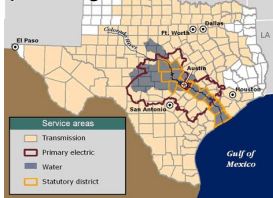
Selected RiverWare Rulebased Simulation Applications



East Bay Municipal Utility District, seasonal and annual operations

Lower Colorado River Authority

Water allocation and planning



Snake River Basin



Figure 522 The Snake River Basin regional aquifer system underlies a large, crescent-shaped basinal in southern Idaho and a small part of northeastern Oregon.

Source: USGS, 2002

Scale: 1:100,000

W. Long. 107°

N. Lat. 40°

Arkansas R. Drainage Divide

Other Drainage Divides

250 km

Arkansas Basin – USACE flood control and water supply

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The Upper Rio Grande Water Operations Model

Upper Rio Grande Basin

Upper Rio Grande Basin

Upper Rio Grande Basin

Upper Rio Grande Basin

Upper Rio Grande Basin

Upper Rio Grande Basin

Upper Rio Grande Basin

Upper Rio Grande Basin

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Multiple Operating Policies and Objectives:



Optimization

Pre-Emptive Linear Goal Programming

A global solution – all objects, all timesteps

- Multi-objectives without user-defined penalties
- Policies (Goals) are Prioritized
- Soft Constraints - Minimize infeasibility
- Economic (hydropower) objective
- Linear or Mixed-Integer Programming
- Goals/constraints formulated in RPL Editor
- Variables automatically linearized
User controls approximation
- Physical constraints generated by objects as needed
- CPLEX solver
 - Can “tune” parameters
- Post-optimization Rulebased Simulation



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Tennessee River System (TVA)

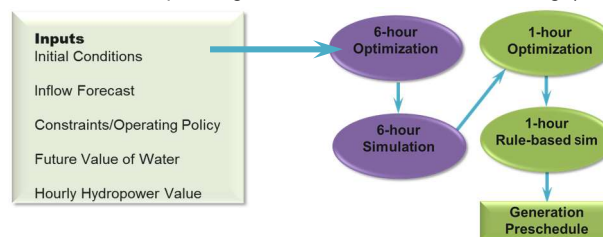
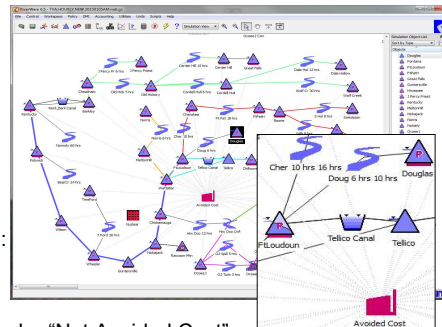
Real time operations (reservoir operations unit)

~1.5 GW Hydropower
10% of TVA's energy capacity

Operating Policy:

Operate within reservoir constraints while utilizing the flexibility of the reservoir system to:

- **Balance system benefits**
(WQ, Water supply, navigation, flood control)
- **Minimize total cost of generation**; Maximize hydro “Net Avoided Cost”
(net avoided cost = max avoided operating cost + cumulative value of storage)



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Columbia River Basin – Bonneville Power Administration



10 Large Federal Projects
5 Tributary systems

84% hydro (22GW+ cap)
10% nuclear
5% purchases
1% wind

Objectives for RT and ST

1. Meet load and reserves
 2. Maximize value/market
- Must look ahead strategically and accurately

Constraints:

flow mins
ramping
spill max/min and priorities
TDGs

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RiverWare's Hydro Optimization schedules 1/3 of US Hydropower

Hydropower	Installed Capacity (MW)	Generation (GWh)
U.S. Total	102,867	322,390
RiverWare Opt Users	32,514	~113,530
Percent	32 %	35%

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Hundreds of users including...

- **Water management agencies**
U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, States, Cities, Water Districts
- **Other Federal Agencies and Tribes**
BIA, USGS, National Park Service, Intern'tl Boundary Water Commission, FERC
- **Power Utilities**
TVA, Bonneville Power, Lower Colorado River Authority, Southwest Power, Idaho Power, Hydro Quebec, B.C. Hydro, Barki Tojik - Tajikistan
- **Consultants**
- **Universities, Research Labs and Institutes**
- **NGOs**
- **International Governments**

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www.RiverWare.org

Support: riverware-support@colorado.edu

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