



Center for Advanced Decision Support for
Water and Environmental Systems (CADSWES)

UNIVERSITY OF COLORADO BOULDER

Keynote Panel

RiverWare technical team

RiverWare Uses and Users

Our Sponsors and Current Major Work

Challenges and Visions for the Future

Center for Advanced Decision Support for Water and Environmental Systems (CADSWES)

Department of Civil, Environmental and Architectural Engineering
College of Engineering and Applied Sciences



University of Colorado **Boulder**





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.colorado.edu/cadswes/



A General River and Reservoir Hydro-policy Modeling Tool

Continuously developed and maintained by CU-CADSWES
1993 to present, through collaborative research and development with
Tennessee Valley Authority
Bureau of Reclamation
U.S. Army Corps of Engineers



Common Applications of RiverWare

- **Long term planning** of river/reservoir system for operating policies, yield analysis, climate change, flood risk and physical modifications of system
- **Policy evaluation** – compare several policies with stochastic inputs and risk-based outputs (especially NEPA processes) with respect to critical decision variables
- Determine **operating plan** for today, this season or this year including hydropower optimization
- **Forecast operations** over next few months or seasons and develop a plan for allocations, curtailments, exchanges, purchases, etc
- **Negotiation** of international or state boundary agreements for water operations
- Keep track of **water allocation and water rights** (official accounting)

On the Agenda....



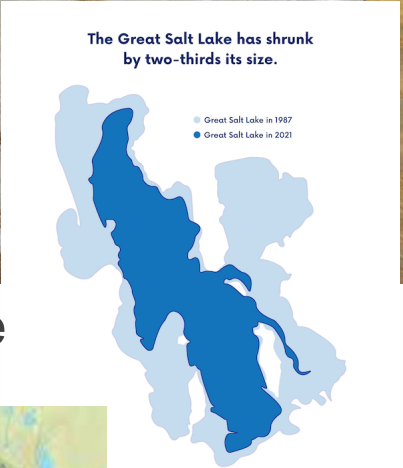
Reclamation – Post 2026 EIS
Colorado River Basin



Tarrant Regional Water District



Great Salt Lake



TVA – HP outage modeling



Truckee-Carson Basin



Klamath

Who Uses RiverWare? Licensed by University to ...

Bureau of Reclamation – 27 offices

Tennessee Valley Authority – River Operations, Knoxville, TN

U.S. Army Corps of Engineers - 13 offices

12 Federal Agencies, Tribes and Research labs

35 State, City and District Water Agencies

11 Electric Utilities – US and Canada

32 Consulting companies and NGOs

14 Universities and research groups

22 Foreign Entities (consultants, govt agencies, universities, utilities)

Sesquiennial RiverWare User Meetings

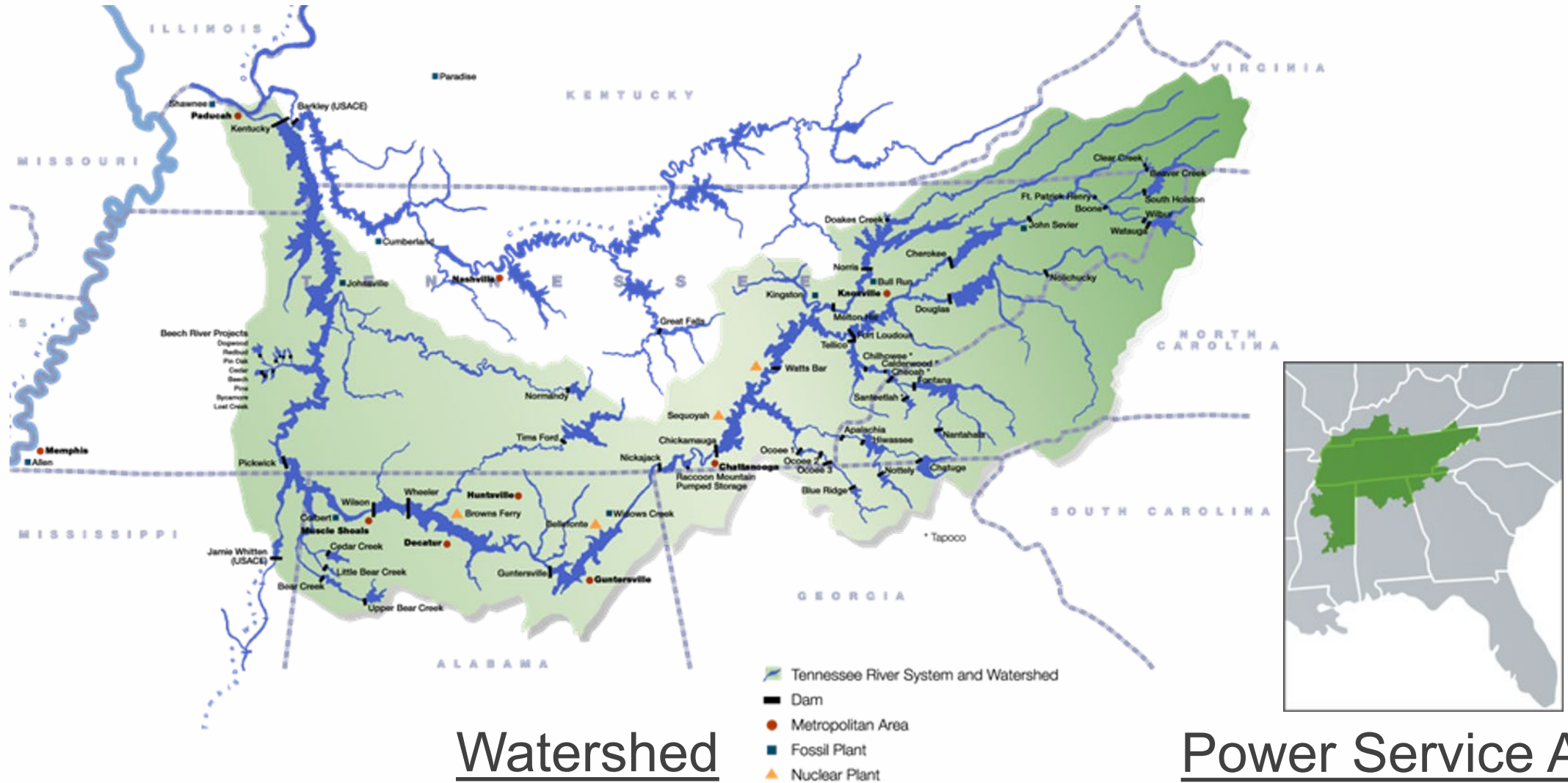
- Find out about new/upcoming enhancements and the future of RiverWare
- Hear about interesting applications
- Meet other users and network
- Get to know the CADSWES Team
- Ask those burning questions
- Voice your opinion about what is needed or what you like/don't like



About the RiverWare Sponsors

...

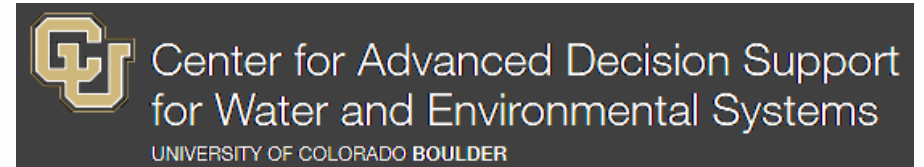
Sponsor: Tennessee Valley Authority



Sponsor: Tennessee Valley Authority

- TVA: System Power Optimization after Soft Constraints
 - Short Term, Mid-Term, Long Term, and Subbasin models

- Intellectual Partnership



- TVA experience with their scheduling and tools
- CADSWES experience with optimization and software design
- RiverWare Optimization: combine experience, innovate, and generalize

- Partnership ➡ Design and Enhancements

Sponsor: U.S. Army Corps of Engineers

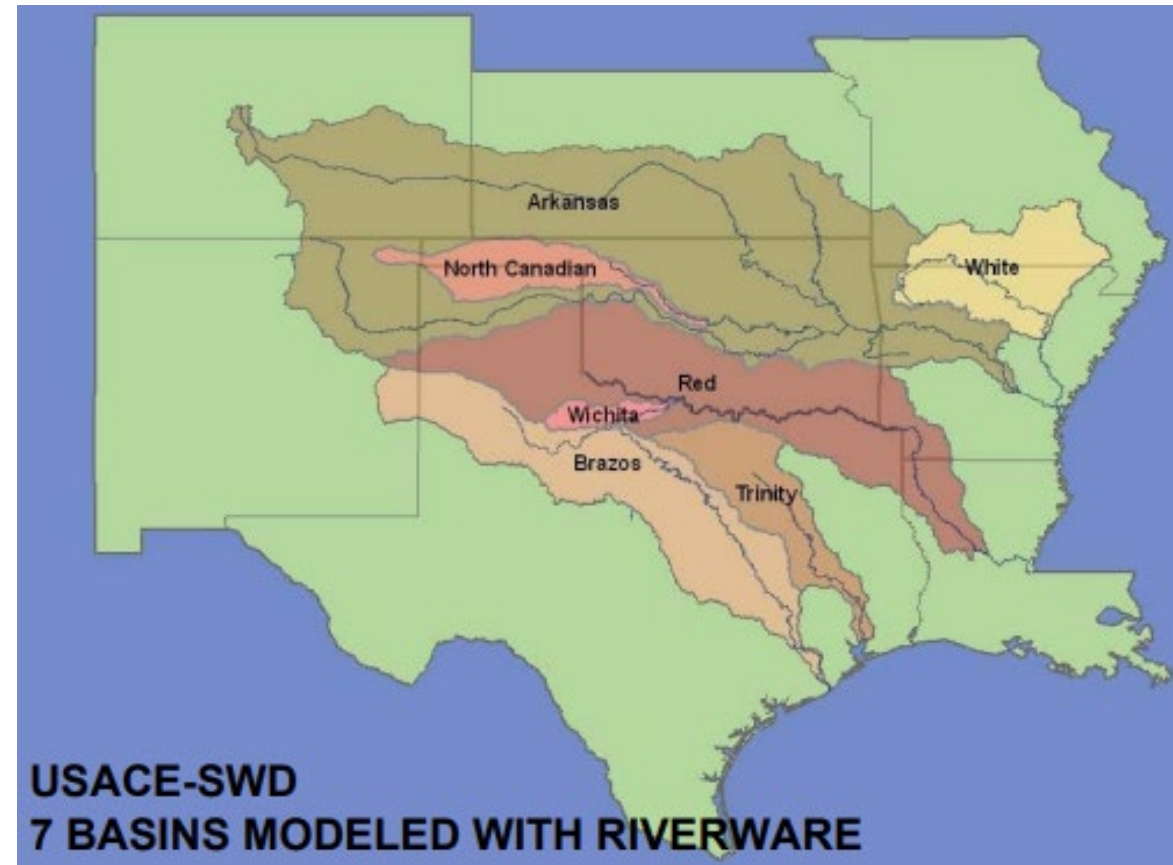
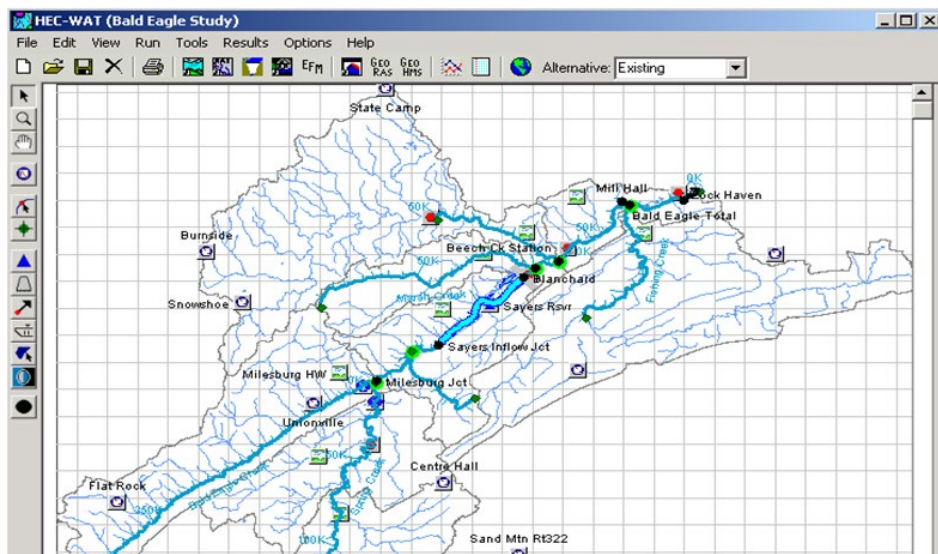
Southwestern Division

Since 1998

Surcharge, Regulation Discharge, Flood Control techniques

Uses:

- Period of Record Planning Studies
- Benefits Analysis
- CWMS / RTS for Operations
- WAT for planning



**USACE-SWD
7 BASINS MODELED WITH RIVERWARE**

Upper Rio Grande Water Operations Model (URGWOM)

- USACE + Reclamation Collaboration
- Planning, Operations, Accounting
- Key driver in development of
 - Water Accounting
 - Scripting
 - Web Maps
 - RiverWISE
 - Many other utilities and usability features!



Sponsor: U.S. Bureau of Reclamation

- Since 1993 in the Colorado River Basin
- Funded much of RiverWare's basic functionality
 - Simulation
 - Rulebased Simulation
 - MRM
 - RiverSMART
 - Borg-RiverWare
- Reclamation offices provide funding for software enhancements and support for model development (UC, LC, LBAO, MB-ART, AAO)

Some Reclamation RiverWare Applications

- Colorado River Basin *
 - CRSS
 - CRMMS
 - San Juan
 - Davis/Parker Operations - Yuma
 - New Operations Models
- Colorado – Big Thompson (C-BT)
- Fryingpan – Arkansas
- Rio Grande
- Pecos
- Great Salt Lake Basin *

- Truckee-Carson *
- Missouri Basin
- N. Platte
- Bighorn
- Klamath *
- Yakima
- Snake
- Many others!

* more on these basins later in this meeting

Hydropower Operations and Optimization

Agencies with direct CADSWES collaboration for optimization models

- Tennessee Valley Authority
- Bonneville Power Administration
- Chelan County PUD, WA
- Idaho Power Company
- USBR – Lower Colorado

Many others using RBS for hydropower!

Operate hydropower for the greatest benefit while meeting all water objectives and requirements

RiverWare Optimization Users

Hydropower	Installed Capacity (GW)	Average Annual Generation (TWh)
U.S. Total	80.6	273.6
RiverWare Opt Users	26.3	96.0
Percentage	33 %	35%

Source: Megan M. Johnson, Shih-Chieh Kao and Rocio Uría-Martínez. 2023. Existing Hydropower Assets (EHA) Plant Database, 2023. HydroSource. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. DOI: [10.21951/EHA_FY2023/1972057](https://doi.org/10.21951/EHA_FY2023/1972057)
<https://hydrosource.ornl.gov/data/datasets/eha2023/> (Retrieved 3/13/26)

Hydropower Operations and Optimization

Applications:

- Real-time scheduling
 - Meet power demand with efficient ops
 - Reserve requirements
- Day-ahead preschedule
 - Economic opportunities
 - Greatest benefit to larger power system
- Short-term planning
 - 1 week to 2 months
 - Marketing opportunities, capacity studies
- Mid-term/long-term planning
 - 1-30 years
 - Ensembles with MRM
 - System resource planning, outage planning...

Timesteps: 5-min to 1-day

Modeling advancements:

- Trial objectives for If/Then logic
- Reserves modeling – plant and system
- Opportunity cost analysis for marketing decisions
- Approximate MIP: unit scheduling, discrete constraints
- Total dissolved gas modeling
- “Solution quality” policies
- Performance – solution time
- Solution analysis – What is driving the optimization solution

Research: Innovation for improved decision making

Grad student or post doc research and pubs – not for software dev



Climate variability/change for adaptive basin management

Collaborate with Prof Balaji;
Reclamation, NOAA

Long-term planning and policy evaluation: Stochastic simulation based on

observed record, paleo reconstructions,
climate change models, weather generators,
teleconnections with global indices

Improved forecasts seasonal to 2-5 years

based on physical/lumped models, ESP,
teleconnections, machine learning



Value of hydropower in the grid as balancing reserve for variable renewables

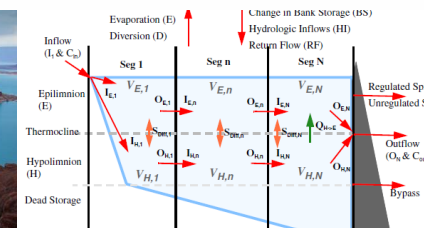
Oak Ridge National Lab, NREL, PNNL
Hydro Research Foundation

Coupling RiverWare with Production Cost Models

to improve efficiency of grid

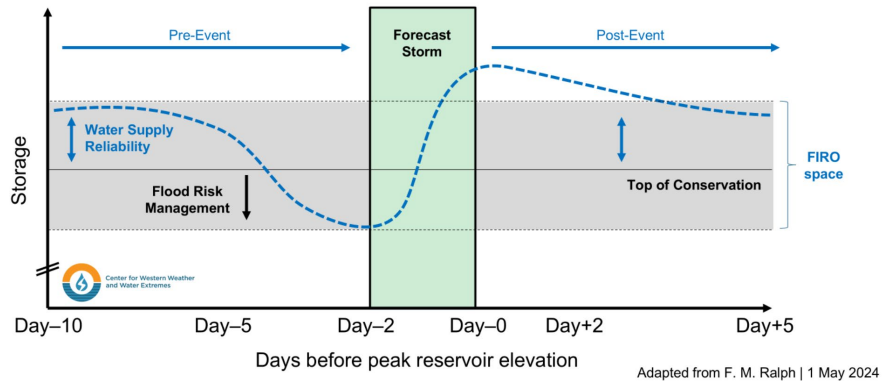
Improve flexibility of river/reservoir/hydropower

systems to increase efficiency and maximize ancillary services.



Basin Scale Physical process modeling for long term planning

Research: Innovation for improved decision making

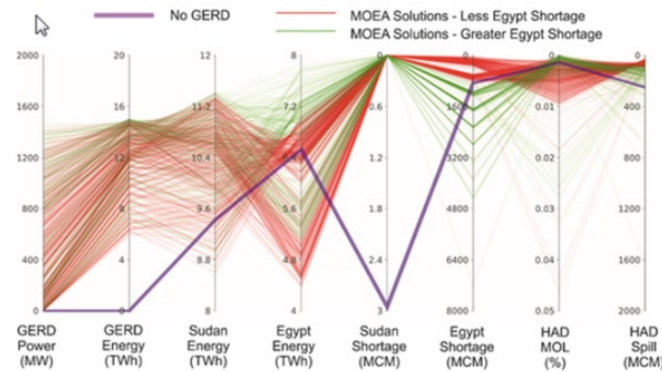
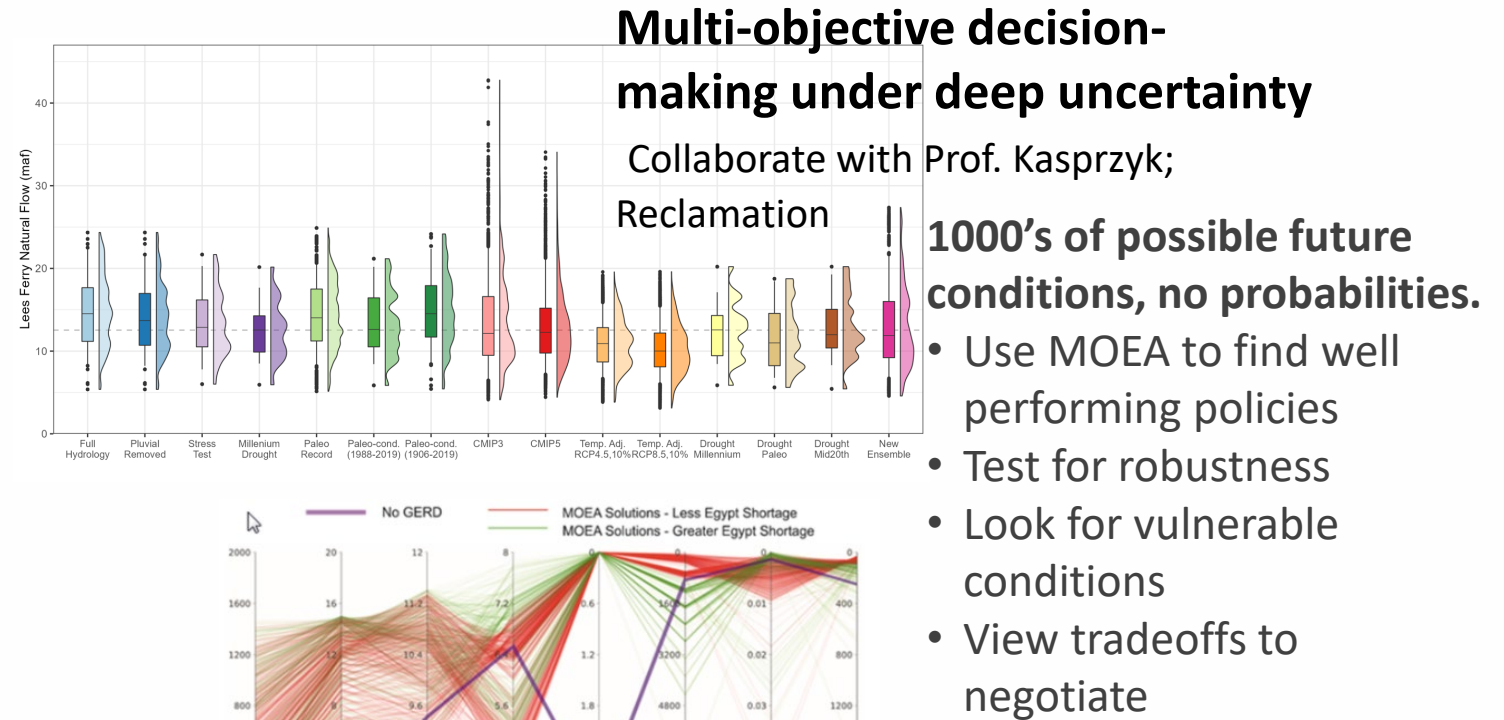


Forecast- or risk-informed reservoir operations with skillful forecasts

Reclamation, USACE

Event-driven: use ensemble to calc risk of flooding; adapt rule curves to reduce flooding and increase storage.

Seasonal: adjust or develop a seasonal rule curve to maximize storage, minimize risk of flood or spill. Use ensemble of seasonal forecasts.



This public-facing decision-support tool was developed by Reclamation and Virga Labs, as a direct result of our Colorado River research

Major ongoing development

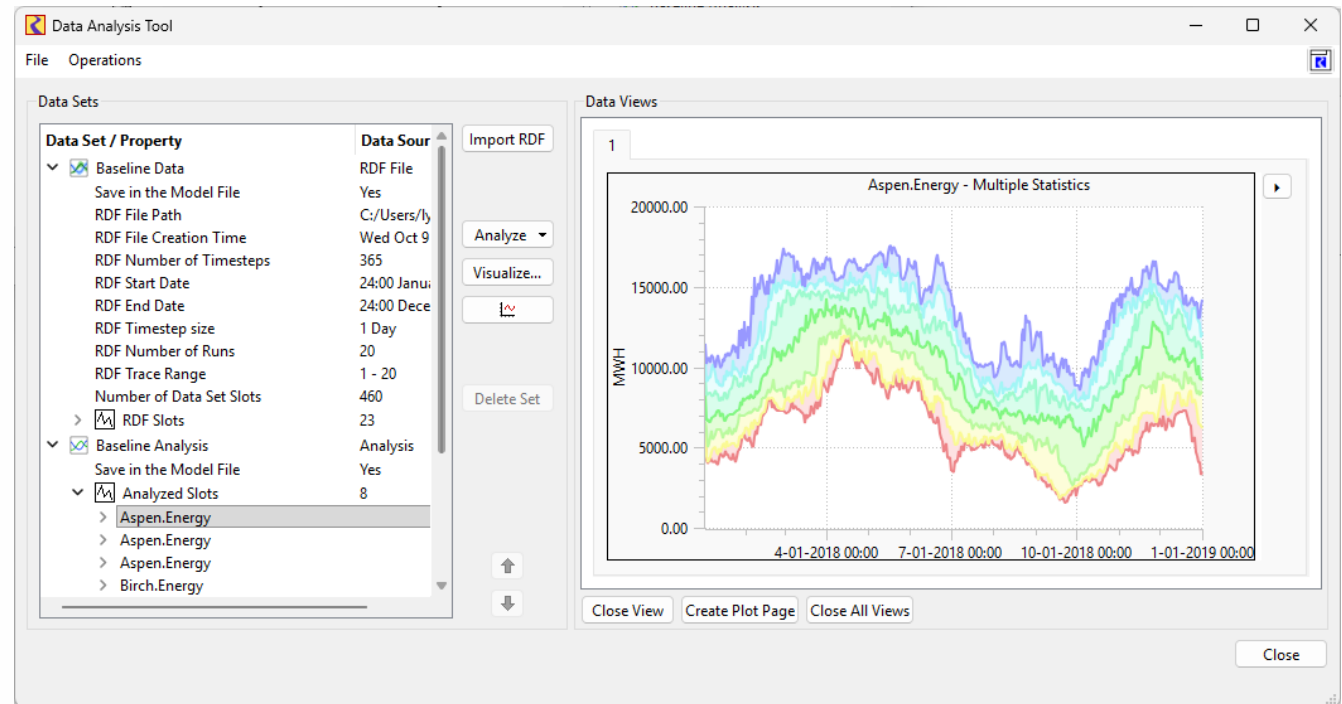
A brief preview; more to come in later presentations
RiverWare 9.7 released July 2026; 9.8 targeted for Jan 2027

Goal of RiverWare enhancements and new features:
*Respond to and anticipate the evolving needs for
modeling tools and analysis capabilities by the water
management community*

Data Analysis & Visualization

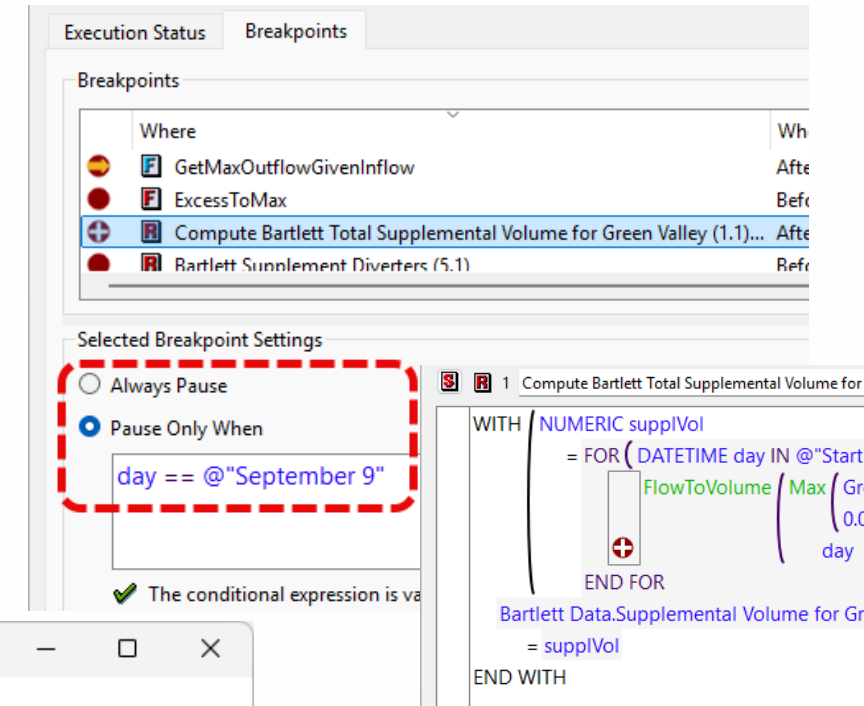
Goal: more post-processing within RiverWare

- RDF Files: produced by MRM runs
 - Slots x Timesteps x Traces
- Data Analysis Tool (DAT)
 - Reads RDF
 - Cross-trace Analysis
 - Visualization
 - Script support



Rulebased Simulation and RPL

- Rulebased Simulation – meeting users' needs
 - Flexible – model any policy
 - Transparent policy
 - Robust – stable, little/no change to core algorithm
- Recent work: RPL debugging and analysis
 - Conditional breakpoints on expressions
 - Assignment tracking
 - More later today...



The screenshot shows the 'RPL Assignment Viewer' window. It has a 'File' menu and a 'Slot' dropdown set to 'Bartlett.Outflow'. The date is set to 'Sep 9, 2024'. Below, the 'Assignments' table is displayed.

	Value	Flags	Priority	Rule	Set
1	66.3 cfs	R	6	Pass Muddy Outflow for Diversers	Basin Operations Rules
2	301.6 cfs	R	5	Bartlett Supplement Diversers	Basin Operations Rules
3	502.0 cfs	R	3	IC Delivery	Basin Operations Rules

Usability Features

Majority of recent RiverWare enhancements are usability features

- **Plotting**
 - Quick plots
 - More easily add and configure multiple curves
- **SCTs**
 - Easier access
 - Save in the model
- **Scripting**
 - Improved Editor
- **Windowing**
 - Viewers
 - Window Layouts
 - Multi-Window
- **Expanded Undo**
 - Existing: RPL, Slot data
 - Upcoming: Workspace

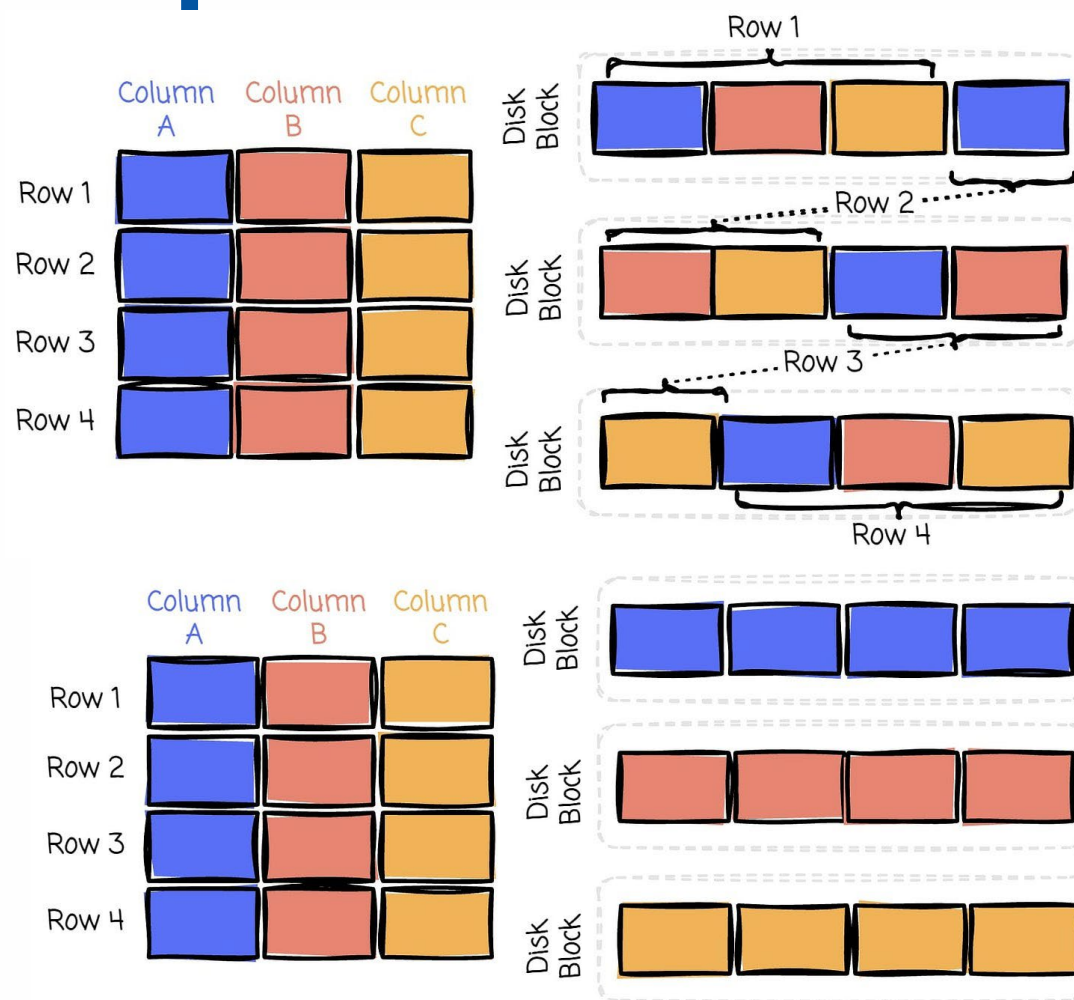
DMIs

- Web service integrations
 - HDB, USGS stream flow data, CWMS data API
 - More details later today
- Using SQLite as a local data store
 - Demand Input Tool
 - CU&L data management tool

Investigation into Parquet + Hive

Developed by Apache and widely supported

- Parquet:
 - Columnar data format
 - Efficient compression and querying
- Hive: Utilizes folder structure for efficient querying. For example:
 - Scenario
 - ObjectName
 - SlotName
 - TraceData.parquet
- Can be written or read by Arrow library



Images from <https://luminousmen.substack.com/p/why-parquet-is-the-go-to-format-for>

Parquet + Hive Support for RiverWare

- Preliminary Requirements:
 - Support for Input and Output via DMLs
 - Read/write from MRM and RiverSMART
 - Configuration should be within RiverWare
 - Should use Arrow library from Apache
- In requirements and scoping phase, so let us know if you have comments.

Long-term Code Maintenance (Refactoring)

- **Technical Debt**
 - Future costs associated with decisions made during software development.
 - Code is less robust and maintainable.
- **Languages, Libraries, and Developers (!) Evolve Over Time**
 - Code written today looks much different, and is much better, than code written decades ago.
 - Code is more robust and maintainable.
- **Prioritize Refactoring**
 - Revisit and improve existing code.
 - Recent efforts include removing Series Sharing, removing COM, and refactoring the Control File-Executable DMI.

Cyber Security

As a developer of software for federal agencies, we aspire to adherence to national security frameworks, especially NIST SP 800-218 (SSDF), with the following core practices:

- Maintain secure computing environment: updates, scanning for vulnerabilities, MFA, VPN, data protection
- Verify third-party dependencies
- Maintain a secure build pipeline
- Static and dynamic code analysis
- Publish Software Bills of Materials (SBOMS)



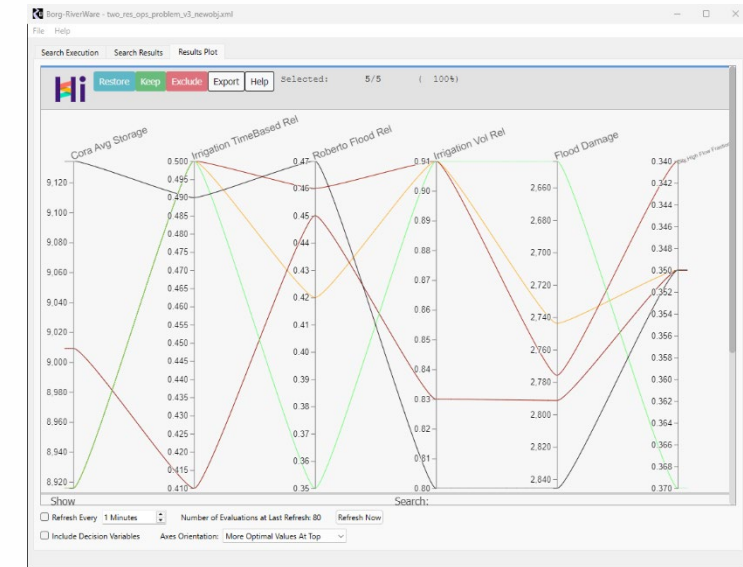
Borg-RiverWare

- New software, under development:
 - Enables simulation-based optimization
 - For multiple competing objectives
 - Directly coupled to RiverWare
- Easy to use
 - Configuration Editor to formulate problems
 - Real-time updates of tradeoff results
- Full presentation later in the meeting!

Properties: Roberto.Flood_Control_Level.txt

Type	Scalar
Slot Name	Roberto.Flood Control Level
Name	Roberto Flood Control Level
Borg-to-RiverWare DMI Data File	N/A (Named Automatically)
# of Variables	1 Edit Limits
Values Lower Limit	1870
Values Upper Limit	1898
Rounding Increment	0.5
Show Example Input Values	

Configuration Editor



Tradeoff Plot

AI and Large Language Models (LLMs)

- Exploratory analysis that couples LLMs and RiverWare:
 - Describe RiverWare models
 - Interactive help
 - Drafting RPL language
 - Creating dashboards and visualizations
- What should (or could) we be doing?
- In a later session, we'll demonstrate the exploratory analysis and get your feedback!

Training

...

Current Training

- Training classes are live on Zoom
 - **Simulation** and/or **Rulebased Simulation** – 5-days – 2-3 times per year – **Next Class October 2026**
 - **Water Accounting** – 3.5-days – offered each Spring
 - **Optimization** – 3-days – offered each Spring
 - Custom classes:
 - custom content
 - on-location, or
 - basin specific

Other Resources

RiverWare.org/tutorials/index.html

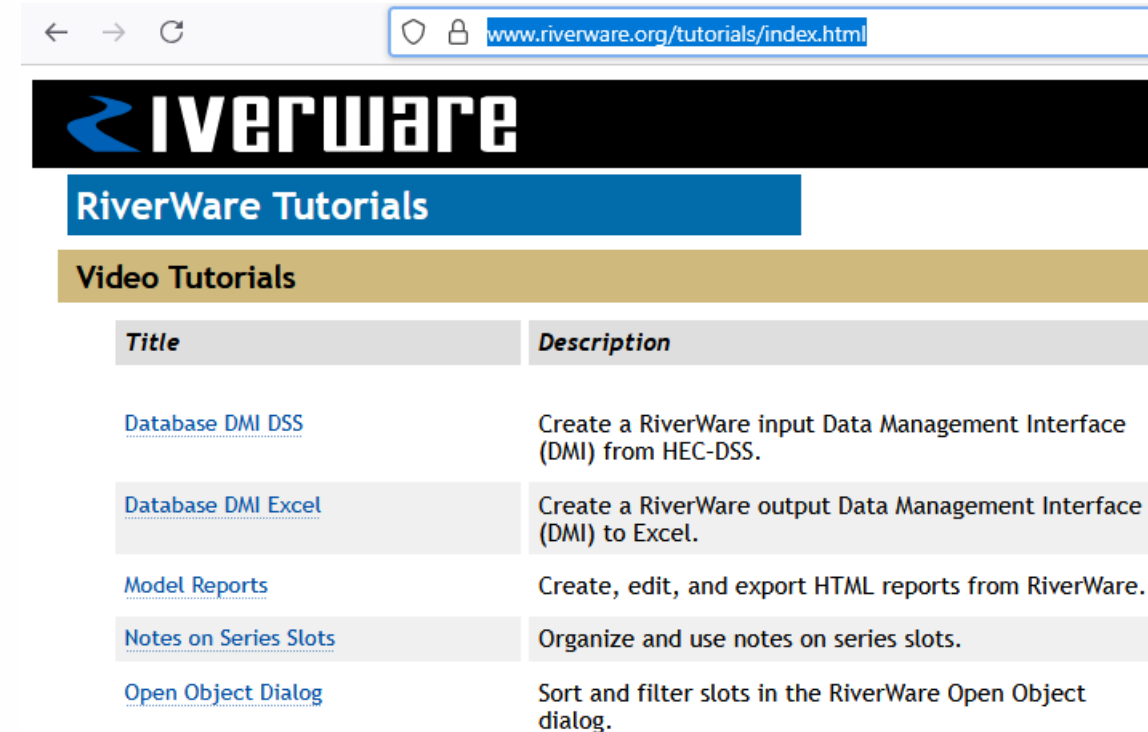
- Online topic-based materials
- Informational tutorials

RiverWare Informational Tutorials

Will RiverWare meet your needs? First, check out this [video demonstration](#). Then, the informational tutorials below will help you to evaluate RiverWare. They will introduce you to the capabilities of RiverWare as an advanced water resource modeling tool. The tutorials consist of three sections: Simulation in RiverWare, Rulebased Simulation, and Multiple Run Management.

Download Informational Tutorials with Models & Files

Section	Tutorial	Models & Files
1. Simulation in RiverWare	Download PDF	Download Models & Files (zip archive)
2. Rulebased Simulation	Download PDF	Download Models & Files (zip archive)
3. Multiple Run Management	Download PDF	Download Models & Files (zip archive)

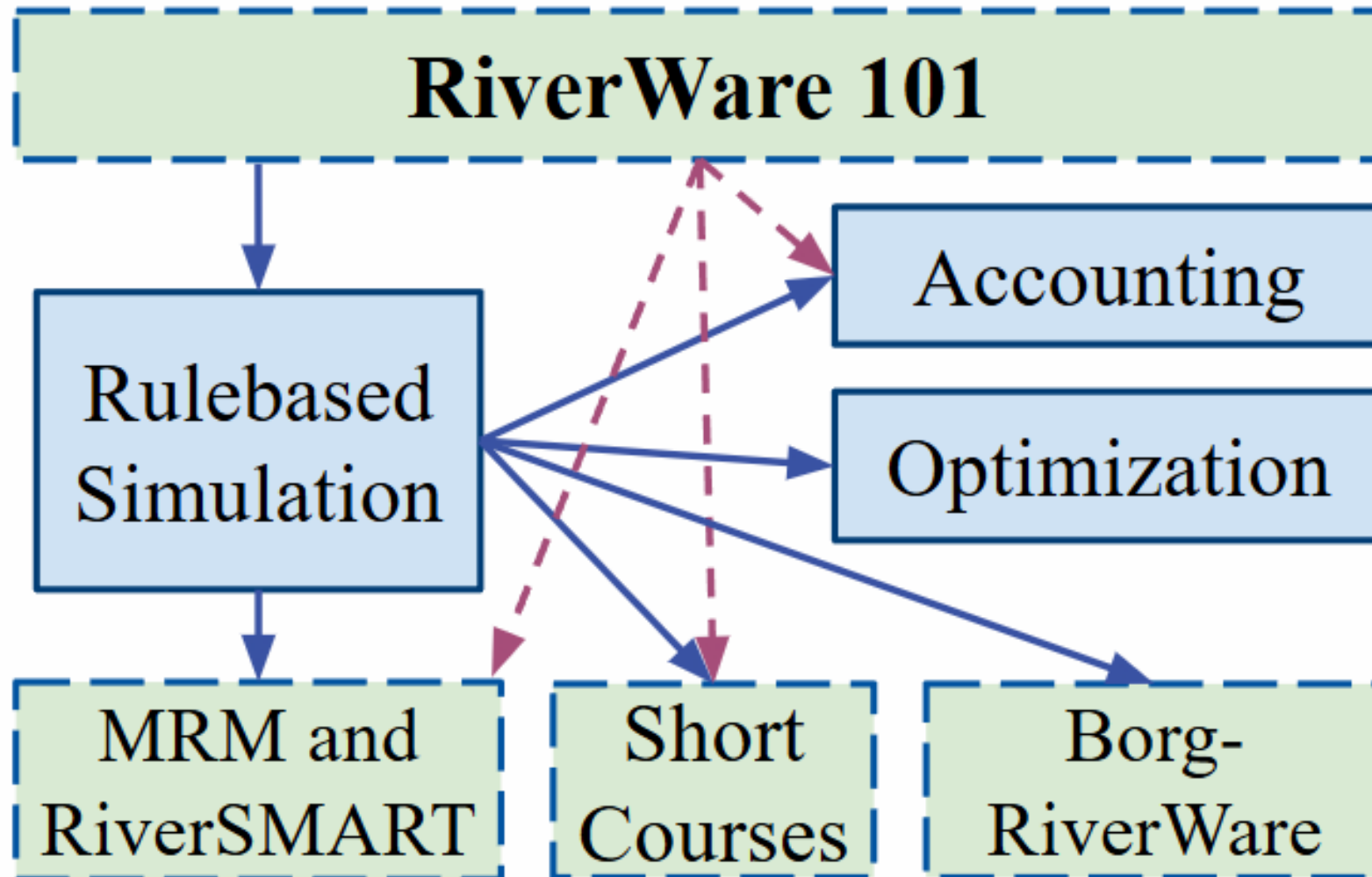
A screenshot of a web browser displaying the RiverWare Tutorials page. The browser's address bar shows the URL 'www.riverware.org/tutorials/index.html'. The page features the RiverWare logo at the top, followed by a blue header with the text 'RiverWare Tutorials'. Below this is a gold-colored section titled 'Video Tutorials'. A table with two columns, 'Title' and 'Description', lists several tutorial topics: 'Database DMI DSS', 'Database DMI Excel', 'Model Reports', 'Notes on Series Slots', and 'Open Object Dialog'. Each title is a blue hyperlink, and each description provides a brief overview of the tutorial's content.

Title	Description
Database DMI DSS	Create a RiverWare input Data Management Interface (DMI) from HEC-DSS.
Database DMI Excel	Create a RiverWare output Data Management Interface (DMI) to Excel.
Model Reports	Create, edit, and export HTML reports from RiverWare.
Notes on Series Slots	Organize and use notes on series slots.
Open Object Dialog	Sort and filter slots in the RiverWare Open Object dialog.

Training Questions Going Forward

- Live or On-Demand?
- Web-based or in-person? → Hybrid
- How long should a class be?
- Content? Topic based or broad overviews?
- Delivery mechanism / format ?
- Who is it for?

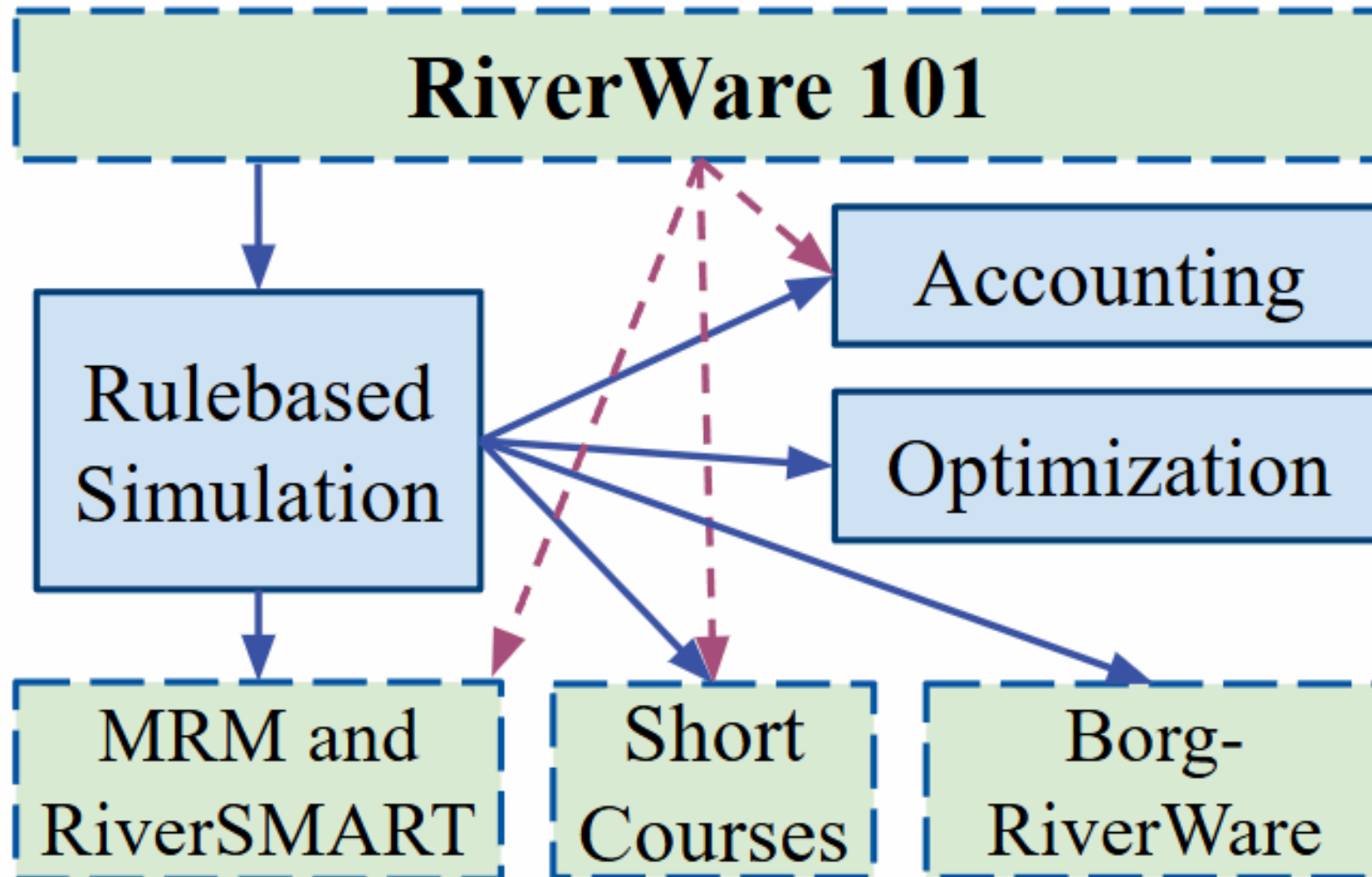
My Proposed Class Structure



RiverWare 101

- Delivery
 - Online
 - On-demand
 - Some type of assessment
 - Low cost; not free
- Learning Objectives
 - Conceptual overview of RiverWare
 - Basics of the Interface
 - Building a small model
 - Reservoirs and reaches
 - Other objects and their physical processes
 - Using System Control Tables (SCTs)
 - Intro to Rulebased Simulation
 - Using RiverWare in your day-to-day workflow

My Proposed Class Structure



Questions or comments?

...