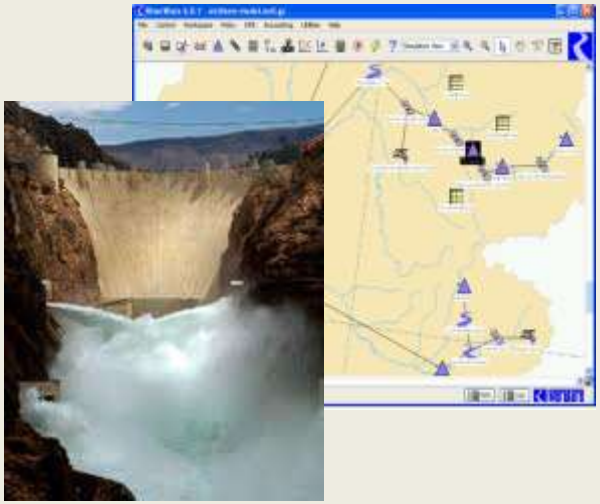
A General River and Reservoir Modeling Tool

Developed at the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CU-CADSWES)
1993 to present through collaborative research and development with

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

Uses of RiverWare

- Planning, reliability assessment and decision-making for
  - New infrastructure development or new demands
  - policy development and evaluation
  - EIS, FERC
  - climate change
  - Compact or treaty negotiations

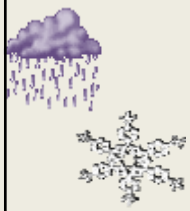


- Scheduling of Operations
  (reservoir releases, diversions, transfers, hydropower optimal generation)

- Water accounting, priority water rights allocation

- Facilitate stakeholder participation and collaborative decision-making

RiverWare's Inputs and Outputs



Hydrology

Forecast

OR

Historic Record

OR

Stochastic Ensemble

OR

Rainfall – Runoff Model

Demands for Water and Energy

Operating Objectives and Constraints (policies)

IN

Models interaction of

Hydrologic response of River /Reservoir system (includes Hydropower)

With

Multi-objective operating policies

OUT

Values of Decision Variables

Values of Performance Indicators

Schedule for Operations (releases, diversions, power)

Water accounting data

Post-Processing

Statistical Analysis

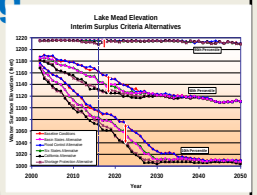
Policy Analysis

Economic Analysis

Environmental analysis

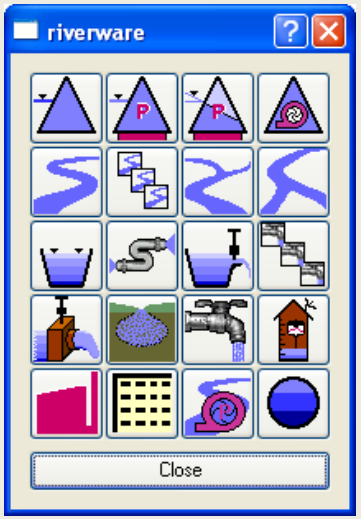
Tradeoff Analysis

Multi-criteria Decision analysis



RiverWare models….

- Reservoir and river flows, storages, gains and losses
- Reservoir releases, regulated and unregulated spill
- Hydropower / pumped storage generation and optimization
- Inline pumping and power plants
- Stream gages and control points for flood control regulation
- Diversions, consumptive use, distribution canals, return flows
- Groundwater – surface water interaction
- Water quality
- Water accounting and water rights
- Operating rules of any structure/complexity
- Timestep sizes: 1hr to 1yr (including daily, monthly)



Multiple objective modeling

River systems are operated for a variety of objectives

RiverWare's Solvers

1. Simulation

   Data-driven; input-output; what-if scenarios

2. Rulebased Simulation

   Solution driven by prioritized objectives (rules)

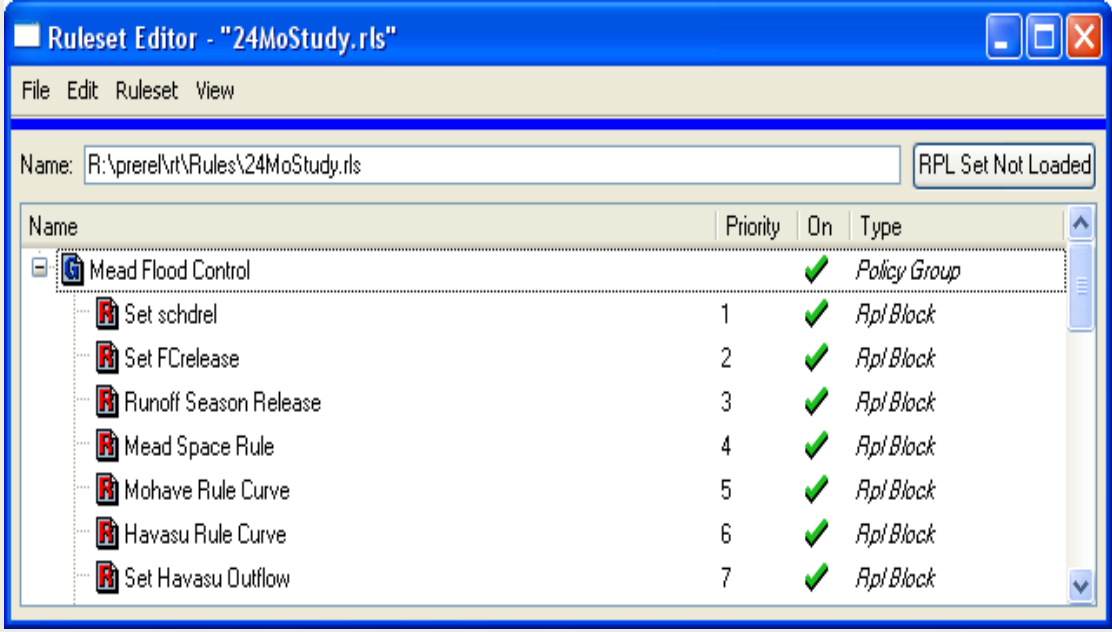
3. Optimization

   Pre-emptive linear goal programming solution; objectives and constraints are prioritized

4. Water Accounting (with or without rules)

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

Rulebased Simulation



Simulation is under-determined

Operating policies are prioritized rules

IF (state of system)

THEN (set value of decision variables)

Rules execute to set values that drive solution

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

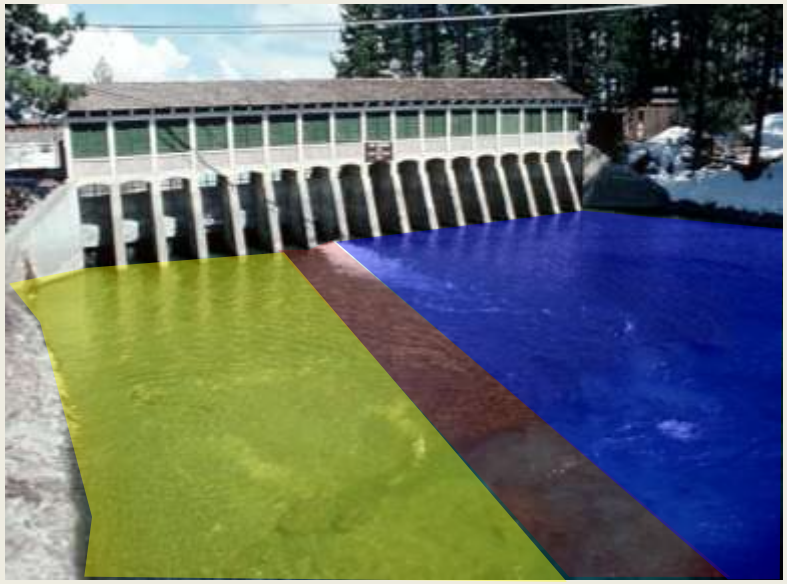
Water Ownership, Water Accounting, Water Rights

- “Paper” Accounting
- Storage, Instream Flow, Diversion Rights
- Classify Accts by Priority Date, Owner, Type
- Exchanges, Loans, Rents, Carryover, Accrual
- Drive the solution using (can be mixed):
  - User Inputs – Spreadsheet like solution
  - Mix with Rulebased Simulation
  - Prioritized Water Rights Allocation

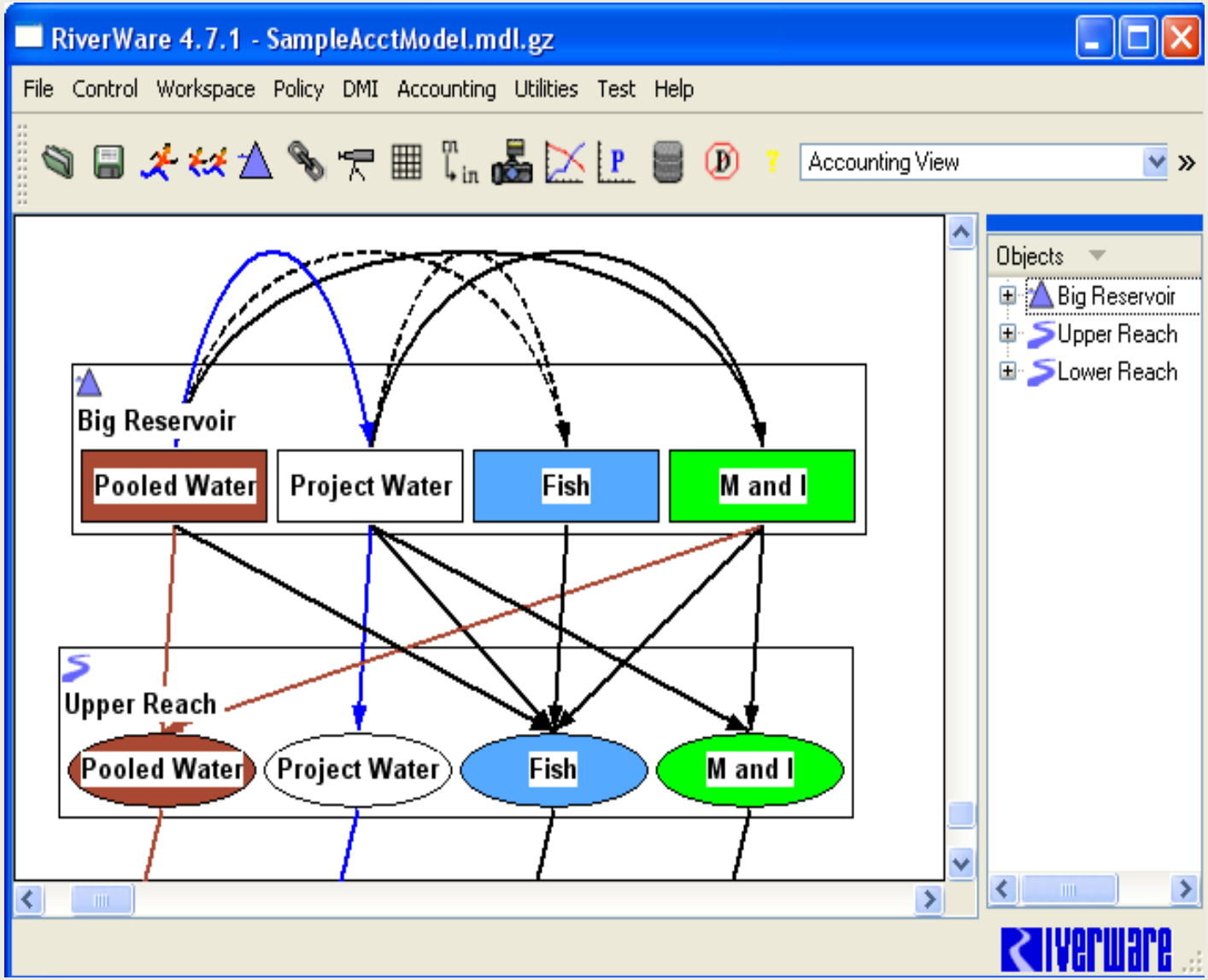
“Physical” vs. “Paper” water modeled in RiverWare

Paper Water - type and ownership (“color”):

Volume/flow of water classified by type or ownership. For example, a certain agency owns 5,000AF of 12,000AF of physical water in the reservoir.



View Account Network on Objects



Optimization

Pre-Emptive Goal Programming

- Multi-objectives without user-defined penalties
- Policies (Goals) are Prioritized
- Soft Constraints - Minimize infeasibilty
- Economic (hydropower) objective
- Linear or Mixed-Integer Programming

Goals/constraints formulated in RPL Editor

Variables automatically linearized

- User controls approximation

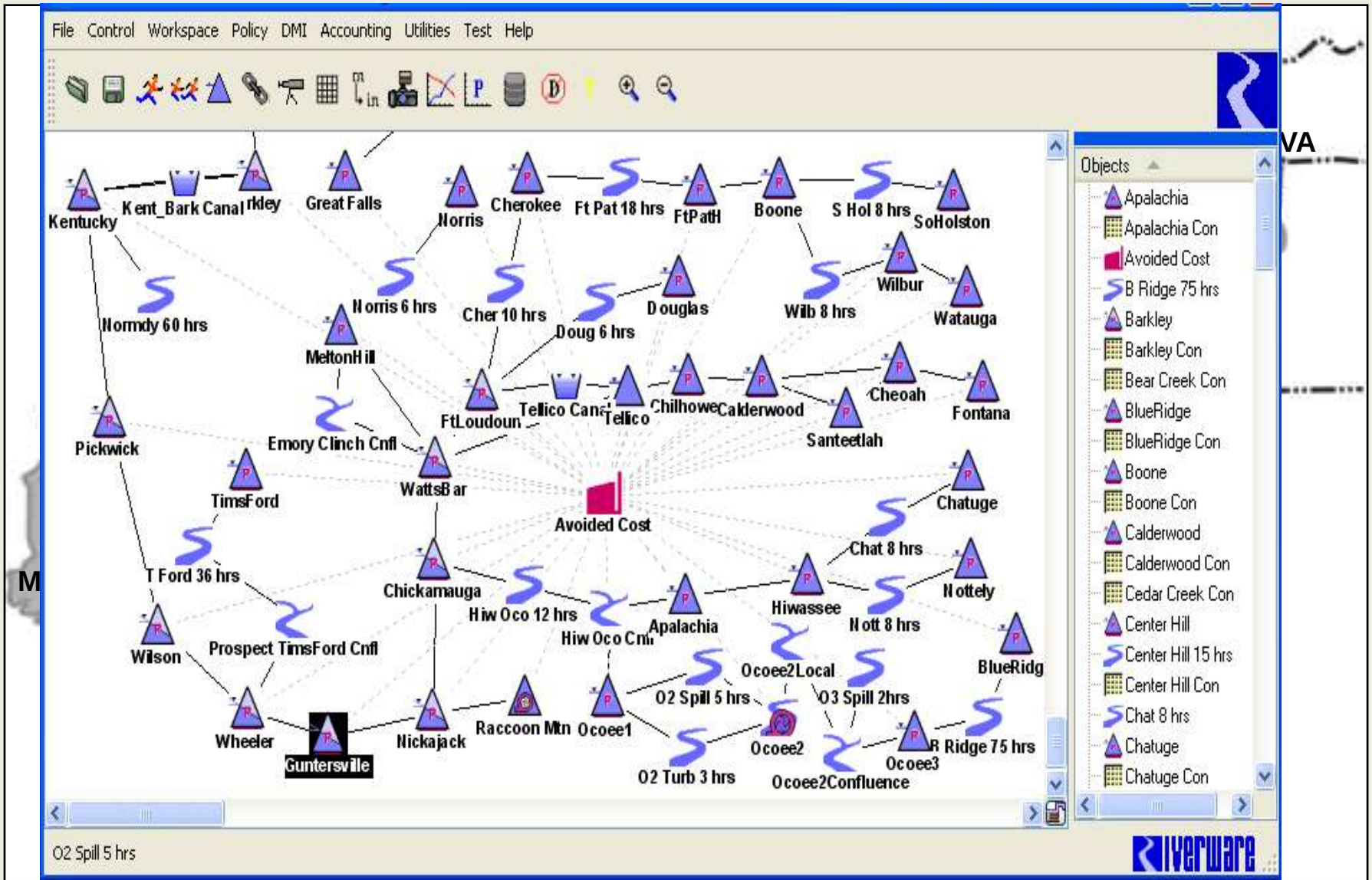
Physical constraints generated by objects as needed

CPLEX solver

- Can “tune” parameters

Post-optimization Simulation

TVA's reservoir system is modeled as a whole for hydropower optimization



Multiple Run Management

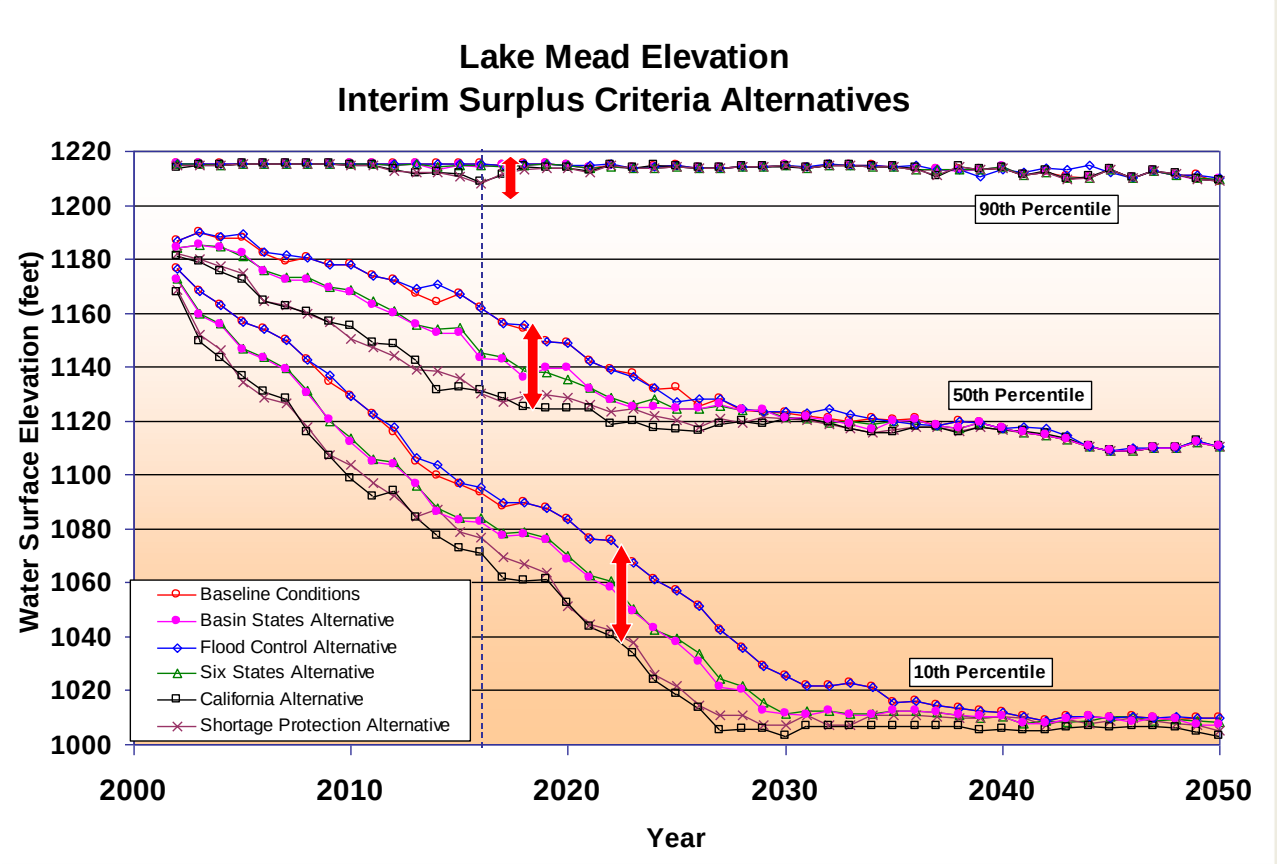
- Stochastic Input
- Stochastic Output
- Evaluate using GPAT (Graphical Policy Analysis Tool)
- Modes:
  - Concurrent
  - Consecutive
  - Iterative
- Distribute runs to many machines or processors

Graphical Policy Analysis Tool (GPAT)

Excel-based Tool for statistical analysis of ensemble output to compare:

- Probabalistic results
- Decision Variables and Performance Indicators

  e.g., storage, P.E., power, flow, risk of shortage
- Compare policies
- See trends over time



U.S. Bureau of Reclamation

Shortage Negotiations and Environmental Impact Studies for Endangered Species on Colorado River

CRSS – Colorado River Simulation System is primary modeling tool for planning operations and evaluating policy

Lake Powell – June 29, 2002

Lake Powell – December 23, 2003

Water Quality

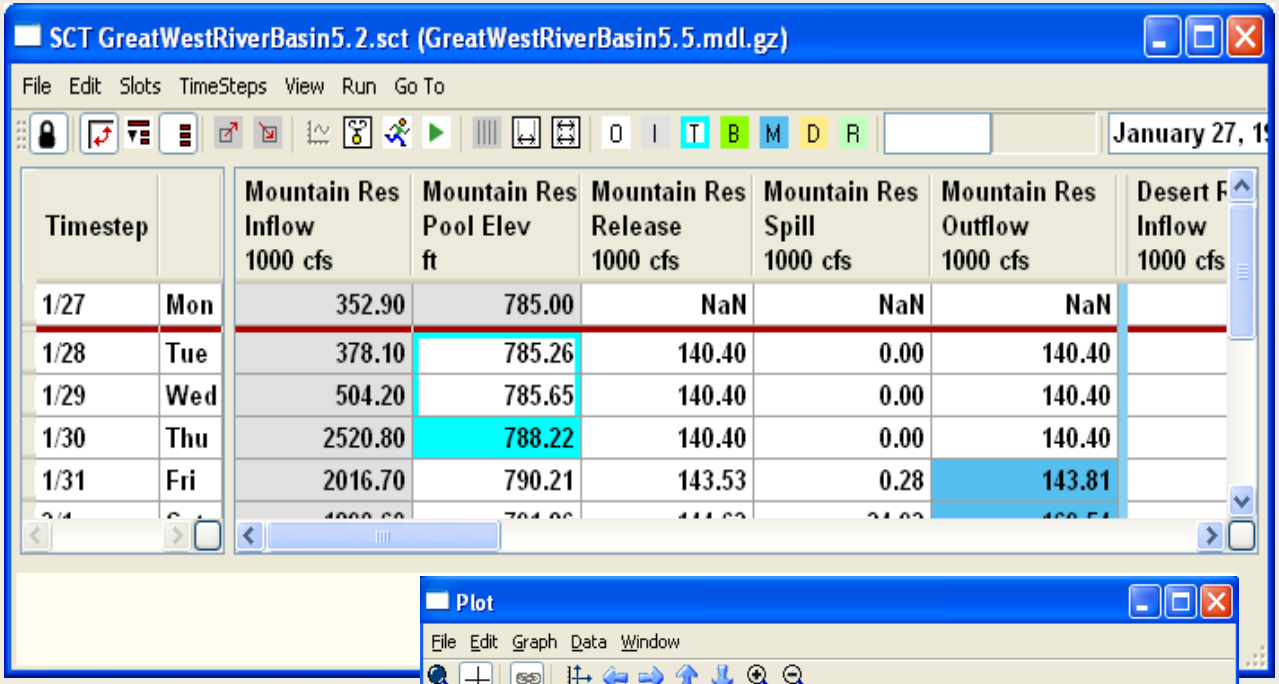
- Simple well-mixed Total Dissolved Solids (TDS)
- Dissolved Oxygen (DO), Temperature, TDS
  - 2-layer reservoir
  - coupled Reach Routing with Advection, Diffusion
- 2-Layer Groundwater modeling for TDS

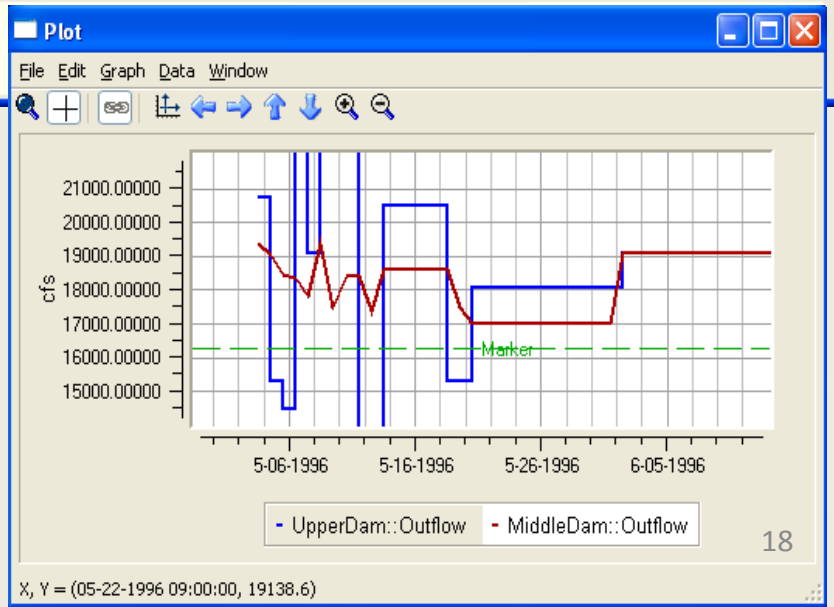
Data Management Interface

- Import or export data from/to any external source (files, databases, spreadsheets, Corps of Engineers DSS)
- Create external routines to tailor your applications
- Define the DMI and execute it from within the RiverWare user interface
- Extend or redefine start/stop time of the runs
- Group DMIs together for operational updates

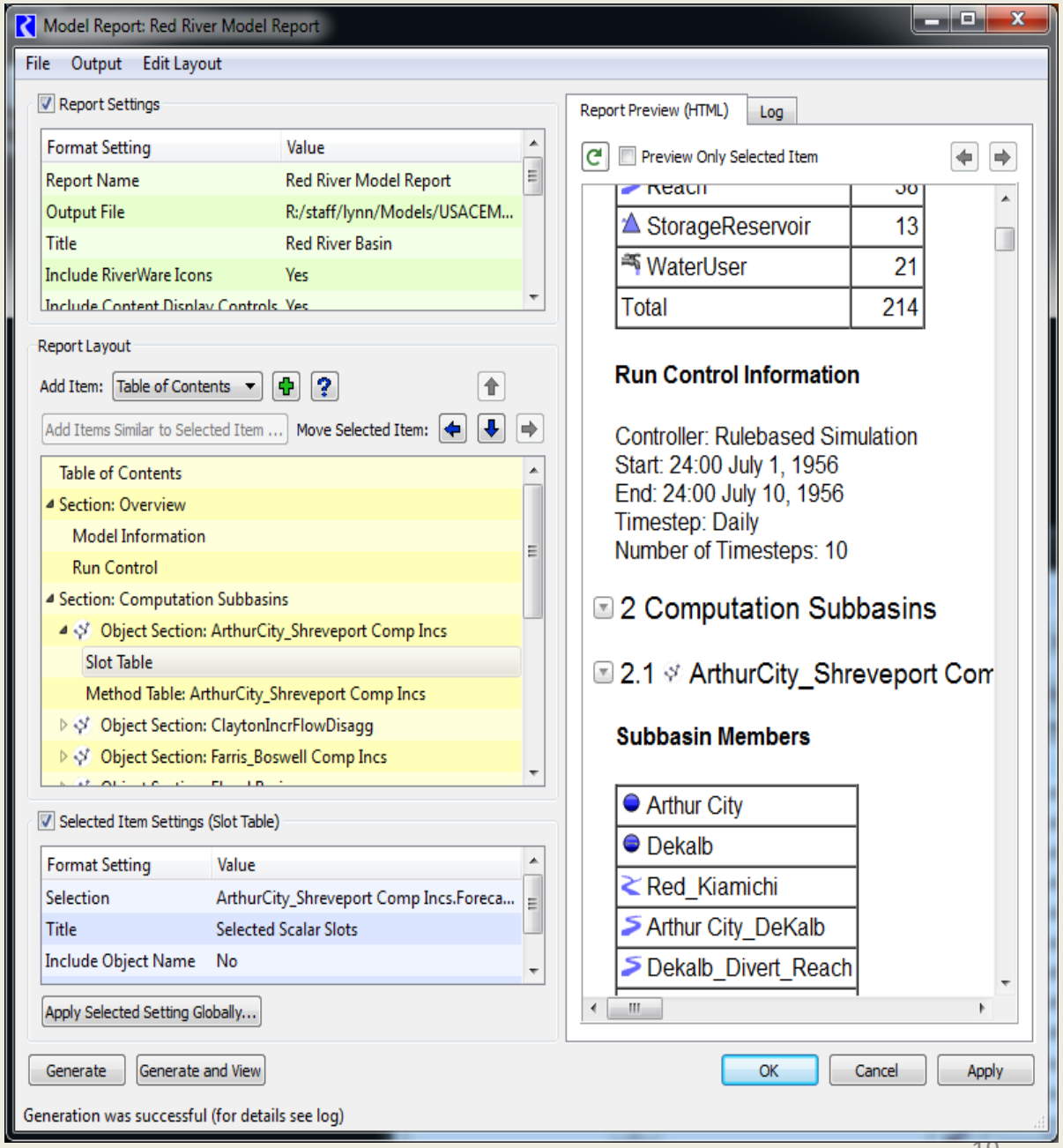
Many other Features

- System Control Table (spreadsheet-like view of data)
- Diagnostics
- Analysis Features
- Output options





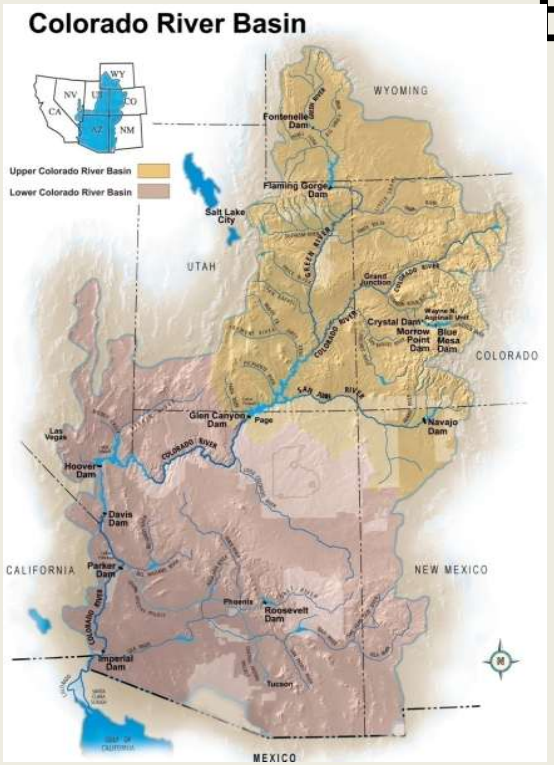
Dynamic Report Generation



Who uses RiverWare?

- **Water management agencies**
  Reclamation, Corps of Engineers, States, Cites, Water Districts
- **Federal Agencies and Tribes**
  BIA, USGS, National Park Service, National Forest Service, Fish and Wildlife Service, Intern'tl Boundary Water Commission
- **Water Utilities**
  TVA, Southwest Power, LCRA, Mid-Columbia PUDs, East Bay Municipal Utility District, Idaho Power
- **Consultants**
  Hydros, Stetson, Riverside Technologies, CDM, Tetra Tech, HDR, AECOM, …
- **Researchers and NGOs**
  Pacific Northwest and Oakridge National Labs, Universities, NGOs …
- **International Governments, Researchers, Consultants….**

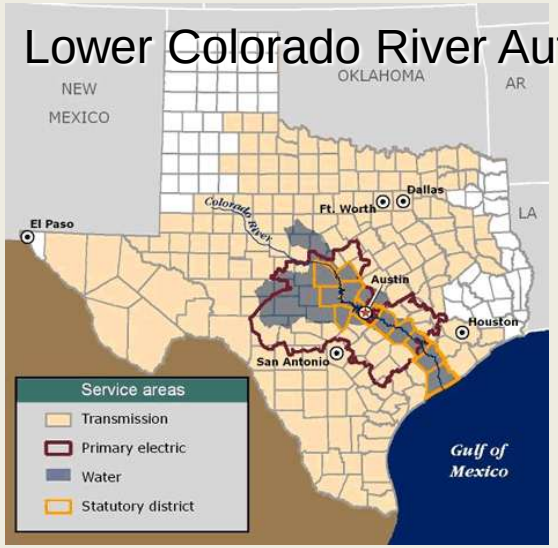
Example Applications

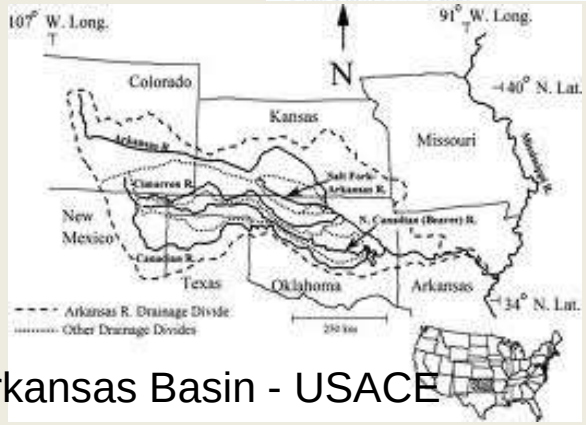


Snake River Basin

The Upper Rio Grande Water Operations Model

Lower Colorado River Authority Texas





Arkansas Basin - USACE

Truckee-Carson

RiverWare – a licensed software product

- Licensing
  - Available through the University of Colorado Office of Technology Transfer
  - License fees contribute to software maintenance
  - RiverWare VIEWER is free – can view models and results
- Developed with a team of professional software developers using standard development processes
- Source control; version control; issue tracking
- Training & User Support
- Continued Enhancements via contracts and grants from sponsoring agencies

Thank you