

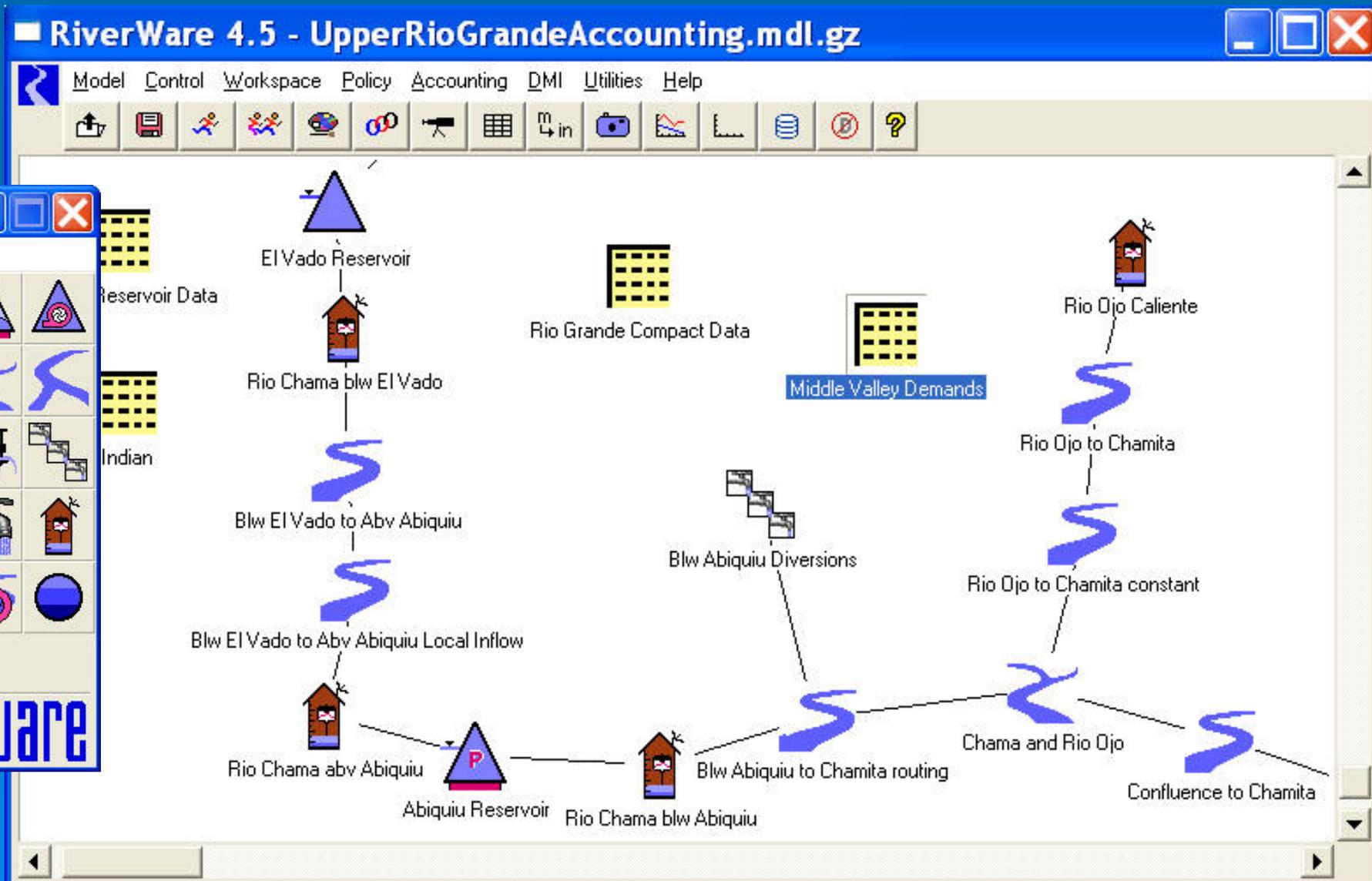
Part 2

Objects, Methods & Simulation

Object-Oriented Modeling Approach

- Objects represent features of the basin
- Objects contain their own physical process algorithms
- Objects contain their own data

The RiverWare Workspace



Objects on the Palette and Their Methods

- Reservoirs *Storage (mass balance, release, spill)*
 - Power Reservoirs *Level (+ tailwater, power, energy, eis)*
 - Sloped (+ wedge storage)*
 - Pumped Storage (+ pump/generators)*
- *Confluence - mass balance*
- *Bifurcation - mass balance*
- *Bi-directional Gravity Flow Canal - bi-directional gravity flow*
- *River Reach / AggReach- routing, water quality*
- *AggDiversion Site - demands, consumption, return flow, available water*
- *Water User - demands, consumption, return flow*
- *Diversion - pumped or gravity diversion structure*
- *Groundwater Storage - gw interaction for return flows, seepage, conjunctive use*
- *AggDistribution Canal - calculates diversion schedules, routes flows*
- *Stream Gage - input for river gage data; propagates flow value u.s. and d.s.*
- *Inline Power Plant – generation is function of flow*
- *Control Point – constrains upstream flood releases*
- *Thermal Object - economics of thermal power system*
- *Data Object - user-specified data*

Open Object.....

Open Object - Abiquiu Reservoir

File Edit View Slot Account

Object Name: Abiquiu Reservoir

Slots Methods Accounts

January 1, 1996

Slot Name	Value	Units	
Inflow	233.88	cfs	<input type="checkbox"/> <input type="checkbox"/>
Outflow	375.24	cfs	<input type="checkbox"/> <input type="checkbox"/>
Storage	218528.85	acre-ft	<input type="checkbox"/> <input type="checkbox"/>
Pool Elevation	6226.93	ft	<input type="checkbox"/> <input type="checkbox"/>
Total Inflows	233.88	cfs	<input type="checkbox"/> <input type="checkbox"/>
Spill	0.00	cfs	<input type="checkbox"/> <input type="checkbox"/>
Turbine Release	375.24	cfs	<input type="checkbox"/> <input type="checkbox"/>
Energy	117.85	MWH	<input type="checkbox"/> <input type="checkbox"/>
Evaporation	11.39	acre-feet	<input type="checkbox"/> <input type="checkbox"/>
Precipitation Rate	0.08	in/day	<input type="checkbox"/> <input checked="" type="checkbox"/>
Power	4.91	MW	<input type="checkbox"/> <input type="checkbox"/>

SLOTS
(data structures)

METHODS (physical
process algorithms)

ACCOUNTS
ownership of water
in this object

Slots - RiverWare's Data Structures

Slots on Objects hold all numerical data

Slot Types:

- Timeseries, Aggseries, Multislots (inputs and outputs)
- Periodic Slots (repeating timeseries data)
- Tables (functional relationships and parameters)
- Scalar Slots – hold a single value

Expression Slots on data objects

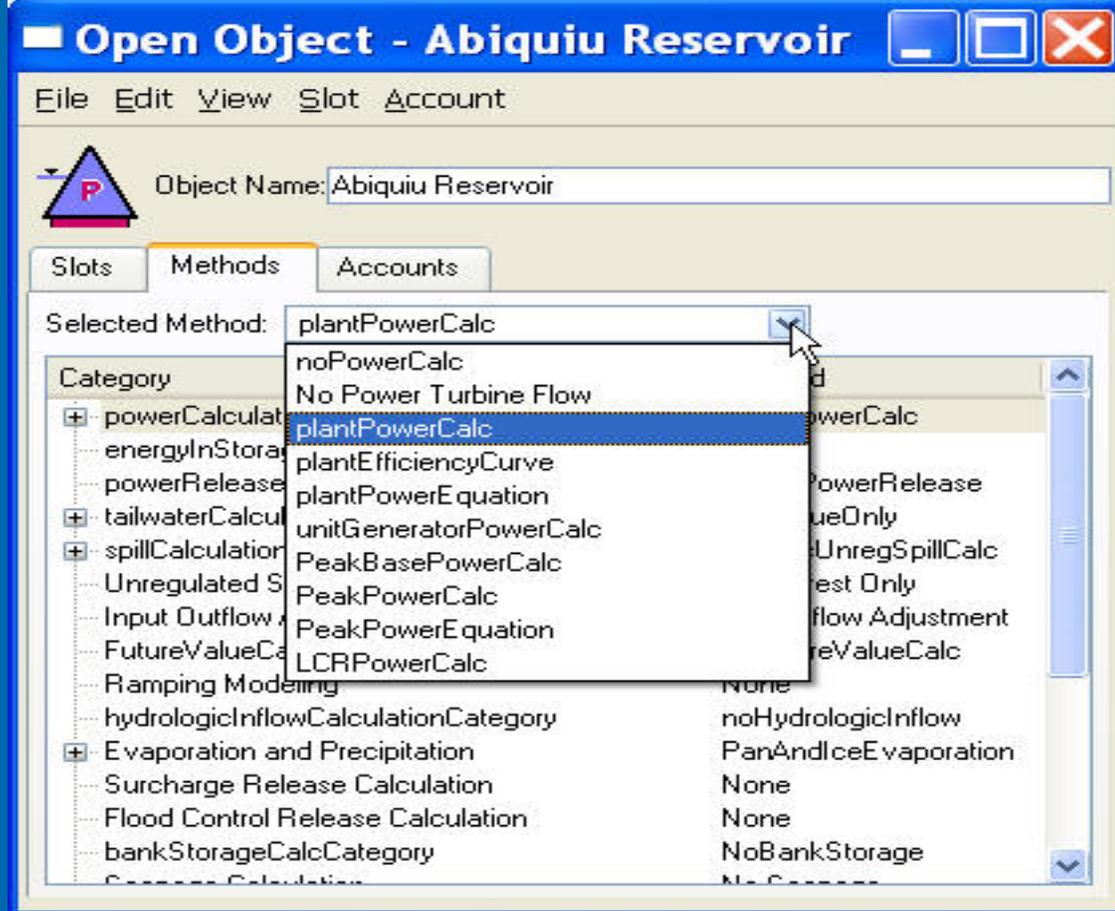
User-Selectable Methods

Method Categories on each object type.

User selects methods based on: timestep size,
available input data,
required outputs
institutional requirements

Power Reservoirs -----> Power Calc Category
*plant power, unit generator power
Peak Power, LCR Power*

Reaches -----> Routing Category
*no routing, Timelag, impulse-esponse,
Muskingum, Muskingum-Cunge,
Kinematic*



Each simulation object has:

- **General slots**
(e.g., reservoirs have inflow, outflow, storage)
- **Method-specific slots**
(e.g., Muskingum has routing coefficients)



Select Solver...

- Simulation
- Rulebased Simulation
- Optimization
- Post-Simulation Accounting
- Inline Simulation and Accounting
- Inline Rulebased Simulation and Accounting

Simulation Model

- Objects on Workspace Represent Features of the River and Reservoir System
- Objects contain their own data
- Objects contain their own physical process models
- Objects know only about themselves
 - when they get a new value
 - how to use their data to simulate
- Simulation is executed by a “controller,” one object at a time, as requested by the objects

Simulation – the OO model

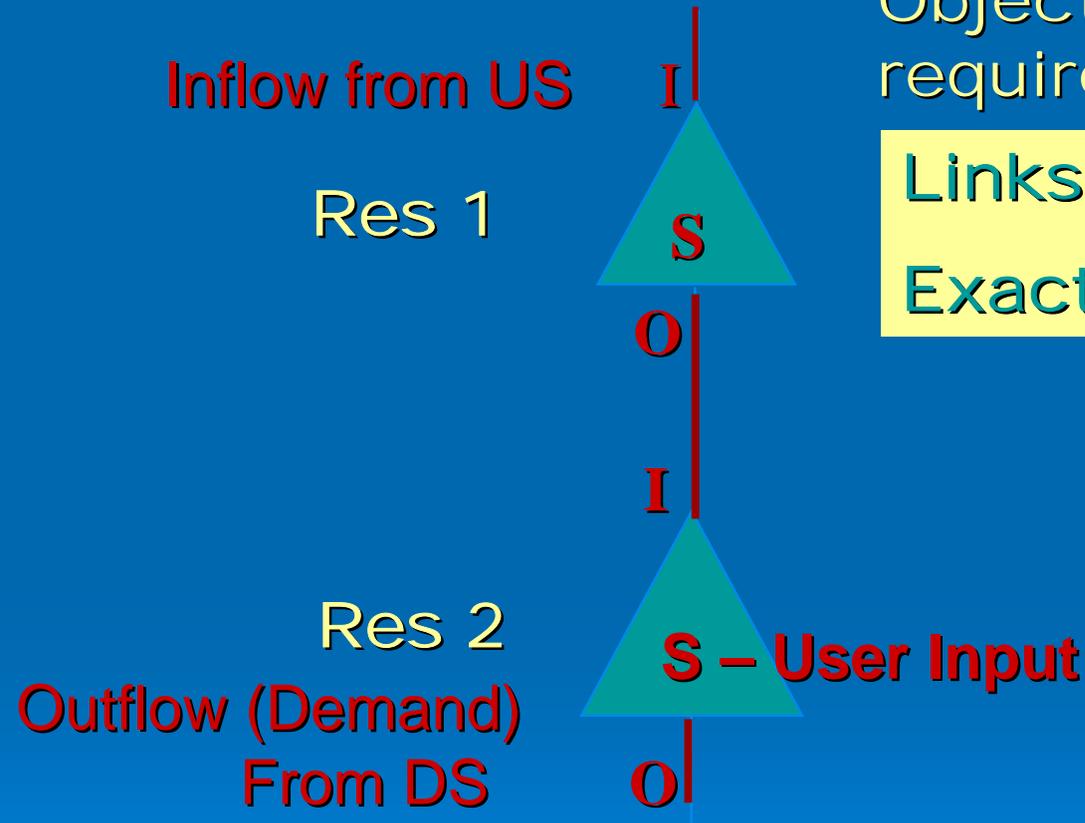
Objects solve when they have required knowns and unknowns

Links propagate values

Exactly determined system

$$S_t = S_{t-1} + I_t - O_t$$

$$I_t = S_t + O_t - S_{t-1}$$



Simulation Analysis Utility

Dispatch Information

File View Object

	06:00 November 29, 1995	12:00 November 29, 1995	18:00 November 29, 1995	24:00 November 29, 1995	06:00 November 30, 1995	12:00 November 30, 1995	18:00 November 30, 1995	24:00 November 30, 1995	06:00 December 1, 1995	12:00 December 1, 1995	18:00 December 1, 1995	06:00 December 2, 1995	12:00 December 2, 1995	18:00 December 2, 1995	06:00 December 3, 1995	12:00 December 3, 1995	18:00 December 3, 1995	06:00 December 4, 1995	12:00 December 4, 1995	18:00 December 4, 1995	06:00 December 5, 1995	12:00 December 5, 1995	18:00 December 5, 1995
Cedar Creek	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Cedar_LBear Cnfl	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Center Hill	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	
Center Hill 15 hrs	D	D	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	
Chat 8 hrs	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Chatuge	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Ceatham	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	
Cheoah	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Cher 10 hrs	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Cherokee	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Chickamauga	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Chilhowee	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Cordell Hull	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	
Cordell Hull 6 hrs	D	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	

Center Hill at 18:00 November 29, 1995
Object Did Not Dispatch

Dispatch Detail

File

Type: LevelPowerReservoir
Name: Center Hill

Methods = Needed = Known

- ▷ solveMB_givenInflowHW
- ▷ solveMB_givenOutflowHW
- ▽ solveMB_givenInflowStorage
 - Diversion
 - Return Flow
 - Hydrologic Inflow
 - Inflow
 - Storage
 - Pool Elevation
 - Outflow
 - Energy
- ▷ solveMB_givenOutflowStorage
- ▷ solveMB_givenInflowOutflow

18:00 November 29, 1995

Part 3

Rulebased Simulation

Multi-objective River and Reservoir System Modeling:

Hydrologic processes + operating policies

Flood Control	23.55	1	Weights/Penalties
Water Supply	19.34	2	
Navigation	16.2	5	
Water Quality	326.9	3	Priorities
Aquatic/Riparian Habitat	4.1	6	
Recreational Flows	9.8	4	
Recreational Lake Levels	0.34	8	
Hydropower	101.9	7	

Rulebased Simulation



Simulation is under-determined

Operating policies are prioritized rules

IF (state of system)

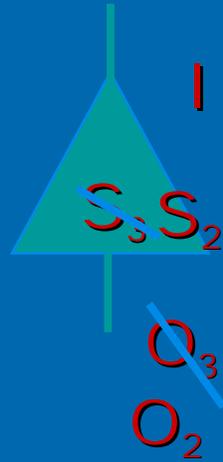
THEN (set decision variables)

Rules alternate with simulation to solve system

Rulebased Simulation

- Same set of decision variables as simulation
- solves system at each timestep using a set of prioritized rules
- Rules set values such as releases and withdrawals based on state of the system after previous rule has fired
- After each rule is executed, the simulation propagates the effects of the rule
- Higher priority rules are special conditions and dominate lower priority rules which represent ideal conditions

RBS example



Forecasted Inflow is Input

Not enough data to solve object

Rule 3: Set Storage to guide curve

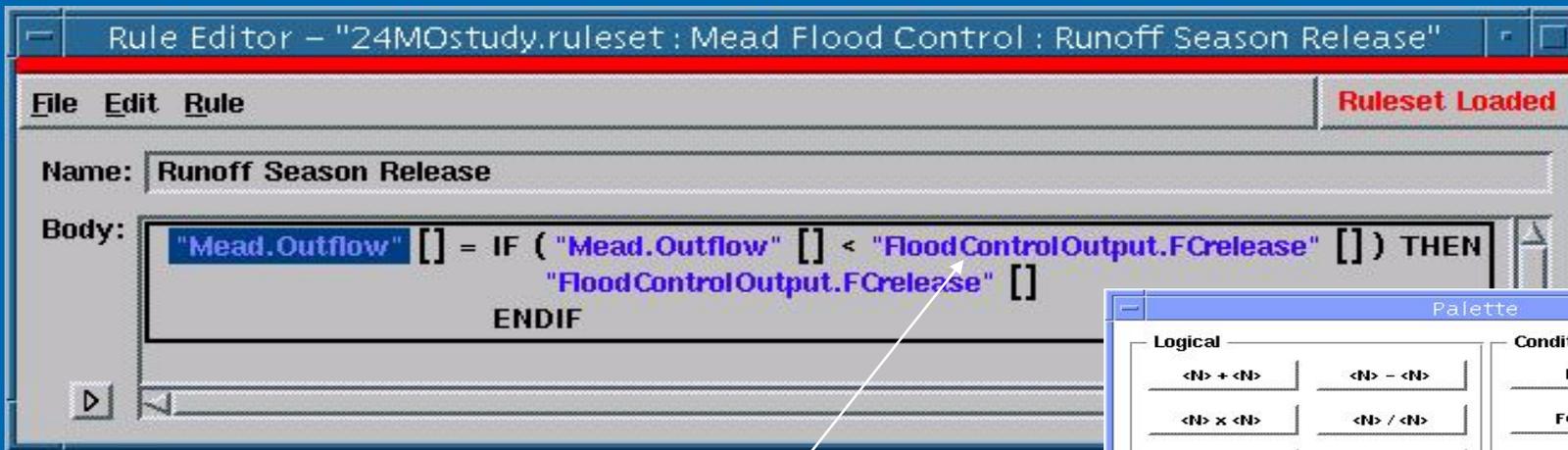
Object Solves for Outflow given
Inflow and Storage at priority 3

Rule 2: If Outflow < Min Flow
Outflow = Min Flow

Object Re-solves for new
storage at priority 2

Rule Language

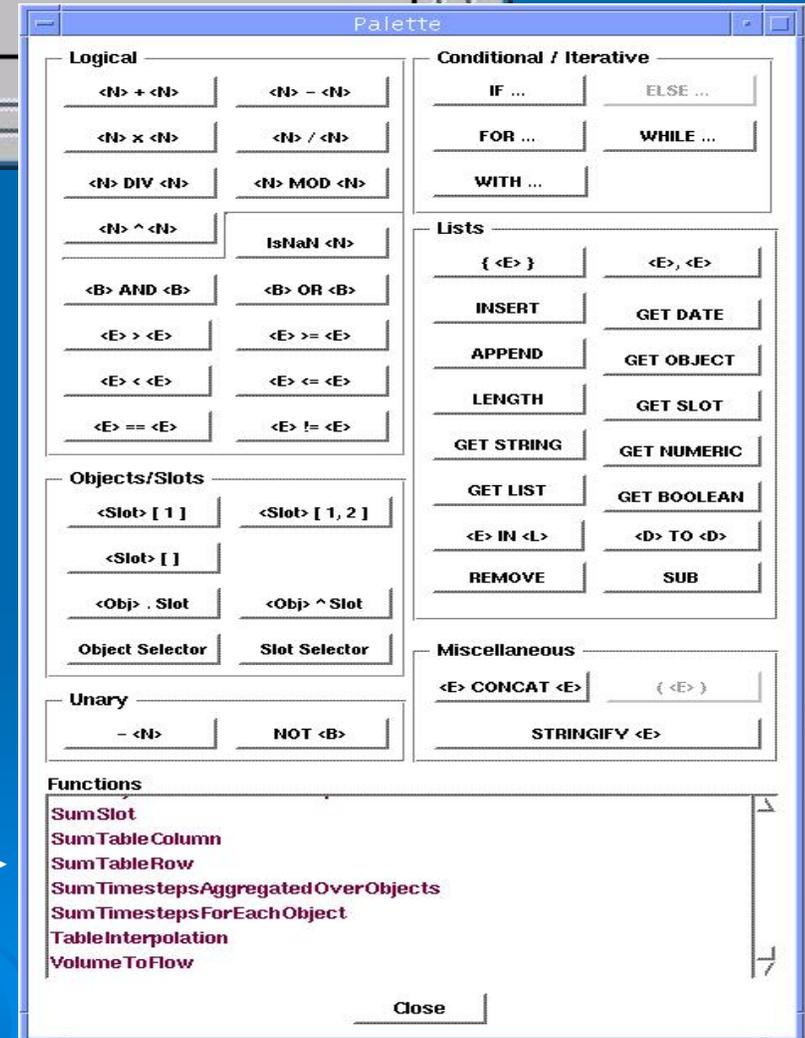
- Rich “programming” language
- Functional language (“referential transparency”)
- Build expressions in
Graphical Syntax-directed Editor
- Expression Validation
- Automatic Unit Management
- Function Libraries
 - user-defined
 - pre-defined



User defined function

Rule Syntax-directed Editor

Pre-defined Function Library



A rule example

Rule Editor - "crssBaselineEIS.rls : Powell and Mead Rules : Powell Spike Flow Rule"

File Edit Rule RuleSet Not Loaded

Name: Powell Spike Flow Rule

Body:

```
Powell.Bypass [] = IF ( CheckSpikeFlowCriteria () ) THEN
    SpikeFlowAdditionalBypass ()
ENDIF

Powell.Storage [] = IF ( CheckSpikeFlowCriteria () ) THEN
    IF ( Powell.Spill [] > 0.00 ["acre-feet/month"] ) THEN
        Powell.Storage []
    ELSE
        ComputeStorageAtGivenOutflow ( % "Powell" , PowellMinSpikeFlowOutflow () + SpikeFlowAdditionalBypass () )
    ENDIF
ENDIF

Powell Spike Flow Data.Spike Flow Flag [] = IF ( CheckSpikeFlowCriteria () ) THEN
    1.00
ELSE
    0.00
ENDIF
```

Ruleset Editor - "crssBaselineEIS.rls"

File Edit Ruleset View Ruleset Not Loaded

Priority	On	Name	Type
	✓	Fontenelle Rules	Policy Group
	✓	Stavation Rules	Policy Group
	✓	Flaming Gorge Rules	Policy Group
	✓	Taylor Park and Aspinall Rules	Policy Group
	✓	Navajo Rules	Policy Group
16	✓	Set NIIP Schedule	Rule
17	✓	Minimum Navajo Release	Rule
18	✗	Navajo Rule Curve (CRSS)	Rule
19	✓	Navajo Rule Curve	Rule
	✓	Powell and Mead Rules	Policy Group
	✓	Mohave Rules	Policy Group
	✓	Havasu Rules	Policy Group
	✓	General Functions	Utility Group
	✓	Get Data Functions	Utility Group
	✓	Rule Curve Functions	Utility Group

RBS Run Analysis

Model Run Analysis -- Rulebased Simulation

File View Object

	01-2000	02-2000	03-2000	04-2000	05-2000
MIUseBtwngreendaleAndOuray	4/0	4/0	4/0	4/0	4/0
MoapaValleyWQIP	32/0	32/0	32/0	32/0	32/0
MogollonProj	32/0	32/0	32/0	32/0	32/0
Mohave	133/44R	134/44R	133/44R	134/44R	134/44
MohaveSteamPlant	44/0	44/0	44/0	44/0	44/0
MohaveValleyIrrAndDrainDist	44/0	44/0	44/0	44/0	44/0
MorrowPoint	113/14R	113/14R	113/14R	113/14R	11/14
MWDAndCAPReach	144/44	144/44	144/44	144/44	14/44

MorrowPoint at 03-2000
 Method solveMB_givenInflowStorage Dispatched At Priority 11 Governed By Slots:
 Storage (Priority 14R) and Inflow (Priority 13)

Dispatch Detail

Type: LevelPowerReservoir
 Name: MorrowPoint

Methods = Needed = Known

- solveMB_givenInflowHW
- solveMB_givenOutflowHW
- solveMB_givenInflowStorage
 - 0 Diversion
 - 0 Return Flow
 - 0 Hydrologic Inflow
 - 13 Inflow
 - 14 R Storage
 - 14 Pool Elevation
 - 14 Outflow
 - 14 Energy
- solveMB_givenOutflowStorage

24:00 March 31, 2000

Close

Part 4

Water Accounting

Rules +
Accounting
Simulation

Rulebased
Simulation

Optimization

Multi-objective

Simulation

Input-Output Modeling

Calibration

If-then scenarios

RiverWare

Water Ownership, Water Accounting, Water Rights

- “Paper” Accounting
optional reconciliation
- Storage, Flow, Diversion Rights
- Exchanges, Loans, Rents,
Carryover
- Accrual
- Spreadsheet Solution
- Mix with Rulebased Simulation
- Network Optimization (future development)



Physical Water:

Modeled in river basin objects (reservoirs, reaches, etc.)
e.g. storage in a reservoir represents volume of physical water in the reservoir

Paper Water - type and ownership:

Modeled in Accounts on the river basin objects
e.g. storage accounts on a reservoir reflect type and ownership of physical water in the reservoir

Reconciliation: controlled by user

Types of Accounts

➤ Legal Accounts:

- Storage Account - on Reservoirs
 - Storage, gain/loss, accrual, carry-over, inflow and outflow
- Diversion Account - on Water Users, AggDiversions
 - diversion, consumption, and return flow
- Instream Flow (implementation not complete)

➤ Non-Legal Accounts

- Pass-through Accounts - Reaches, Confluences, Gages, Reservoirs
 - keep track of water moving between legal accounts
 - $\text{outflow} = \text{inflow} + \text{lags, gain/losses}$
 - Diversion and return flow

RioGrande
Heron Reservoir --
RioGrande StorageAccount

Storage Account

- ◆ Flow
- ◇ Vol

Inflow (Willow) cfs	Outflow cfs	Gain Loss cfs	Slot Inflow cfs	Storage acre-ft	Accrual acre-ft
				I -190.00	I 0.00
P 0.11	P 0.00	M -2.51	M 2.40	A -190.00	A 4.97
P 0.11	P 0.00	M -2.51	M 2.40	A -190.00	A 9.94
P 0.11	P 0.00	M -2.51	M 2.40	A -190.00	A 14.91
P 0.11	P 0.00	M -2.51	M 2.40	A -190.00	A 19.88

Maximum Accr. m3	Flow Allocation cms	Begin Year Alloc m3	Carry Over m3

December 31, 1995
January 1, 1996
January 2, 1996
January 3, 1996
January 4, 1996

December 31, 1995
January 1, 1996
January 2, 1996

RioGrande
Heron Reservoir Ou
RioGrande PassThroug

Pass-through Account

- ◆ Flow
- ◇ Vol

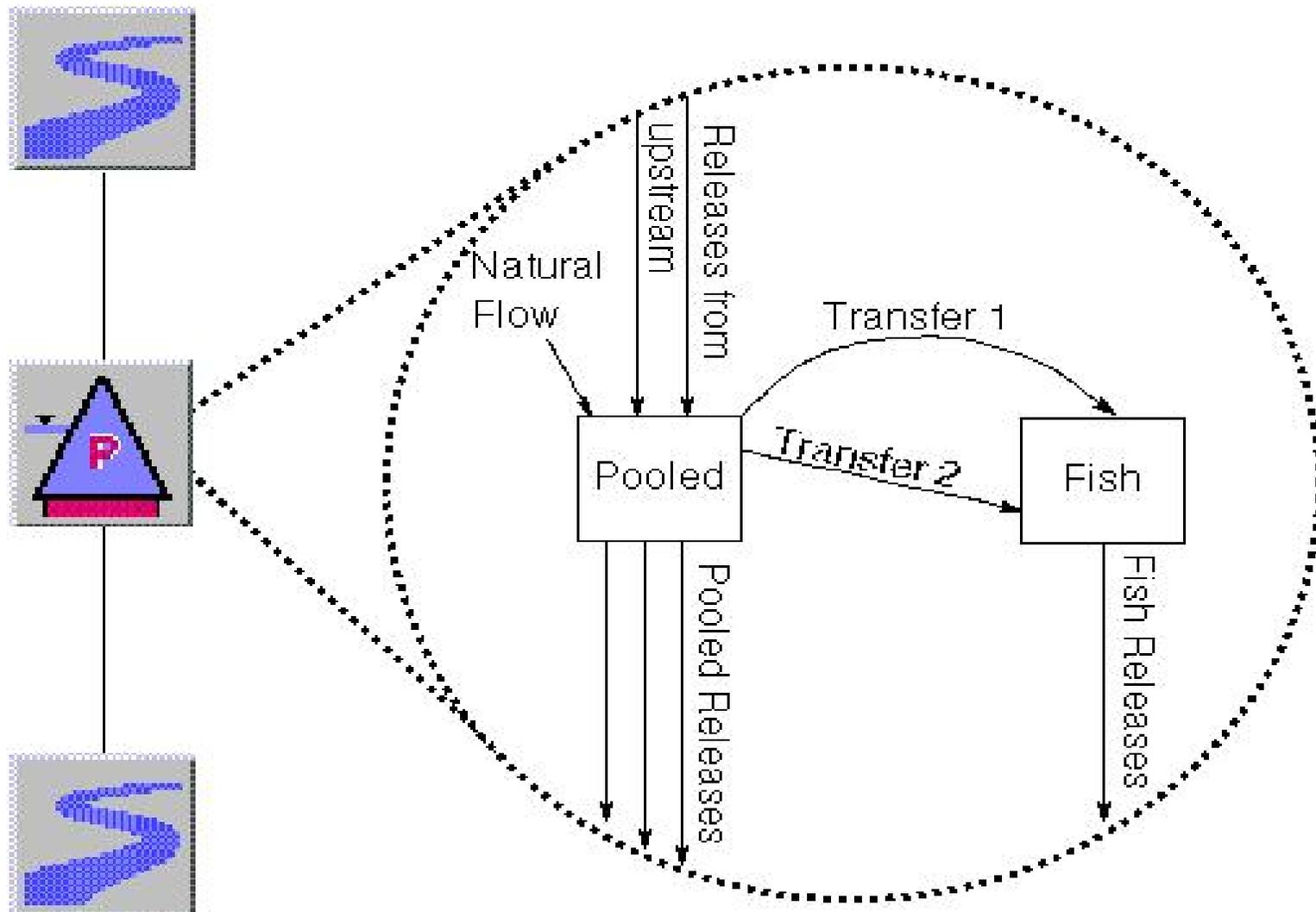
Inflow cfs	Outflow (Heron) cfs	Gain Loss cfs	Slot Inflow cfs	Diversion cms	Return Flow cms	Storage acre-ft
P 0.00	A 0.00		I 0.00			
P 0.00	A 0.00		I 0.00			
P 0.00	A 0.00		I 0.00			
P 0.00	A 0.00		I 0.00			
P 0.00	A 0.00		I 0.00			

December 31, 1995
January 1, 1996
January 2, 1996
January 3, 1996
January 4, 1996
January 5, 1996

Linking Accounts

- Accounting network is formed by links between inflows and outflows of accounts called “supplies”
- Supplies are software objects, can eventually have preferences; amenable to a network solution
- Each supply has the following attributes:
 - Type – Inflow/Outflow or Diversion/Return Flow
 - Destination
 - Release Type

Diagram of Accounts



Accounting Methods

- Introduce water into accounting system through slotInflow, Gain/loss method categories on objects e.g. distribute losses or inflows to the accounts
- Carryover methods on accounts
- Methods are site-specific - defined by user in interpreted language
- Methods have dependencies and re-execute when new values are introduced

Accounting Solution

- “Spreadsheet” type solution
 - account solves whenever it gets a new value (not controlled by dispatcher)
- “After the fact” accounting
 - assumes physical model has solved
- Current solutions:
 - storage accounts solve only for storage balance (user specifies storage account outflows)
 - pass-through accts solve only downstream
- Account slots are set by user input or rules
- On supplies, a NaN is interpreted as zero

Three Accounting Controllers

1. Inline with simulation –
after each simulation timestep

2. Post simulation -
after entire simulation run

3. Inline with rulebased simulation

(execution of accounting methods and rules controls when
the accounting solution can take place)

Use Rules to Control Accounting

- Rules can be used to set supplies

For example:

$$\text{FishSupply}[\text{Current Timestep}] =$$
$$\text{FlowTarget}() -$$
$$\text{SumOtherReservoirReleasesOfType}(\text{"Fish"})$$

- If account Inflow is known, this causes the account to solve for Storage

Water Exchanges

- **Borrow** - a supply to an account or a user input
- **Source Payback** - an outflow (demand) from an account
- **Destination Payback** (optional) - a supply to an account

Account balance is updated whenever a new value is set in the borrow or payback

Account balances can be accessed by rules

Future Accounting Enhancements

- Visualization of accounting network
- Automatic generation of pass-through accounts
- Implementation of legal “Instream Flow” accounting
- Automatic reconciliation of paper and physical water
- Network optimization for complete water rights solution