The 3rd NARBO
Training Workshop

K-MODSIM DSS
Features and Applications

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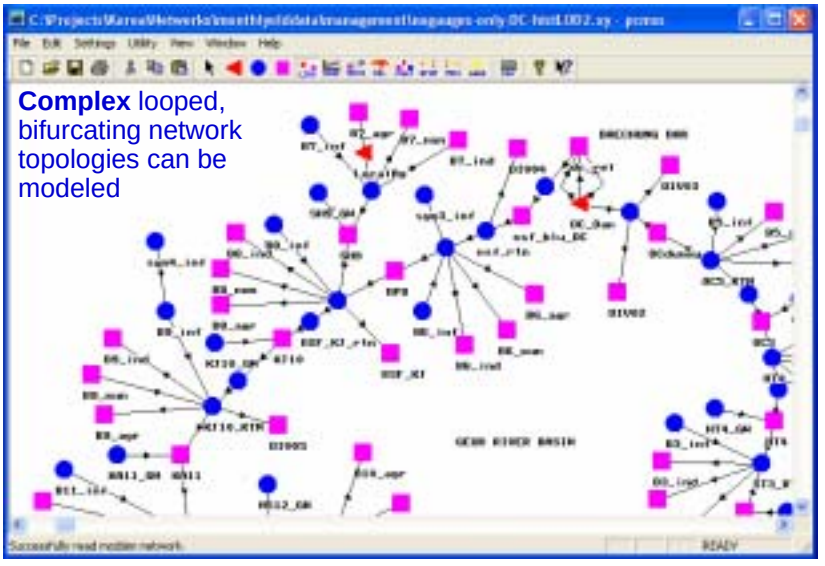
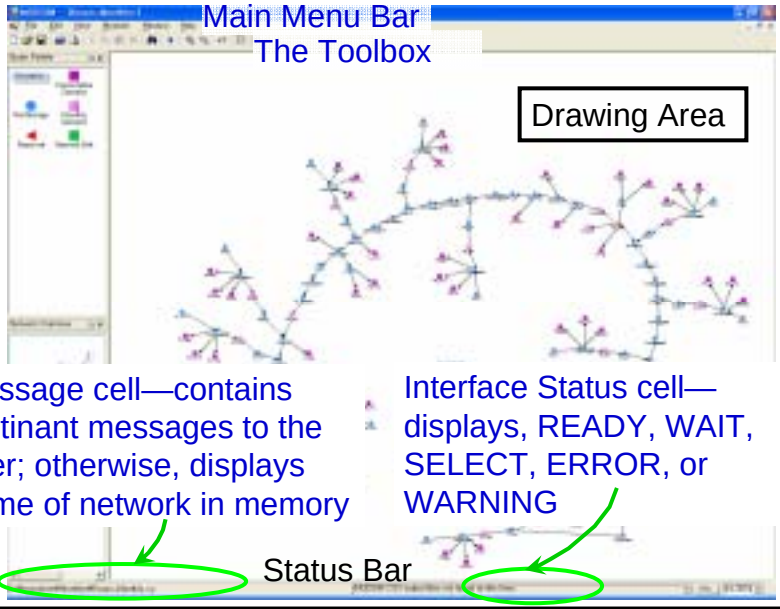
Complex River Basin Topologies

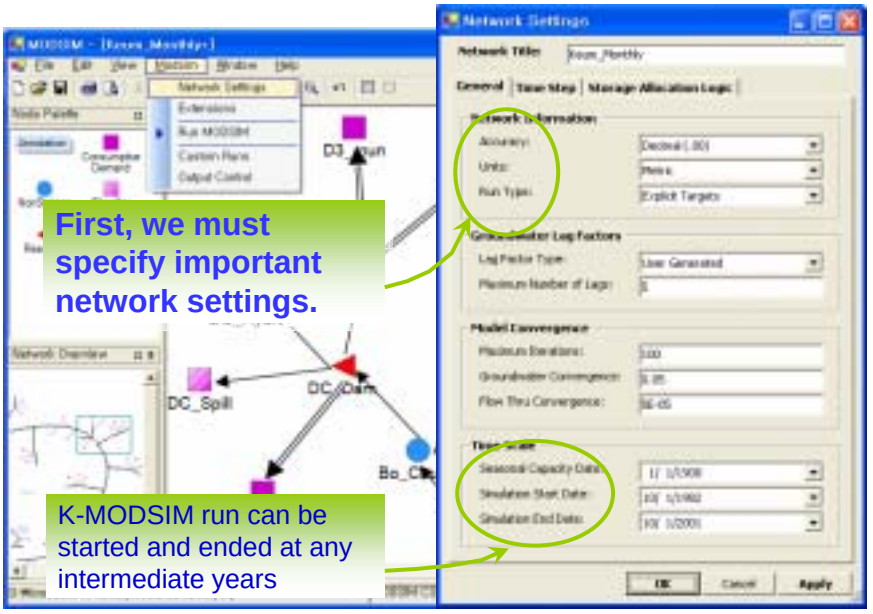
- Networks define the simulation



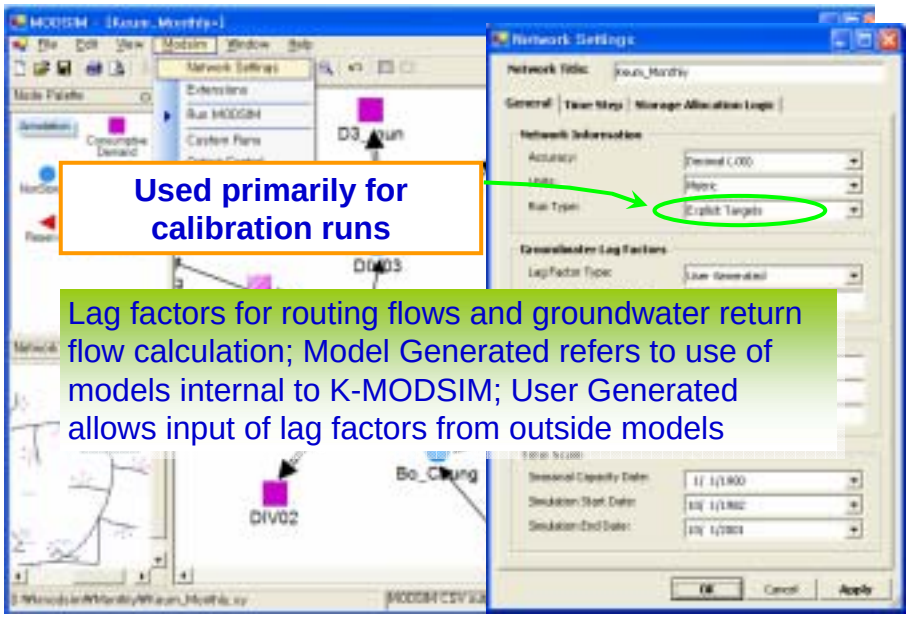
Features of K-MODSIM GUI



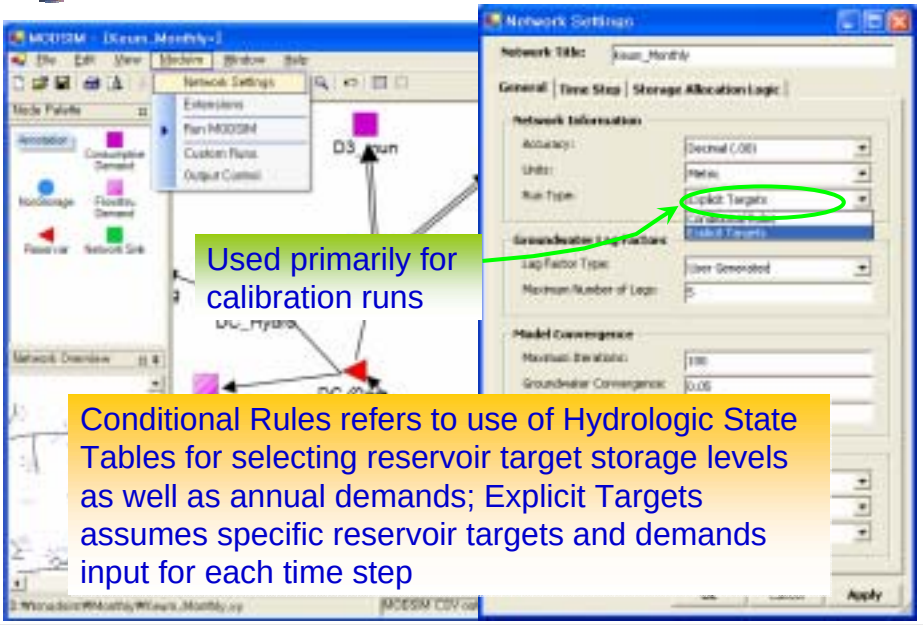
K-MODSIM Network Settings



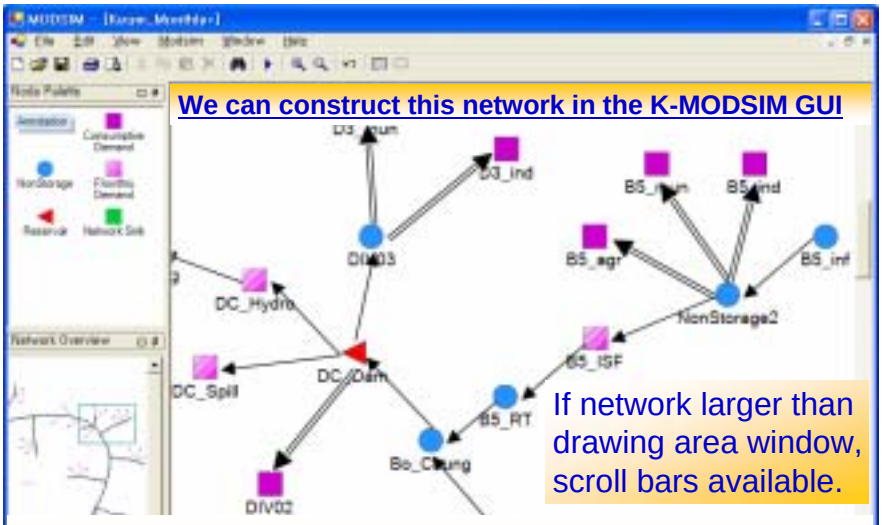
K-MODSIM Network Settings



K-MODSIM Network Settings

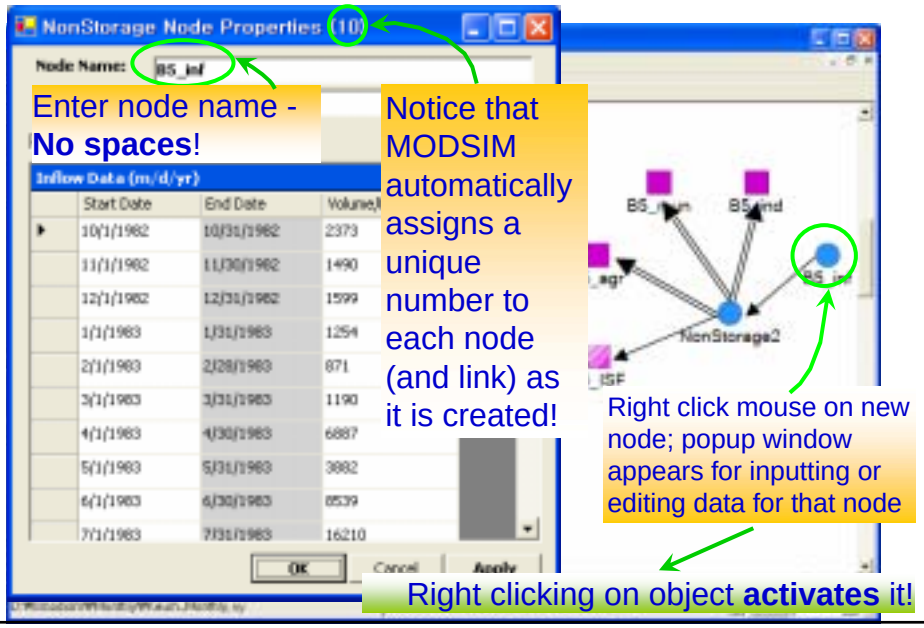


K-MODSIM Network Creation

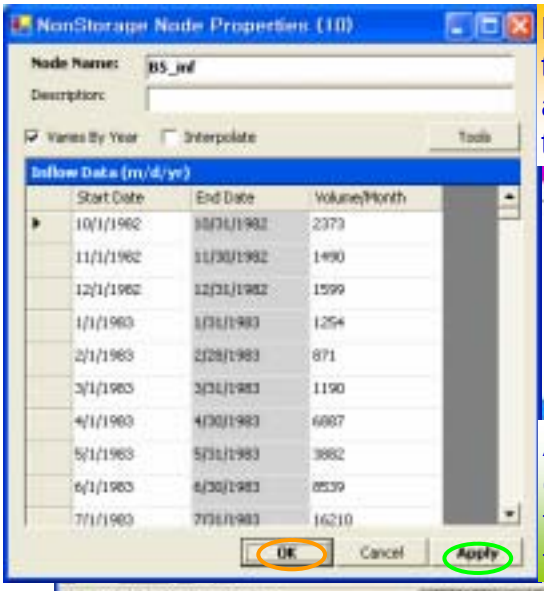


Most of the time, the network will be larger than the drawing area, so only a portion of the network can be seen at once.

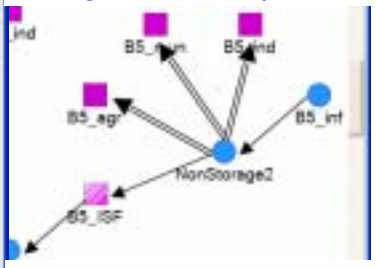
K-MODSIM Properties



K-MODSIM Properties

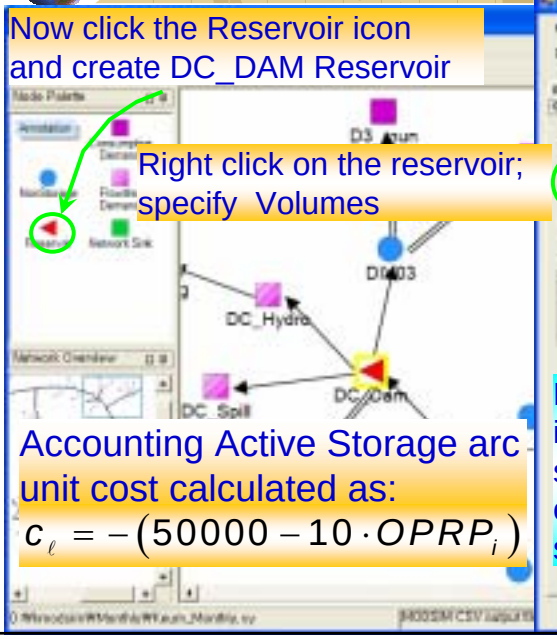


For multi-year simulations, time series data can be automatically entered through flat file import--

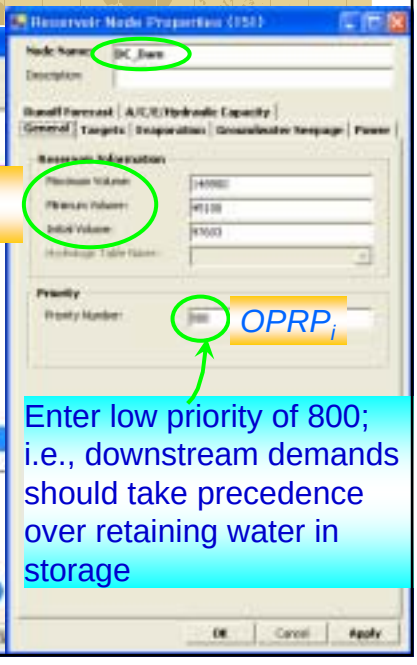


After entering new data or editing existing data, don't forget to click Apply first—then click OK!

Now click the Reservoir icon and create DC_DAM Reservoir



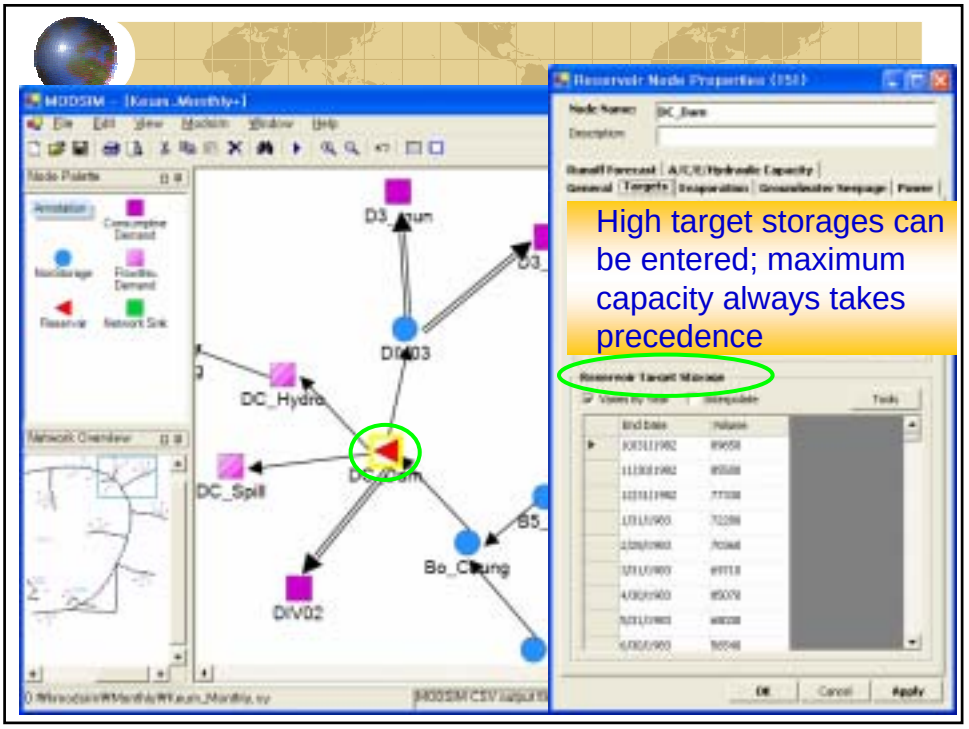
Right click on the reservoir; specify Volumes

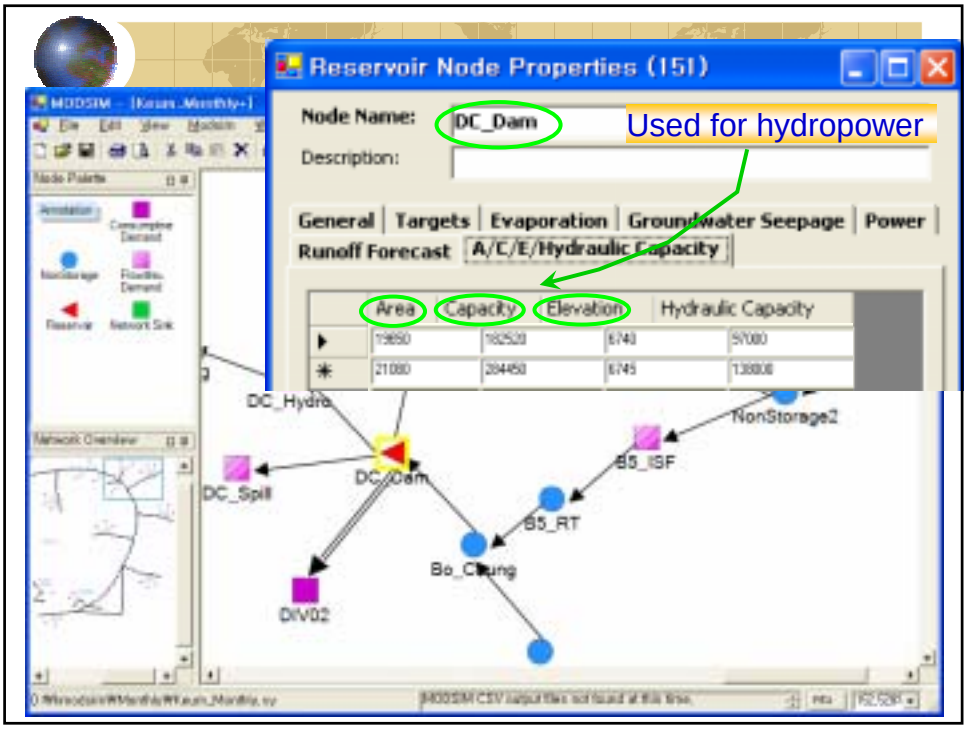


Enter low priority of 800; i.e., downstream demands should take precedence over retaining water in storage

Accounting Active Storage arc unit cost calculated as:

$$c_\ell = -(50000 - 10 \cdot OPRP_i)$$

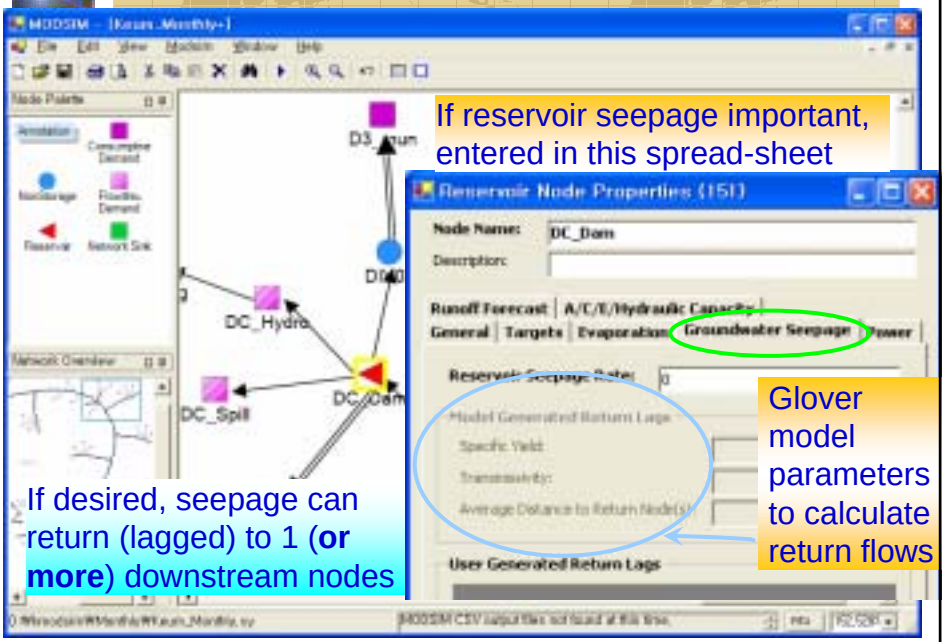

High target storages can be entered; maximum capacity always takes precedence
DC_Hydro
DC_Spill
DIV02

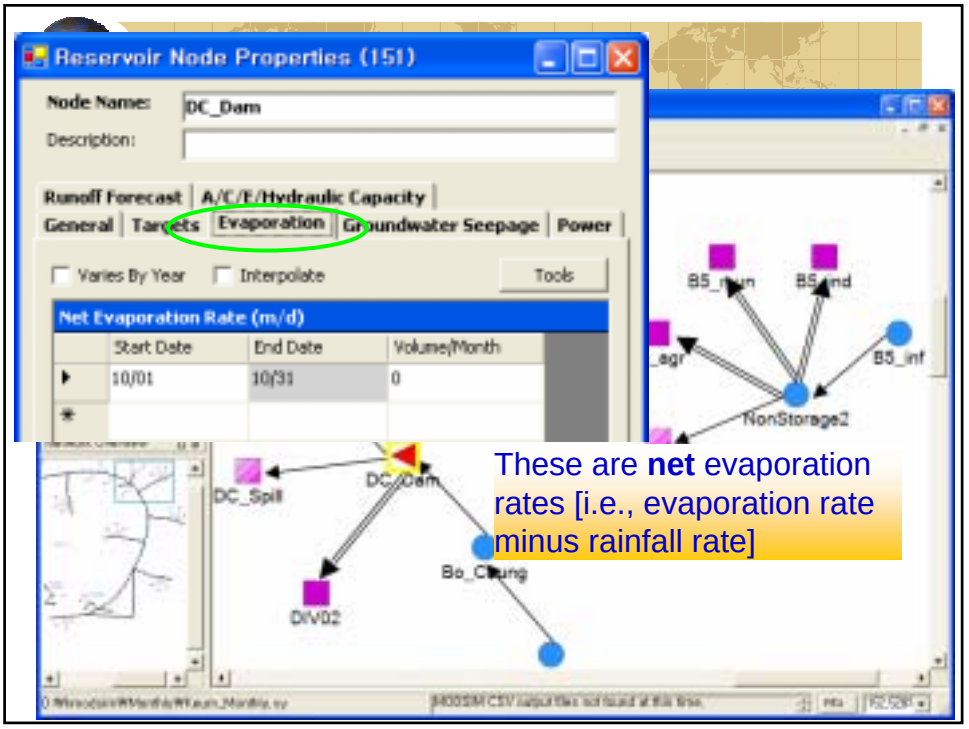

Reservoir Node Properties (151)
Node Name:
DC_Dam
Description:
Used for hydropower
General
Targets
Evaporation
Groundwater Seepage
Power
Runoff Forecast
A/C/E/Hydraulic Capacity
Area
Capacity
Elevation
Hydraulic Capacity
DC_Hydro
DC_Spill
DC_Dam
NonStorage2
B5_ISF
B5_RT
Bo_Chung
DIV02

Accurate Calculation of Losses

- Evaporation loss (function of average surface area in reservoir over time interval)

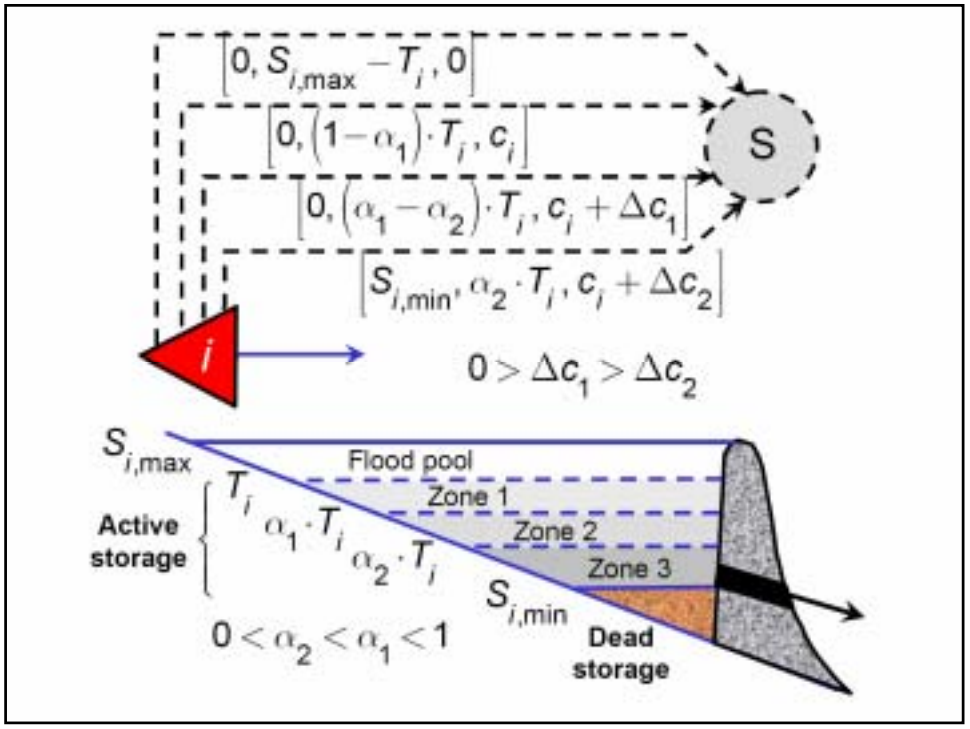
- Channel loss (function of average flow entering channel or river reach)
- Reservoir seepage (function of average storage in reservoir)

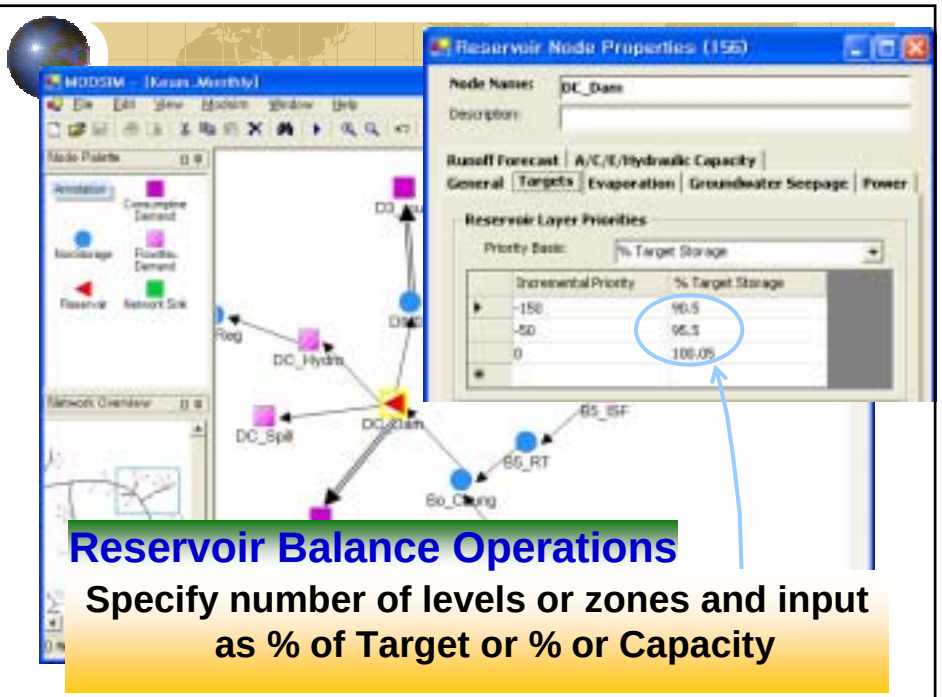




Reservoir Balance Operations

- K-MODSIM includes **reservoir balance tables** that allow reservoirs to be divided into arbitrary number of **operating zones**
- For multi-reservoir systems, allows operations that **balance water levels** in all projects (to avoid emptying some reservoirs and overfilling others)
- K-MODSIM defines additional accounting active storage arcs representing each zone
  - slightly more negative cost for lower zones
  - lower zones fill first since have slightly more negative cost





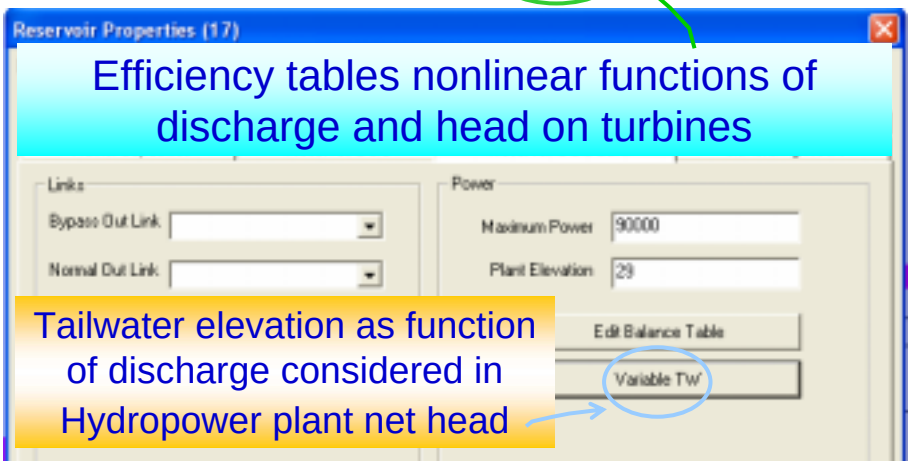
Reservoir Balance Operations

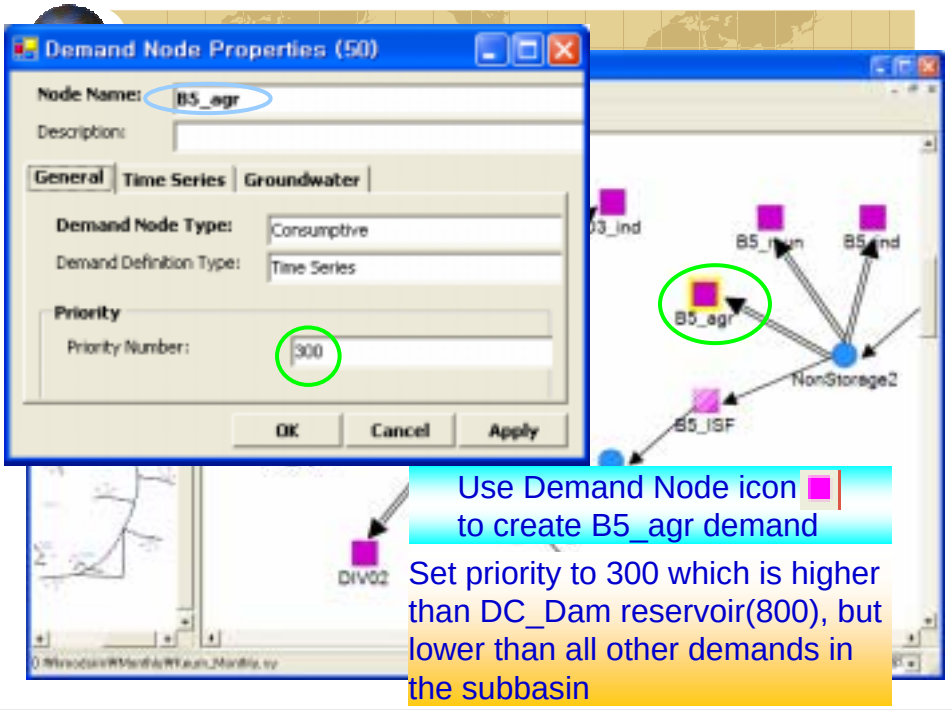
Specify number of levels or zones and input as % of Target or % or Capacity

Hydropower Calculations

Accurate hydropower calculations in K-MODSIM

$$P = K \cdot Q \cdot H \cdot e(Q,H)$$



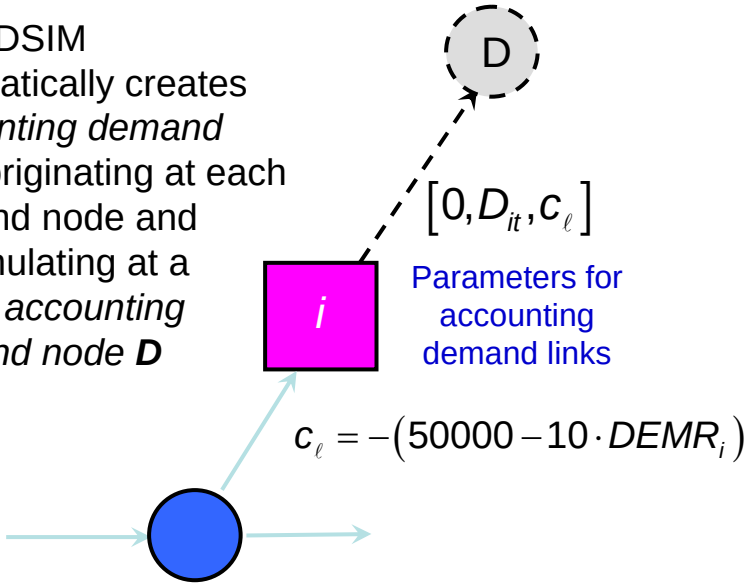


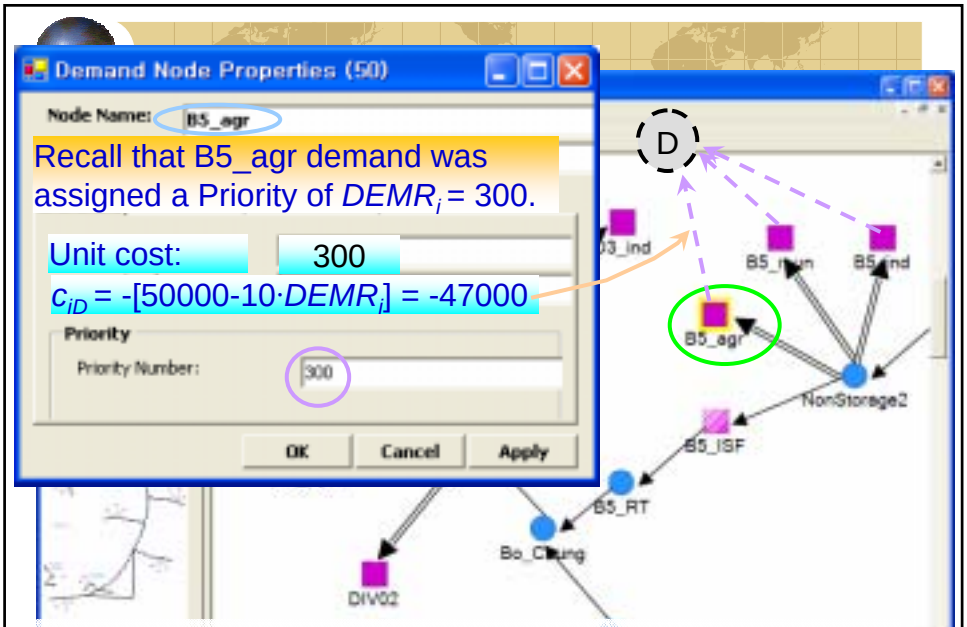
Types of Demands

- Historical **diversions**
- Decreed **natural flow** right amounts
- **Storage rights**
- Predicted agricultural demands based on "outside" **consumptive use** calculations (performed outside K-MODSIM)
- Projected **municipal and industrial** demands

Consumptive Demands

- K-MODSIM automatically creates *accounting demand links* originating at each demand node and accumulating at a single *accounting demand node* ***D***

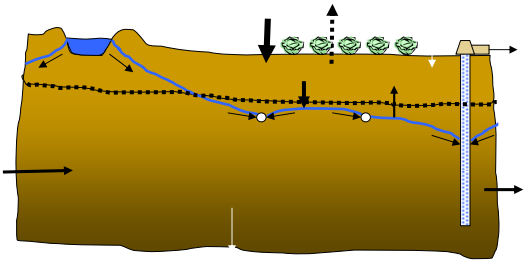




The unit cost formula in K-MODSIM translates this into a unit cost of -47000 for flow on the accounting demand link.

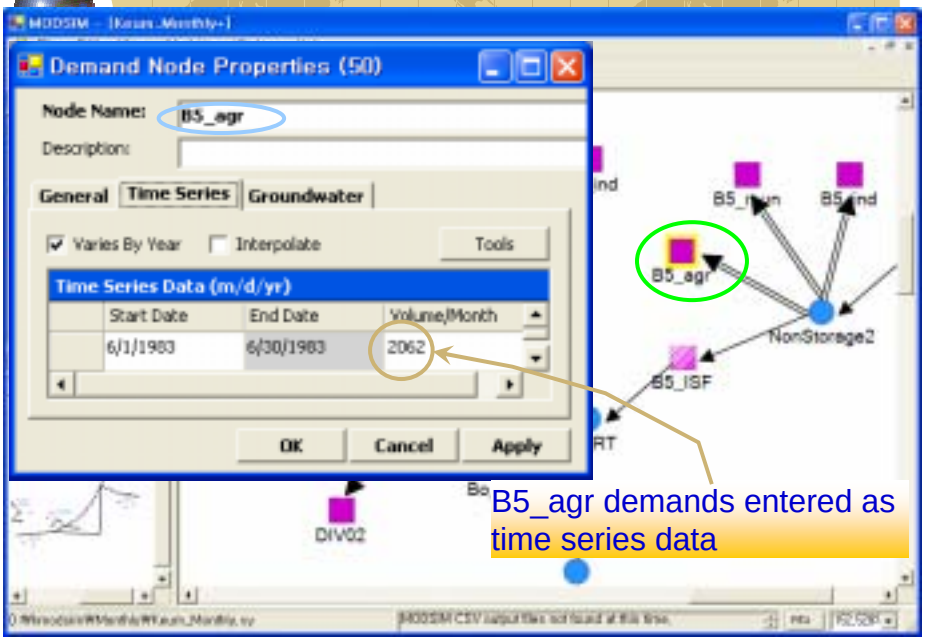
Conjunctive Use of Surface and Groundwater in K-MODSIM

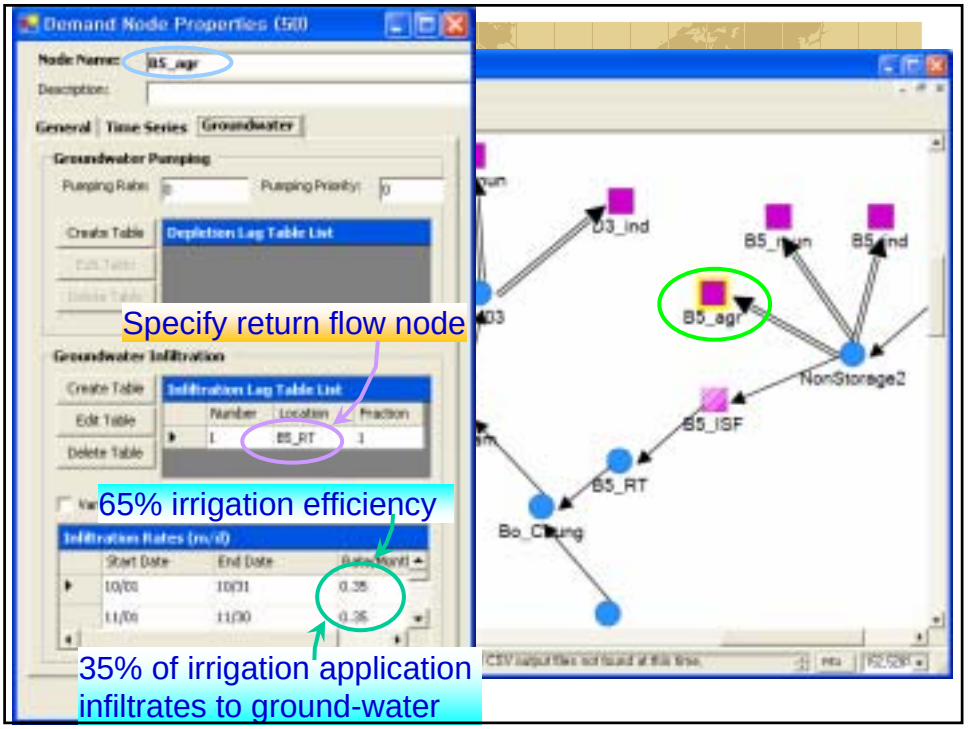
- Reservoir seepage
- Irrigation
- Infiltration
- Channel loss
- Well pumping
- Return flows
- River depletion due to pumping

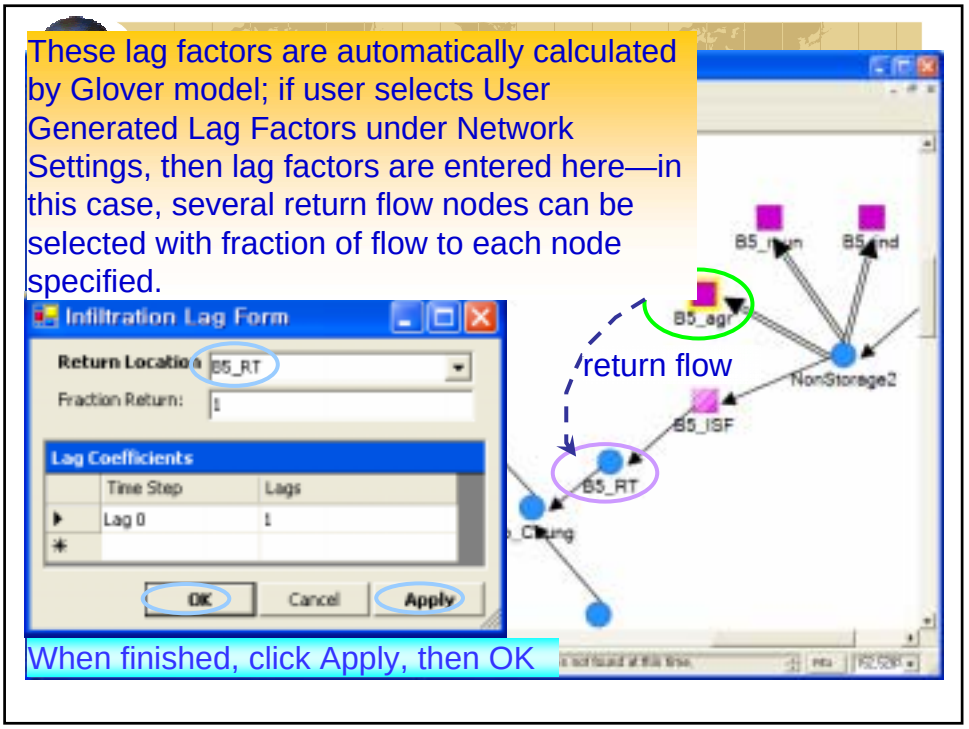


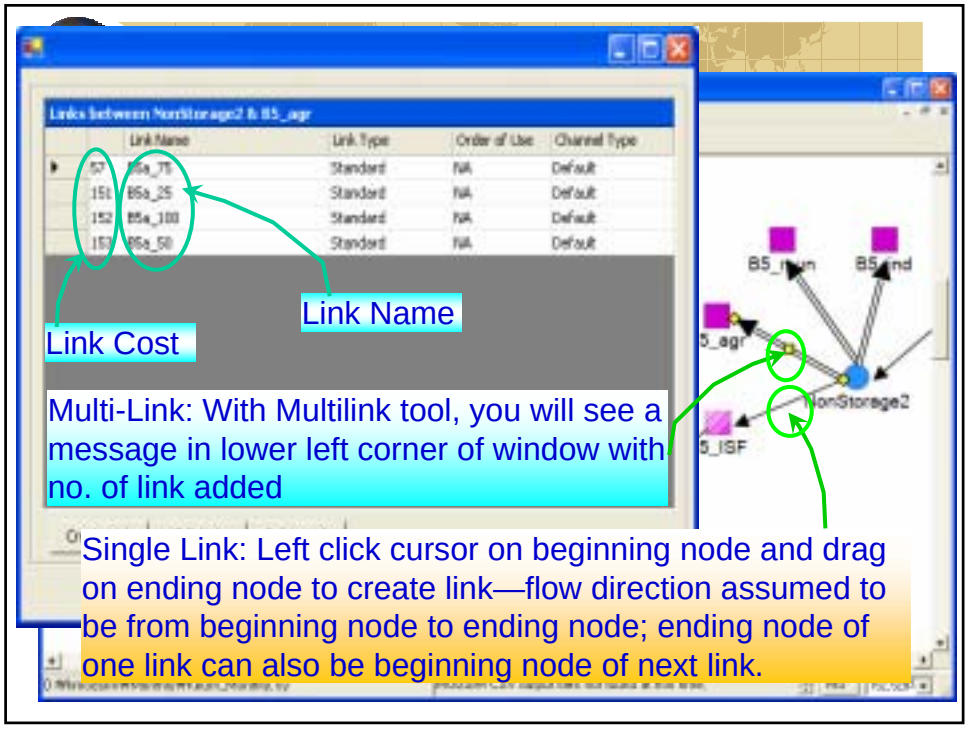
Lumped Approaches to Calculating Stream-Aquifer Response

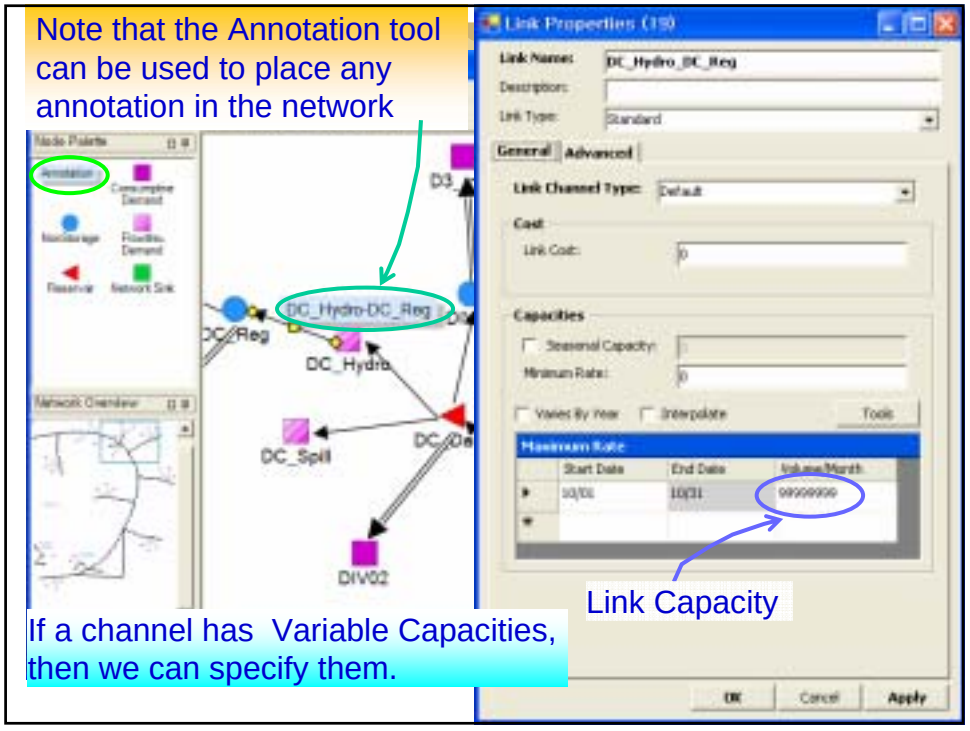
- Stream-aquifer return/depletion flows can be simulated using 1-dimensional eqs. developed by Maasland, Glover, McWhorter
  - built into MODSIM
- Alternatively, groundwater response coefficients estimated from other methods:
  - stream depletion factor (SDF) method (Jenkins, USGS)
  - also available in K-MODSIM




Demand Node Properties (50)
Node Name: B5_agr
Description:
General
Time Series
Groundwater
Groundwater Pumping
Pumping Rate:
Pumping Priority:
Create Table
Depletion Lag Table List
Groundwater Infiltration
Create Table
Edit Table
Delete Table
Infiltration Lag Table List
Number
Location
Fraction
1
B5_RT
1
Infiltration Rates (m/d)
Start Date
End Date
10/01
10/31
0.35
11/01
11/30
0.35
Specify return flow node
65% irrigation efficiency
35% of irrigation application infiltrates to ground-water
D3_ind
B5_agr
NonStorage2
B5_ISF
B5_RT


These lag factors are automatically calculated by Glover model; if user selects User Generated Lag Factors under Network Settings, then lag factors are entered here—in this case, several return flow nodes can be selected with fraction of flow to each node specified.
Infiltration Lag Form
Return Location:
B5_RT
Fraction Return:
1
Lag Coefficients
Time Step
Lags
Lag 0
1
OK
Cancel
Apply
return flow
B5_agr
NonStorage2
B5_ISF
B5_RT
When finished, click Apply, then OK

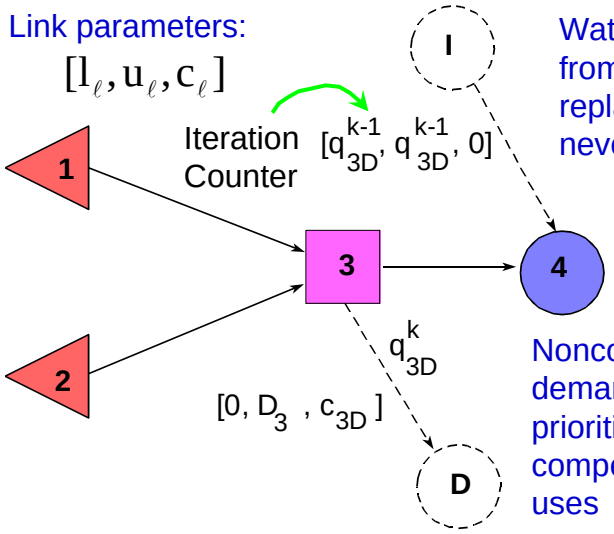

Link Name
Link Cost
Multi-Link: With Multilink tool, you will see a message in lower left corner of window with no. of link added
Single Link: Left click cursor on beginning node and drag on ending node to create link—flow direction assumed to be from beginning node to ending node; ending node of one link can also be beginning node of next link.


Note that the Annotation tool can be used to place any annotation in the network
Link Properties (19)
Link Name:
DC_Hydro_DC_Reg
Description:
Link Type:
Standard
General
Advanced
Link Channel Type:
Default
Cost
Link Cost:
Capacities
Seasonal Capacity:
Minimum Rate:
Varies By Year
Interpolate
Tools
Maximum Rate
Start Date
End Date
Volume/Month
OK
Cancel
Apply
DC_Hydro-DC_Reg
DC_Hydro
DC_Spill
DIV02
Link Capacity
If a channel has Variable Capacities, then we can specify them.

Instream Flow Uses Simulated using "Flow-Through" Demands

Link parameters:

$[l_\ell, u_\ell, c_\ell]$

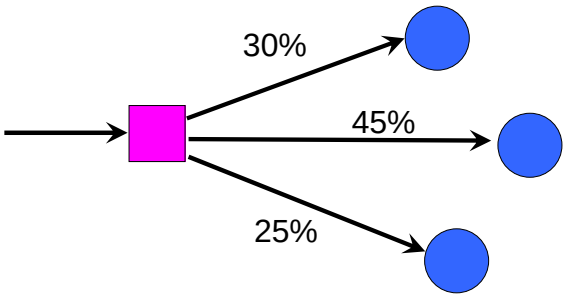


Water diverted from from river and then replaced—conceptually, never removed

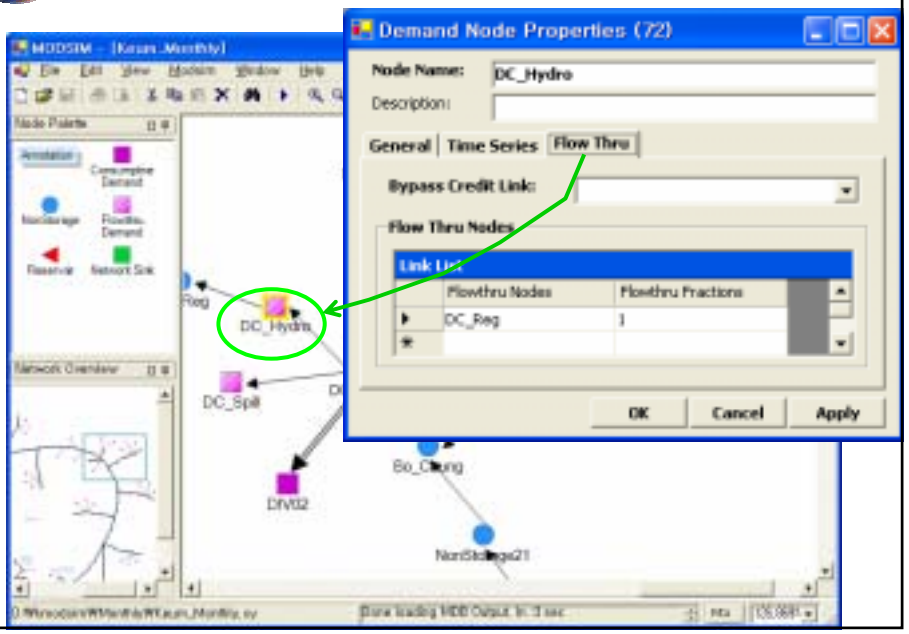
Nonconsumptive demand for water with priorities assigned to compete with other uses

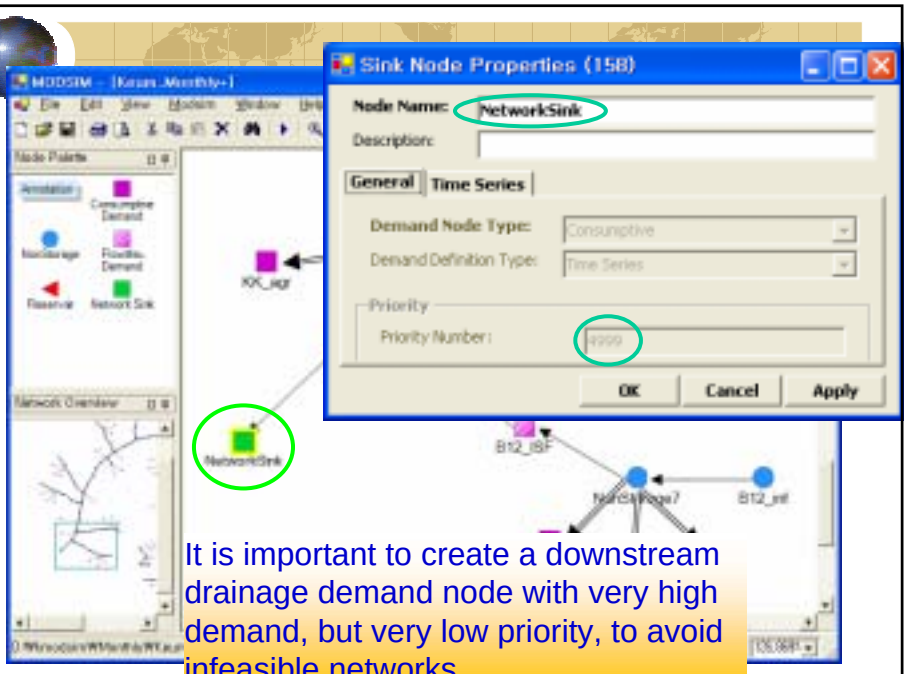
Water Allocation According to Fixed Percentages

Flow-Through demands also used to allocate water according to fixed percentages, rather than water rights



Flow-Through Demands in K-MODSIM





It is important to create a downstream drainage demand node with very high demand, but very low priority, to avoid infeasible networks

Hydrologic States

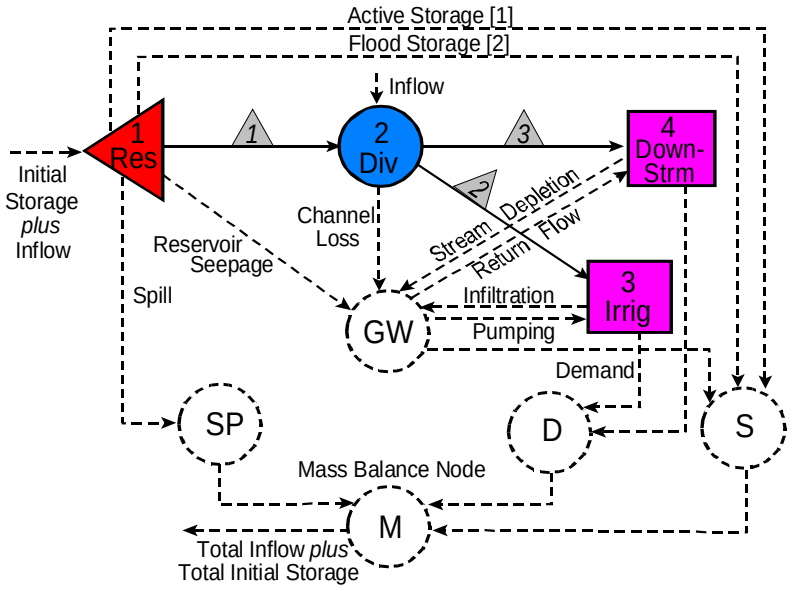
- K-MODSIM computes system **hydrologic states** by considering current reservoir storage levels and current period inflows for user specified subset of reservoirs that indicative of hydrologic conditions
- Several different **system state subset** designations may be specified as needed.
  - associated with each of these states (which may be classified as average, dry, and wet, for example) is corresponding set of operating rules with ranking priorities.

Streamflow Routing

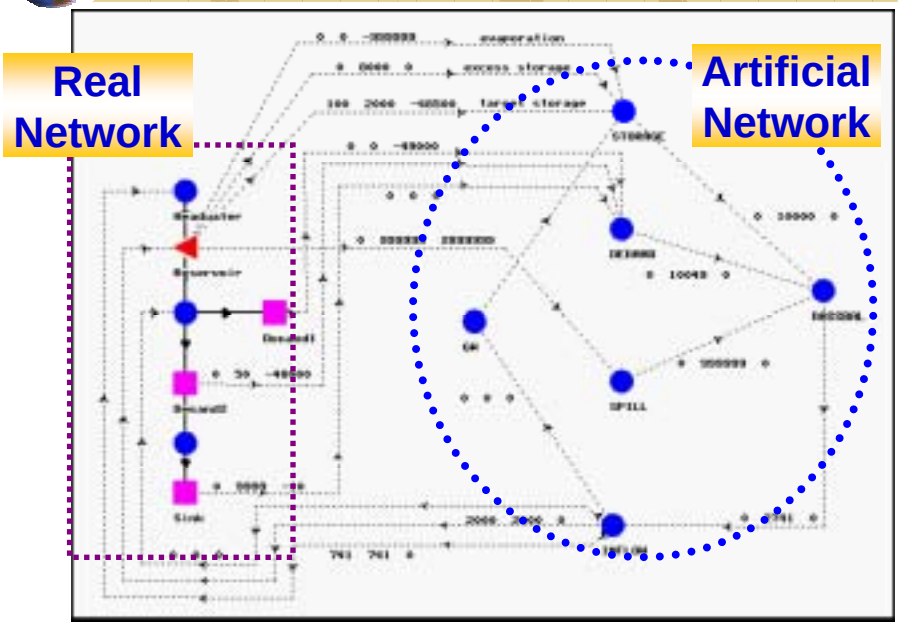
- For simulation of **daily** streamflow, necessary to consider **channel routing**
- Designate network link as **routing link**
- Inflow to this link distributed over time in accordance with routing coefficients calculated by **Muskingum** formula or **Backrouting method**
- User may also directly **input** any desired **routing coefficients** and lagging factors

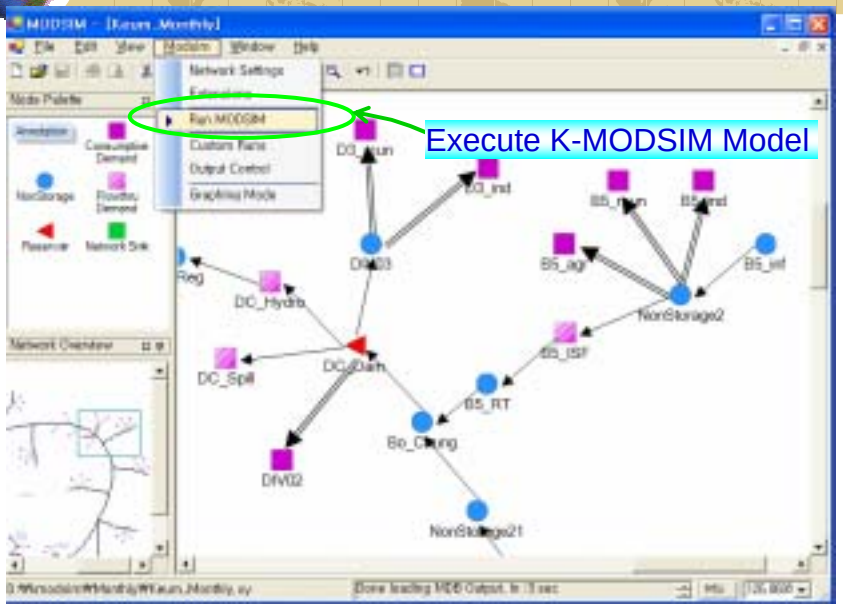
Accounting Nodes and Links

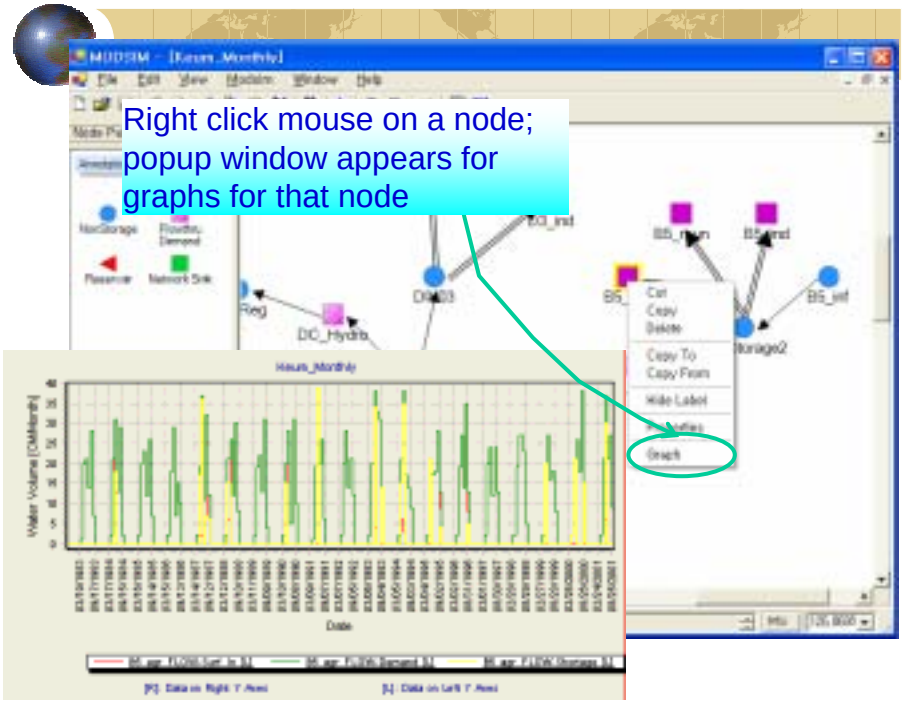
- When user constructs K-MODSIM network, certain artificial or accounting nodes and links are automatically created (not seen by user):
  - these insure maintenance of mass balance throughout network
  - useful for modeling complex administrative and legal mechanisms governing water allocation



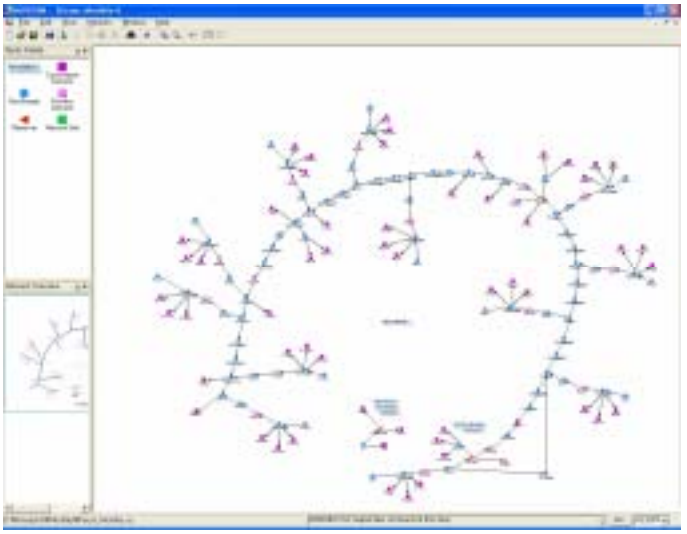
Real and Artificial Network





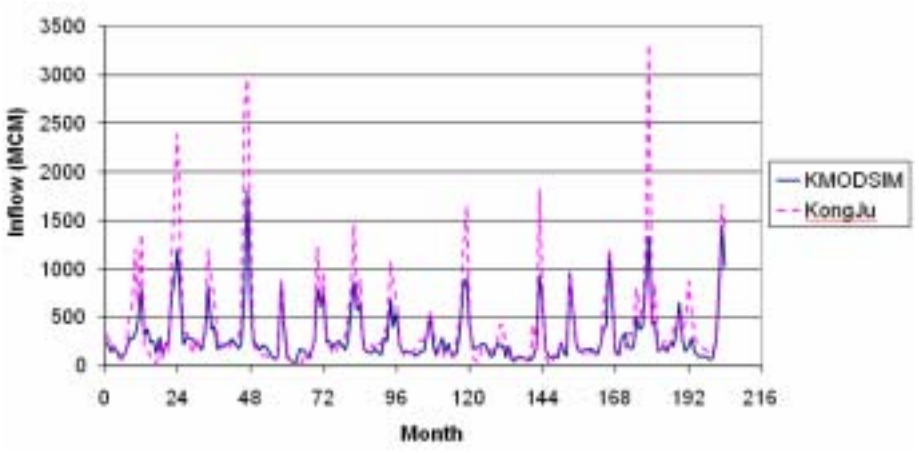


Application Results of Geum River Basin



Monthly Calibration Results

Daecheong Reservoir Inflow: r^2 = 0.78; ave. RMSE = 10.3 (MCM/mo)
Gongju gage: r^2 = 0.73; ave. RMSE = 39.4 (MCM/mo)
Gyuam gage: r^2 = 0.66; ave. RMSE = 27.3 (MCM/mo)

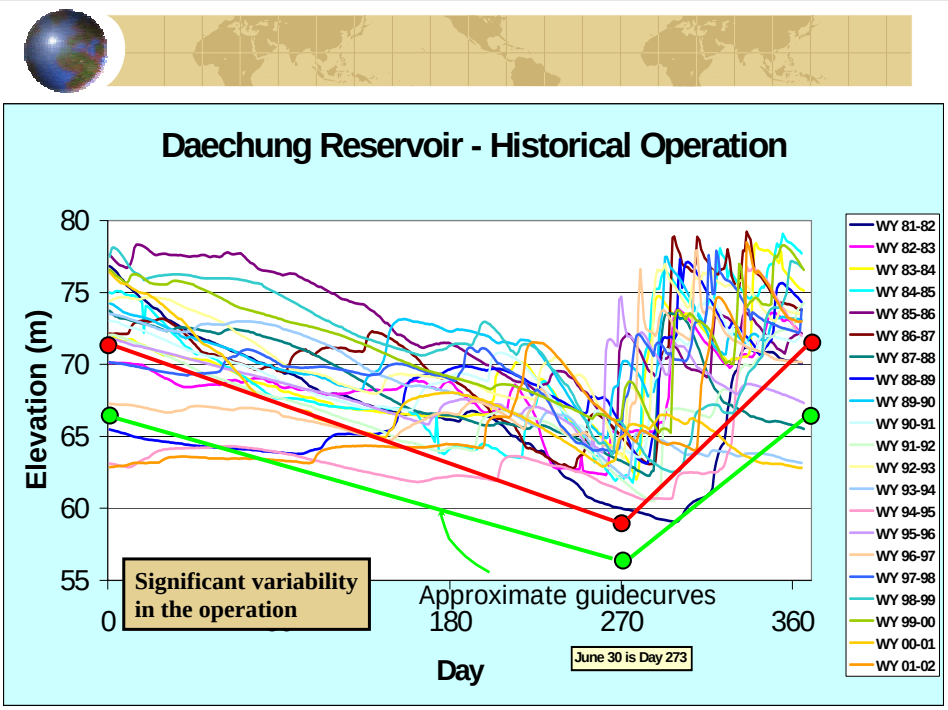


Daily Calibration

- Calibration of monthly model also used to identify year selected for calibration of **daily model**
  - water year October 1994 – September 1995
  - inspection of monthly results show simulated values reasonably close to observed monthly data for this water year
- Daily Geum network similar to monthly, except for inclusion of **routing links**

Management System Calibration

- Historical operation of Daecheong reservoir analyzed to develop operational rules that reasonably represent the historical operation
- Derived historical rules used in K-MODSIM to represent base-line historical conditions



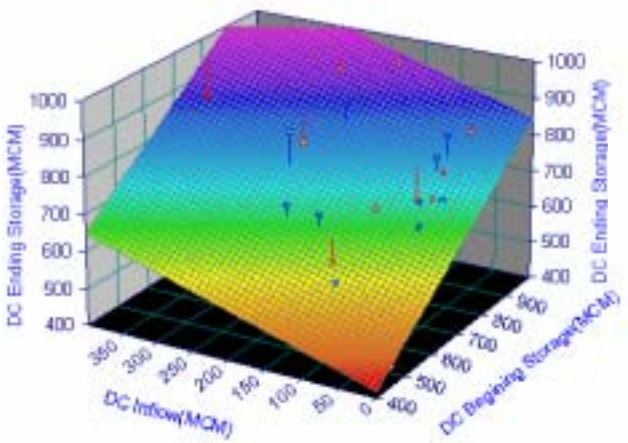
Guide Curve Analysis

- Analyzed monthly historical storage, releases and inflows over 19 yr. period
- Developed both storage rules (for normal seasons) and release rules (for flood seasons) using linear and nonlinear regression models:

  e.g.

$$S_{t+1} = a_0 + a_1 S_t^2 + a_2 I_t^{0.5}$$
$$S_{t+1} = a_0 + a_1 S_t + a_2 I_t$$

Adaptive Guide Curves for Historical Daecheong Operation

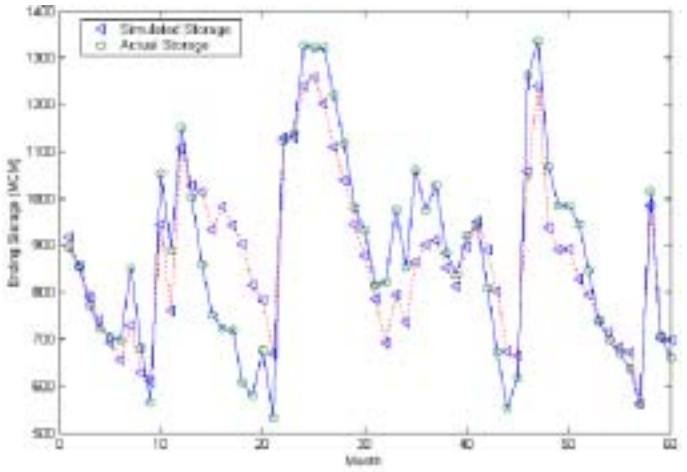


April

z=a+bx+cy

a=130.22677 b=0.71533612 c=0.58411222

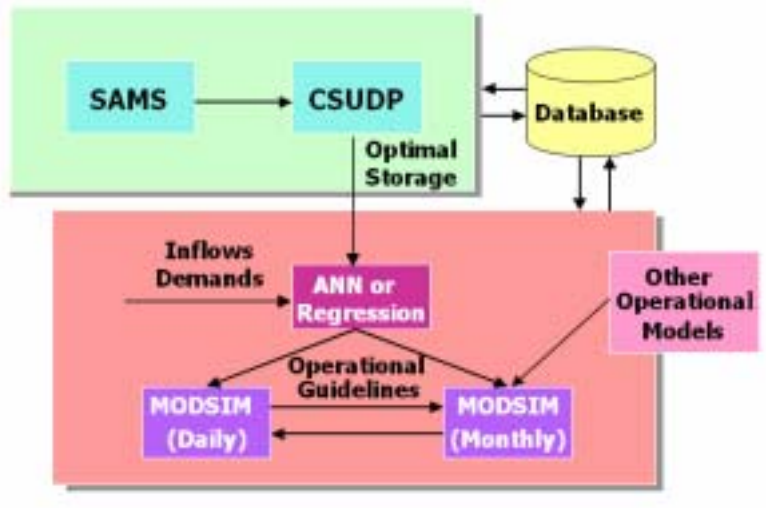
Comparison of Simulated and Actual Daecheong Storage (1984-1988)



ANN vs. Regression Analysis

- Artificial neural networks (ANN) also tested to represent historical Daecheong operations, but did not perform any better than the regression rules in this case
- r^2 values range from 0.60 in May to 0.98 in October

Optimal Integrated Operations

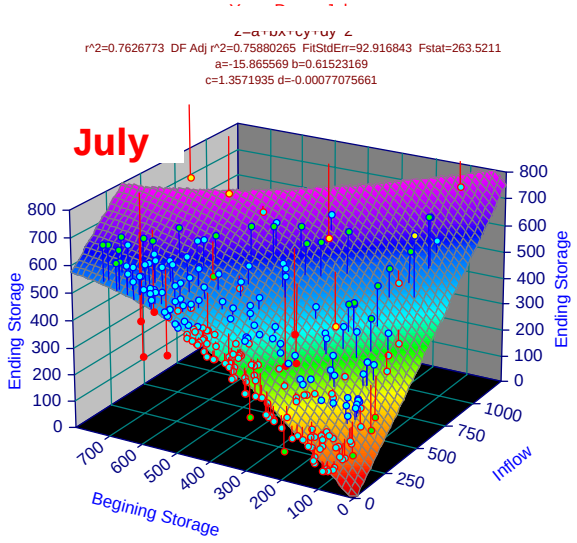


Implicit Stochastic Optimization

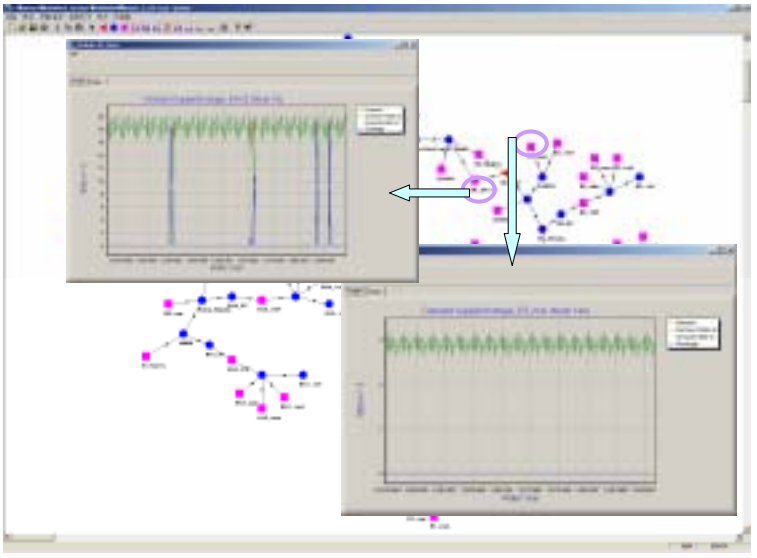
- Stochastic generation of 10 sets of 50 years of monthly data using the **SAMS** (Stochastic Analysis, Modeling, and Simulation Computer Software Package; J. Salas, Colorado State University)
  - preserves annual statistics better than multi-variate AR model
- Input into **CSUDP** Generalized Dynamic Programming Package (J. Labadie, Colorado State University)

CSUDP Operation Rules--Yongdam

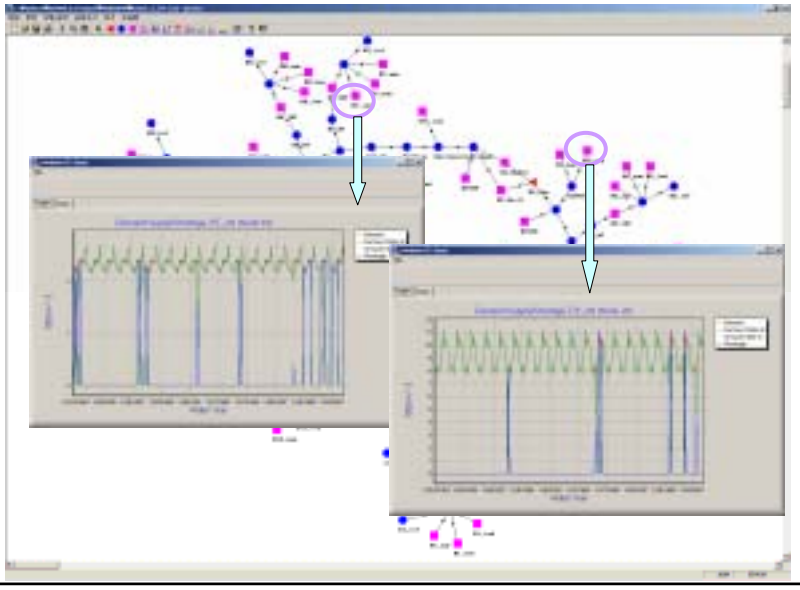
r^2 values range from 0.70 in July to 0.96 in October



Integrated Monthly Operation (Municipal Water)

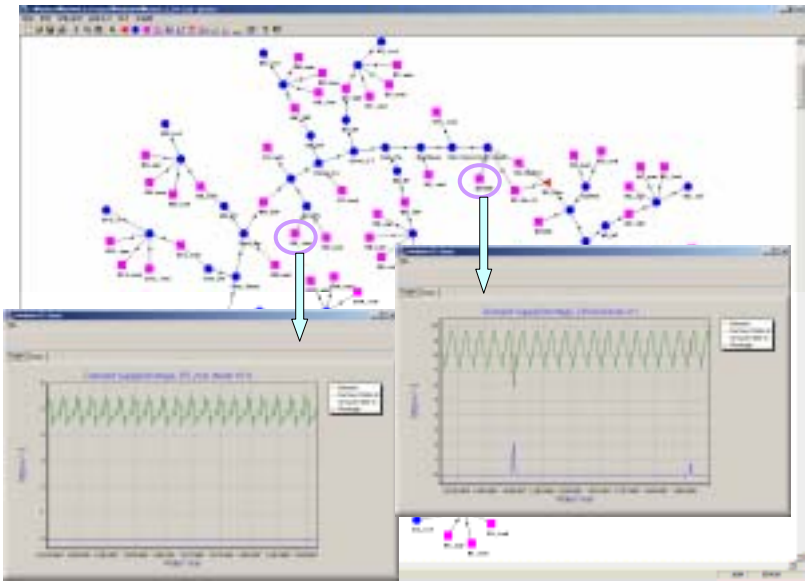


Integrated Monthly Operation (Industrial Water)

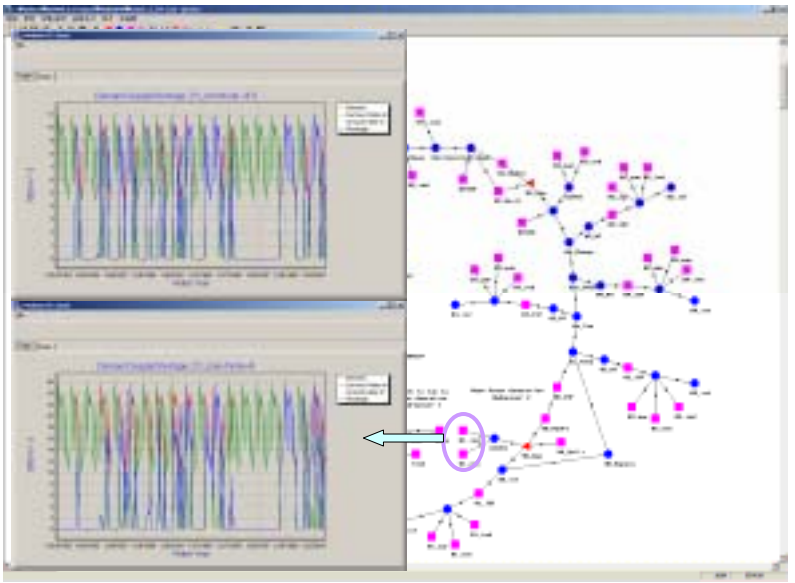


Integrated Monthly Operation (Agricultural Water)

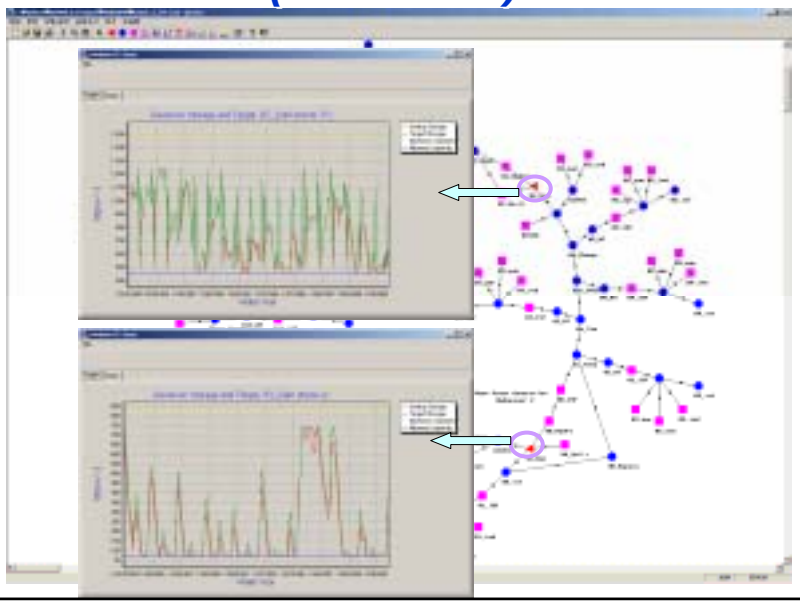
Integrated Monthly Operation (Trans-mountain Water)



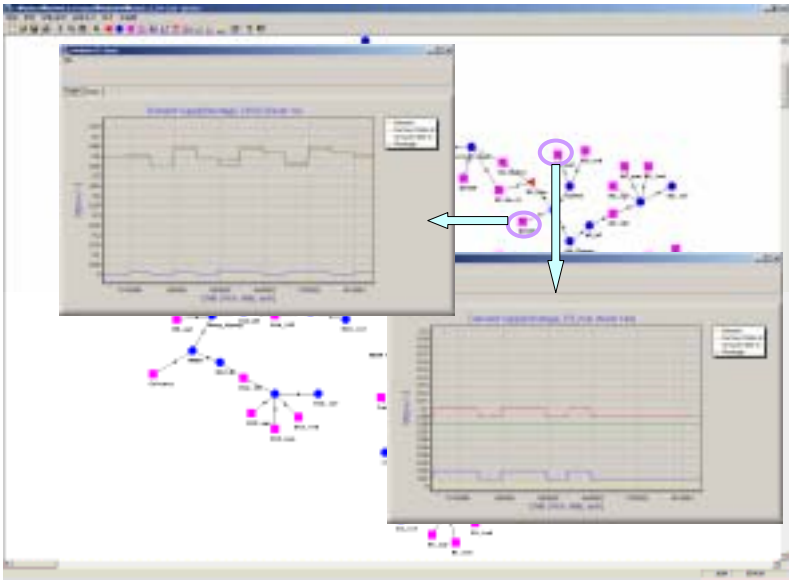
Integrated Monthly Operation (Jeonju Diversion)



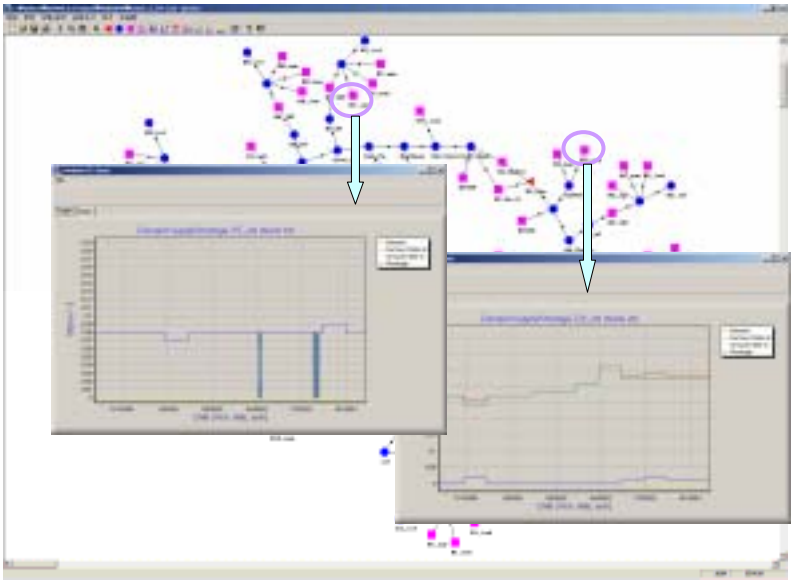
Integrated Monthly Operation (Reservoirs)



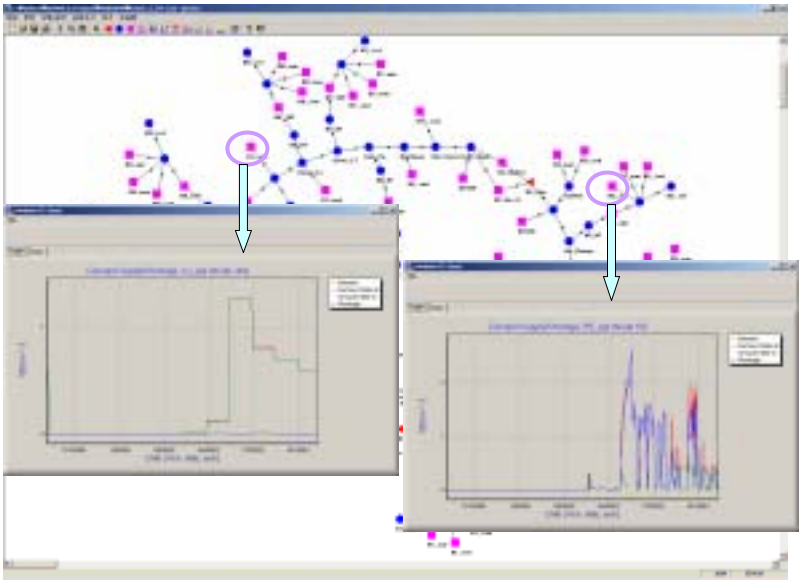
Daecheong - Daily (Municipal Water)



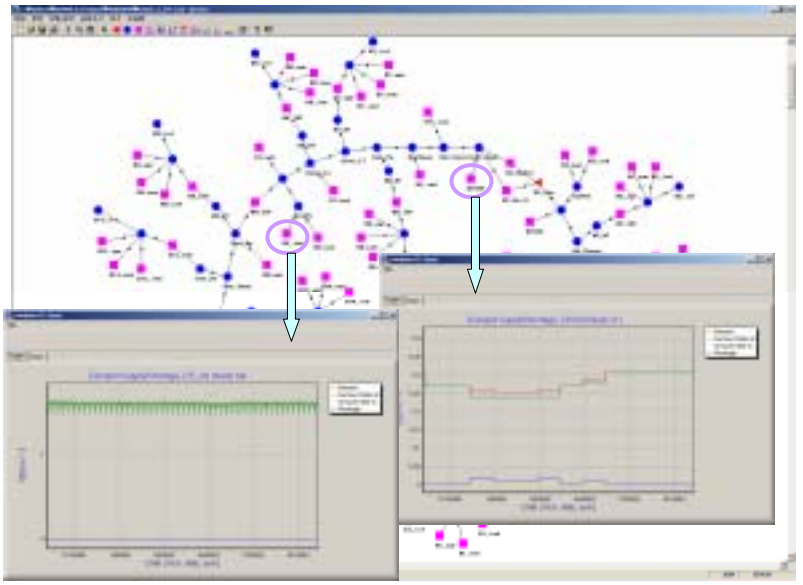
Daecheong - Daily (Industrial Water)



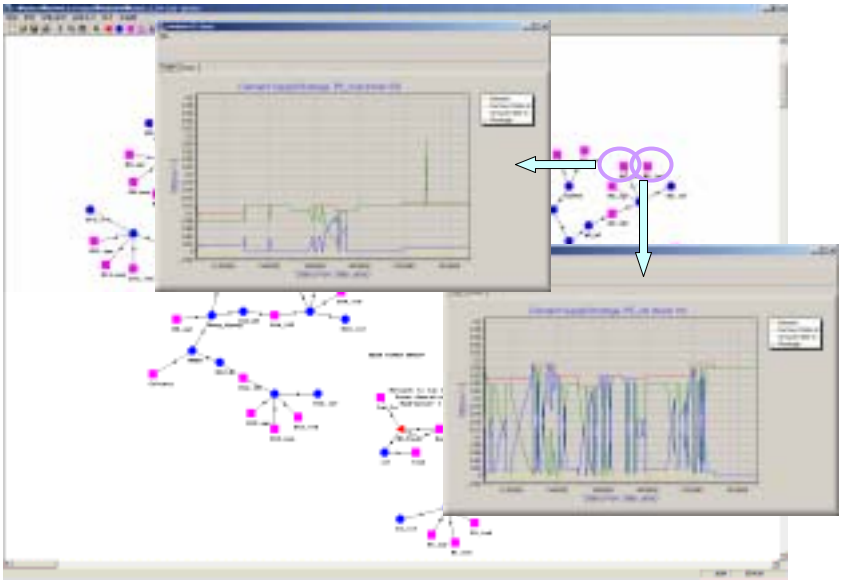
Daecheong - Daily (Agricultural Water)



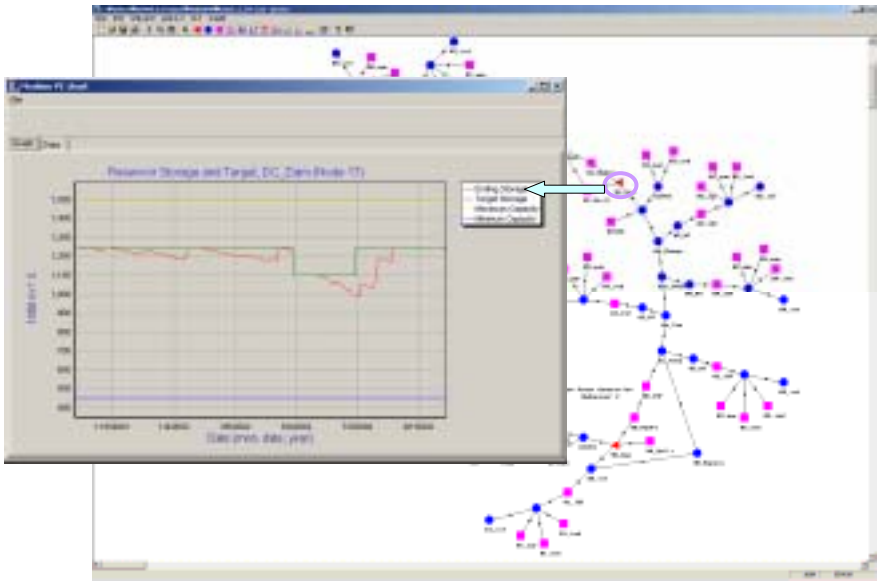
Daecheong - Daily (Trans-mountain Water)



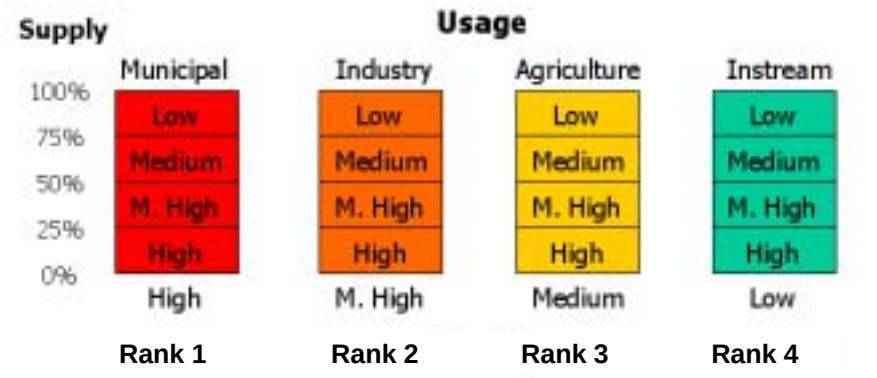
Daecheong - Daily (Subbasin Water)



Daecheong - Daily (Reservoirs)



Deficit Sharing Policy



Impact of Yongdam Reservoir on Performance of Geum River Basin

- All historical demands satisfied in both cases
- Inflows to Daecheong Dam significantly reduced, but instream flow at Gyuam increased during low flow season (January to May)
- Hydropower generation increased with integrated operation of Daecheong and Yongdam reservoirs
  - Daecheong Dam only operation: 204.42 GWh
  - With integrated operation: 176 GWh at Daecheong Dam; 202 GWH at Yongdam

Impact of Increased Demands on Integrated Operation

- With increased future demands, flows at Gongju gaging station slightly decreased during April and October; however, instream flow targets at Gyuam gaging station satisfied
- Hydropower generation decreased due to the increased demand
  - Daecheong Dam hydropower generation decreased from 176.11 GWh to 159.24 GWh
  - Yongdam hydropower generation unaffected by increased demands