

K-MODSIM DSS Features and Applications

16 November 2005

Dr. Jin Hee Lee (KICT)

Dr. Jaewon Kang (KOWACO)

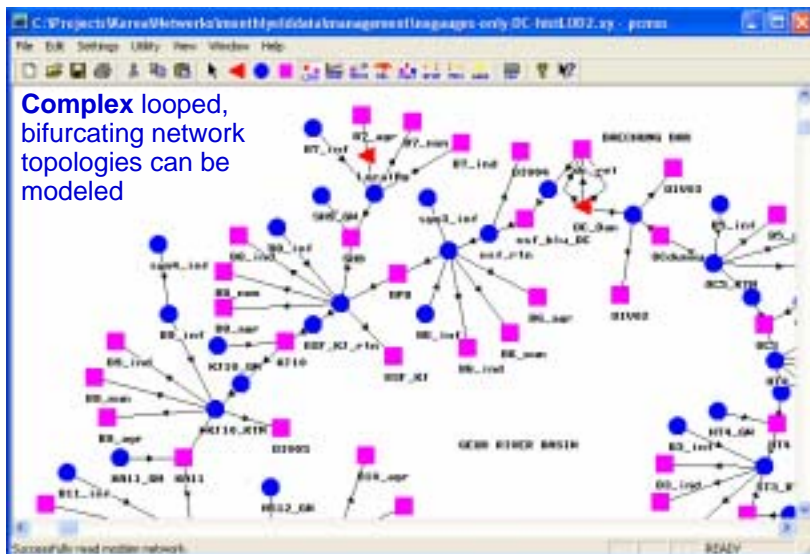
Mr. Seung Yup Rieu (KOWACO)



Complex River Basin Topologies

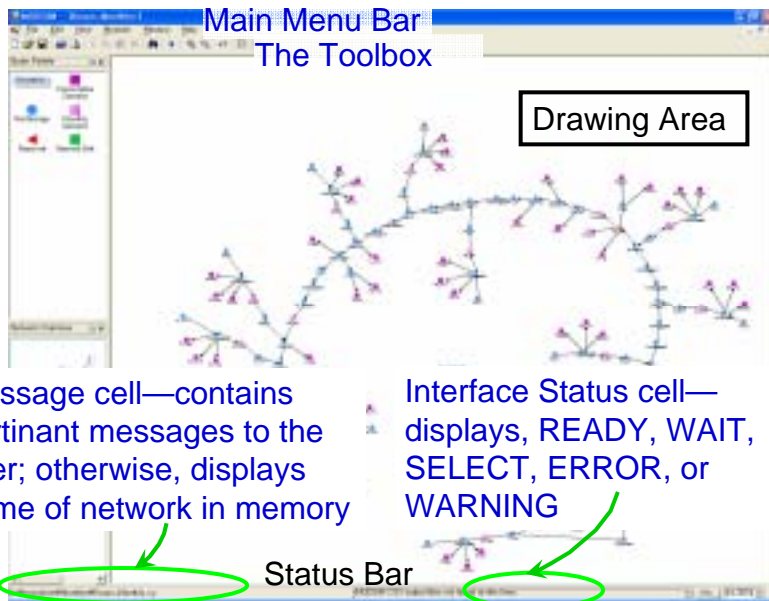
- Networks define the simulation

Complex looped,
bifurcating network
topologies can be
modeled





Features of K-MODSIM GUI



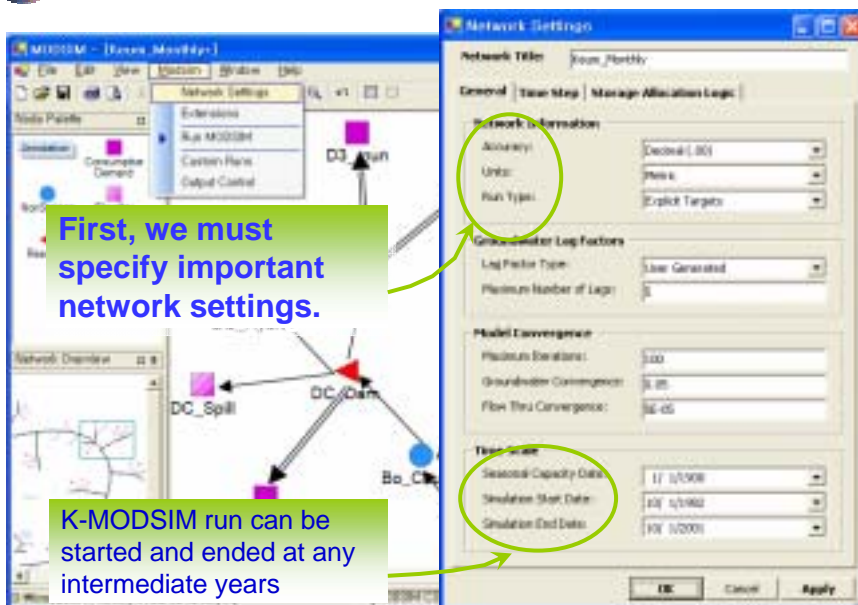
Message cell—contains pertinent messages to the user; otherwise, displays name of network in memory

Interface Status cell—displays, READY, WAIT, SELECT, ERROR, or WARNING

Status Bar



K-MODSIM Network Settings





K-MODSIM Network Settings

Used primarily for calibration runs

Lag factors for routing flows and groundwater return flow calculation; Model Generated refers to use of models internal to K-MODSIM; User Generated allows input of lag factors from outside models



K-MODSIM Network Settings

Used primarily for calibration runs

Conditional Rules refers to use of Hydrologic State Tables for selecting reservoir target storage levels as well as annual demands; Explicit Targets assumes specific reservoir targets and demands input for each time step



K-MODSIM Properties

NonStorage Node Properties (10)

Node Name: **BS_inf**

Description:

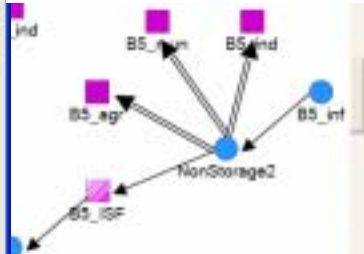
☒ Varies By Year ☐ Interpolate

Tools

Start Date	End Date	Volume/Month
10/1/1982	10/31/1982	2373
11/1/1982	11/30/1982	1490
12/1/1982	12/31/1982	1599
1/1/1983	1/31/1983	1254
2/1/1983	2/28/1983	871
3/1/1983	3/31/1983	1190
4/1/1983	4/30/1983	6887
5/1/1983	5/31/1983	3882
6/1/1983	6/30/1983	8539
7/1/1983	7/31/1983	16210

OK Cancel Apply

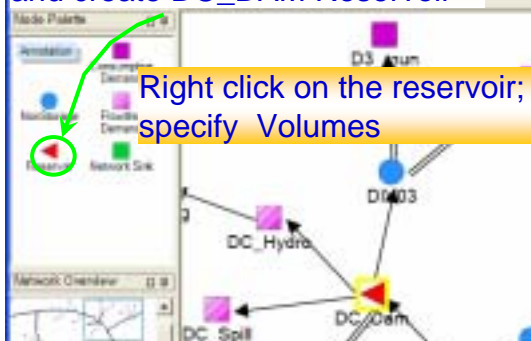
For multi-year simulations, time series data can be automatically entered through flat file import--



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

Accounting Active Storage arc unit cost calculated as:

$$c_l = -(50000 - 10 \cdot OPRP_i)$$

Reservoir Node Properties (152)

Node Name: **DC_Dam**

Description:

General | Targets | Evaporation | Groundwater Storage | Power

Reservoir Information

Reservoir Volume: **14000**

Storage Volume: **41000**

Spill Volume: **17000**

Priority

Priority Number: **800** **OPRP_i**

OK Cancel Apply

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

The screenshot shows the MODSIM software interface. On the left, a network diagram displays various nodes including DC_Dam, DC_Hydro, DC_Spill, DC_Run, DC3, B5, Bo_Chang, and DIV02. A red triangle icon on the DC_Dam node is circled in green. On the right, the 'Reservoir Node Properties (151)' dialog box is open, showing the 'General' tab. The 'Node Name' is 'DC_Dam'. A yellow text box with a blue border contains the text: 'High target storages can be entered; maximum capacity always takes precedence'. Below this, a table titled 'Reservoir Target Storage' is visible, showing a list of dates and values.

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

End Date	Value
10/11/1982	89058
11/10/1982	85058
12/10/1982	77058
1/11/1983	72058
2/10/1983	70058
3/11/1983	69113
4/10/1983	65079
5/11/1983	60058
6/10/1983	50048

The screenshot shows the MODSIM software interface. On the left, a network diagram displays various nodes including DC_Hydro, DC_Spill, DC_Dam, DC_Run, DC3, B5, Bo_Chang, and DIV02. A red triangle icon on the DC_Dam node is circled in green. On the right, the 'Reservoir Node Properties (151)' dialog box is open, showing the 'General' tab. The 'Node Name' is 'DC_Dam'. A yellow text box with a blue border contains the text: 'Used for hydropower'. Below this, a table titled 'Reservoir Target Storage' is visible, showing a list of dates and values.

Used for hydropower

Area	Capacity	Elevation	Hydraulic Capacity
13650	162500	6743	57000
21080	264450	6745	138806



Accurate Calculation of Losses

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



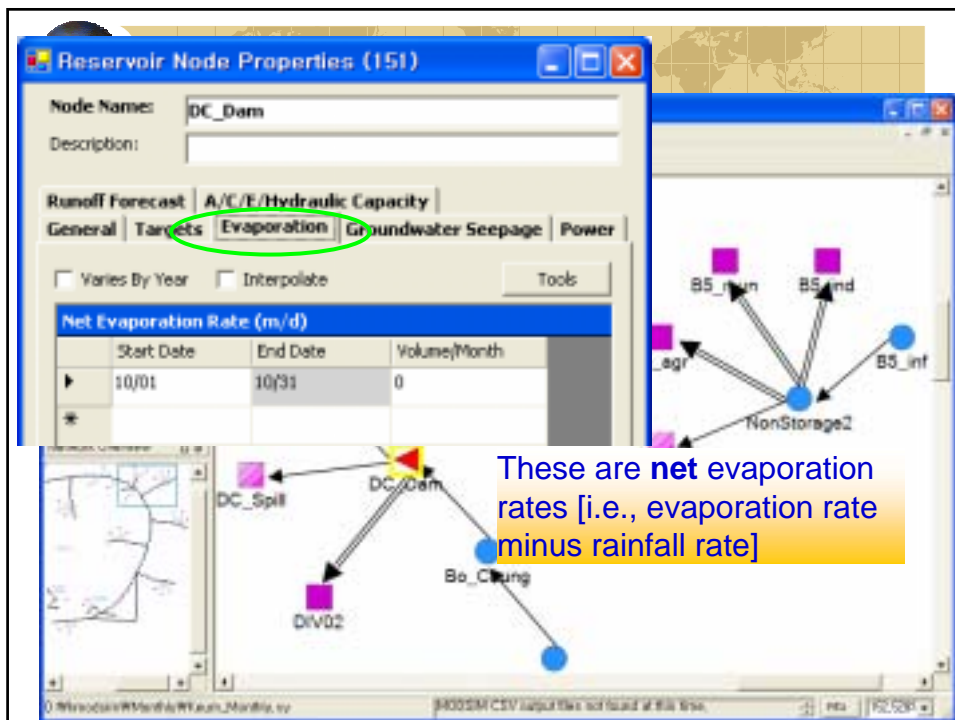
- Channel loss (function of average flow entering channel or river reach)
- Reservoir seepage (function of average storage in reservoir)

The screenshot displays the MODSIM software interface. On the left, a network diagram shows nodes labeled DC_Hydro, DC_Dam, DC_Spill, and DC_Dam. A yellow circle highlights the DC_Dam node. On the right, the 'Reservoir Node Properties (151)' dialog box is open. The 'General' tab is selected, and the 'Groundwater Seepage' checkbox is checked. The 'Reservoir Seepage Rate' is set to 0. The 'Model Generated Return Lags' section is highlighted with a blue circle, and the 'User Generated Return Lags' section is also visible. A yellow callout box points to the 'Groundwater Seepage' checkbox with the text: 'If reservoir seepage important, entered in this spread-sheet'. Another yellow callout box points to the 'Model Generated Return Lags' section with the text: 'Glover model parameters to calculate return flows'. A blue callout box at the bottom left of the network diagram states: 'If desired, seepage can return (lagged) to 1 (or more) downstream nodes'.

If reservoir seepage important, entered in this spread-sheet

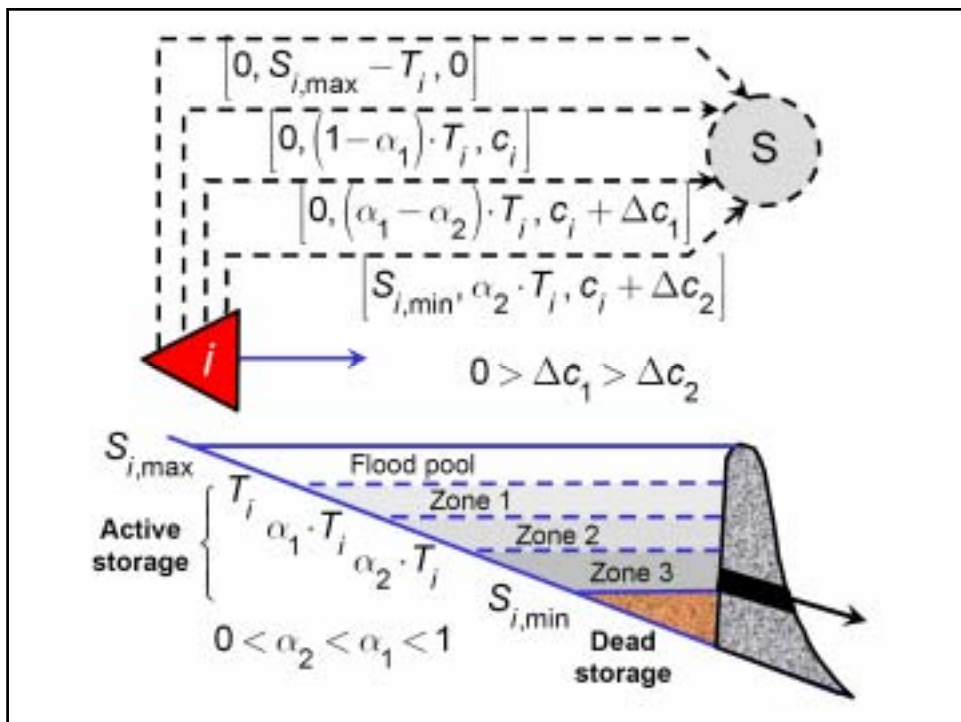
Glover model parameters to calculate return flows

If desired, seepage can return (lagged) to 1 (or more) downstream nodes



Reservoir Balance Operations

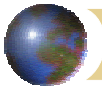
- K-MODSIM includes **reservoir balance tables** that allow reservoirs to be divided into arbitrary number of **operating zones**
- For multi-reservoir systems, allows operations that **balance water levels** in all projects (to avoid emptying some reservoirs and overfilling others)
- K-MODSIM defines 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



The screenshot shows the MODSIM software interface. The main window displays the Reservoir Node Properties (156) dialog box. The dialog box has tabs for General, Targets, Evaporation, Groundwater Seepage, and Power. The General tab is selected, showing the Node Name (DC_Dam) and Description. The Reservoir Layer Priorities section is expanded, showing a table with Incremental Priority and % Target Storage values. The table has three rows: -150 (90.5), -50 (95.5), and 0 (100.0). A blue arrow points to the 100.0 value in the % Target Storage column. The background shows a network diagram with various nodes and connections.

Reservoir Balance Operations

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



Hydropower Calculations

Accurate hydropower calculations in K-MODSIM

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

Reservoir Properties (17)

Efficiency tables nonlinear functions of discharge and head on turbines

Links:

Bypass Out Link:

Normal Out Link:

Power:

Maximum Power:

Plant Elevation:

Edit Balance Table

Variable Tw

Tailwater elevation as function of discharge considered in Hydropower plant net head

Demand Node Properties (50)

Node Name:

Description:

General Time Series Groundwater


Demand Node Type:

Demand Definition Type:

Priority

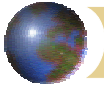
Priority Number:

OK Cancel Apply

Use Demand Node icon  to create B5_agr demand

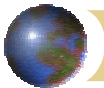
Set priority to 300 which is higher than DC_Dam reservoir(800), but lower than all other demands in the subbasin

Diagram showing a network of nodes and links. A pink square icon is highlighted, representing the demand node B5_agr. The diagram includes nodes like B5_ind, B5_agr, B5_ISF, and NonStorage2, connected by arrows representing links.



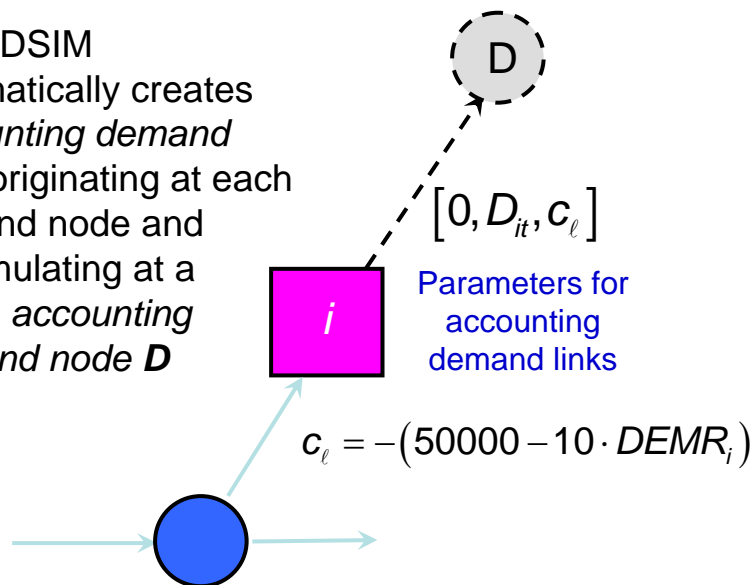
Types of Demands

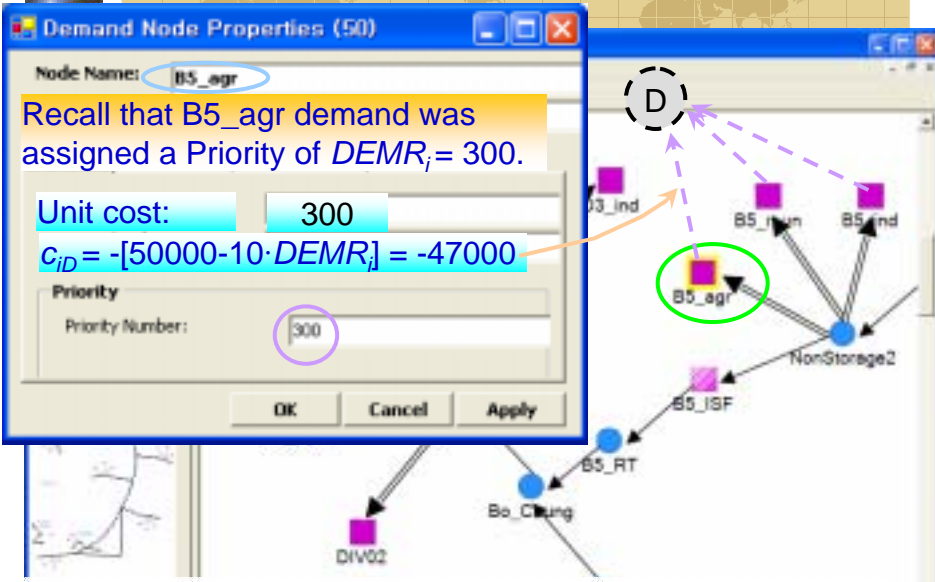
- Historical **diversions**
- Decreed **natural flow** right amounts
- **Storage rights**
- Predicted agricultural demands based on “outside” **consumptive use** calculations (performed outside K-MODSIM)
- Projected **municipal and industrial** demands



Consumptive Demands

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





Demand Node Properties (50)

Node Name: B5_agr

Recall that B5_agr demand was assigned a Priority of $DEMR_i = 300$.

Unit cost: 300

$C_{iD} = -[50000 - 10 \cdot DEMR_i] = -47000$

Priority

Priority Number: 300

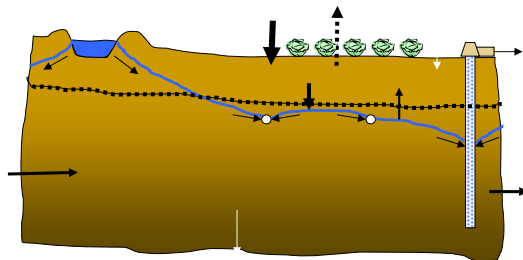
OK Cancel Apply

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

☒ Varies By Year ☐ Interpolate

Tools

Time Series Data (m/d/yr)

Start Date	End Date	Volume/Month
6/1/1983	6/30/1983	2062

OK Cancel Apply

B5_agr demands entered as time series data

Demand Node Properties (500)

Node Name: B5_agr

Description:

General | Time Series | Groundwater

Groundwater Pumping

Pumping Rate: 0 Pumping Priority: 0

Create Table: Depletion Lag Table List

Edit Table:

Delete Table:

Groundwater Infiltration

Create Table: Infiltration Lag Table List

Edit Table:

Number	Location	Fraction
1	<u>B5_RT</u>	1

Delete Table:

☐ Variable

65% irrigation efficiency

35% of irrigation application infiltrates to ground-water

Infiltration Rates (in/d)

Start Date	End Date	Rate (in/d)
10/01	10/31	0.35
11/01	11/30	0.35

CSV reports the software at this time.

Network Diagram:

Flow from Bo_Chang to B5_RT to B5_ISF to B5_agr to B5_run and B5_ind.

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

When finished, click Apply, then OK

Network Diagram:

Flow from Bo_Chang to B5_RT to B5_ISF to B5_agr to B5_run and B5_ind.

Links between NonStorage2 & B5_agr

Link Name	Link Type	Order of Use	Channel Type
57 B5a_75	Standard	NA	Default
151 B5a_25	Standard	NA	Default
152 B5a_100	Standard	NA	Default
153 B5a_50	Standard	NA	Default

Link Cost

Link Name

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 (150)

Link Name: DC_Hydro_DC_Reg

Description:

Link Type: Standard

General Advanced

Link Channel Type: Default

Cost:

Link Cost: 0

Capacities

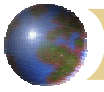
☐ Seasonal Capacity: Minimum Rate: 0

☐ Varies By Year ☐ Interpolate Tools

Start Date	End Date	Volume/Month
10/01	10/31	99999999

Link Capacity

If a channel has Variable Capacities, then we can specify them.



Instream Flow Uses Simulated using “Flow-Through” Demands

Link parameters:

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



Iteration
Counter

$$[q_{3D}^{k-1}, q_{3D}^{k-1}, 0]$$

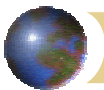
$$[0, D_3, c_{3D}]$$

$$q_{3D}^k$$



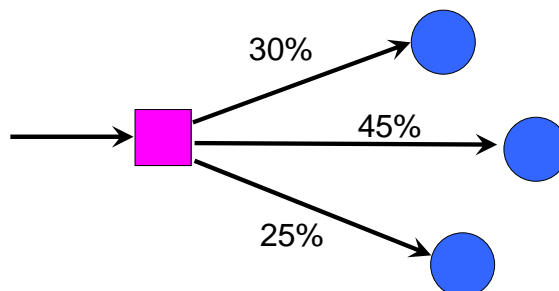
Water diverted from
from river and then
replaced—conceptually,
never removed

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

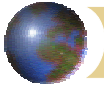
The screenshot shows the KMODSIM software interface with a network diagram. A node labeled 'DC_Hydro' is highlighted with a green circle. A green arrow points from this node to the 'Demand Node Properties (72)' dialog box. The dialog box has three tabs: 'General', 'Time Series', and 'Flow Thru'. The 'Flow Thru' tab is selected. It contains a 'Bypass Credit Link' dropdown and a 'Flow Thru Nodes' table.

Link Link	Flowthru Nodes	Flowthru Fractions
	DC_Reg	1

The dialog box also has 'OK', 'Cancel', and 'Apply' buttons.

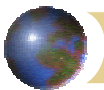
The screenshot shows the KMODSIM software interface with a network diagram. A node labeled 'NetworkSink' is highlighted with a green circle. A green arrow points from this node to the 'Sink Node Properties (158)' dialog box. The dialog box has two tabs: 'General' and 'Time Series'. The 'General' tab is selected. It contains a 'Node Name' field with 'NetworkSink' entered, a 'Demand Node Type' dropdown set to 'Consumptive', a 'Demand Definition Type' dropdown set to 'Time Series', and a 'Priority Number' field with '1' entered. The 'Priority' label is also circled in green. The dialog box also has 'OK', 'Cancel', and 'Apply' buttons.

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



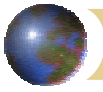
Hydrologic States

- 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.



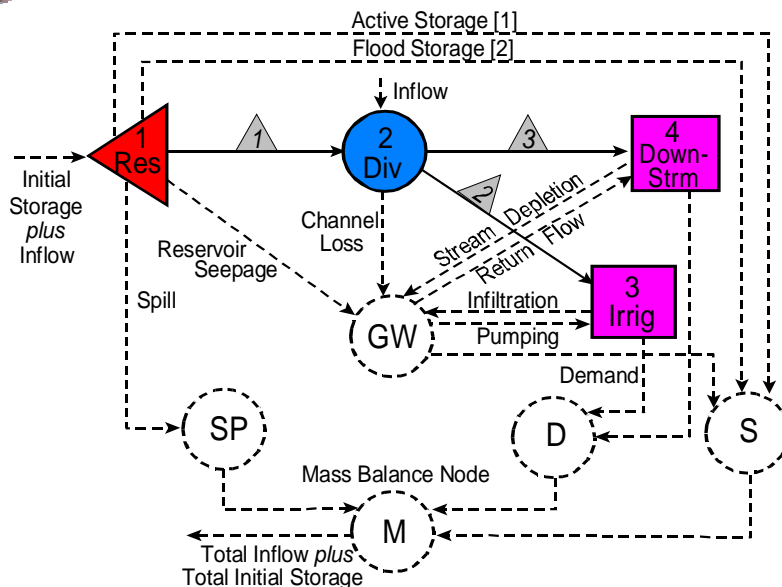
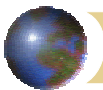
Streamflow Routing

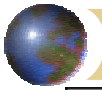
- For simulation of **daily** streamflow, necessary to consider **channel routing**
- Designate network link as **routing link**
- Inflow to this link distributed over time in accordance with routing coefficients calculated by **Muskingum** formula or **Backrouting method**
- User may also directly **input**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

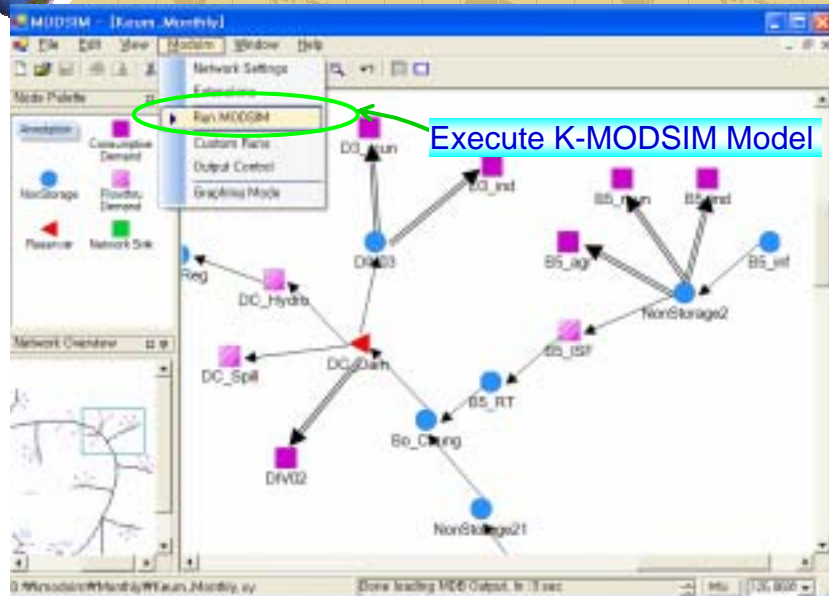
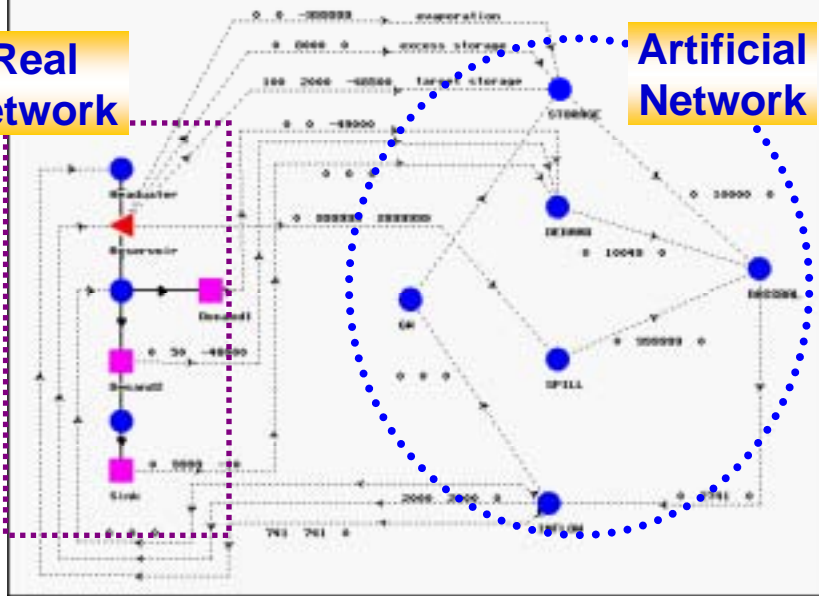




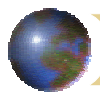
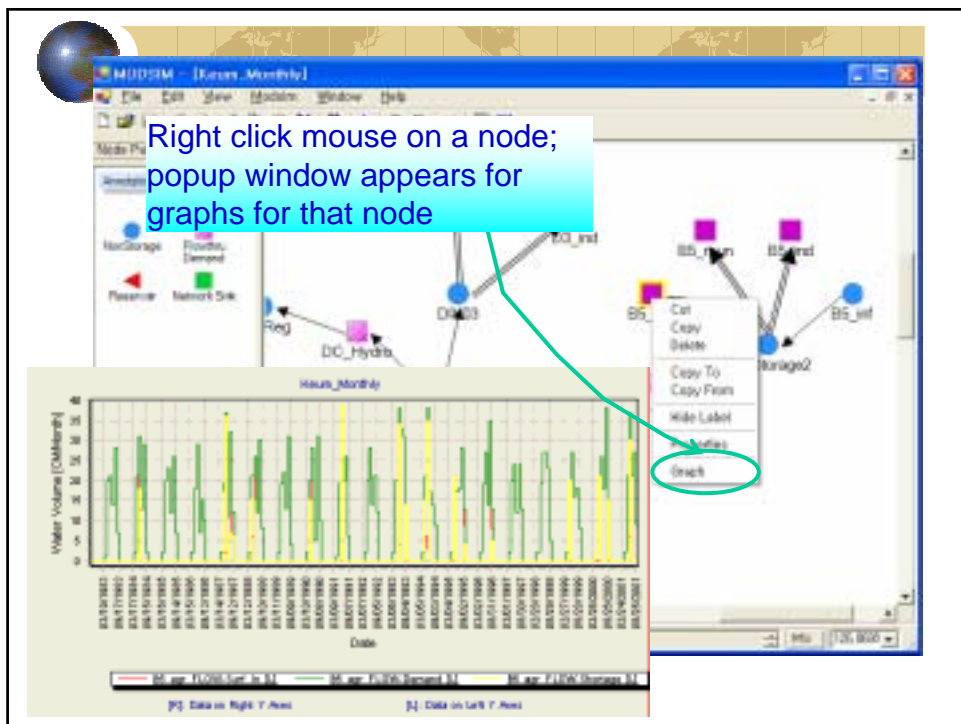
Real and Artificial Network

Real
Network

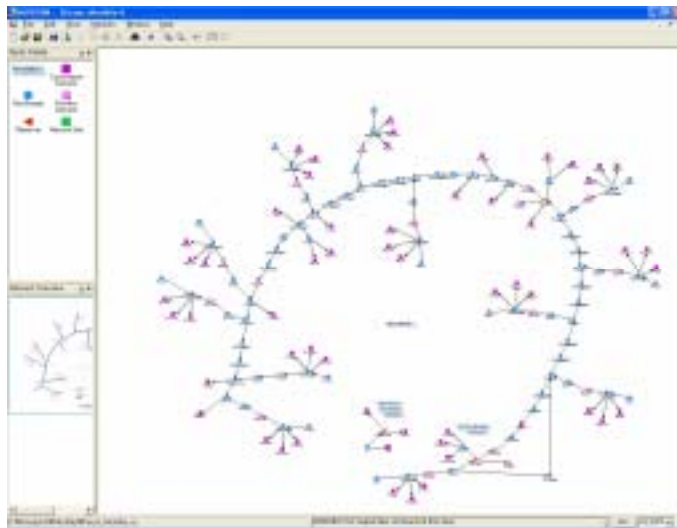
Artificial
Network

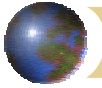


Execute K-MODSIM Model



Application Results of Geum River Basin



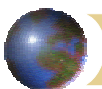
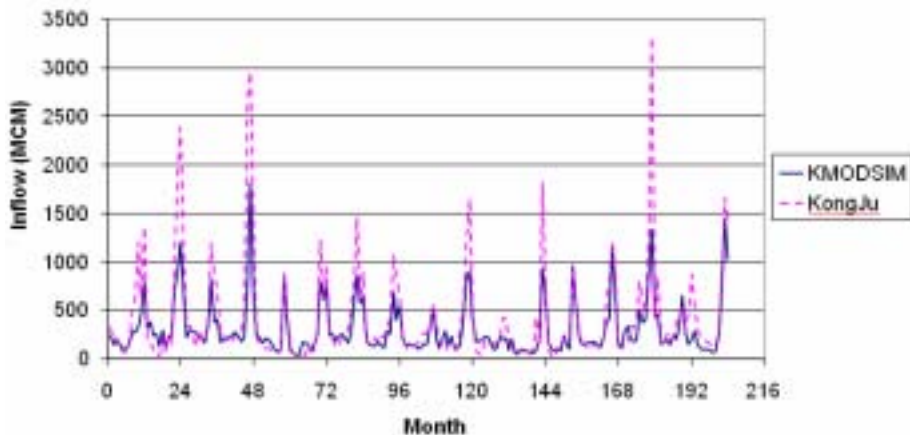


Monthly Calibration Results

Daecheong Reservoir Inflow: $r^2 = 0.78$; ave. RMSE = 10.3 (MCM/mo)

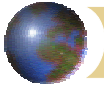
Gongju gage: $r^2 = 0.73$; ave. RMSE = 39.4 (MCM/mo)

Gyuam gage: $r^2 = 0.66$; ave. RMSE = 27.3 (MCM/mo)



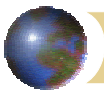
Daily Calibration

- 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**

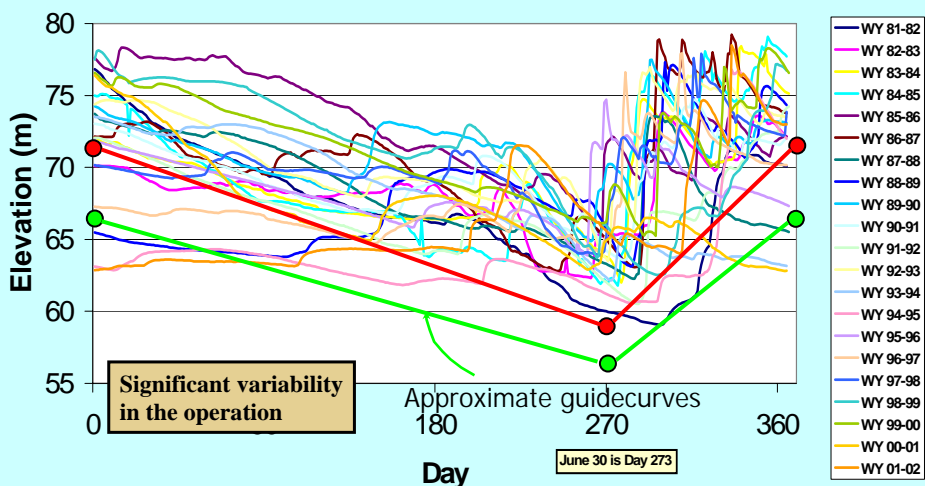


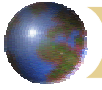
Management System Calibration

- 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



Daechung Reservoir - Historical Operation





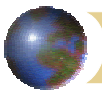
Guide Curve Analysis

- 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:

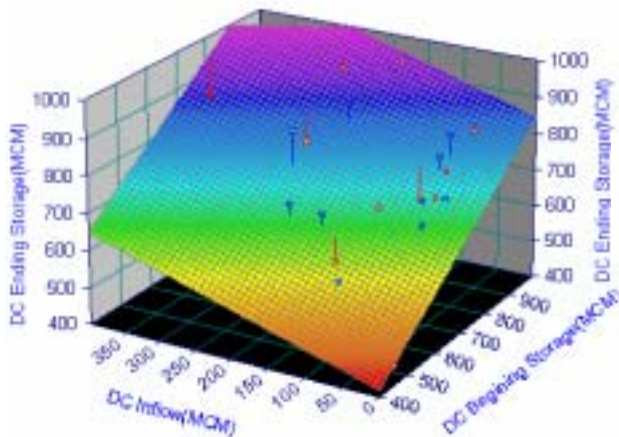
e.g.

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

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



Adaptive Guide Curves for Historical Daechong Operation



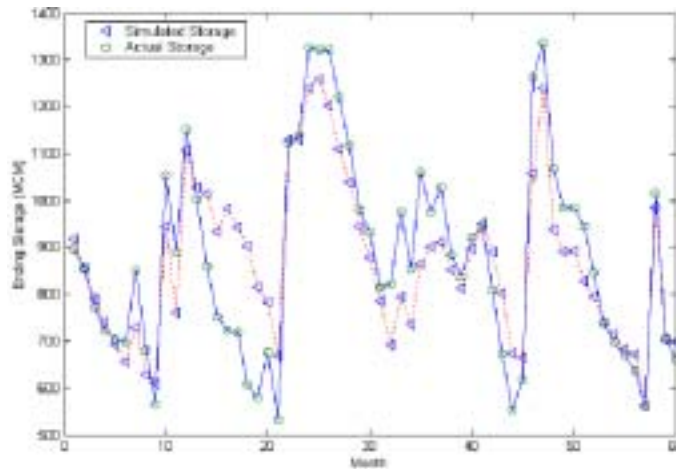
April

$$z = a + bx + cy$$

$a = 130.22677$ $b = 0.71533612$
 $c = 0.58411222$



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

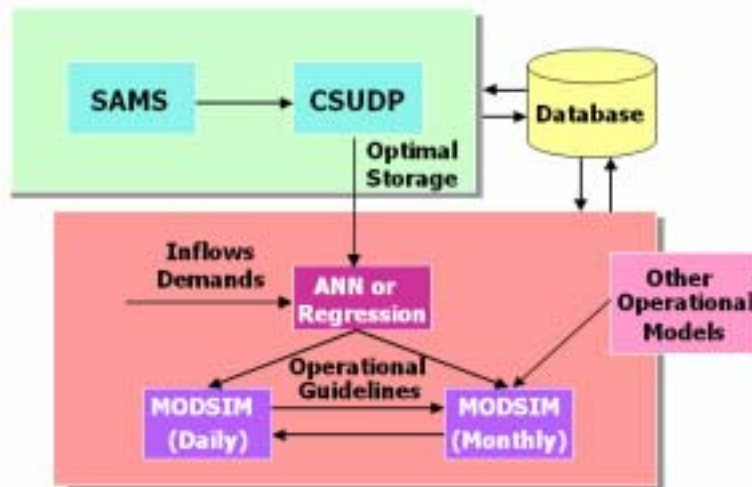


ANN vs. Regression Analysis

- 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



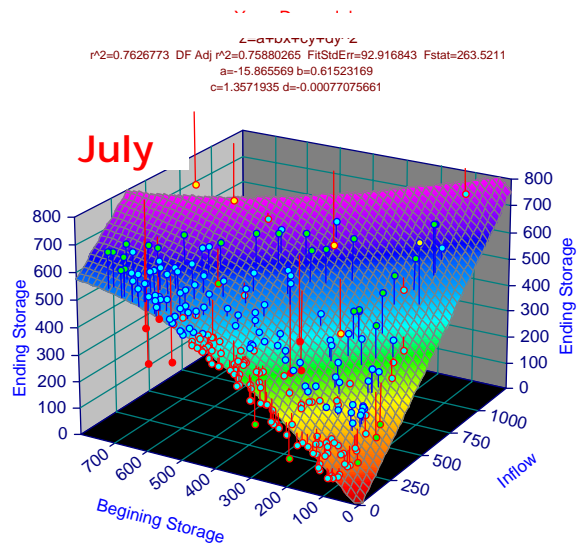
Implicit Stochastic Optimization

- 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 multivariate AR model
- Input into **CSUDP** Generalized Dynamic Programming Package (J. Labadie, Colorado State University)

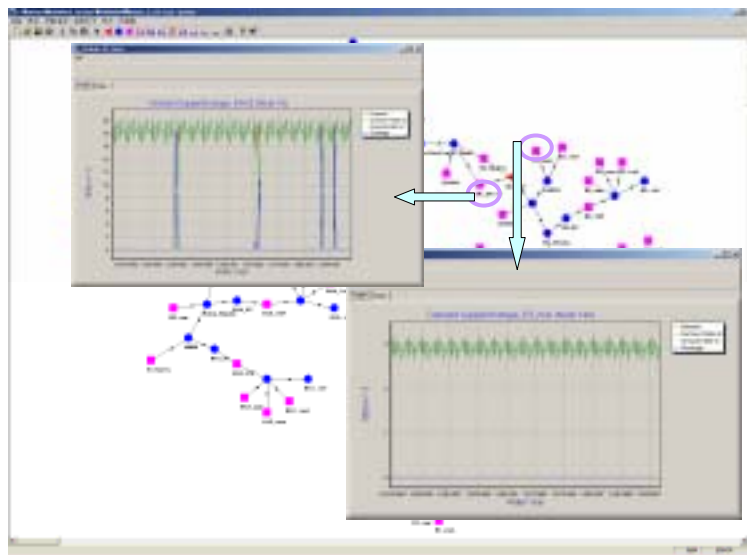


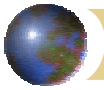
CSUDP Operation Rules--Yongdam

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

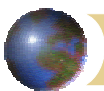
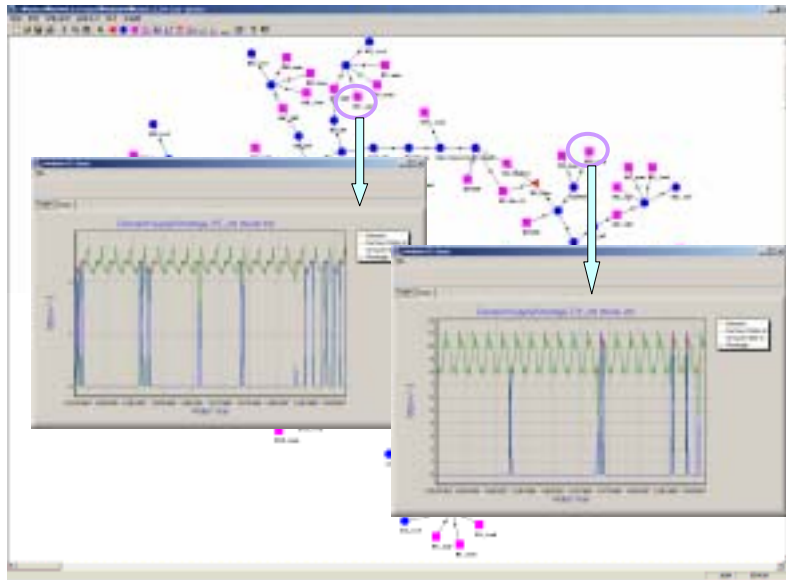


Integrated Monthly Operation (Municipal Water)

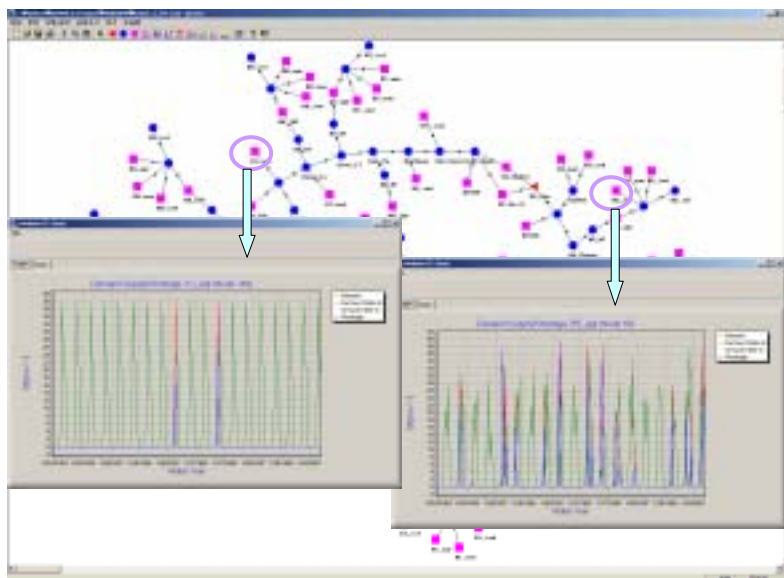


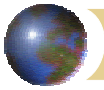


Integrated Monthly Operation (Industrial Water)

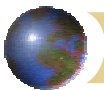
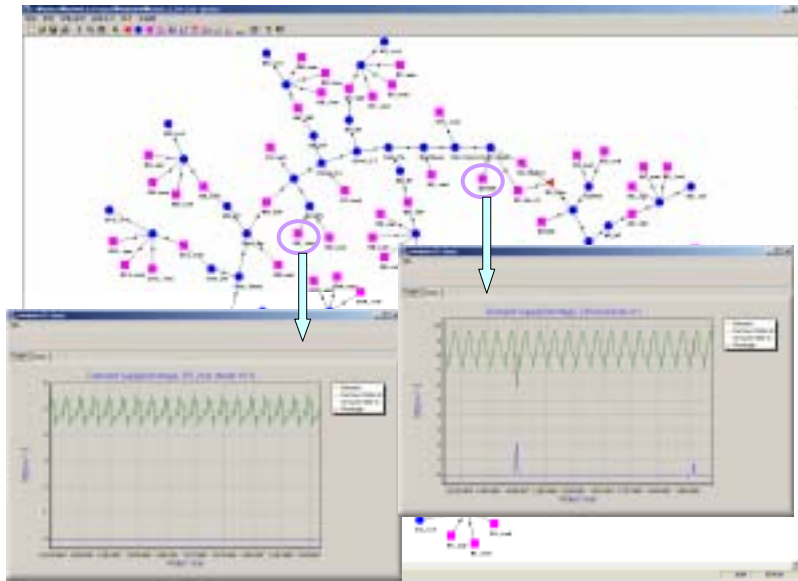


Integrated Monthly Operation (Agricultural Water)

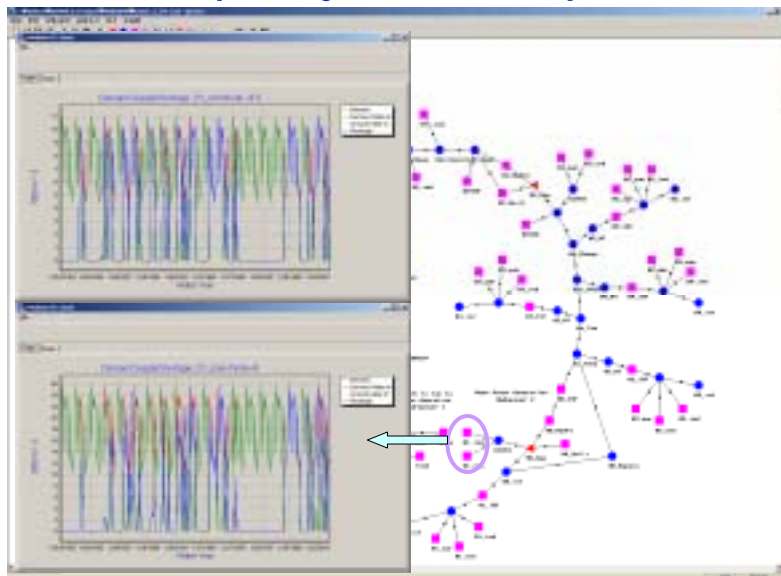


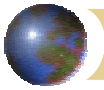


Integrated Monthly Operation (Trans-mountain Water)

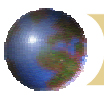
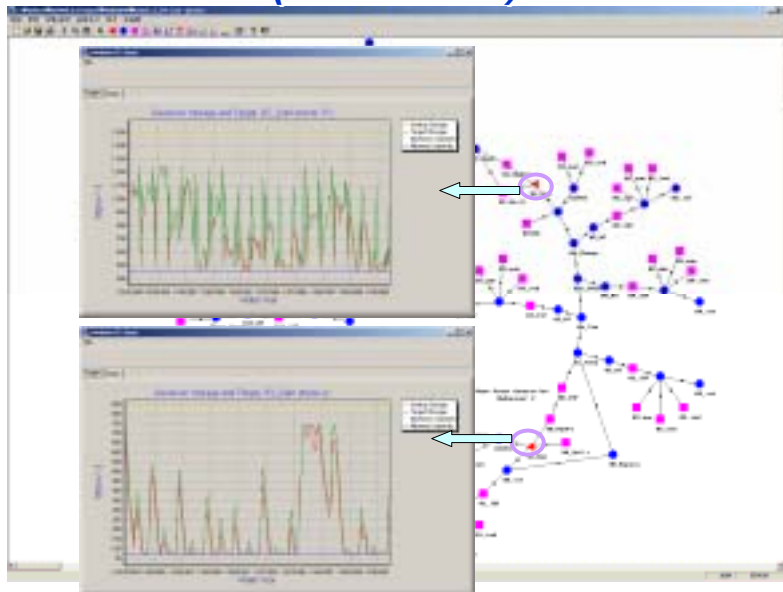


Integrated Monthly Operation (Jeonju Diversion)

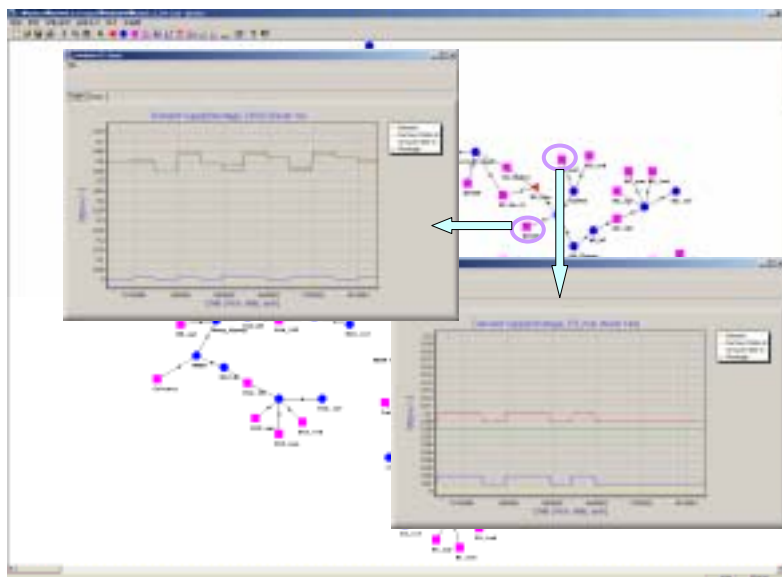




Integrated Monthly Operation (Reservoirs)

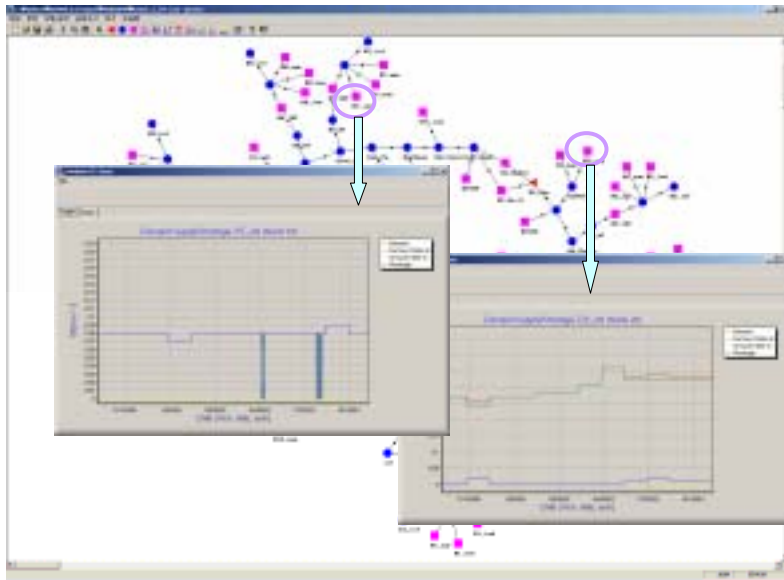


Daechong - Daily (Municipal Water)

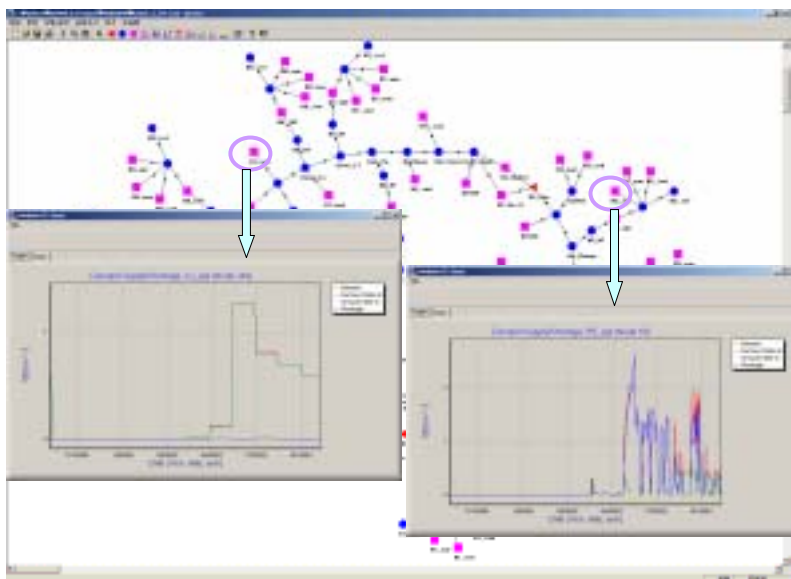




Daechong - Daily (Industrial Water)

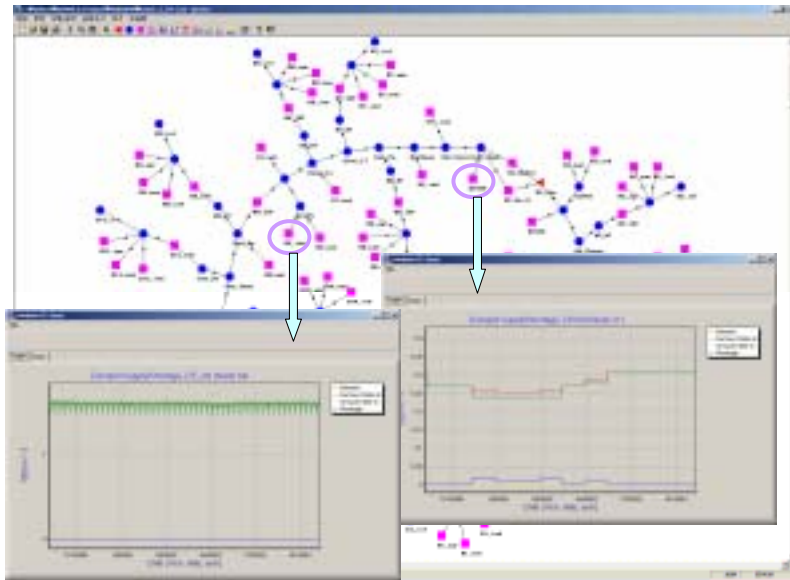


Daechong - Daily (Agricultural Water)

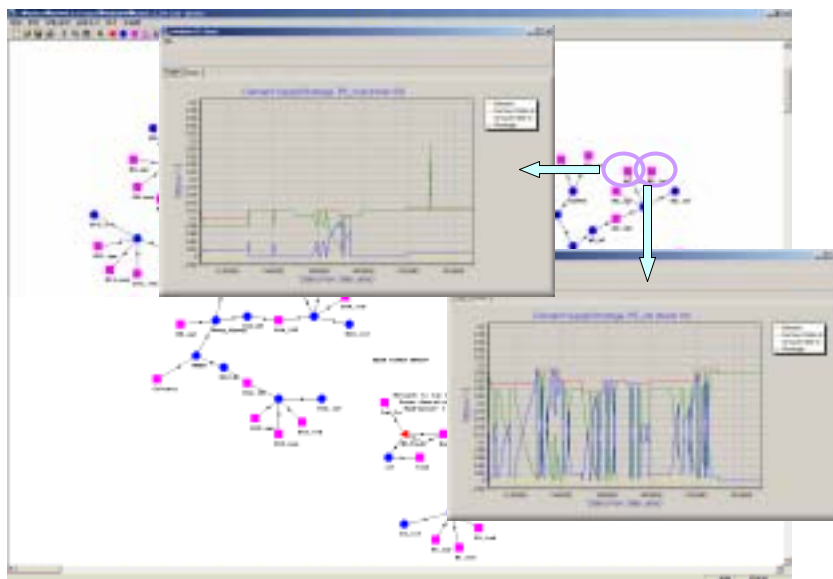


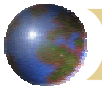


Daecheong - Daily (Trans-mountain Water)

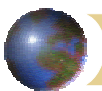
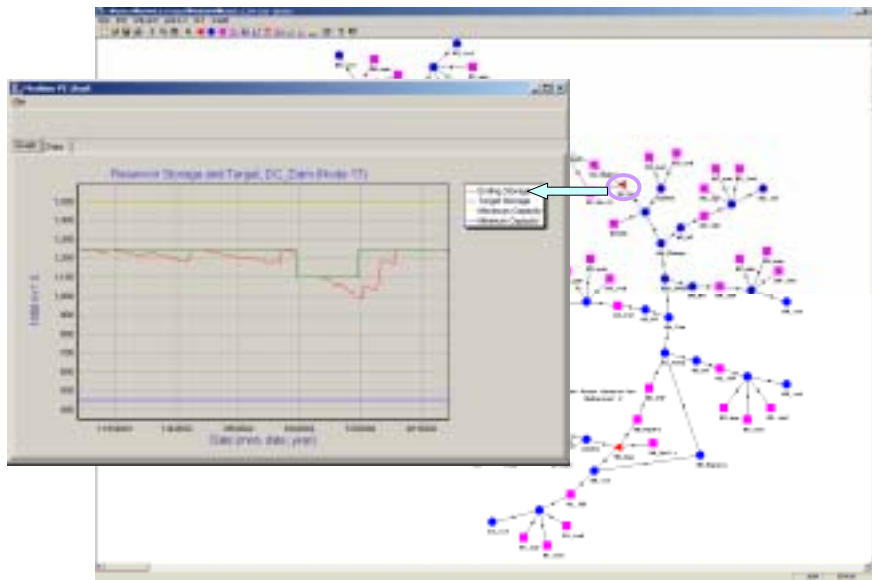


Daecheong - Daily (Subbasin Water)

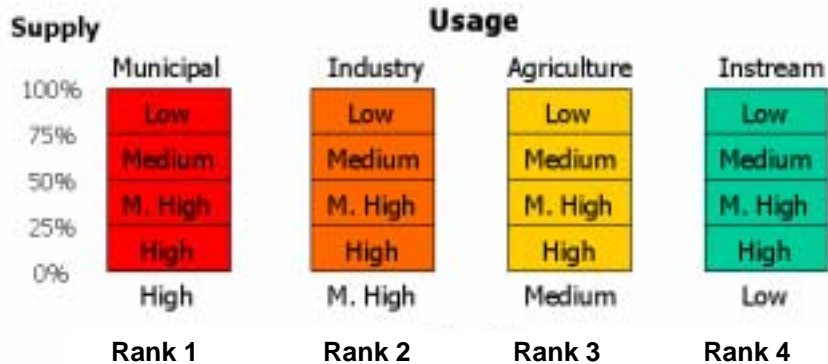


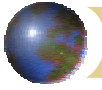


Daecheong - Daily (Reservoirs)



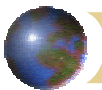
Deficit Sharing Policy





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