Tutorial of QUAL2E-Plus

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Qual2E-Plus Exercise

- Generals of Qual2E-Plus
- BOD & DO Simulation
- Heat Balance
  - Difference between with or without heat balance
- Eutrophication
  - Nutrients (N, P) & Algae
- Geum River Applications
- Water Quality Improve Increasing Discharge Release

Generals of Qual2E-Plus

Introduction

- Water Quality Model for River Water Quality
  - Steady State (Qual2E-Plus)
  - Unsteady State (Koriv1-Win)
- Assume Lateral, and Vertical Mixing is Completed
- Simulating 15 Water Quality Constituents
- Multiple Discharge, Withdrawal, Tributaries, Inflow and outflow

Governing Equation

1D Convection & Diffusion

$$V\frac{\partial c}{\partial t} = \frac{\partial (A_c E \frac{\partial c}{\partial x})}{\partial x} dx - \frac{\partial (A_c U c)}{\partial x} dx + V\frac{dc}{dt} + s$$

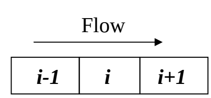
Accumulation **Dispersion** **Convection** **Kinetics** **S/Sink**

Transport (Dispersion + Convection)

Where, $V =$ Volume, $c =$ Concentration
$A_c =$ Cross section Area
$E =$ Longitudinal Dispersion, $x =$ Distance
$U =$ Averaged Velocity
$s =$ Sources(+)/sink (-)

Numerical Algorithm

$$\frac{\partial c}{\partial t} = \frac{\partial \left(A_c E \frac{\partial c}{\partial x} \right)}{A_c \partial x} - \frac{\partial (A_c U c)}{A_c \partial x} + rc + p + \frac{s}{V}$$



$$\frac{\partial c}{\partial t} = \frac{(A_c E)(c_{i+1} - c_i)}{V_i \Delta x_i} + \frac{(A_c E)(c_{i-1} - c_i)}{V_i \Delta x_i} + \frac{Q_{i-1} c_{i-1} - Q_i c_i}{V_i} + r_i c_i + p_i + \frac{s_i}{V_i}$$

$$\frac{c_i^{l+1} - c_i^l}{\Delta t} = \frac{(A_c E)_{i,i+1} \left(c_{i+1}^{l+1} - c_i^{l+1} \right)}{V_i \Delta x_i} + \frac{(A_c E)_{i-1,i} \left(c_{i-1}^{i+1} - c_i^{l+1} \right)}{V_i \Delta x_i} + \frac{Q_{i-1} c_{i-1}^{l+1} - Q_i c_i^{l+1}}{V_i}$$

$$+ r_i c_i^{l+1} + p_i + \frac{s_i}{V_i}$$

Transport

- advection
  - Based on the assumption of Steady State Varied flow. Flow Balance is

$$Q_{i-1} \pm Q_{x,i} - Q_i = 0$$

1. Power Equation for Velocity and Discharge.

$$U = aQ^b$$

$$H = \alpha Q^\beta$$

2. Manning Formula for Channel and Flow.

$$A_C = \frac{Q}{U} \qquad Q = \frac{1}{n} A_C R^{2/3} S_E^{1/2}$$

Dispersion

- Longitudinal Dispersion.

$$E = 3.11 KnUH^{5/6}$$

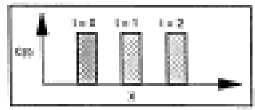
where,
E = Longitudinal Dispersion (m^2/s) , H = Depth (m)
n = Manning, K = Parameter
U = Velocity

where, $K = \frac{E}{HU^*}$

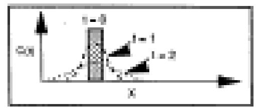
U^* = shear velocity (m/s)

- Transport = Advection+ Diffusion (or Dispersion)

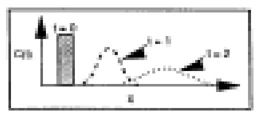
1) Due to advection: organized flow



2) Due to diffusion or diffusion-like processes which tend to reduce gradients



3) Due to advection and diffusion



Mixing Processes

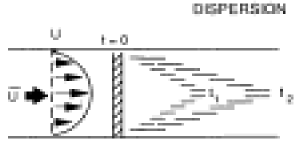
MOLECULAR DIFFUSION

Due to random molecular motion.

TURBULENT DIFFUSION

Due to random turbulent eddie.

DISPERSION



Due to systematic non-uniformatives in velocity distribution.

Problem #1 BOD & DO Simulation

- Objectives
  - Acquire an understanding of BOD & DO relationships, Basic modeling scheme
- Problem description
  - 2 tributaries act as point sources, find out BOD and DO concentrations of main stream

Kinetics

- Carbonaceous BOD (CBOD) and DO

$$\frac{dL}{dt} = -K_1 L - K_3 L$$

and

$$\frac{do}{dt} = -K_2(o_S - o) - K_1 L - \frac{K_4}{L}$$

Where,

L = CBOD (mg/l), o = DO (mg/l)
K_1 = BOD decay (d^{-1}), K_2 = reaeration (d^{-1})
K_3 = BOD settling (d^{-1}), o_S = Saturated DO (mg/l)
K_4 = Sediment Oxygen Demand ($mg^{-2}d^{-1}$)

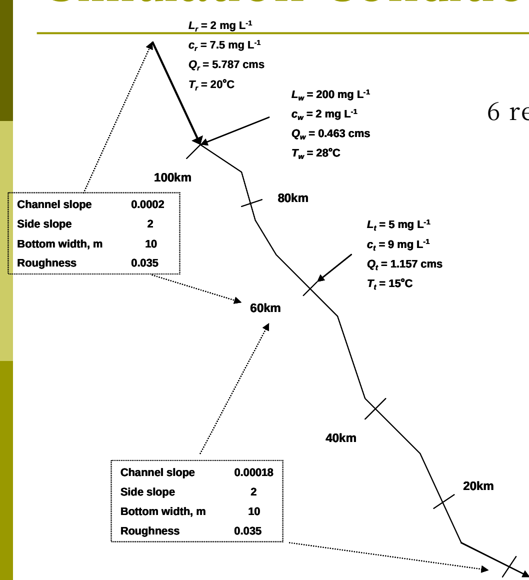
- Reaction Rate K is Temperature related

Reach Configuration

- WWTP is located at 100 km (KP100), and tributary is located at KP60 from downstream
- decay rate of CBOD K_1 is $0.5 d^{-1}$ at 20 ° C
- At Downstream 20km from WWTP CBOD settling rate K_3 is $0.25 d^{-1}$, SOD (Sediment Oxygen Demand) is $5 gm^{-2}d^{-1}$
- O'connor-Dobbins for reaeration rate K_2
- Temperature

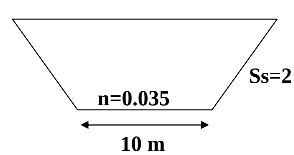
Parameter	KP>100	KP100-80	KP 80-60	KP<60
Temp(°C)	20	20.59	20.59	19.72

Simulation Condition

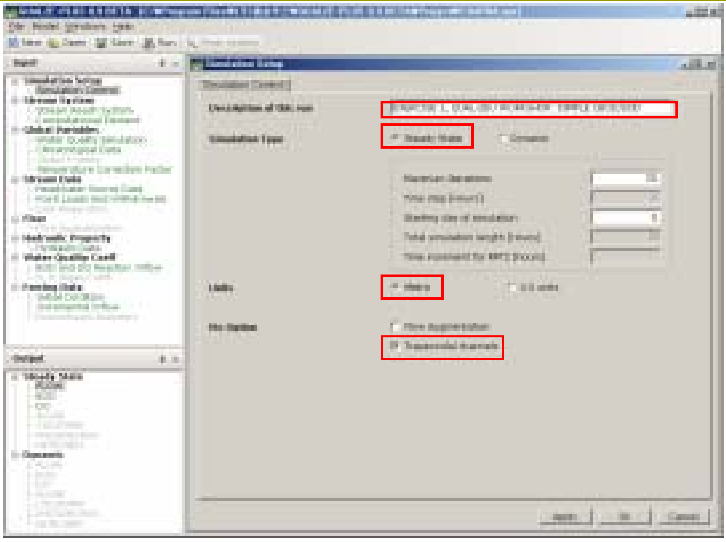


6 reaches, 2 Point Sources

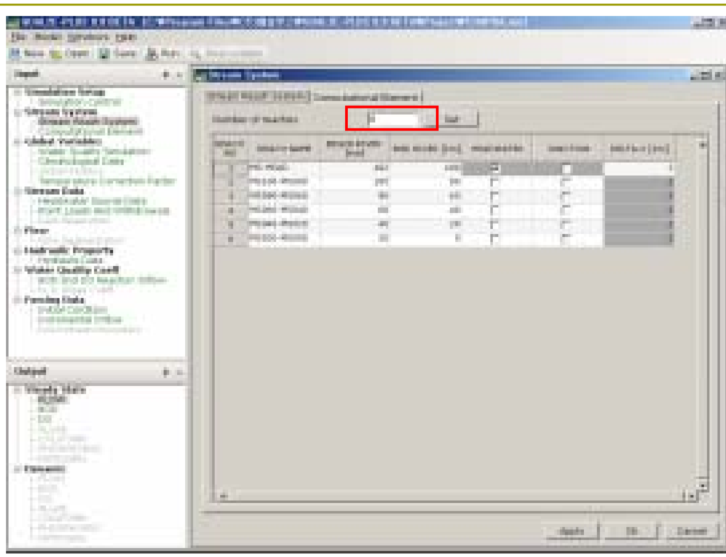
1. MS-HEAD
2. MS100-MS080
3. MS080-MS060
4. MS060-MS040
5. MS040-MS020
6. MS020-MS000



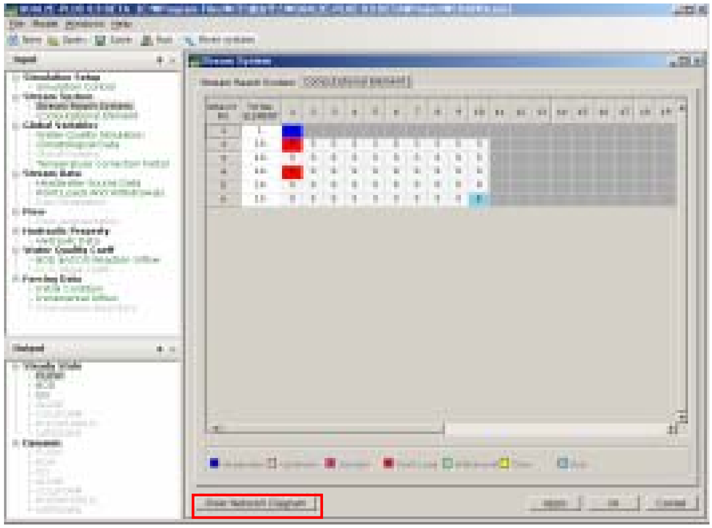
Simulation Description



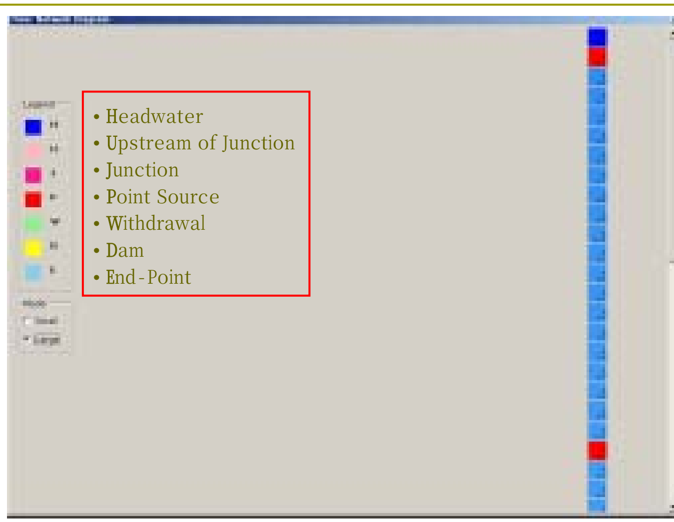
Stream System (Stream Reach)



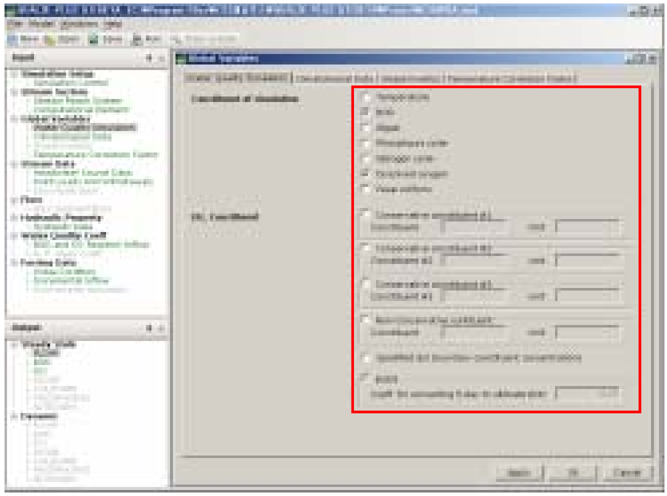
Stream System (Computational Element)



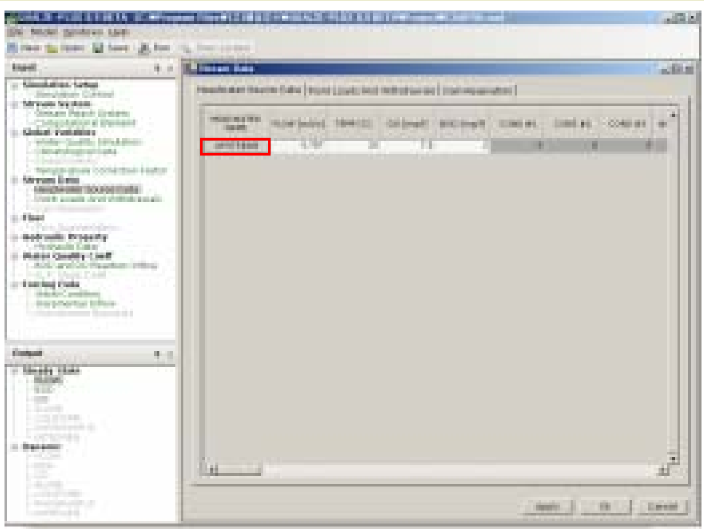
River Network Diagram



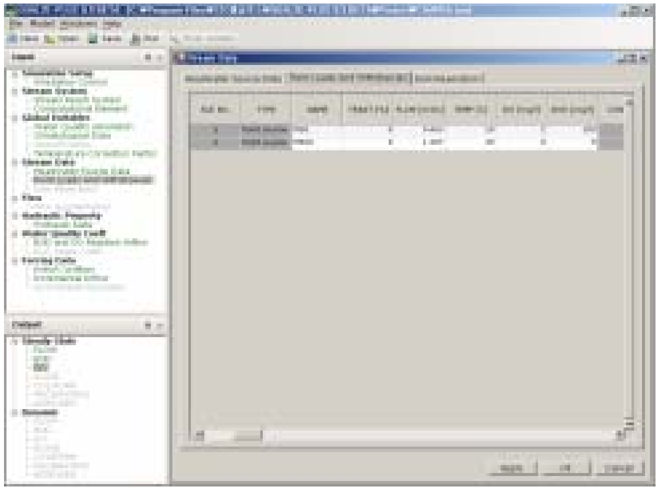
Global Variables (Water Quality Simulation)



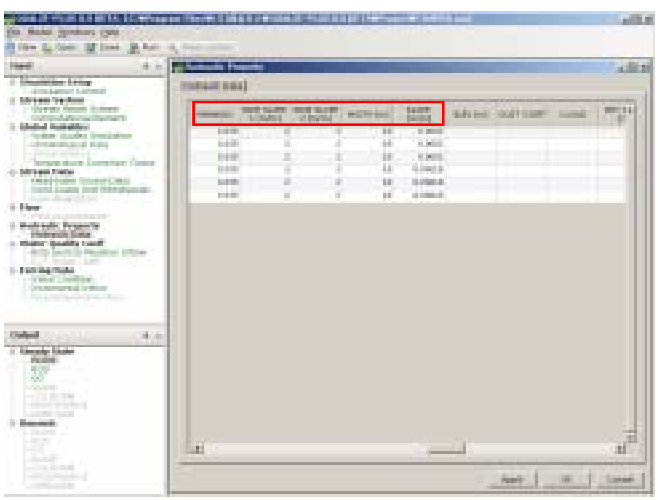
Stream Data (Headwater Source)



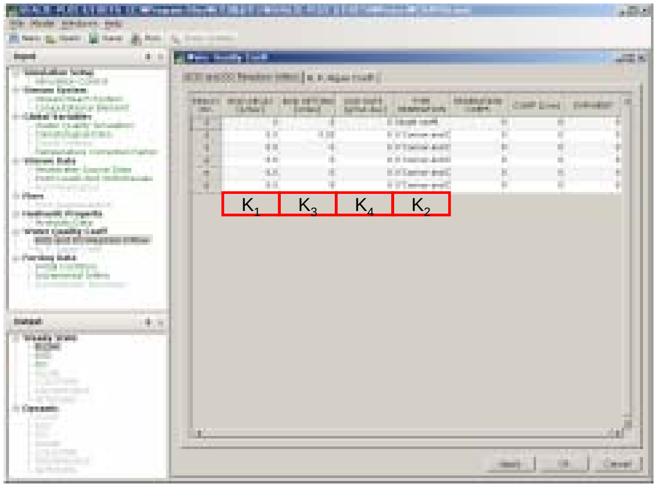
Stream Data
(Point Loads and Withdrawal)



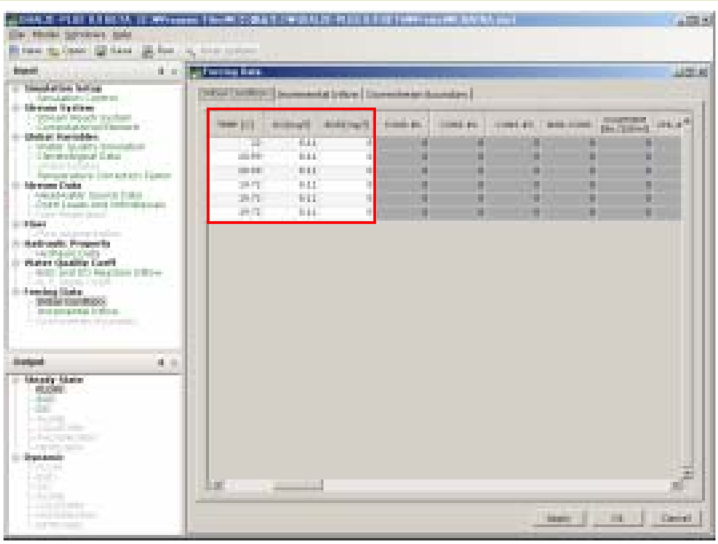
Hydraulic Property



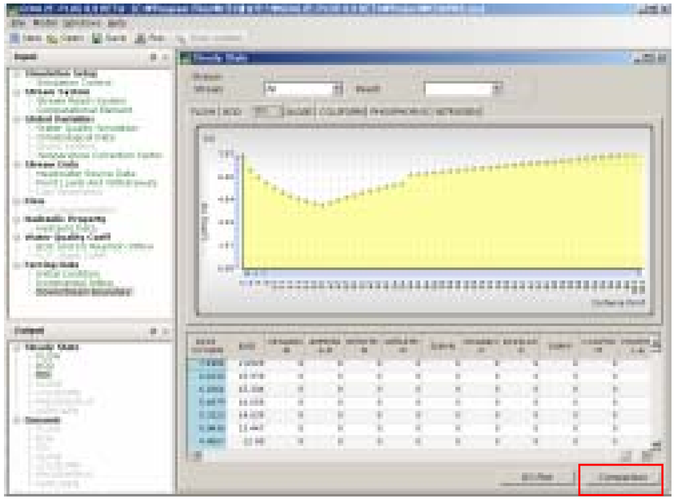
Water Quality Coefficients



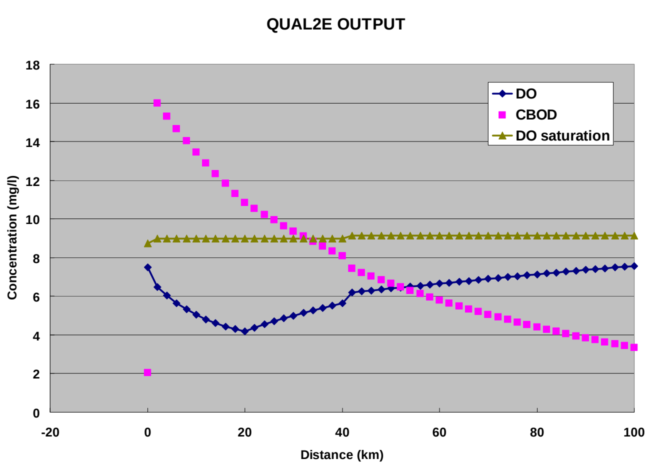
Forcing Data (Initial Conditions)



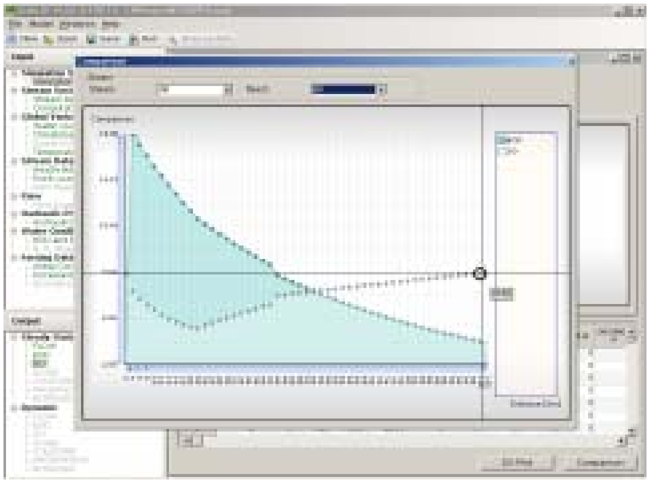
Output Results



Output



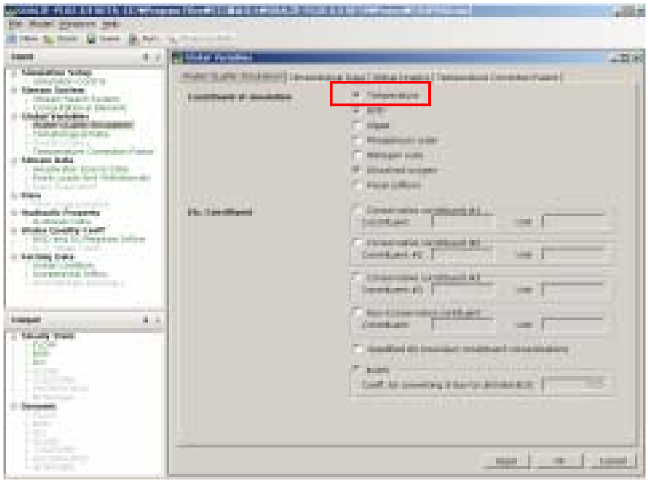
Qual2E-Plus Output



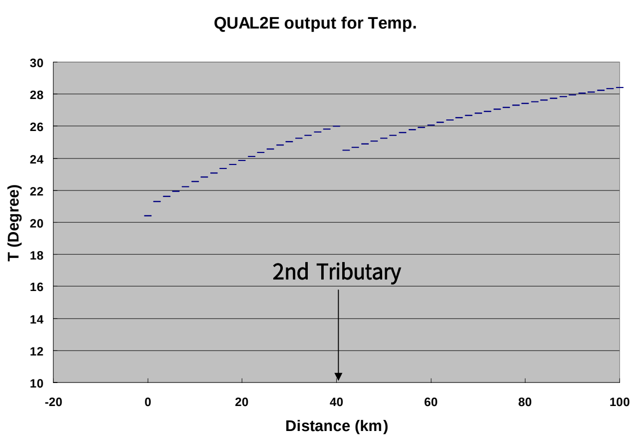
Problem #2 Heat Balances

- Objectives
  - Enabling temperature condition, check the difference between with and without temperature
- Problem Description
  - Find out the DO recovery rate considering temperature

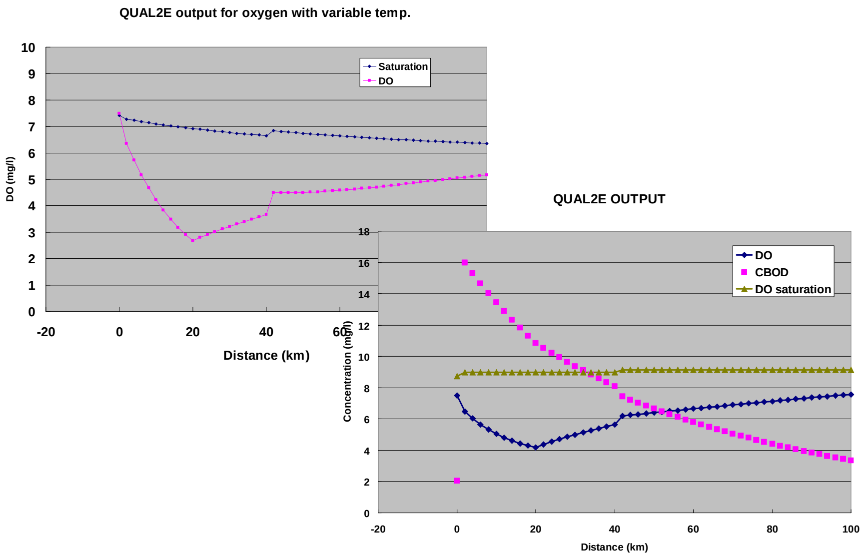
Enable Temperature



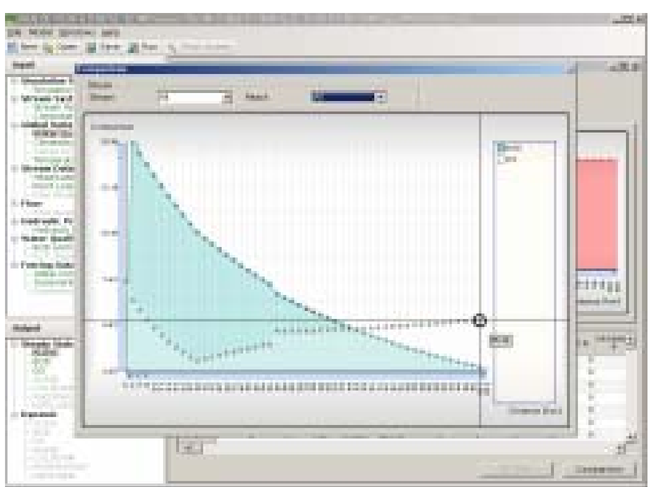
Temperature Variation



DO Variation with Temperature



Qual2E-Plus Output



DO concentration of previous run is 7.53 ppm

Problem #3 Eutrophications

- Objectives
  - Understanding Interactions of BOD & DO with other water quality constituents
- Problem
  - Enable N, P, and Algae and find out DO & BOD concentration and compare with the results of previous run

Kinetics

BOD-DO Simulation

$$\frac{dL}{dt} = -K_1 L - K_3 L$$

$$\frac{dO}{dt} = K_2(O_s - O) - K_1 L - \frac{K_4}{H}$$

where, L= BOD Conc., O= DO
O_S= DO Saturation
K_1= decay, K_2=reaeration
K_3= settling, K_4=SOD
H = depth

Temperature

$$s = \underbrace{H_{sn} + H_{an}}_{\text{Raduation}} - (\underbrace{H_{br} + H_c + H_e}_{\text{Water Body}})$$

where, H_{sn}= Net solar , H_{an}=Net atmosphere
H_{br}= reverse radiation
H_c= Overturn, H_e= Evaporation

Nutrients and Algae

- Algae (A)

$$\frac{dA}{dt} = \mu A - \rho A - \frac{\sigma_1}{H} A$$

Acc. growth respiration settling

- Org-N (N_4)

$$\frac{dN_4}{dt} = \alpha_1 \rho A - \beta_3 N_4 - \sigma_4 N_4$$

Acc. respiration hydrolysis settling

- DO (O)

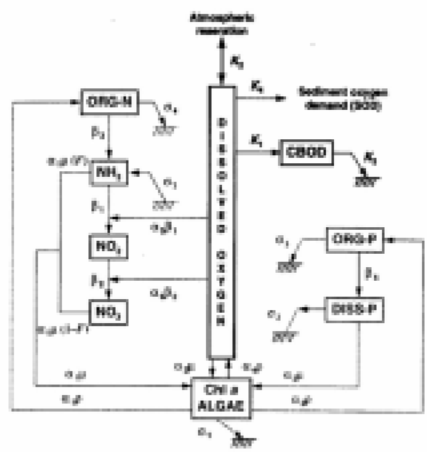
$$\frac{dO}{dt} = K_2(O_s - O) - K_1 L - \frac{K_4}{H}$$

Acc. reaeration Decay SOD

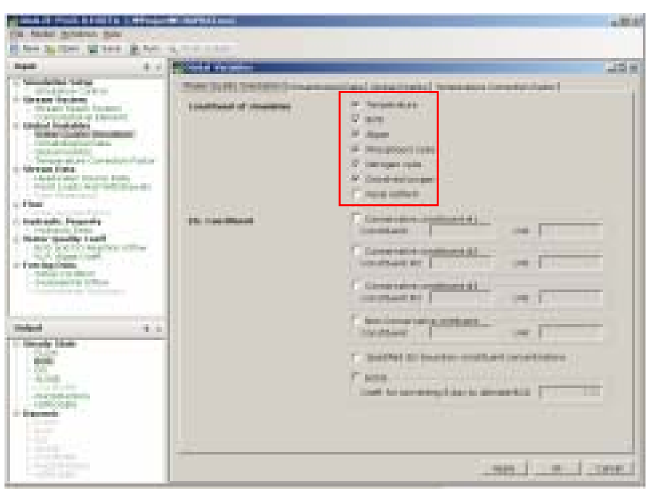
$$-(\alpha_3 \mu - \alpha_4 \rho)A - \alpha_5 \beta_1 N_1 - \alpha_6 \beta_2 N_2$$

growth-resp. nitrification

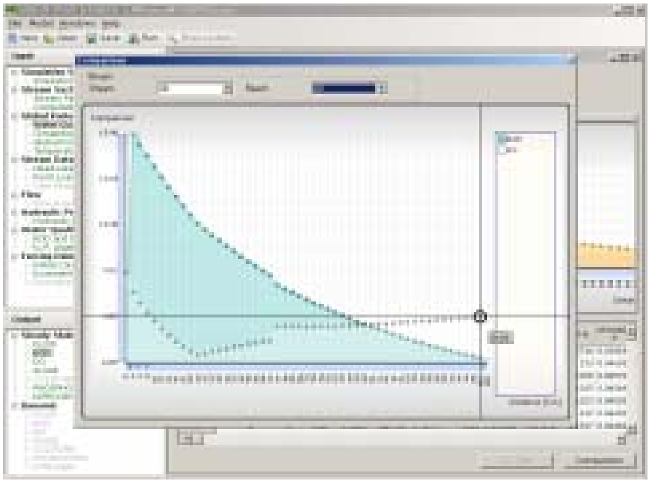
- Kinetics of QUAL2E Model



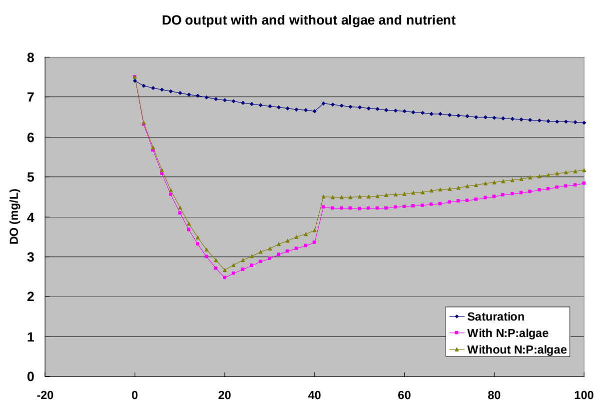
Nutrients (N,P) and Algae



BOD & DO Results



Relation of Nutrients and DO



- Algae consumes DO for respiration

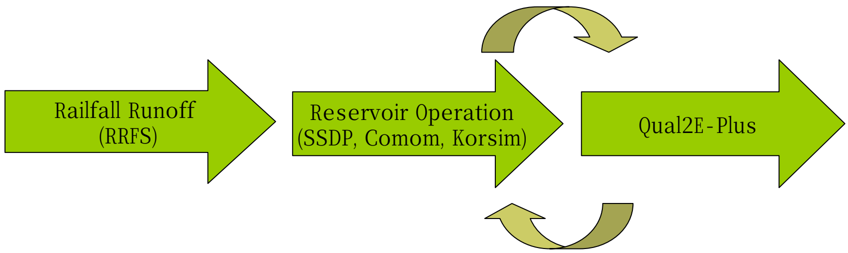
Geum River Application

Simulation Configuration

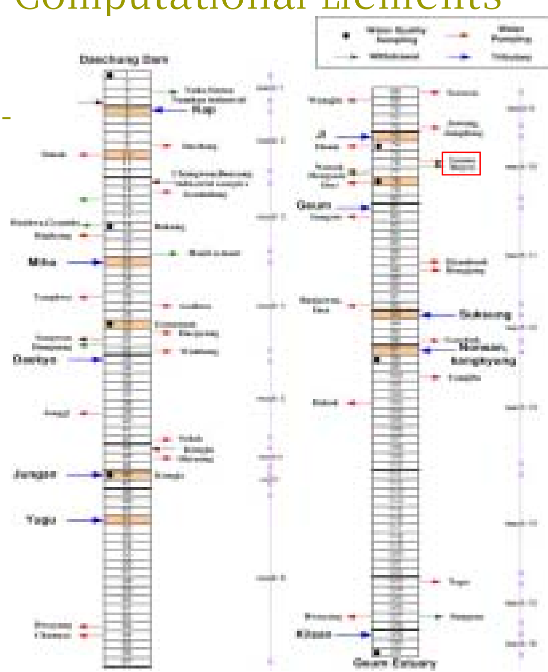
- From the Daechung Dam to Estuary (130.47km 16 reaches)
- Reach velocity and Depth is given regression analysis using HEC-RAS
- Temp, BOD, COD, Algae, N, P, and DO
- Pollution sources:
  - 10 tributaries and 3 WWTP as Point Source
- Pumping station, drinking water station data
- Assuming 50% operation
- return ratio of Irrigation water is 35%
  - Incremental Inflow

Basin Water Resources Management

- IRWMS is Developed to Support
  - Rainfall-runoff for Reservoir and Watershed Inflow Estimation
  - Reservoir Operational Planning
  - Water Quality Evaluations

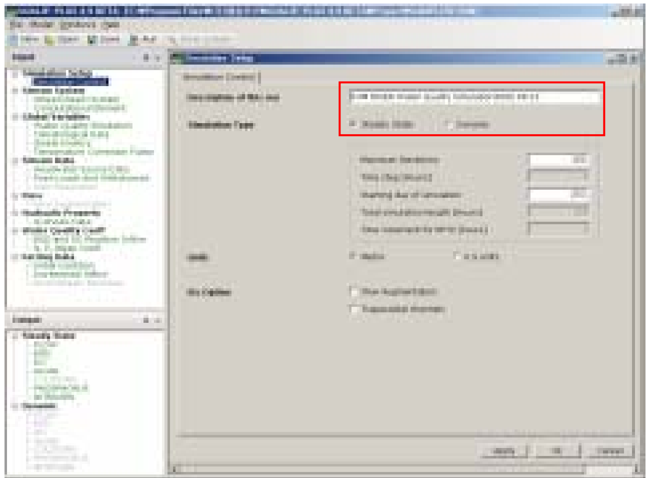


Computational Elements

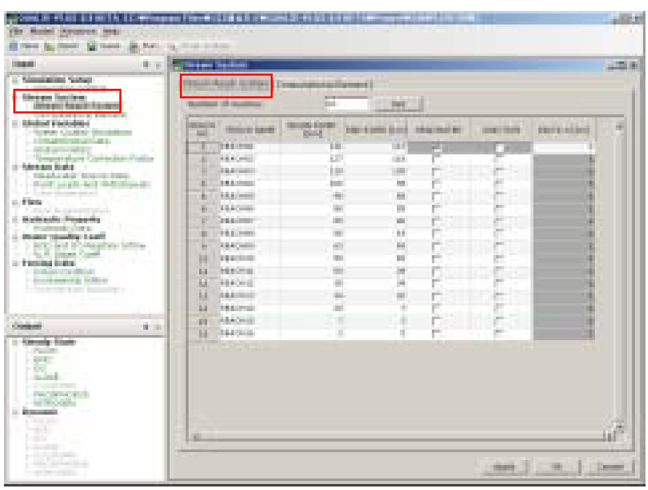


- 16 reaches
- 131 elements
- 10 tributaries
- Water intakes, Pumping
- Water Elevation Stages

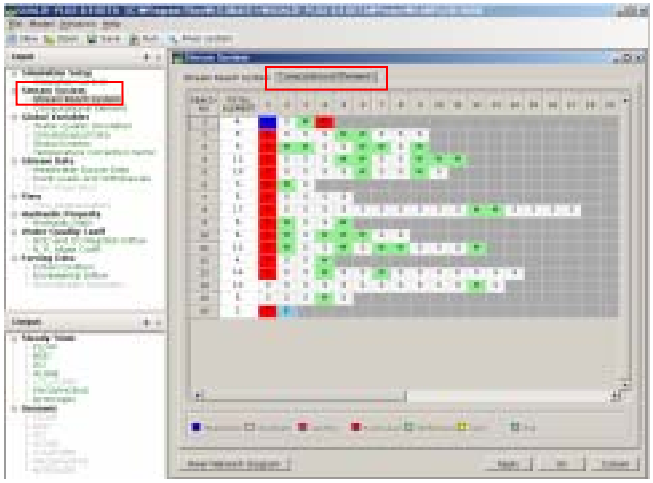
Simulation Control



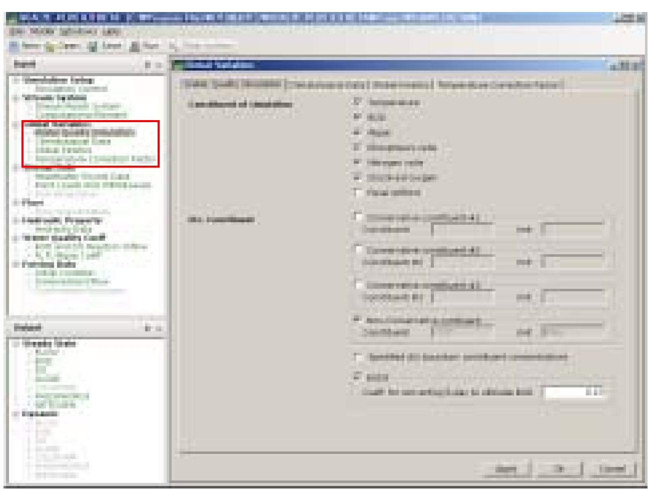
Stream Reach



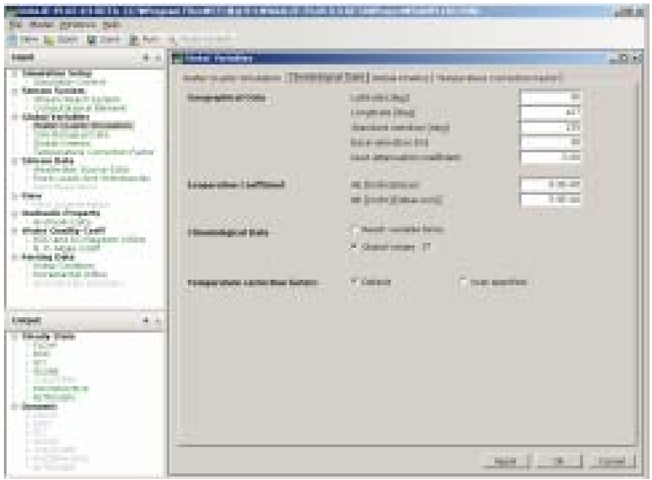
Computational Element



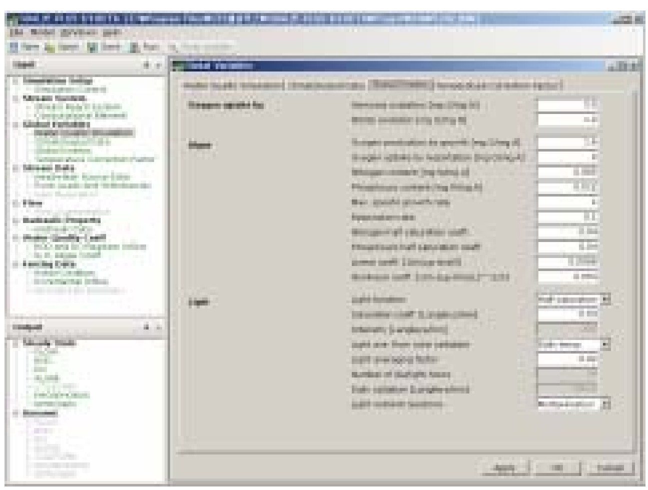
Target Water Quality Constituents



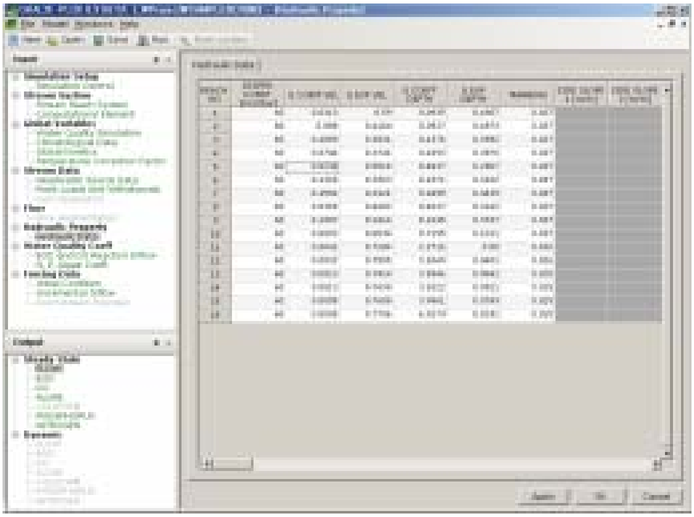
Climatological Data



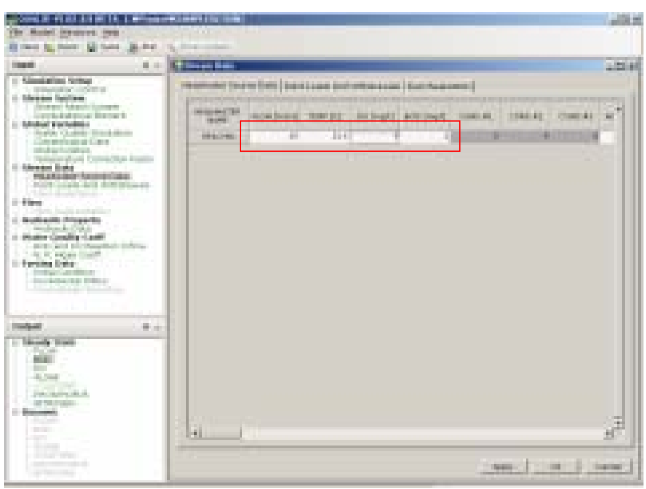
Global Kinetics



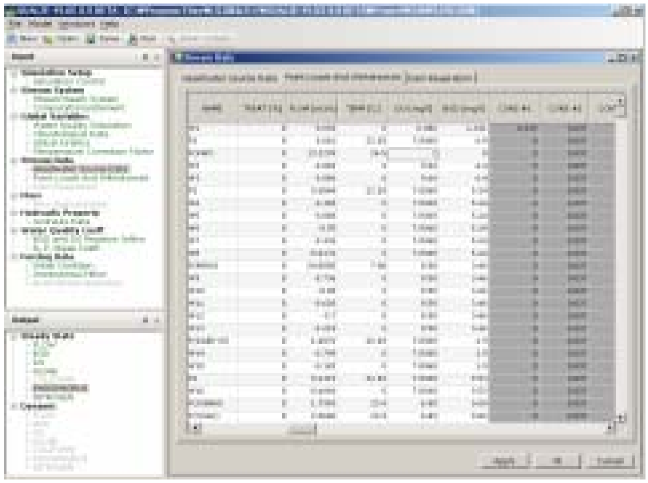
Hydraulic Coefficients



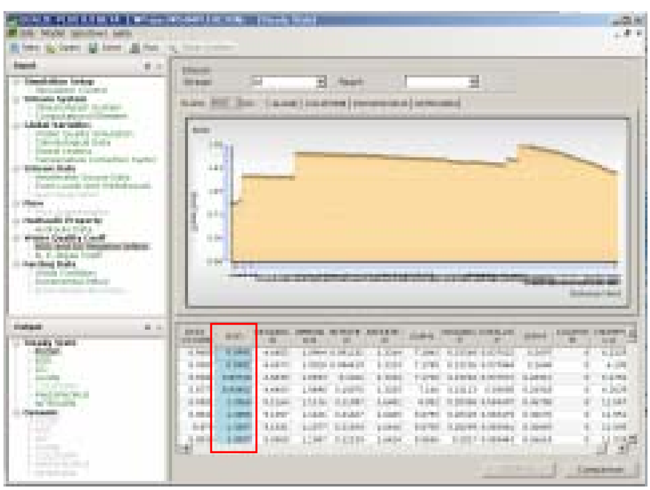
Headwater Source Data



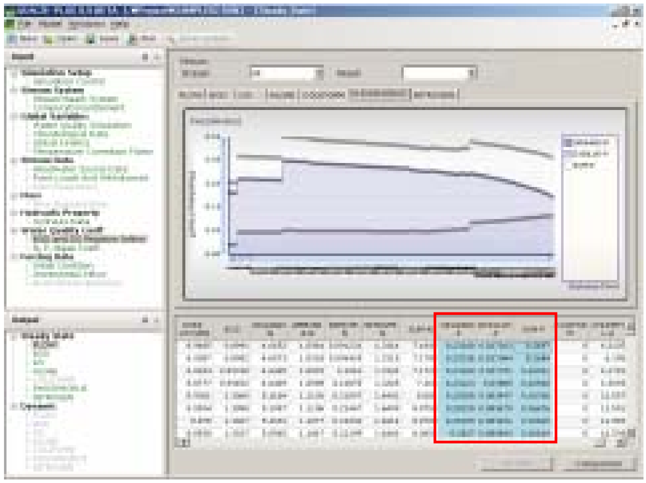
Point Load & Withdrawal



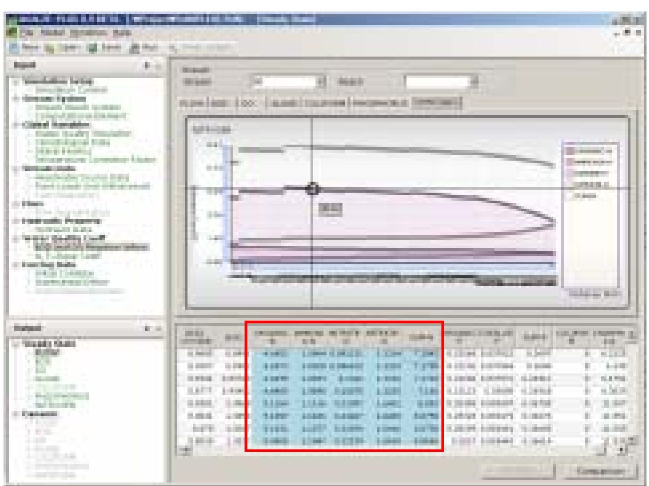
Simulation Result of BOD



P-Groups

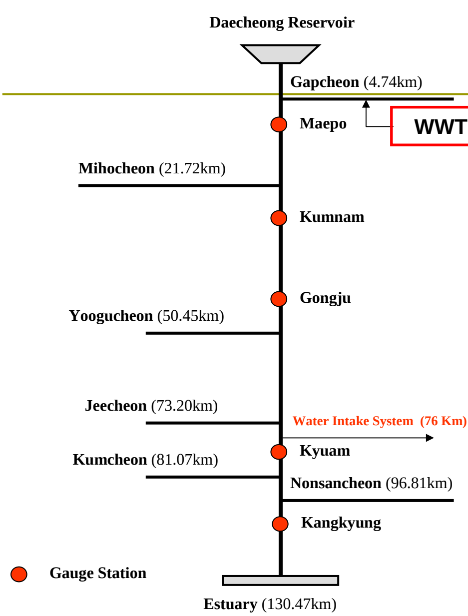


N-Groups

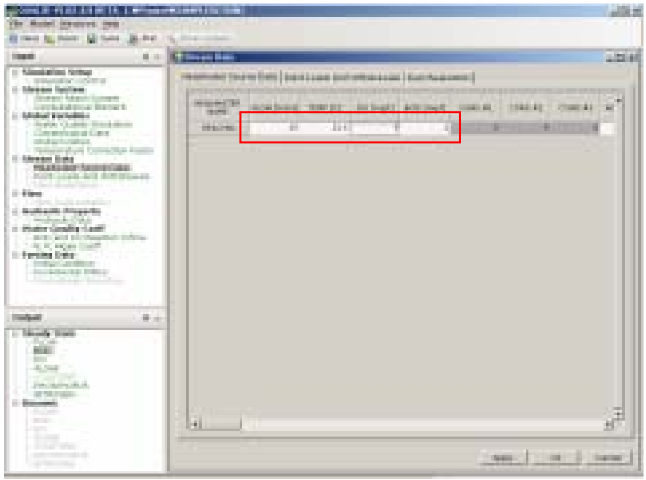


Problem #4 Discharge Estimation

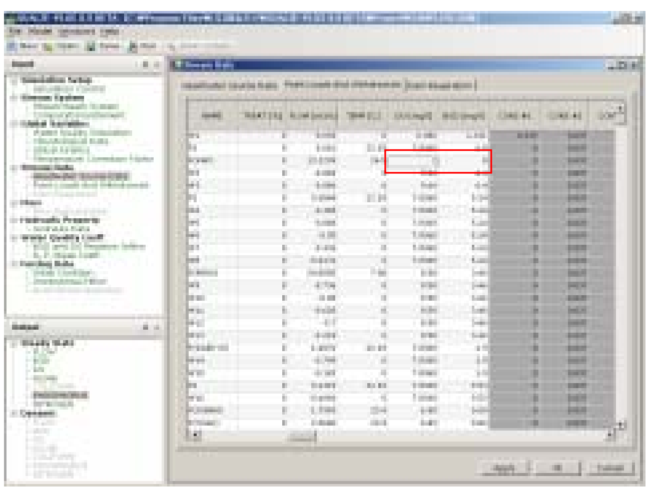
- Objectives
  - Understanding water quality control by increasing the reservoir discharge to find improve downstream water quality improvement
- Problem
  - Find discharge release to maintain BOD concentration below 3 ppm at downstream water intake system
- Description
  - Starting from 10 CMS and check the BOD concentration at node#76 where the water intake system is located.



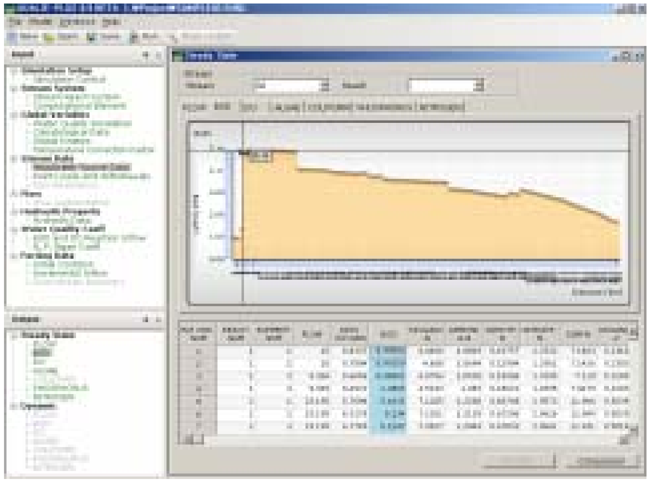
Headwater Source Data



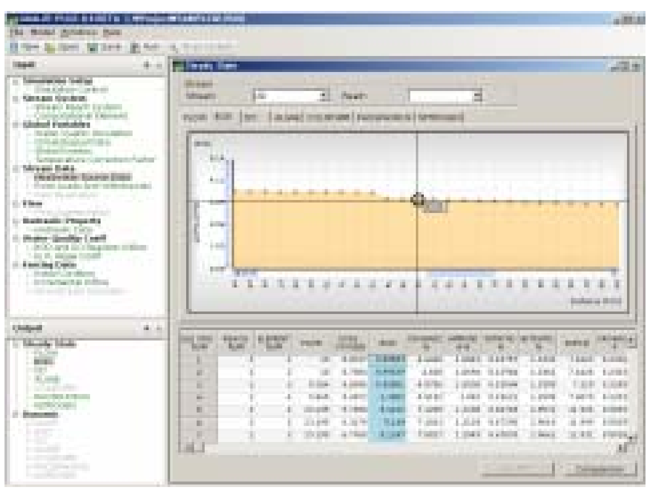
Point Load & Withdrawal



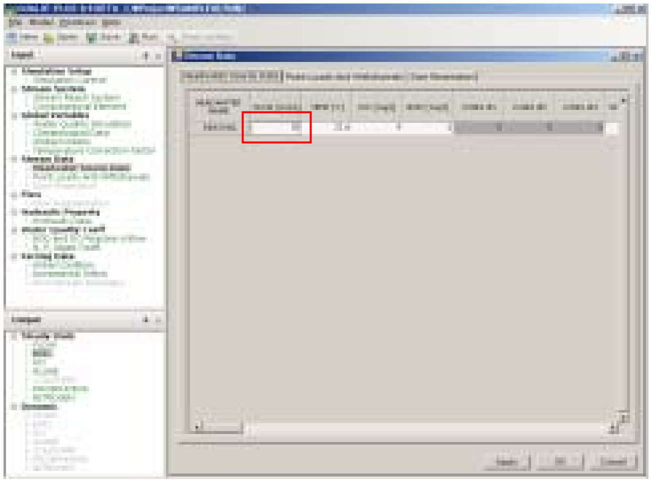
BOD at Kap Stream



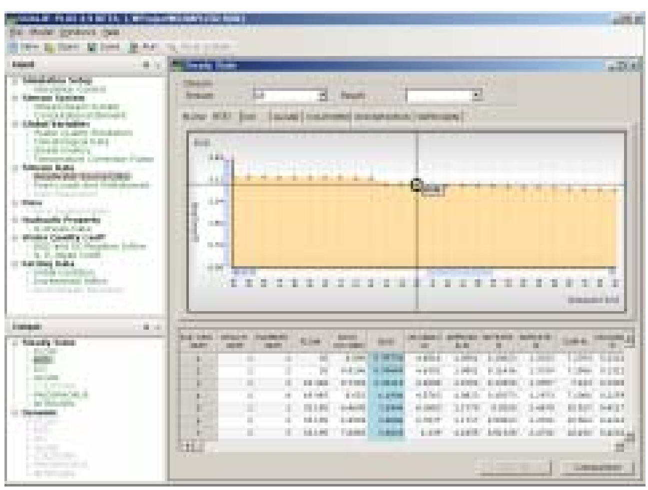
At node#76 (Water Intake System)



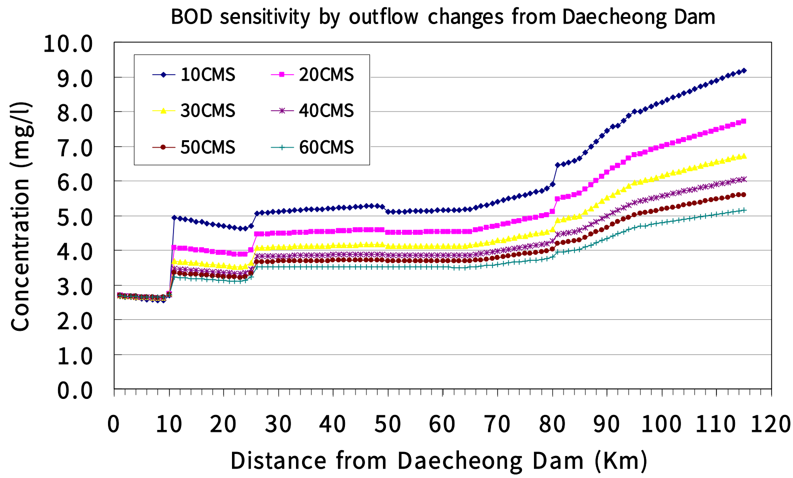
Increase FLOW as 20 CMS



BOD at node #76



Flow sensitivity to BOD concentration



Flow sensitivity to NH3-N concentration