SWAT-K

Integrated Modeling of Surface Water and Groundwater by Using Combined SWAT-MODFLOW

N. W. Kim, I. M. Chung*, Y. S. Won**, J. Lee*, J. G. Arnold****

** Korea Institute of Construction Technology*
***River Information Center of Han River Flood Control Office*
**** USDA-Agricultural Research Service*

KOREA INSTITUTE OF CONSTRUCTION TECHNOLOGY

21C Frontier R&D Program
Sustainable Water Resources Research Center

Content

- Background and Purpose
- Overview of SWAT-K and SWAT-MODFLOW
- Application to test watersheds
- Results of simulation
- Conclusion

BACKGROUND

- **Current issues on water management in Korea :**

✓ **Water rights (and regulations) on groundwater use near streams**

✓ **Accurate estimation of groundwater recharge / discharge**

✓ **Potential amount of groundwater development based on groundwater recharge**

✓ **Groundwater is an alternative water resources in Korea**

BACKGROUND

- **Problems**

✓ **Hydrologic component analysis in Korea has concentrated on surface water management, so problems related to groundwater were not dealt with rigorously**

✓ **In groundwater modelling, groundwater recharge could not be considered in terms of hydrological processes**

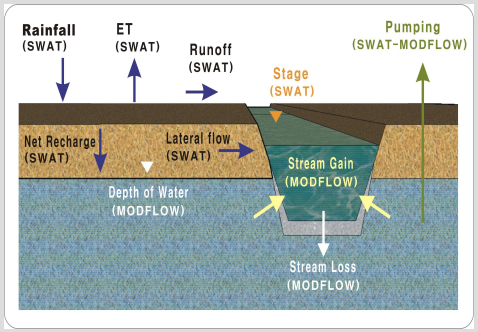
✓ **The role of groundwater model in surface water management was less significant**

PURPOSE

- **Construction of a long term rainfall runoff model, producing integrated analysis for both the groundwater and surface water**
- **To explain the effects of spatial-temporal distributions of recharge and groundwater head**
- **To examine the hydrological effects allowing hydraulic interaction between surface water and groundwater**
- **Application to Underground dam / River intake / Reservoir capacity/ Potential amount of groundwater development / Stream flow decrease in urbanized watershed**

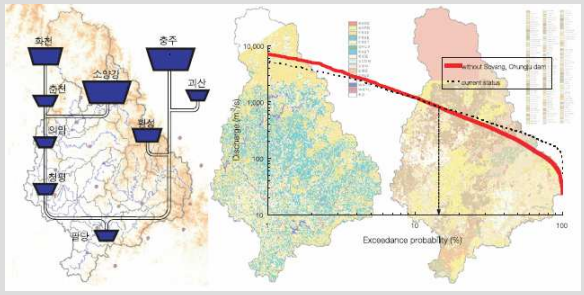
What is SWAT-K(Korea)?

SWAT+Variation of water cycle structure (Natural+Artificial)

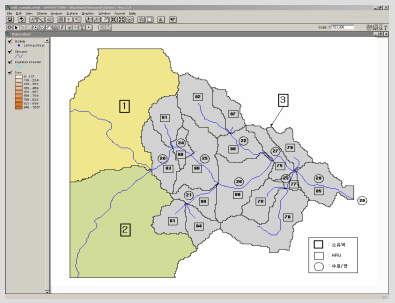


SWAT-MODFLOW

SWAT-AGRIMAN

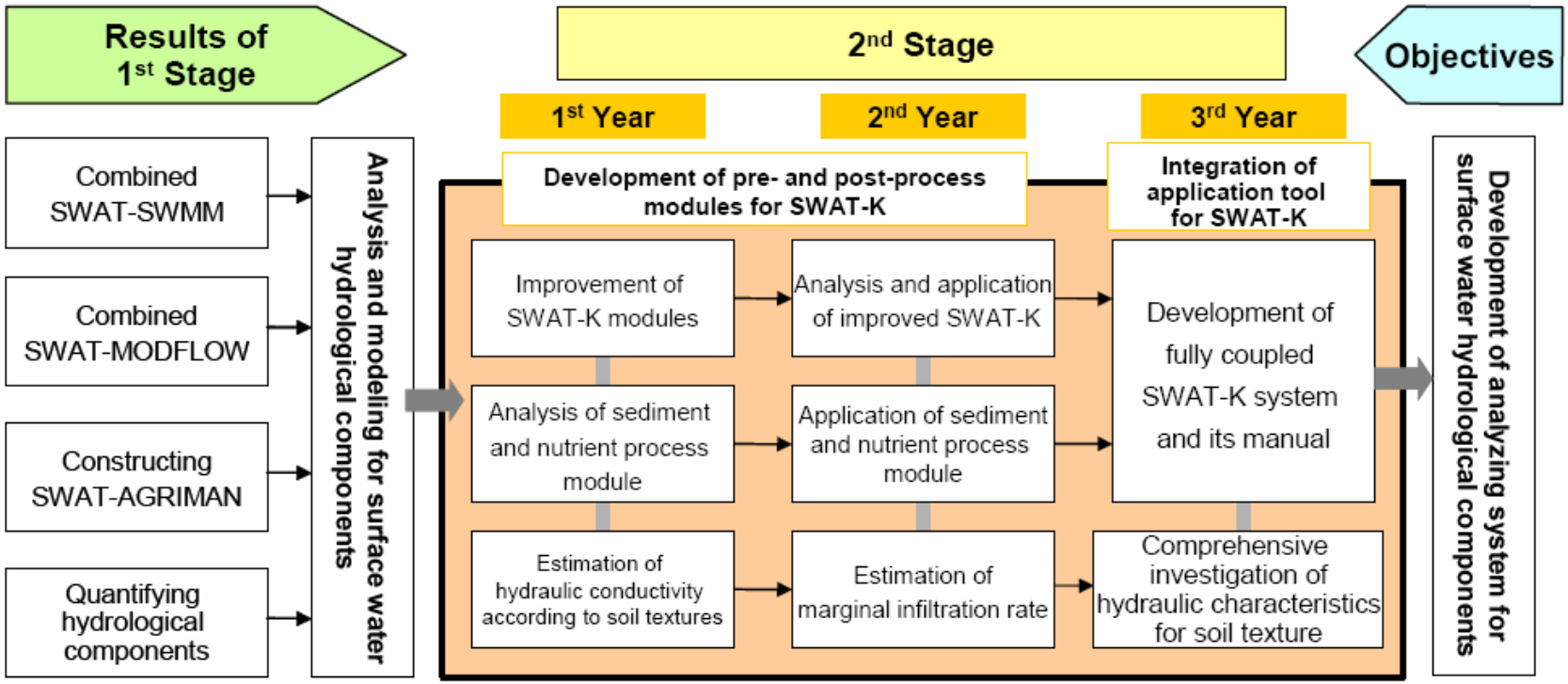


SWAT-ROM



SWAT-SWMM

▸ Technological Roadmap



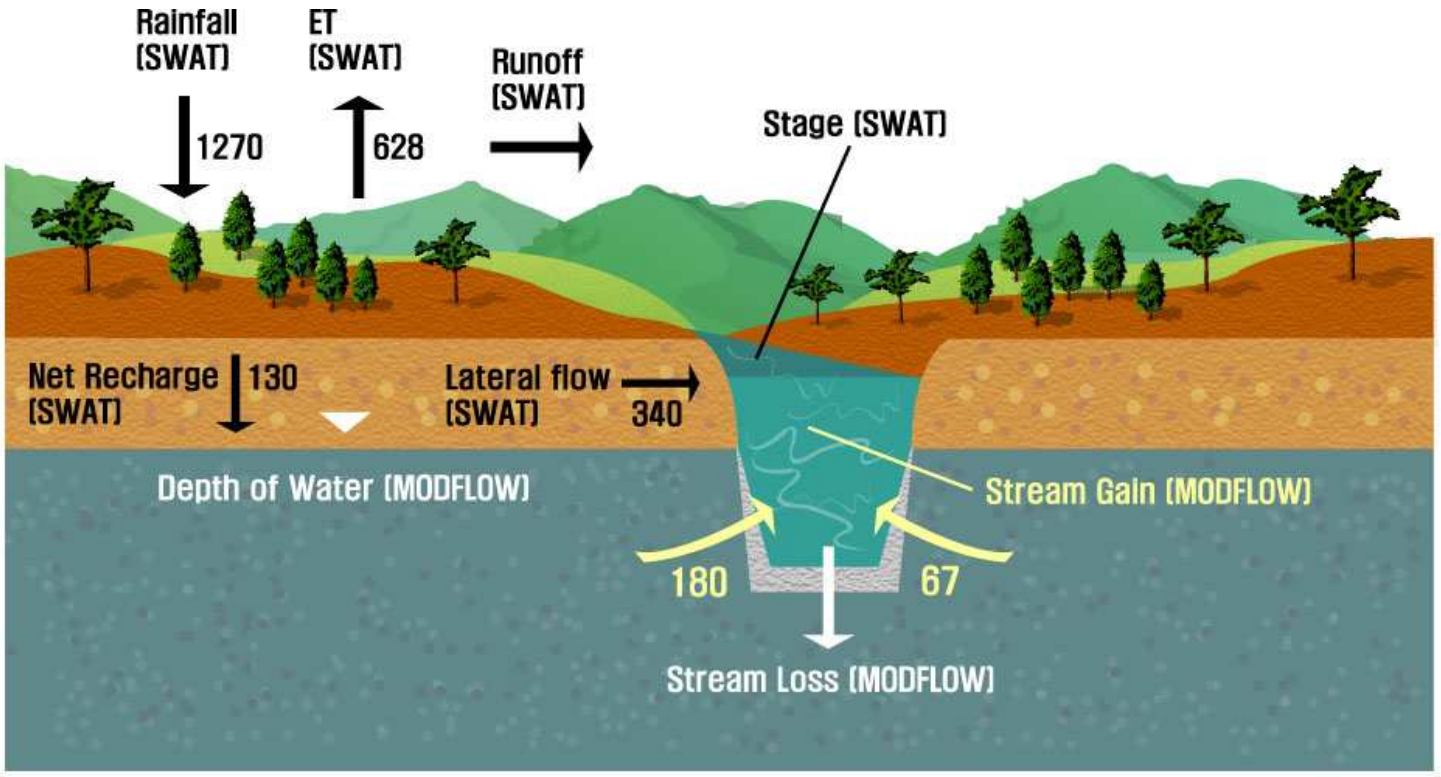
SWAT-MODFLOW

Fully combined SWAT-MODFLOW

- ✓ **Development of tool for exchanging characteristics between HRU(Hydrologic Response Unit) of SWAT and CELL of MODFLOW**
- ✓ **Groundwater module in SWAT is replaced by MODFLOW**
- ✓ **Spatially distributed GW recharge rates and heads can be simulated by SWAT-MODFLOW**
- ✓ **Stream-aquifer interactions by RIVER package in MODFLOW**

SWAT-MODFLOW

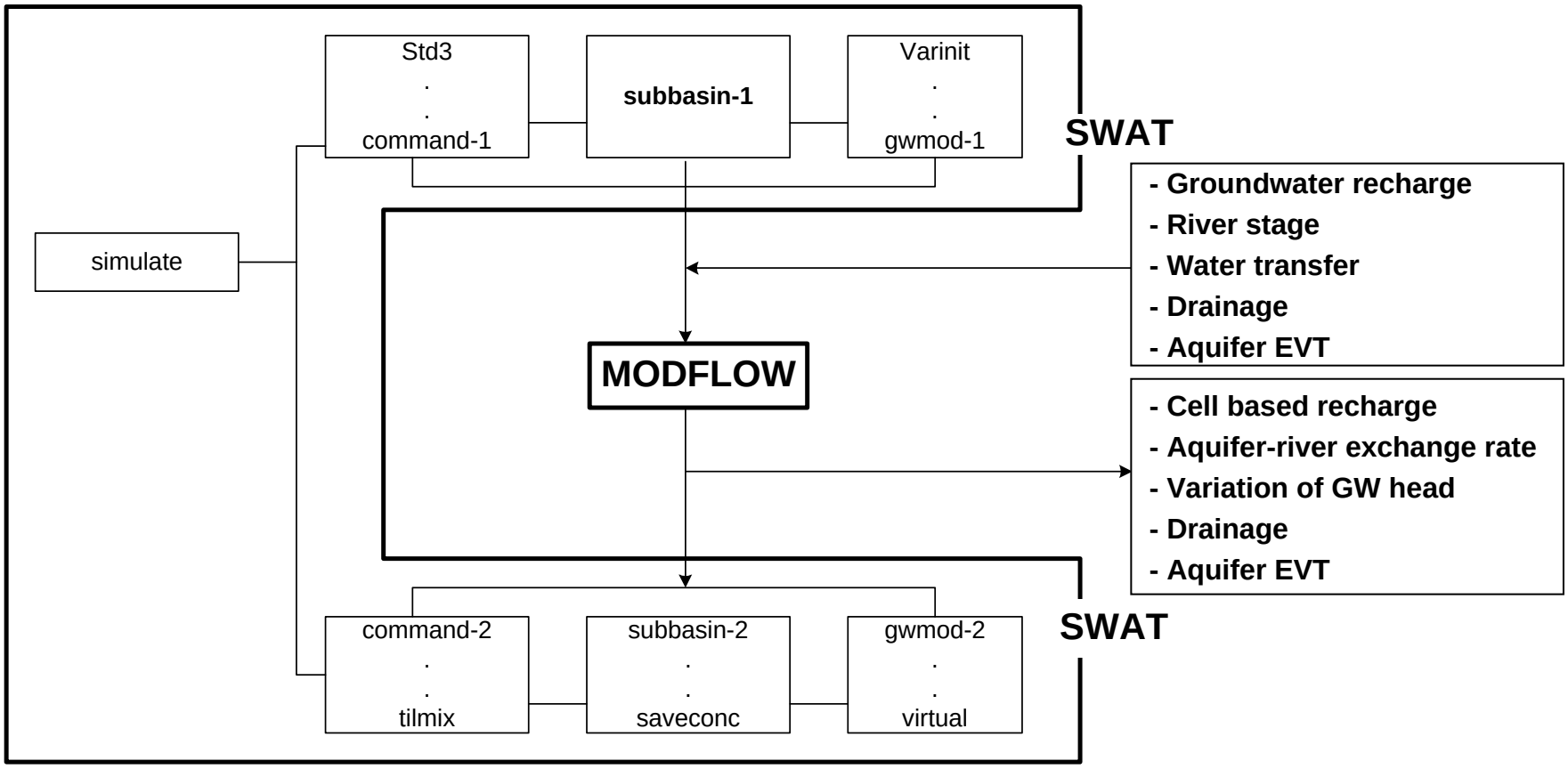
Schematic diagram



* This approach is quite different to the method used by Sophocleous et al.(1997) which involves separate modelling by sequential linkages.

SWAT-MODFLOW

Fully coupled work by Serial linkage



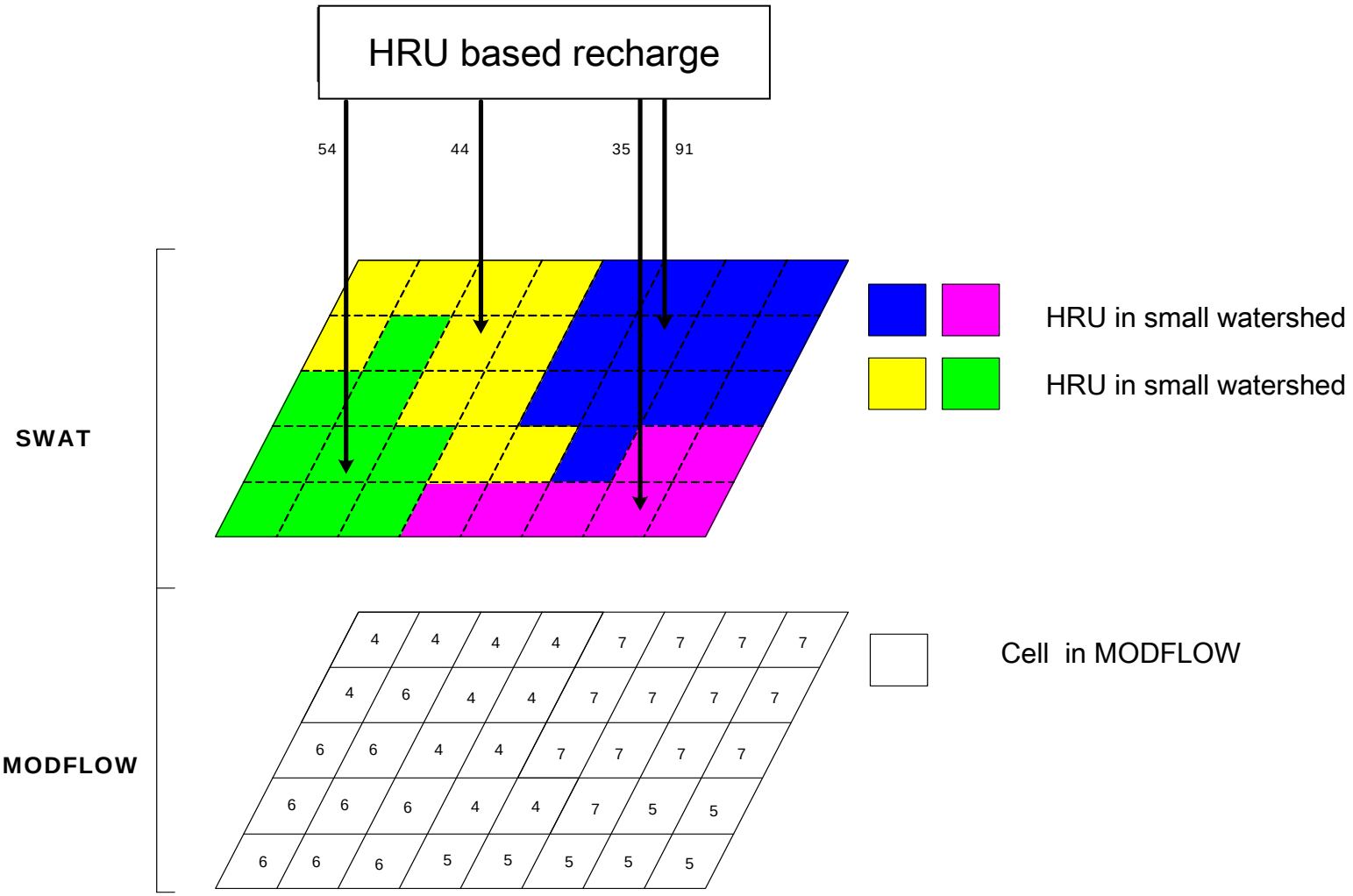
SWAT-MODFLOW

- **Major input data for SWAT-MODFLOW**

  - ✓ **HRU distribution which links HRU with MODFLOW grids**
  - ✓ **Cell based recharge rate which is made by HRU based in SWAT**
  - ✓ **Stream data(stage, width) is common to both model**
  - ✓ **Data for water transfer of shallow aquifer in SWAT is commonly used in WELL package in MODFLOW**

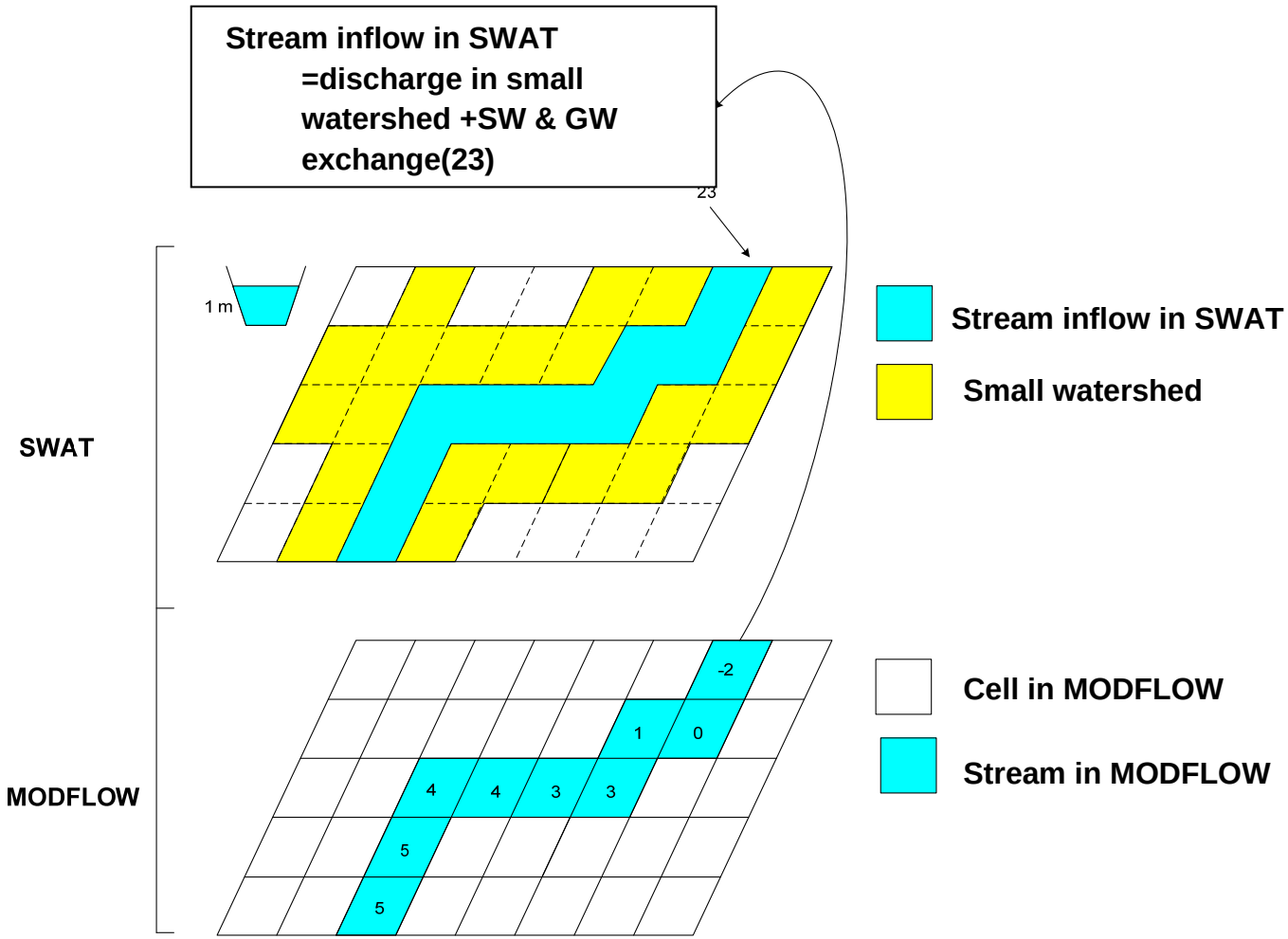
SWAT-MODFLOW

Linking RECHARGE in MODFLOW with SWAT



SWAT-MODFLOW

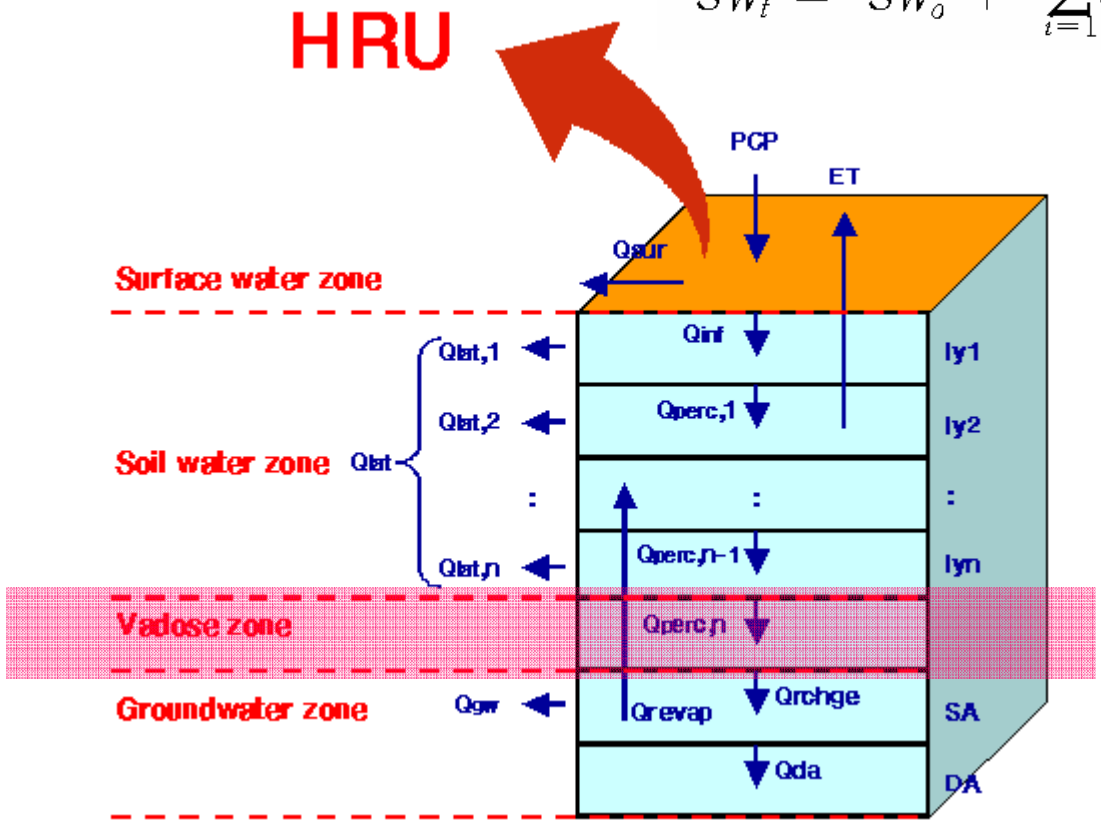
Linking RIVER in MODFLOW with SWAT



Runoff Process

- Behavior of hydrological components in single **HRU**

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$



- Processes -

1. **Qsur, Qinf**
2. **Qlat, Qperc**
3. **ET**
4. **Qrchge**
5. **Qgw**
6. **Qrevap**
7. **Qda**

■ Enhancement of recharge parameter estimation for vadose zone modeling

$$w_{rchrg,i} = (1 - \exp[-1/\delta_{gw}])\, w_{seep} + \exp[-1/\delta_{gw}]\, w_{rchrg,i-1}$$

→ Single linear reservoir

$w_{rchrg,i}$: recharge from soil zone to aquifer (mm)

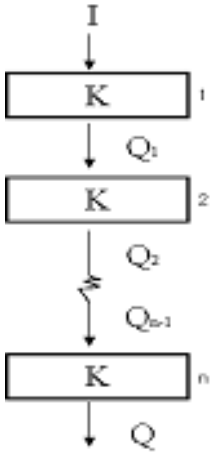
δ_{gw} : delay parameter (day)

w_{seep} : amount of water exiting the bottom of soil profile (mm)

$$\frac{dS}{dt} = I - O \qquad \text{Continuity Eq.}$$

$$S = KO \qquad \text{Storage Eq.}$$

n system of Eq.



→ Multiple linear reservoir

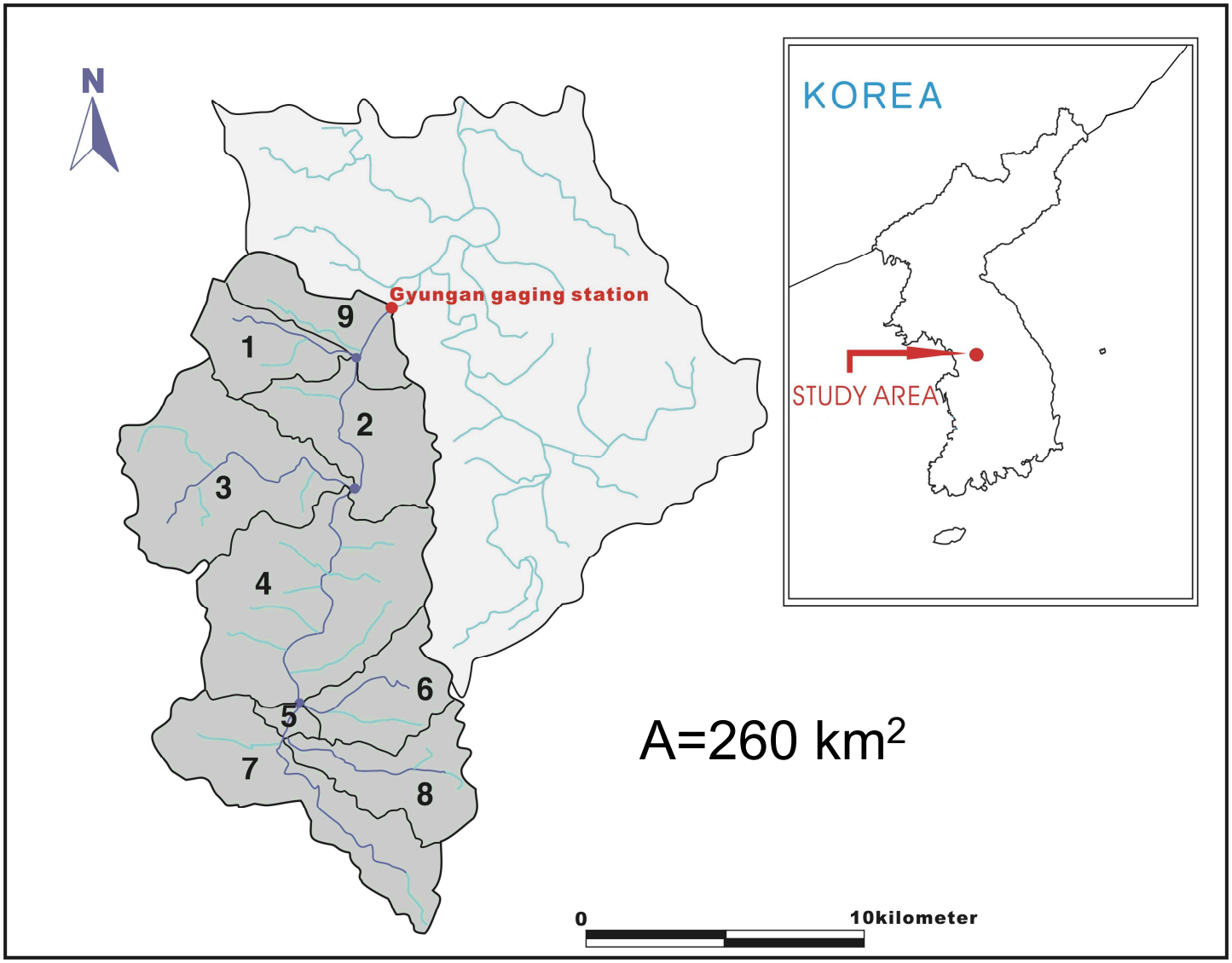
SWAT-MODFLOW

- **Enhancement of water transfer in SWAT-MODFLOW**

  ✓ **In SWAT's water transfer option, when the source type is aquifer, then this case is related with Well package in MODFLOW**

  ✓ **Water transfer rate in HRU is correspondent to pumping rate Q (discharge or recharge)**

GYUNGANCHEON WATERSHED



APPLICATION

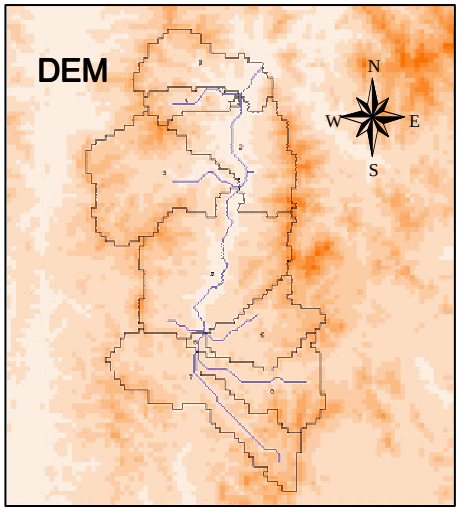
- The characteristics of subbasins

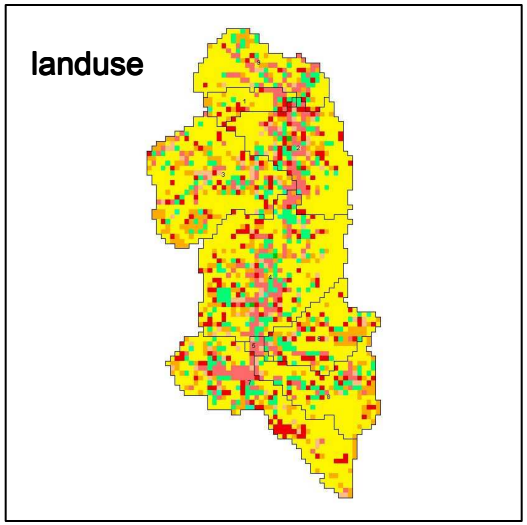
Number	Area (km^2)	Length (km)	Slope (m/m)	Width (m)
1	16.91	8.226	0.043	7.038
2	29.38	10.322	0.050	9.833
3	47.44	15.194	0.017	13.070
4	59.29	19.446	0.026	14.941
5	6.96	5.484	0.067	4.132
6	20.01	8.295	0.039	7.789
7	38.74	12.809	0.025	11.575
8	22.62	12.264	0.029	8.380
9	17.68	10.167	0.030	7.229

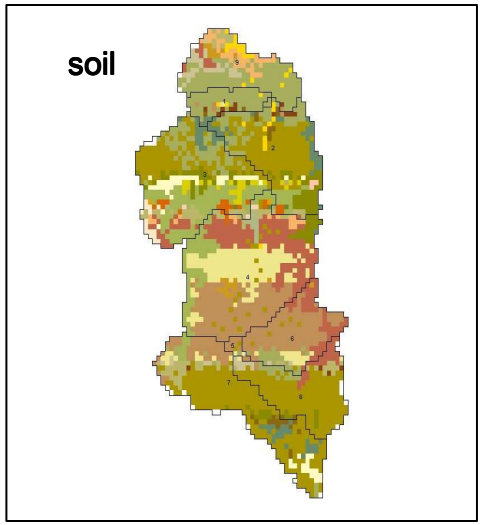
Input data for SWAT

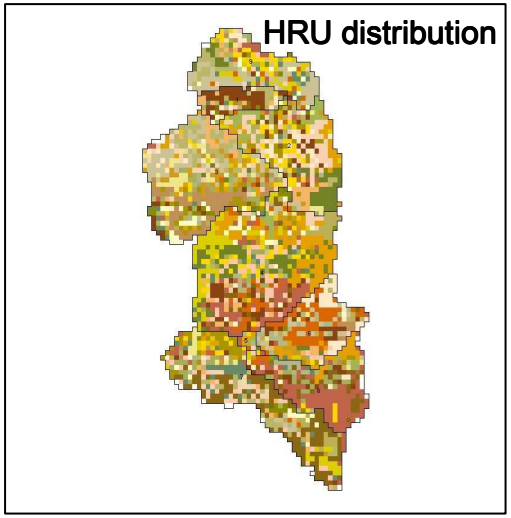
✓AVS2000 (DiLuzio et al., 2001) was used to automate the construction of model input parameters
✓Daily precipitation of Suwon gauging station (MOCT)
✓Daily values of temperatures, solar radiation, wind speed etc.(KMA)
✓Land use digital data(1:25,000) (MOCT)
✓The detailed soil association map(1:25,000) was used for selection of soil attributes. 38 hydrologic soil groups within basin were used.
✓Related soil physical properties (texture, bulk density, available water capacity, saturated hydraulic conductivity, soil albedo and some additional factors) were obtained from the Agricultural Soil Information System (http://asis.rda.go.kr)

APPLICATION









The spatially distributed HRUs are used to match discretised basin with MODFLOW grids.

Input data for MODFLOW

✓ GW information from GIMS(http://www.gims.go.kr) was used

- Hydraulic conductivity in alluvial aquifer : 2.1×10^{-3}cm/sec.
- Specific yield ranges from 0.1 to 0.3.

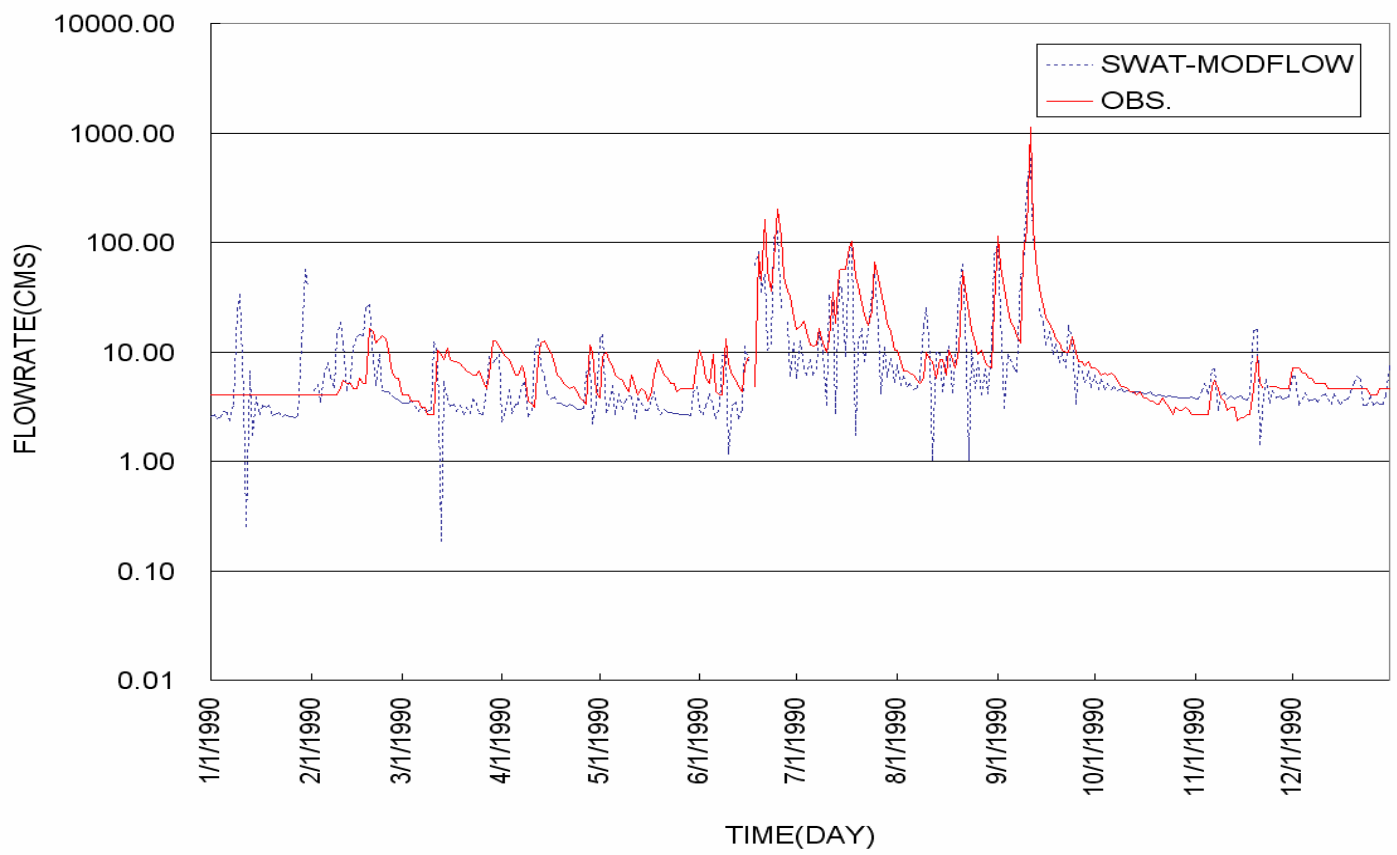
✓ The boundaries of basin were designated as no-flow cells.

✓ Recharge was distributed according to SWAT simulation outputs for each day

✓ River stage of MODFLOW is imported from SWAT's daily simulation outputs

RESULTS

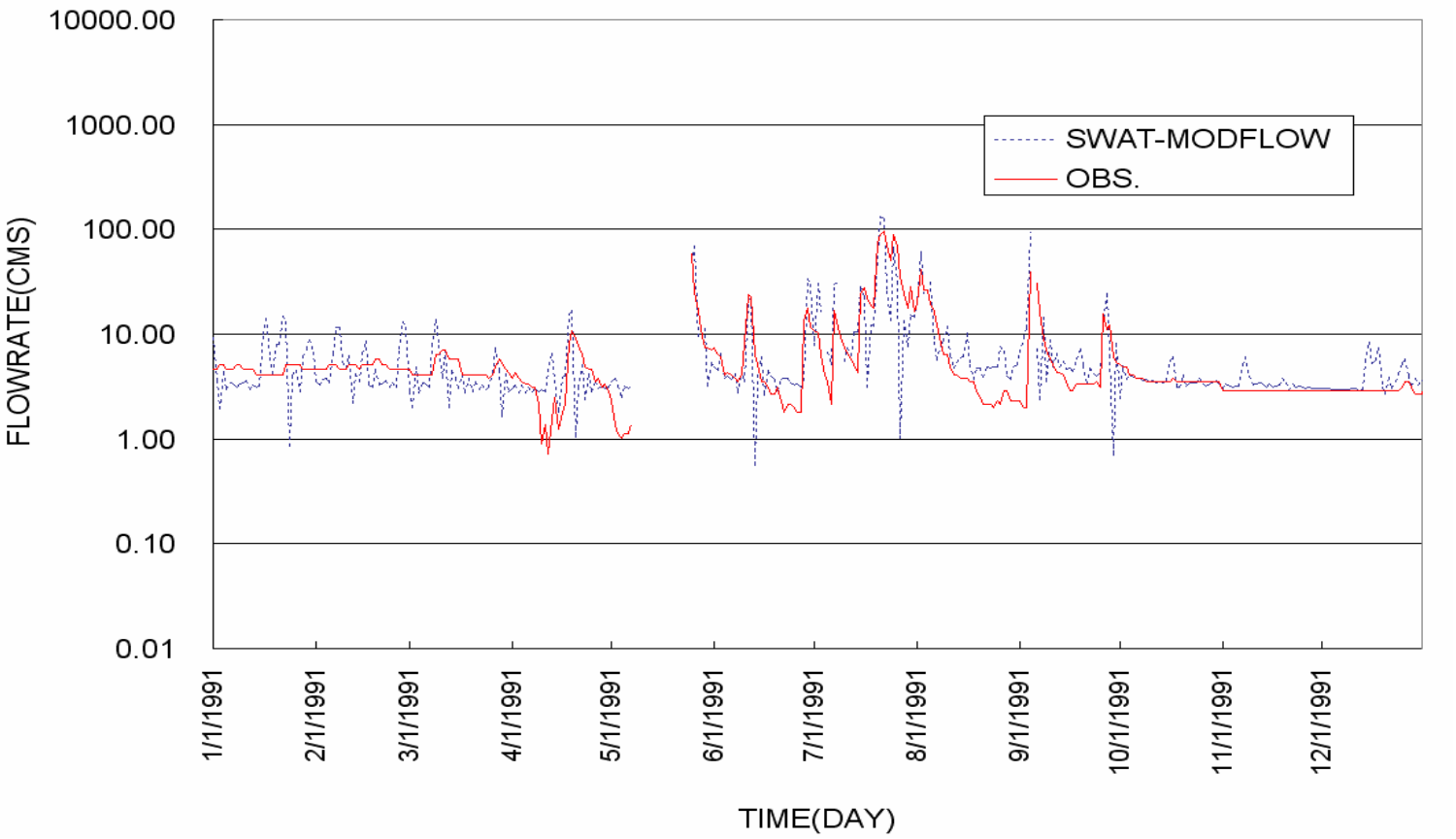
- **Model calibration (R^2=0.79)**



Measured and simulated runoff for studied basin during 1990

RESULTS

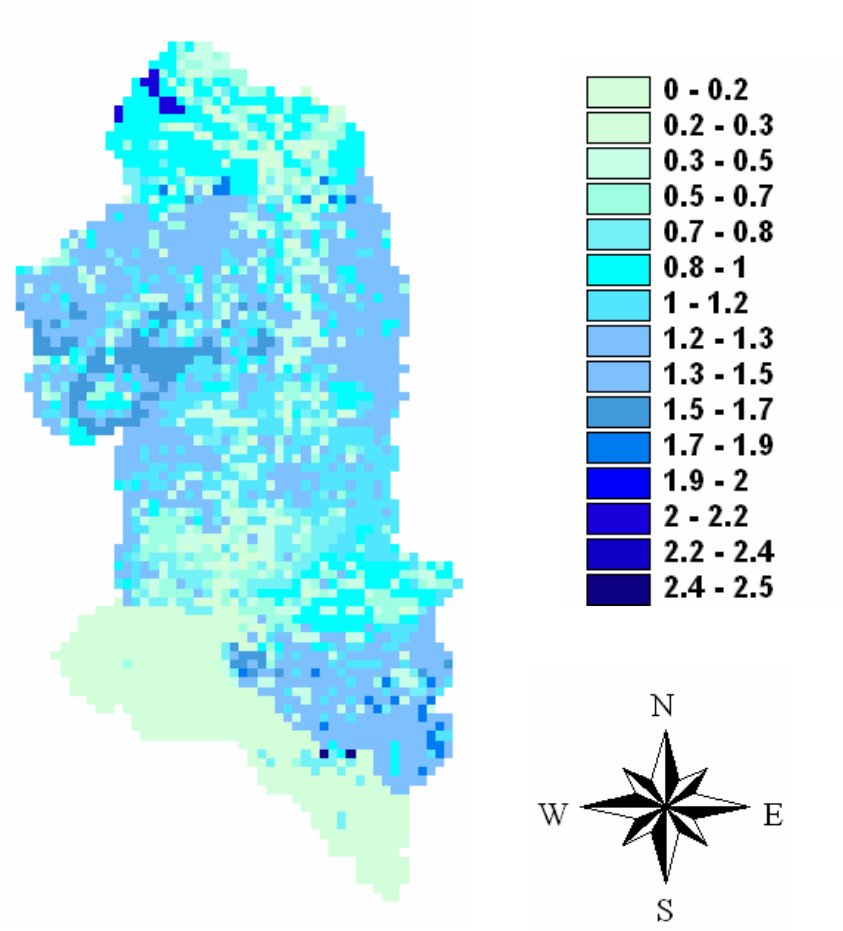
- **Model validation (R^2=0.66/ME=0.65)**



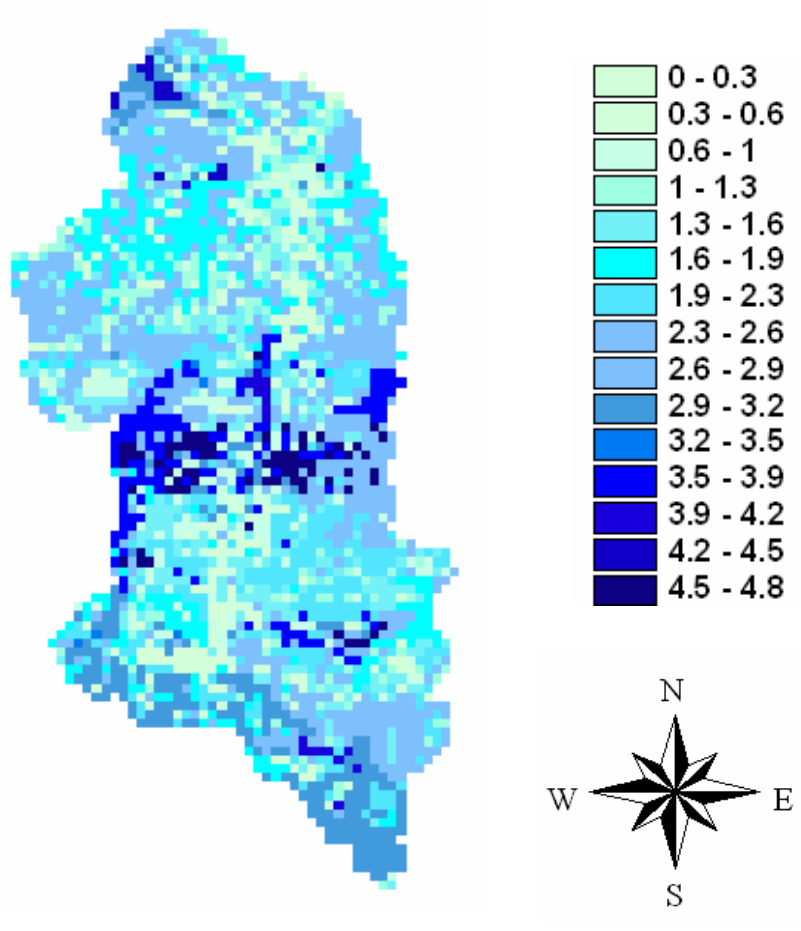
Measured and simulated runoff for studied basin during 1991

RESULTS

- **Spatial-temporal variation of groundwater recharge**



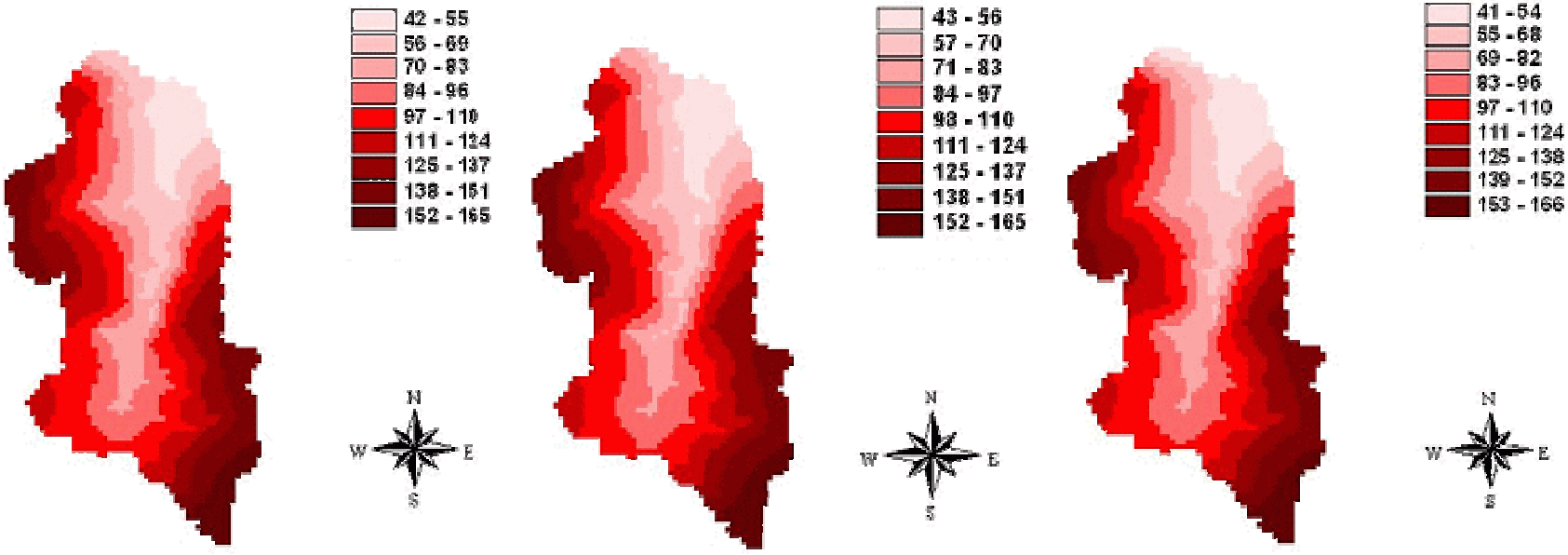
T=500days



T=1000days

RESULTS

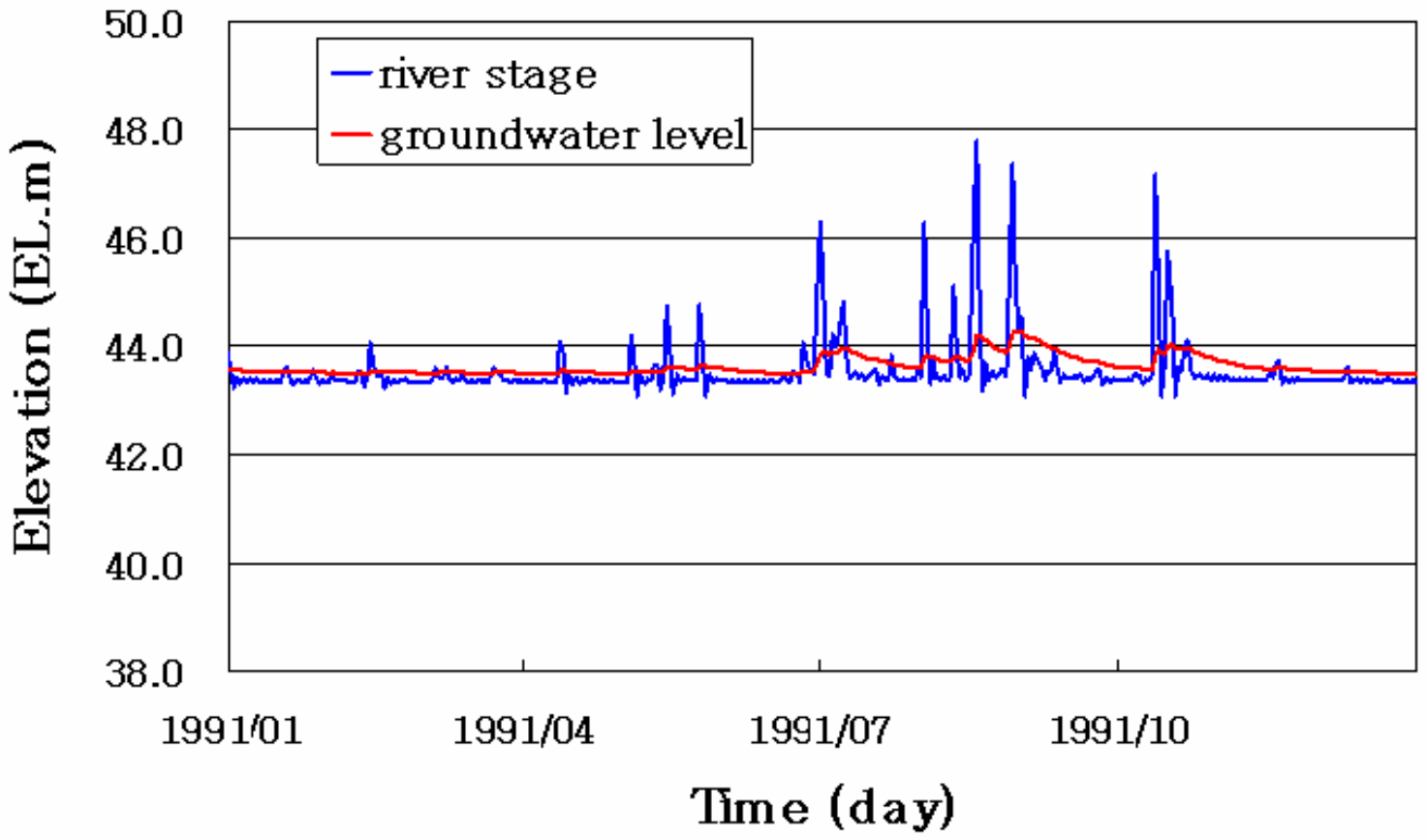
- **Spatial-temporal variation of groundwater heads**



T=500days **T=800days** **T=1000days**

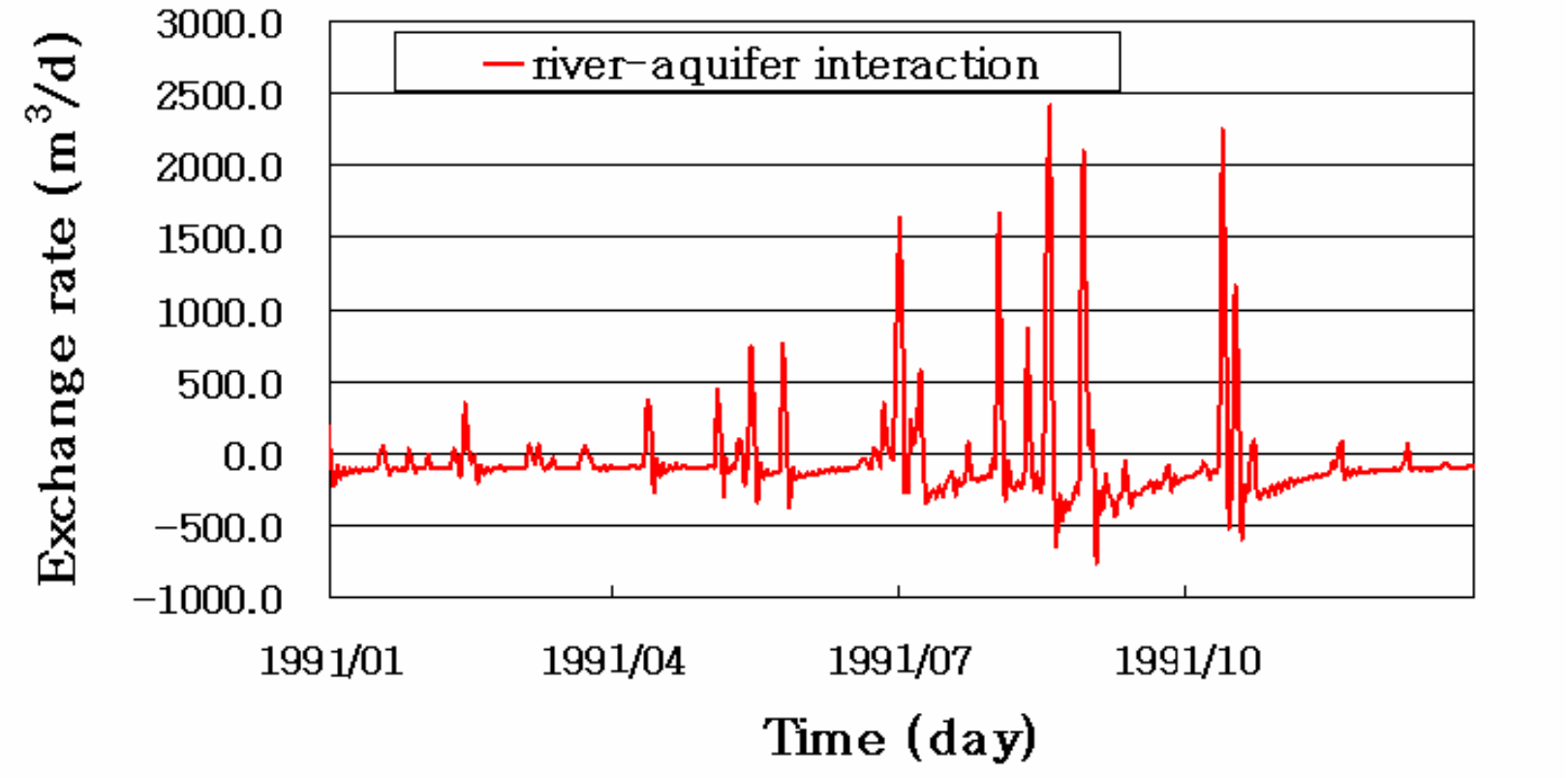
RESULTS

- **Groundwater level variation near stream**



RESULTS

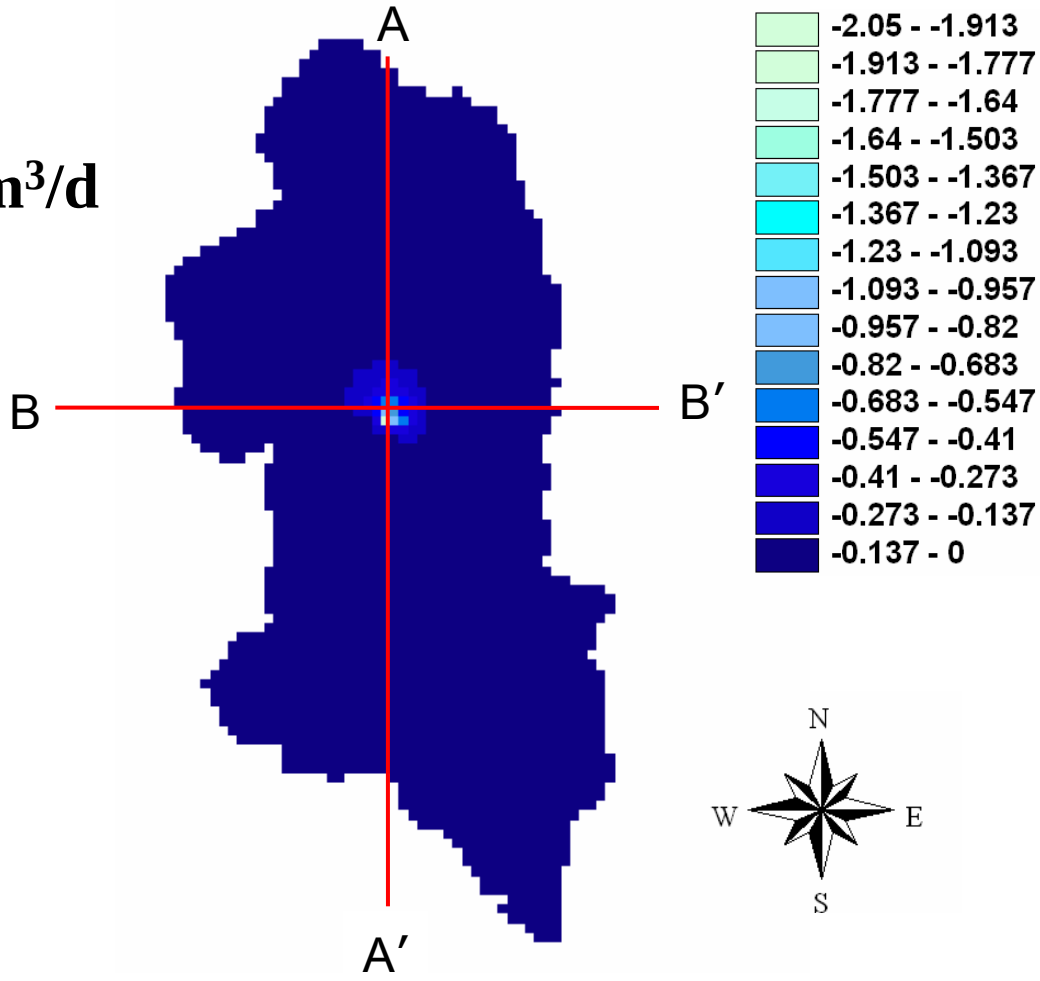
- **River aquifer interaction**



RESULTS

- **Application of SWAT-MODFLOW pumping module**

Q=1000m^3/d



RESULTS

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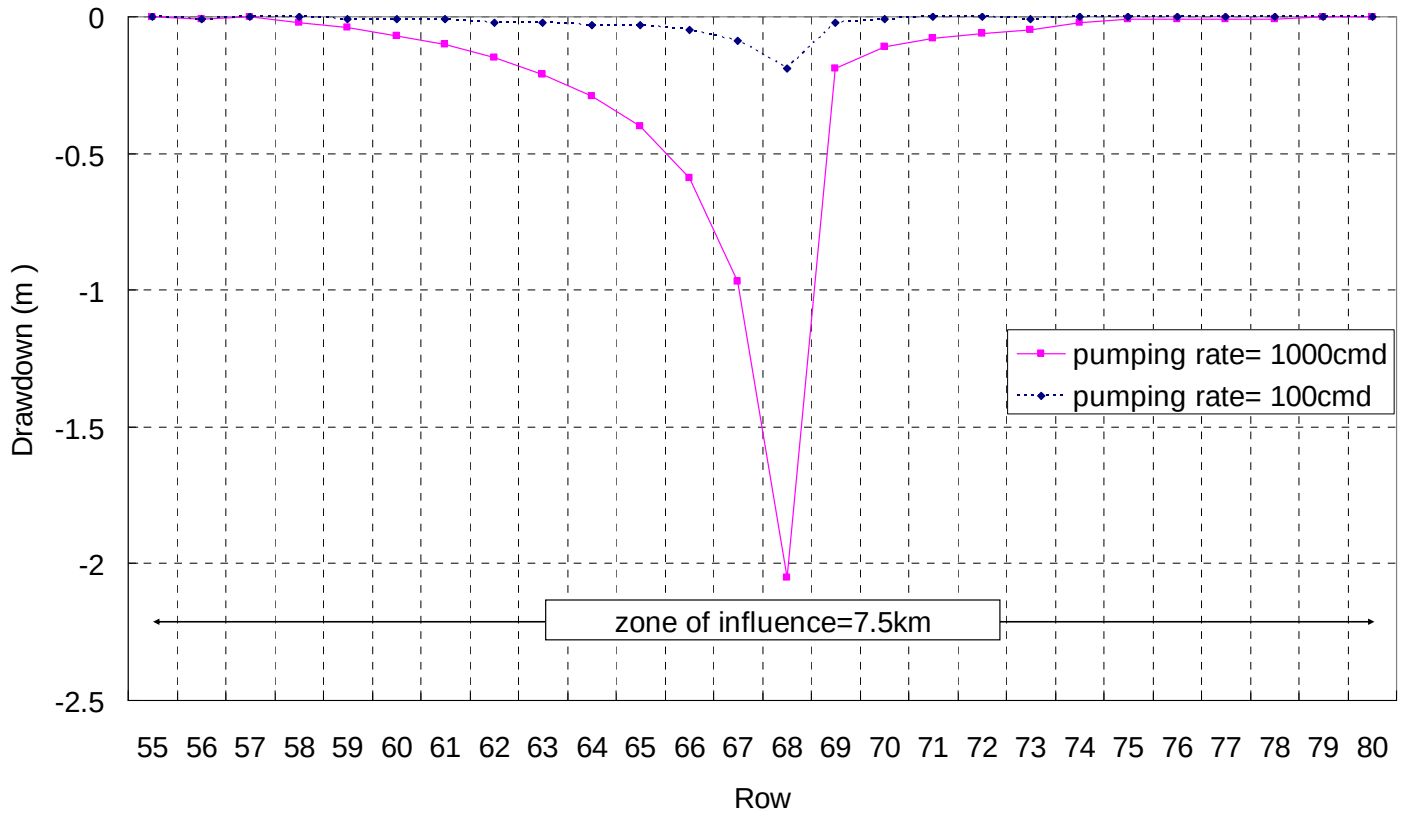
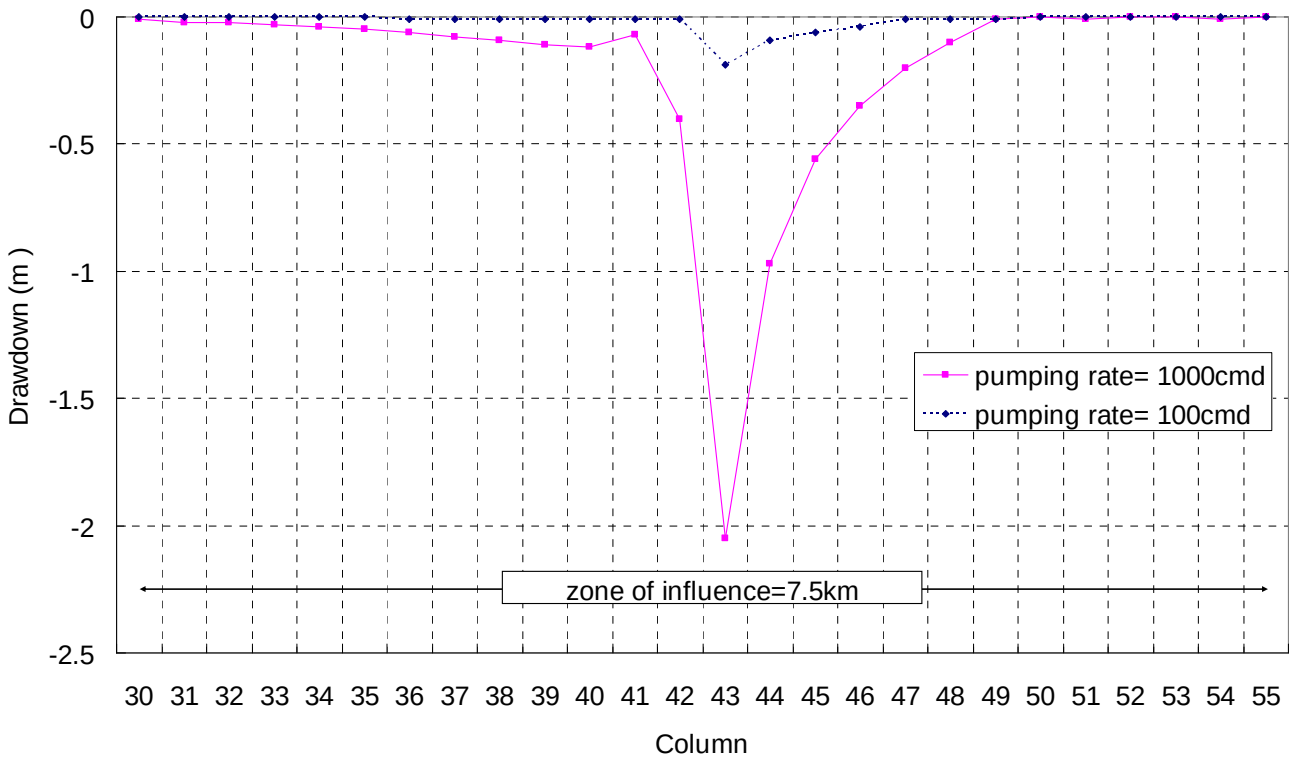


Drawdown of groundwater level at the cross section of south to north direction

RESULTS

- **Application of SWAT-MODFLOW pumping module**



Drawdown of groundwater level at the cross section of east to west direction

MUSIM WATERSHED

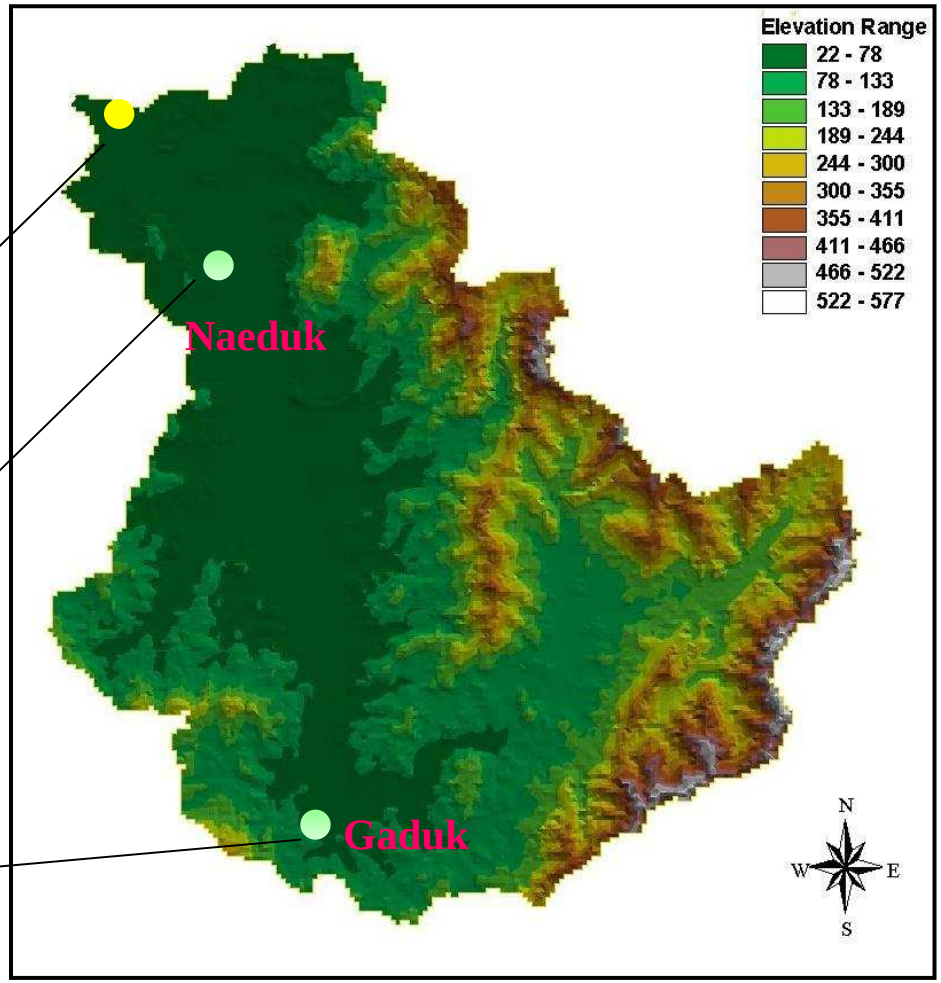
- Watershed information

-Area : 198 km^2
-No. of subbasins : 34
-Simulation period: 2001~2005

DEM

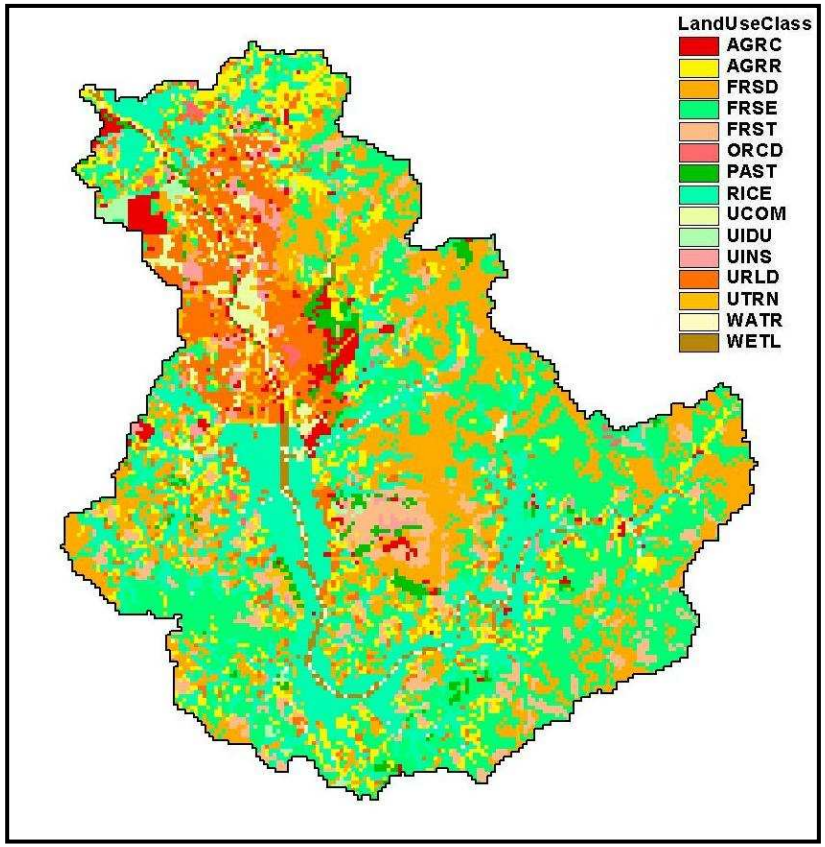
Stream gauging station

Groundwater stations

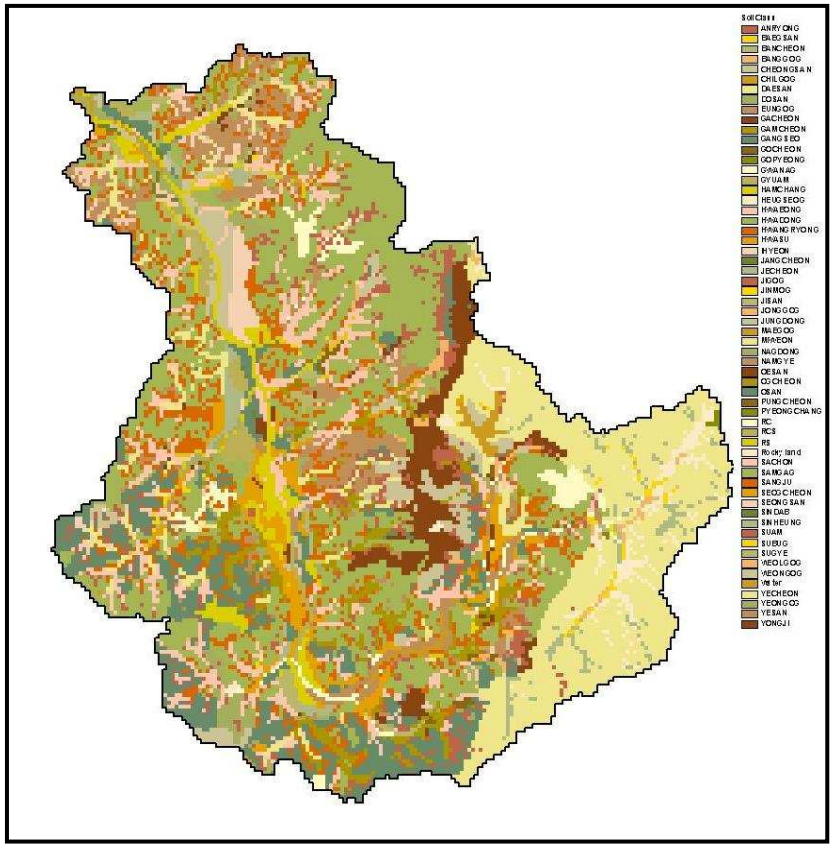


MUSIM WATERSHED

- Spatial information



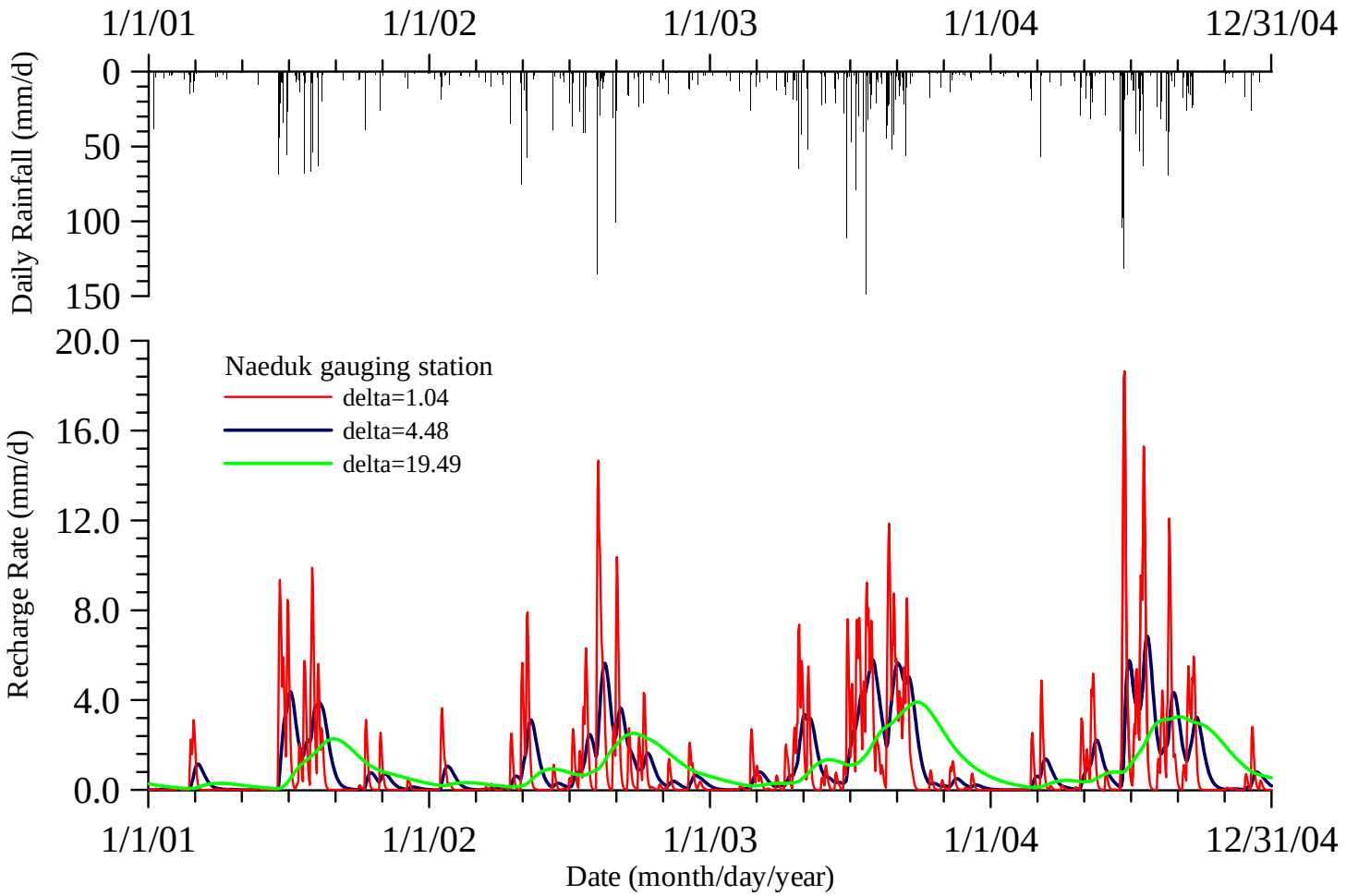
Land use



Soil association map

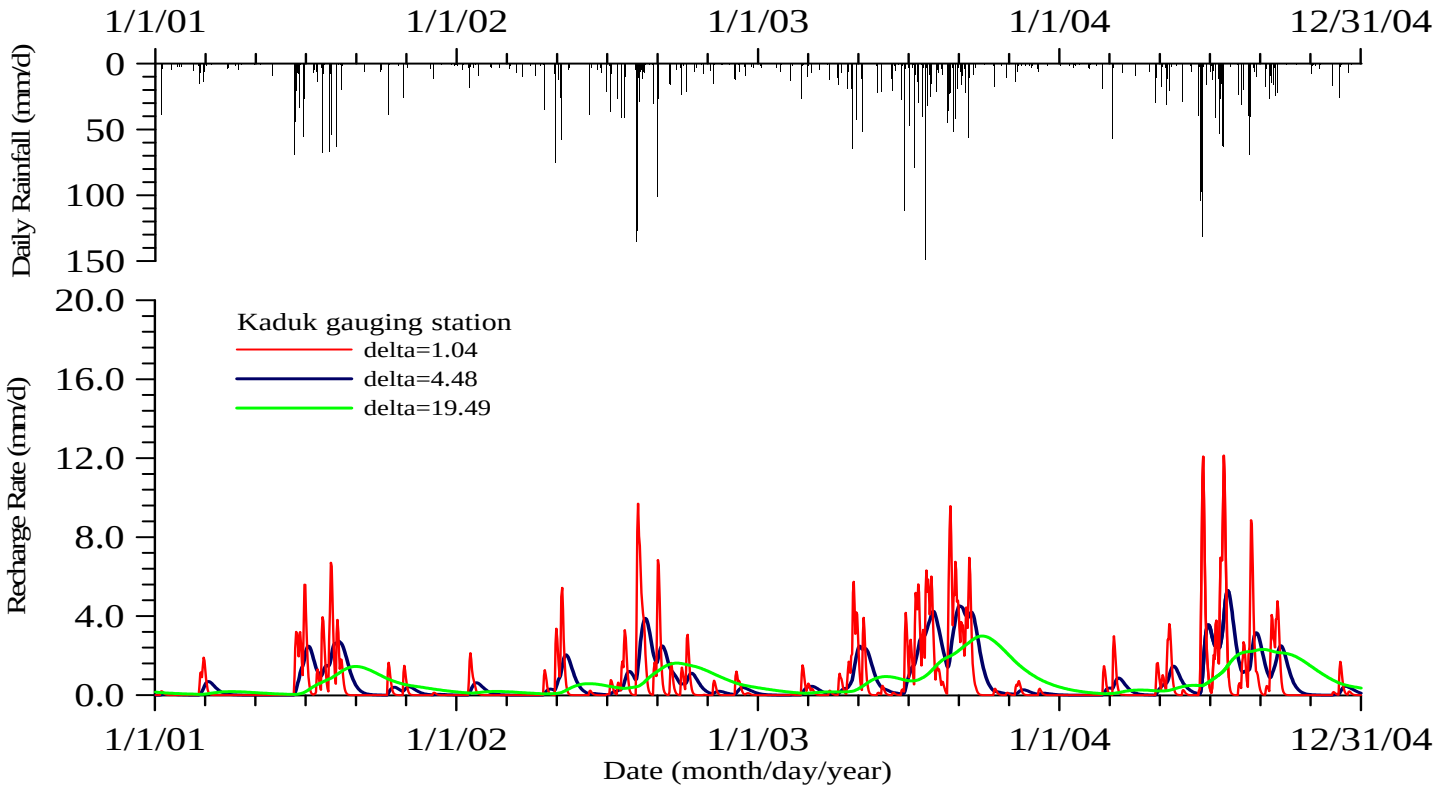
RECHARGE SIMULATION

- **Recharge according to time delay (Naeduk station)**



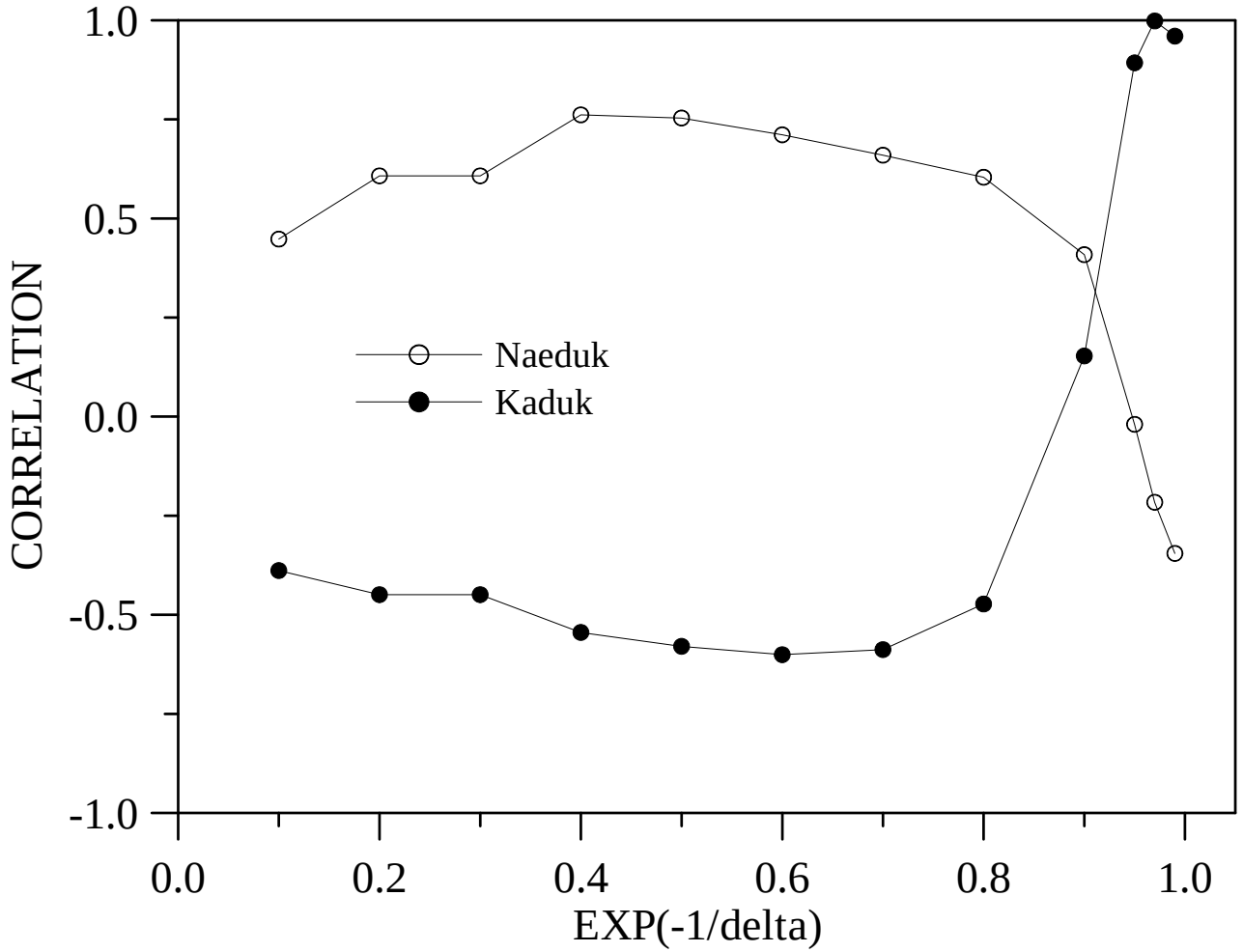
RECHARGE SIMULATION

- **Recharge according to time delay(Gaduk obsevatory)**



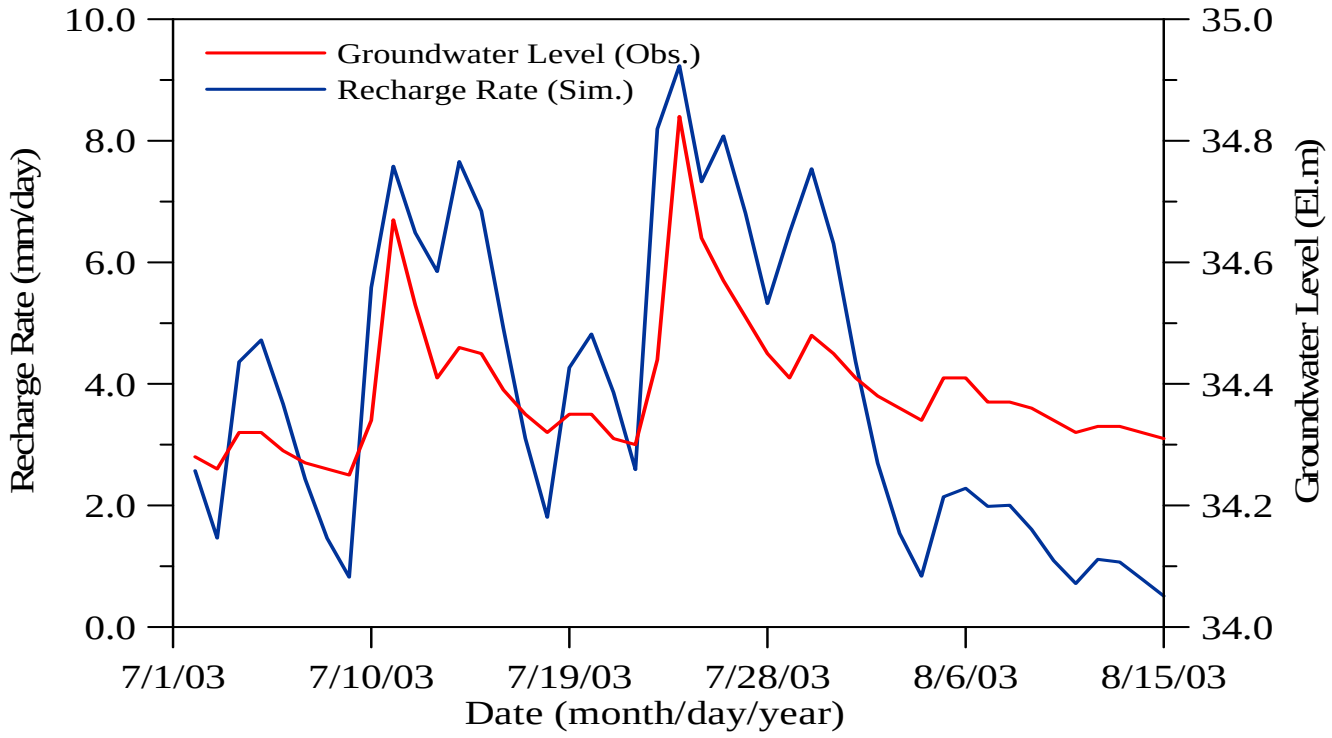
RECHARGE SIMULATION

- **Correlation with GW level according to exp(-1/δ_{gw})**



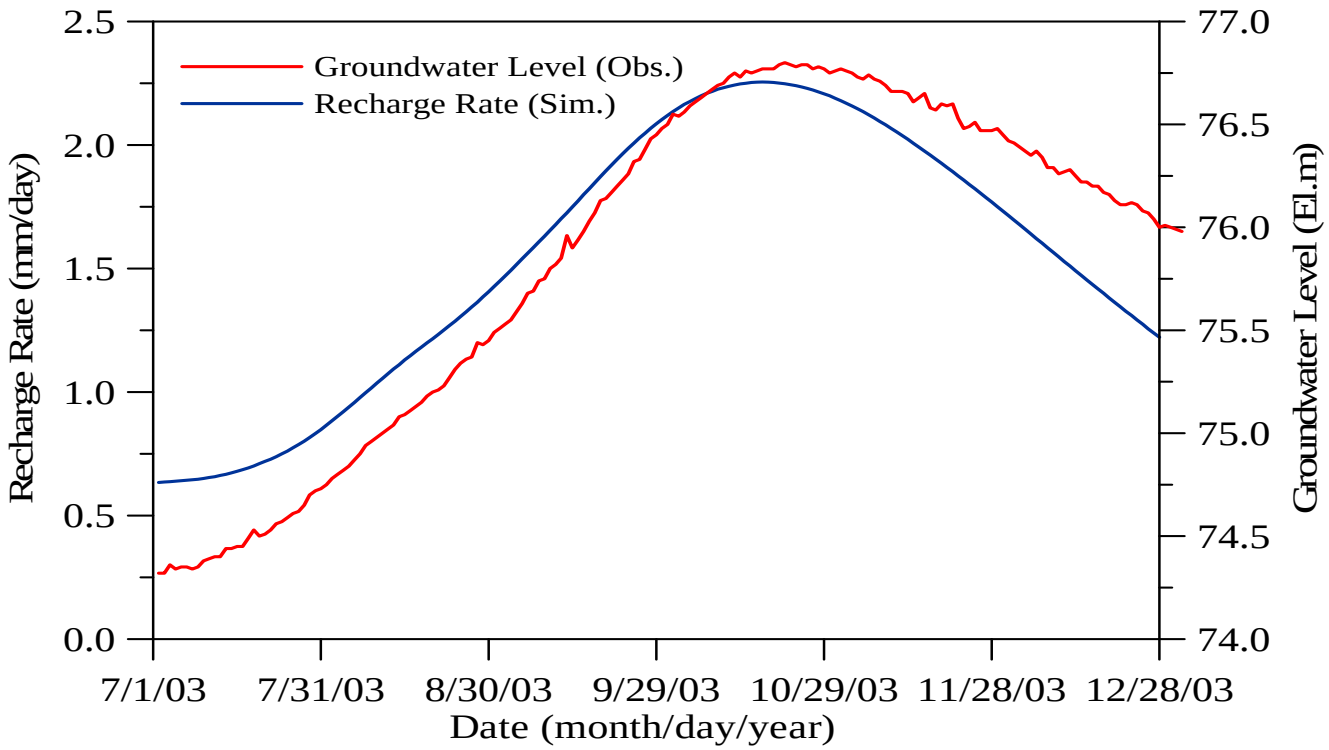
RECHARGE SIMULATION

- **Simulated recharge and measured groundwater level (Naeduk)**



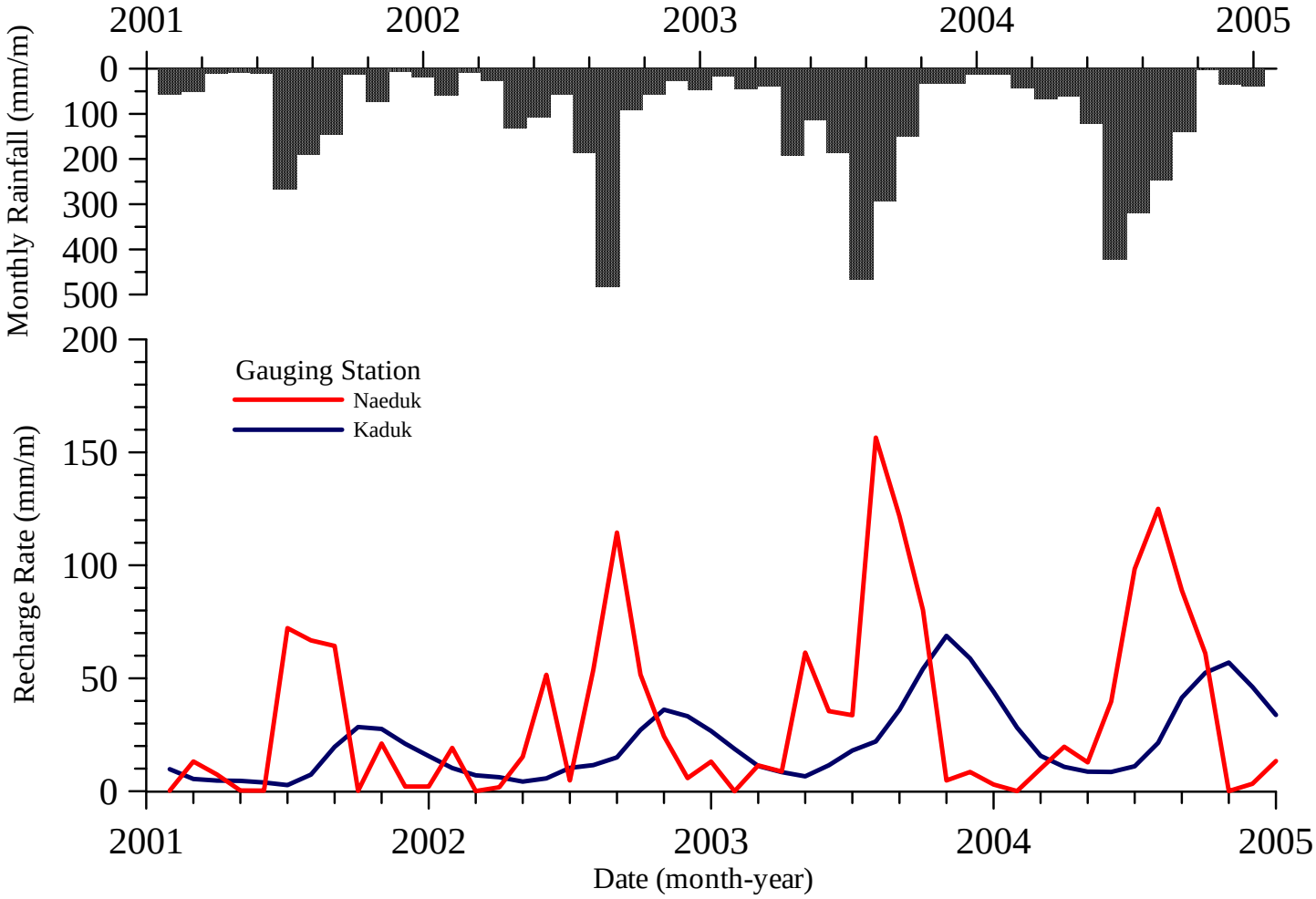
RECHARGE SIMULATION

- **Simulated recharge and measured groundwater level (Gaduk)**



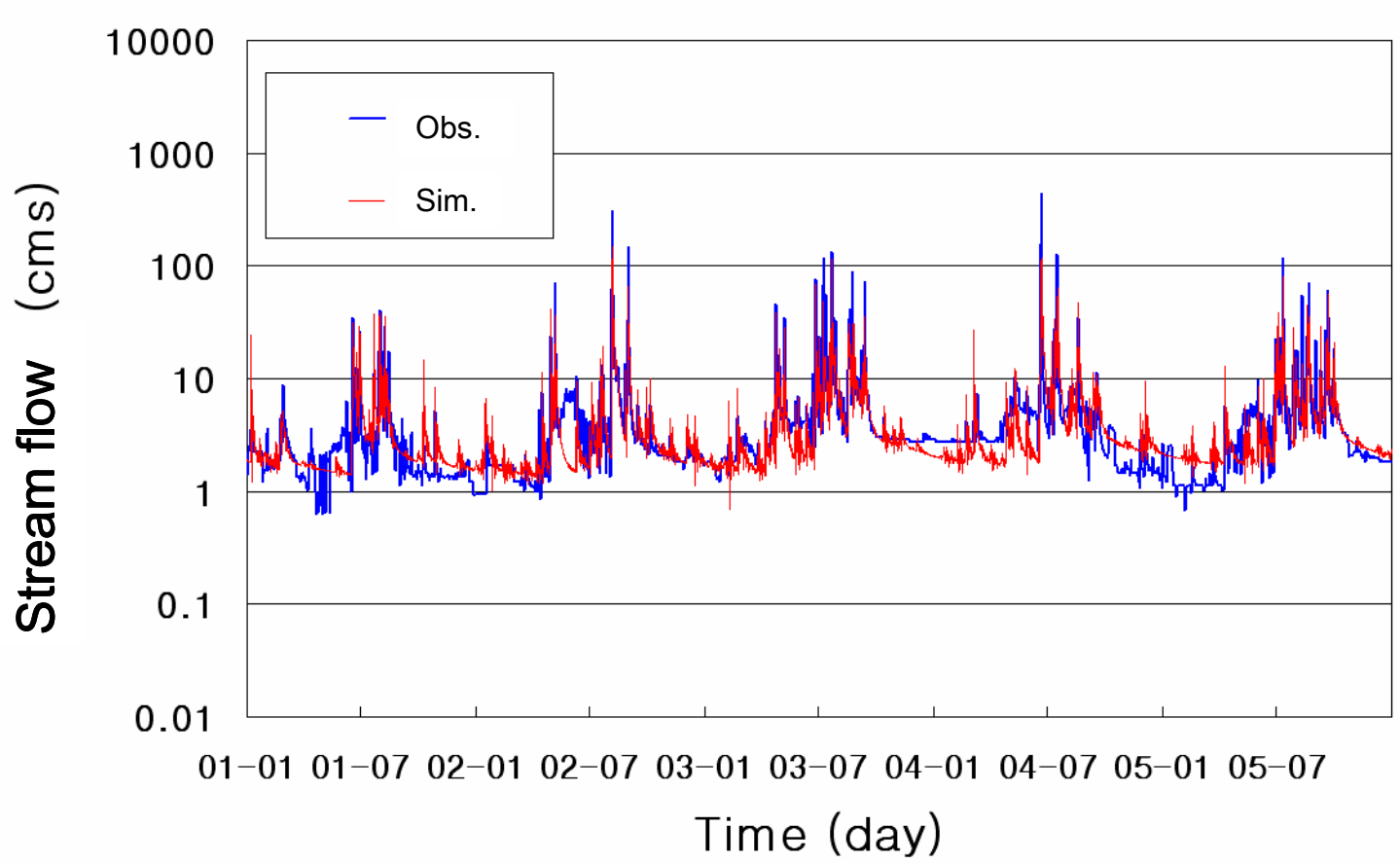
RECHARGE SIMULATION

- **Monthly recharge**



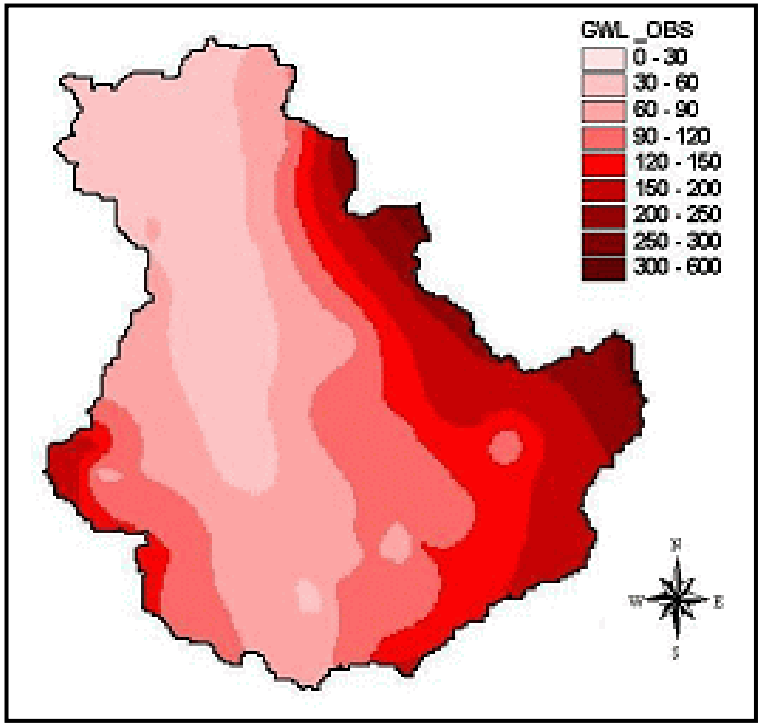
RUNOFF SIMULATION

- **Simulated stream flow (2001~2005)**
  - **Overall correlation (R^2=0.75)**

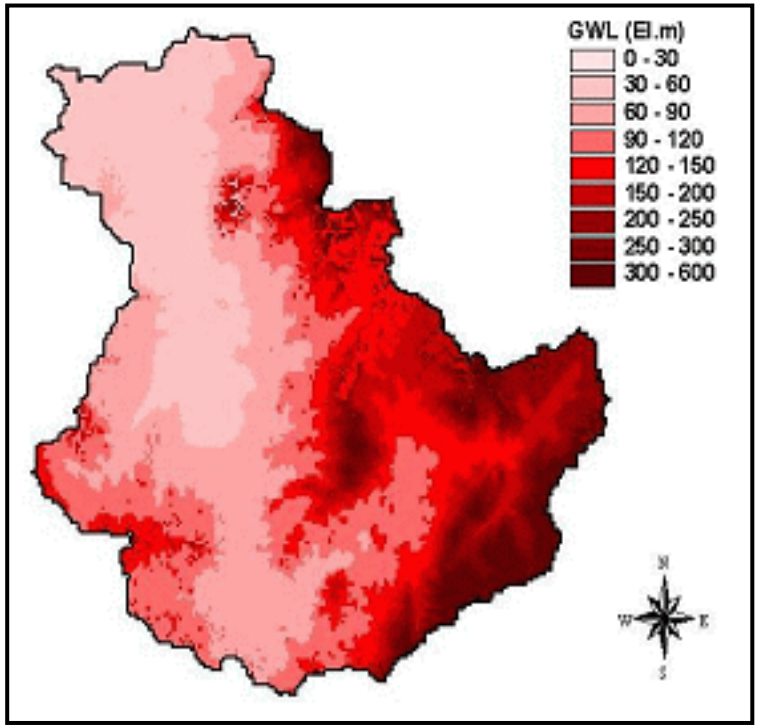


GROUNDWATER SIMULATION

- **Groundwater head simulation**
  - R^2=0.95



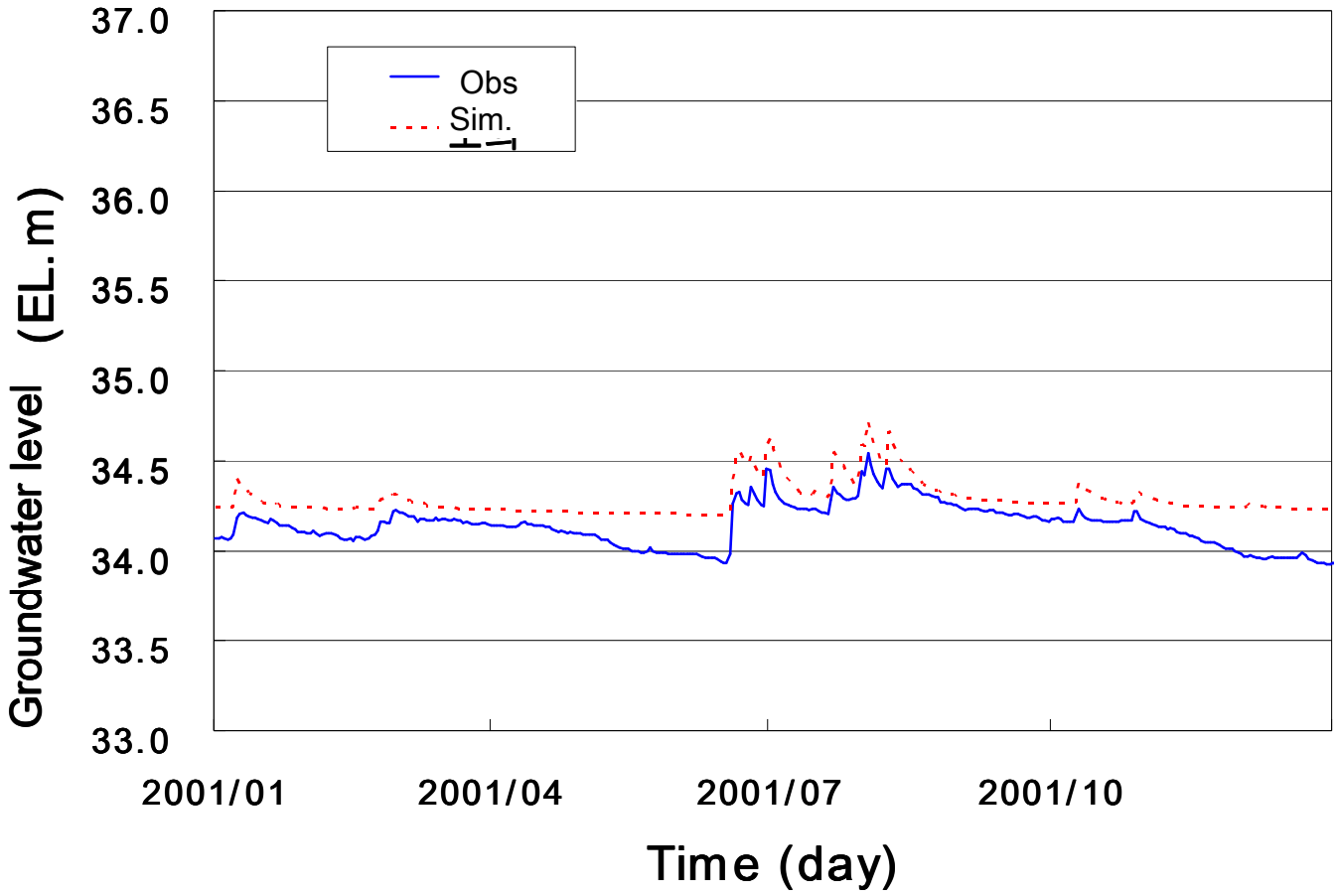
Observed



Simulated

GROUNDWATER SIMULATION

- **Verification of groundwater level**



GROUNDWATER SIMULATION

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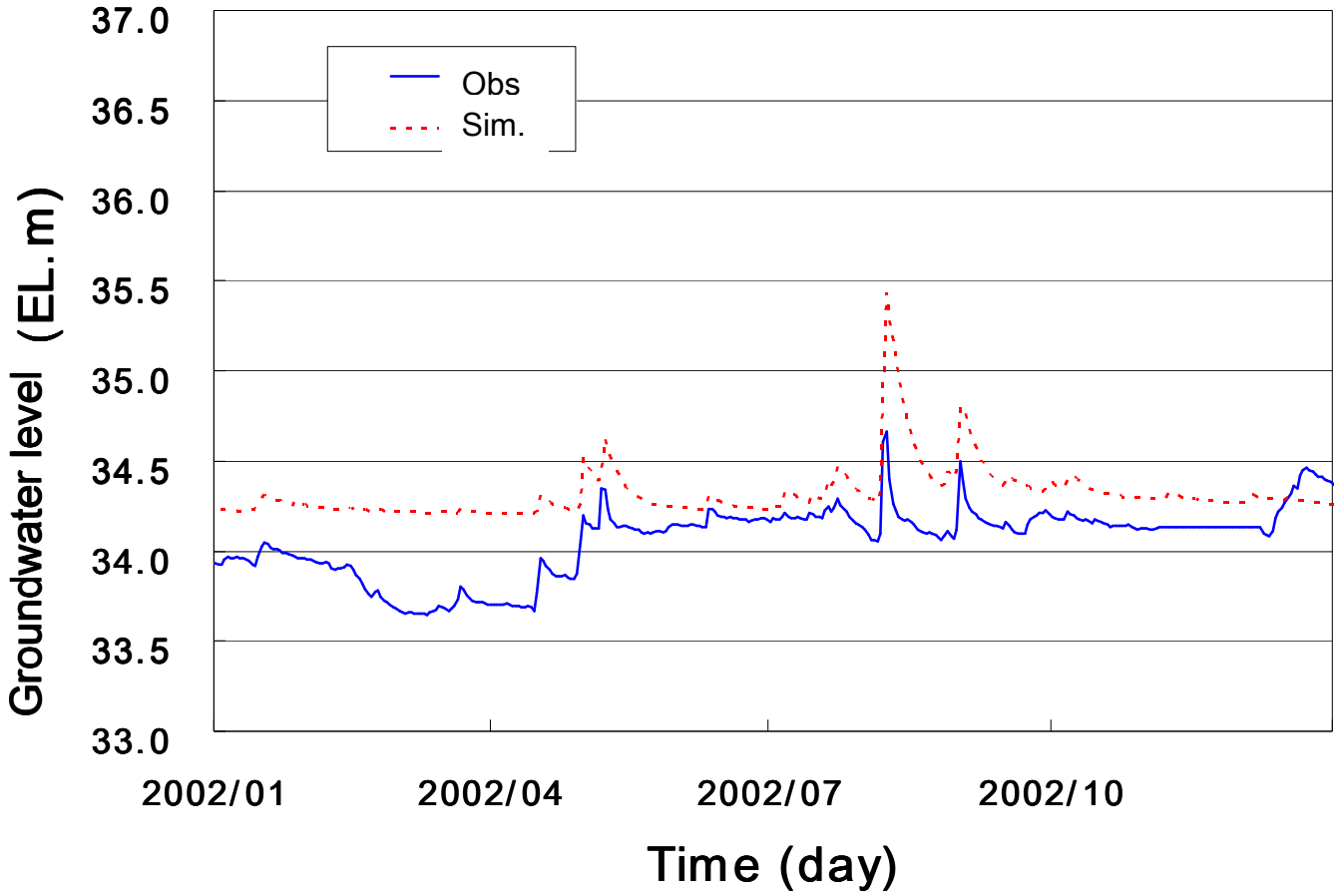

GROUNDWATER SIMULATION

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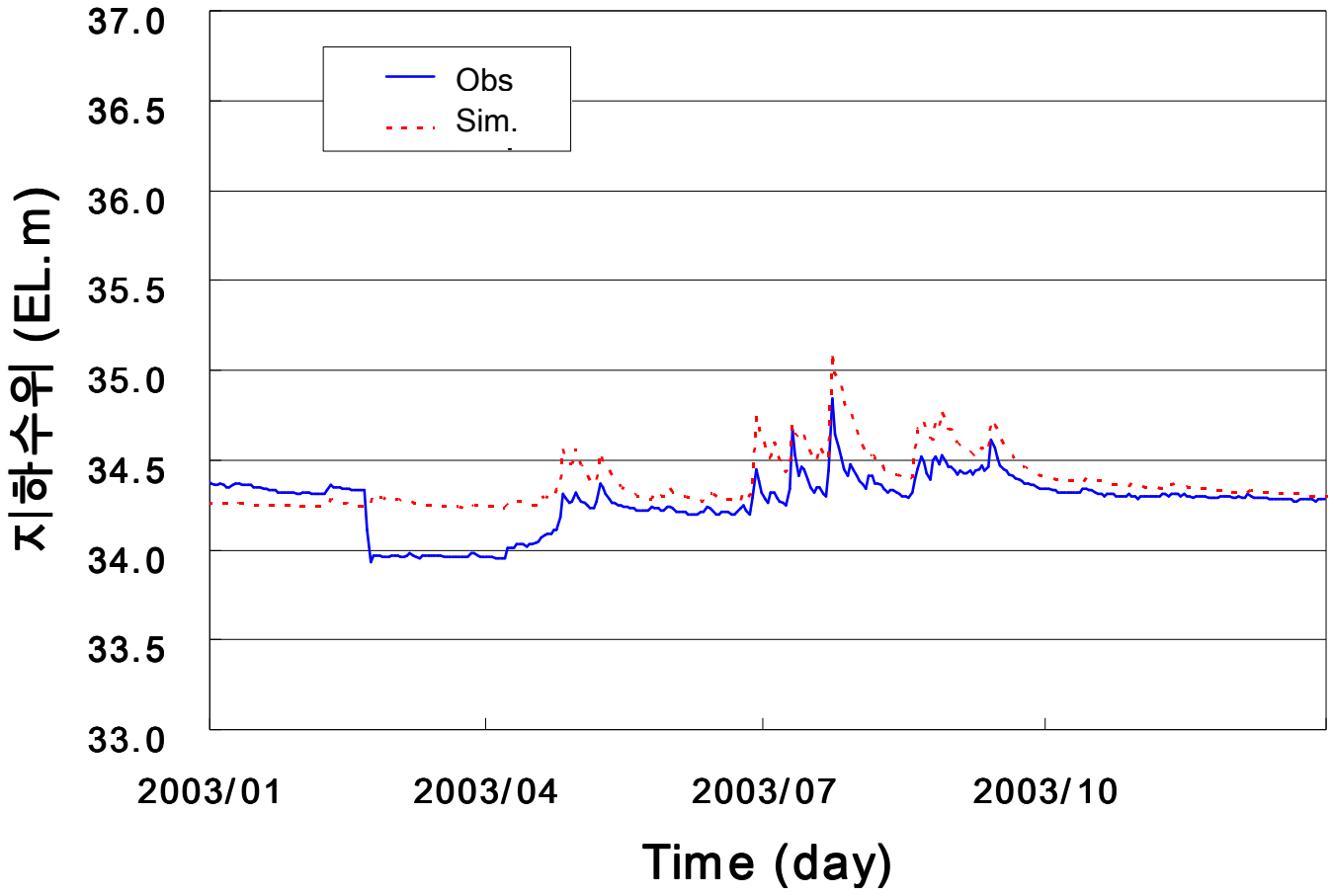
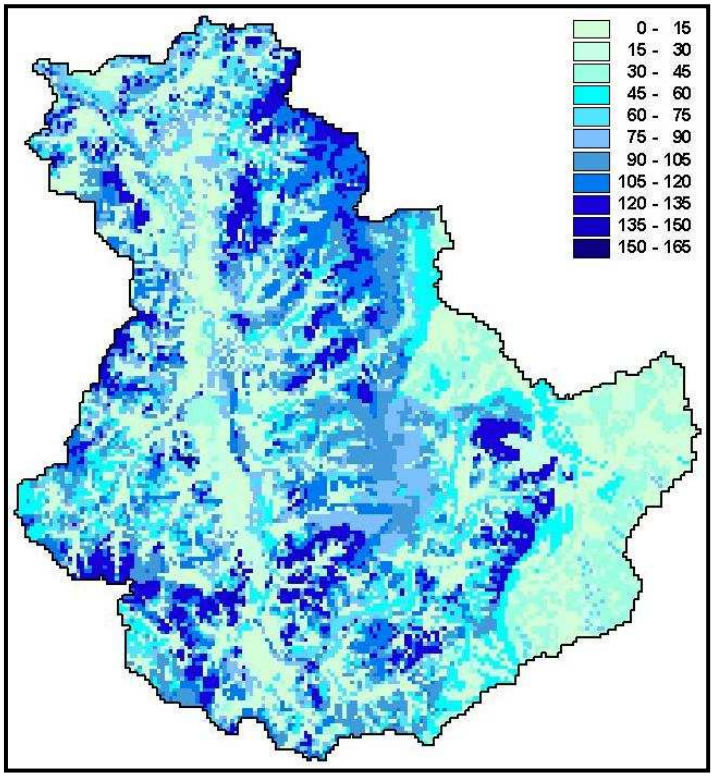
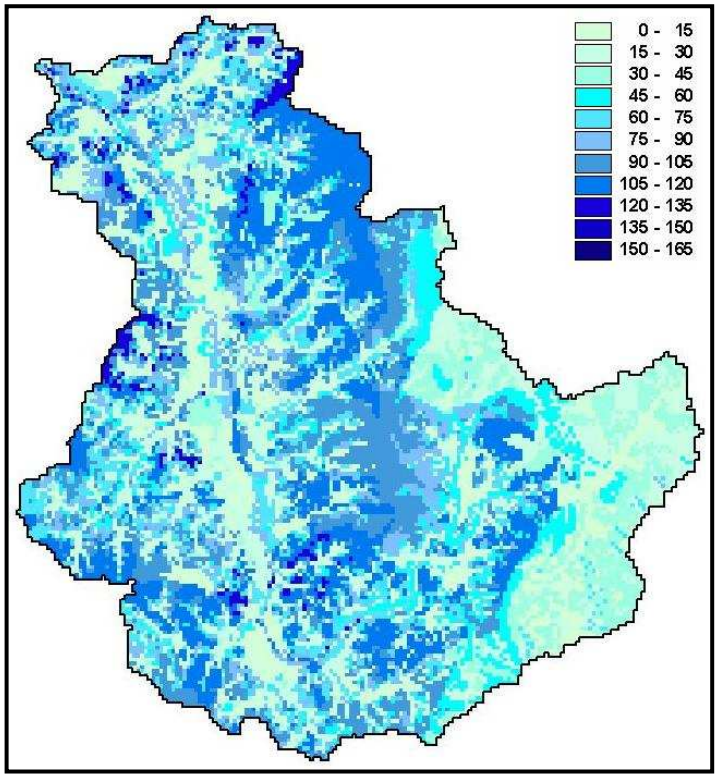


RECHARGE DISTRIBUTION

Distributed recharge (mm)



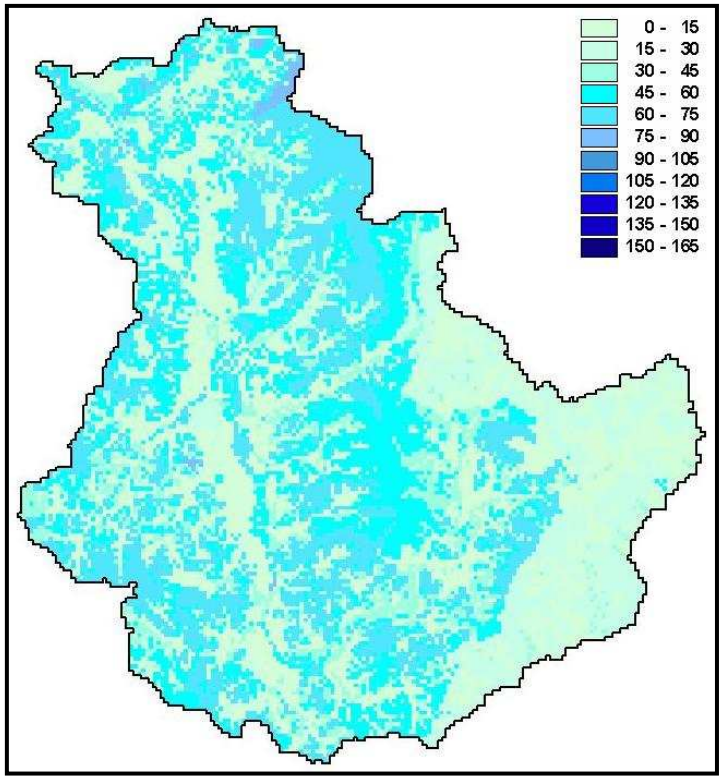
Recharge(Aug. 2002)



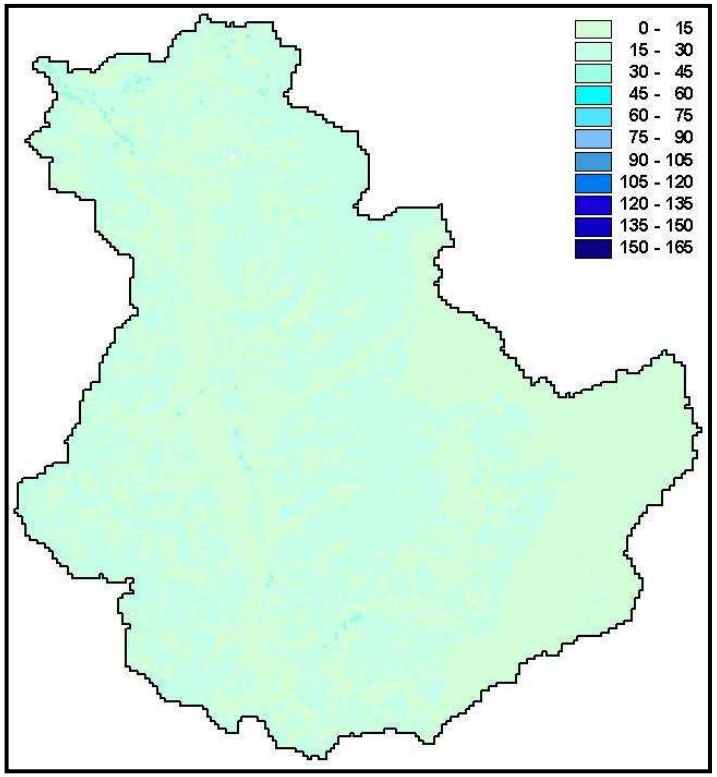
Recharge(Sep. 2002)

RECHARGE DISTRIBUTION

- Distributed recharge (mm)



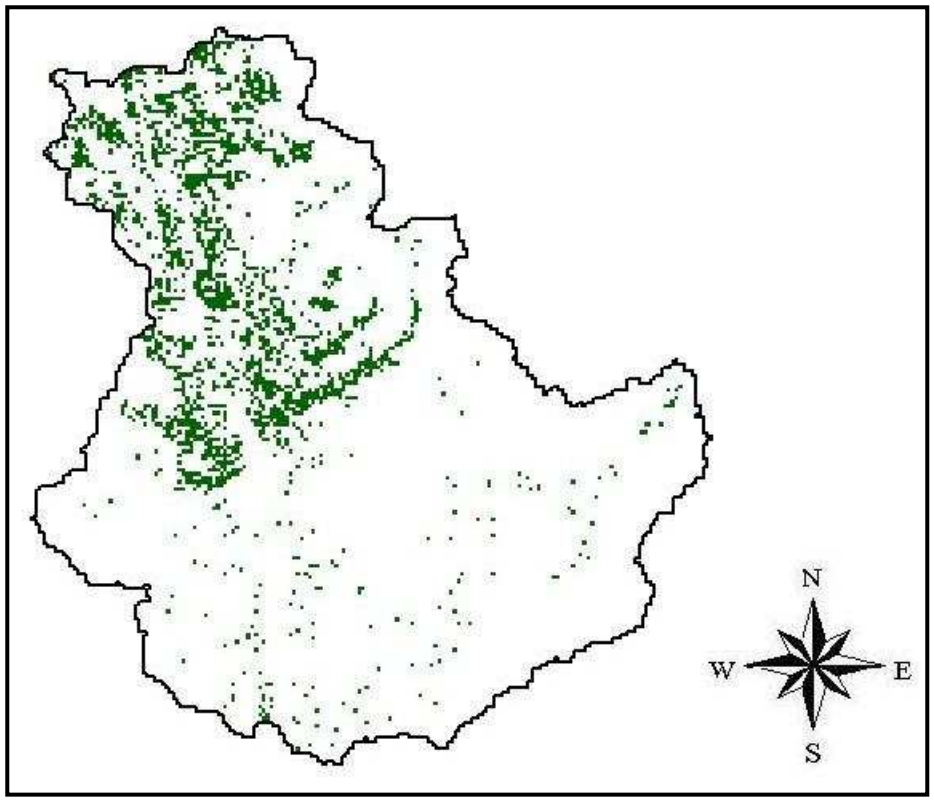
Recharge(Oct. 2002)



Recharge(Nov. 2002)

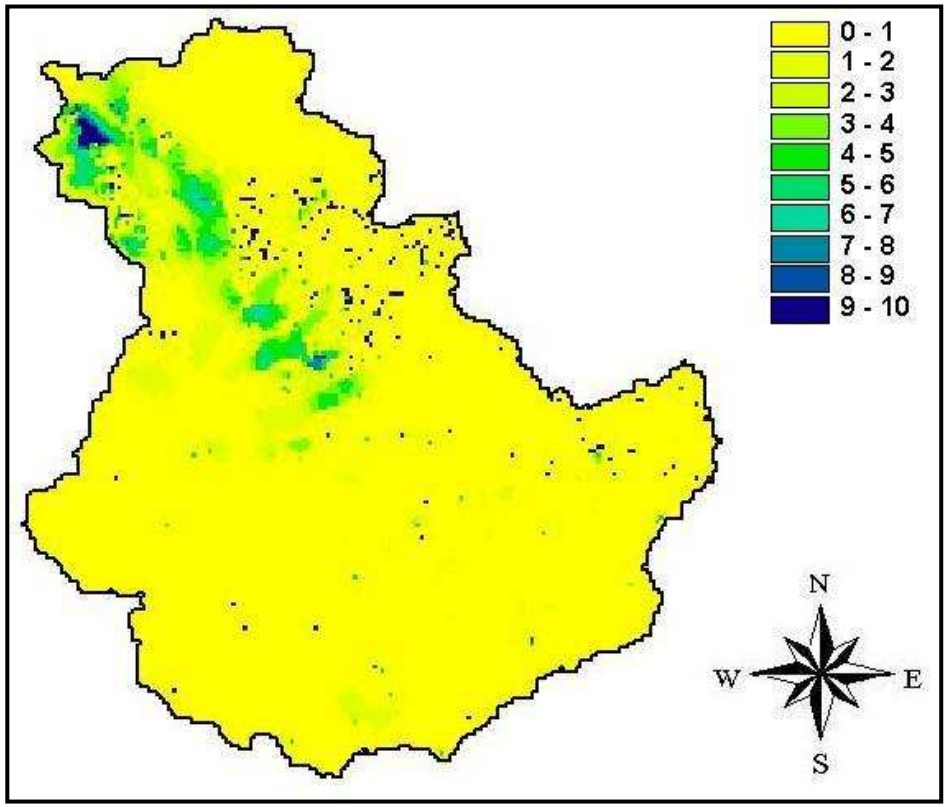
EFFECTS OF WELL PUMPING

- **Distribution of wells (N=2,176)**



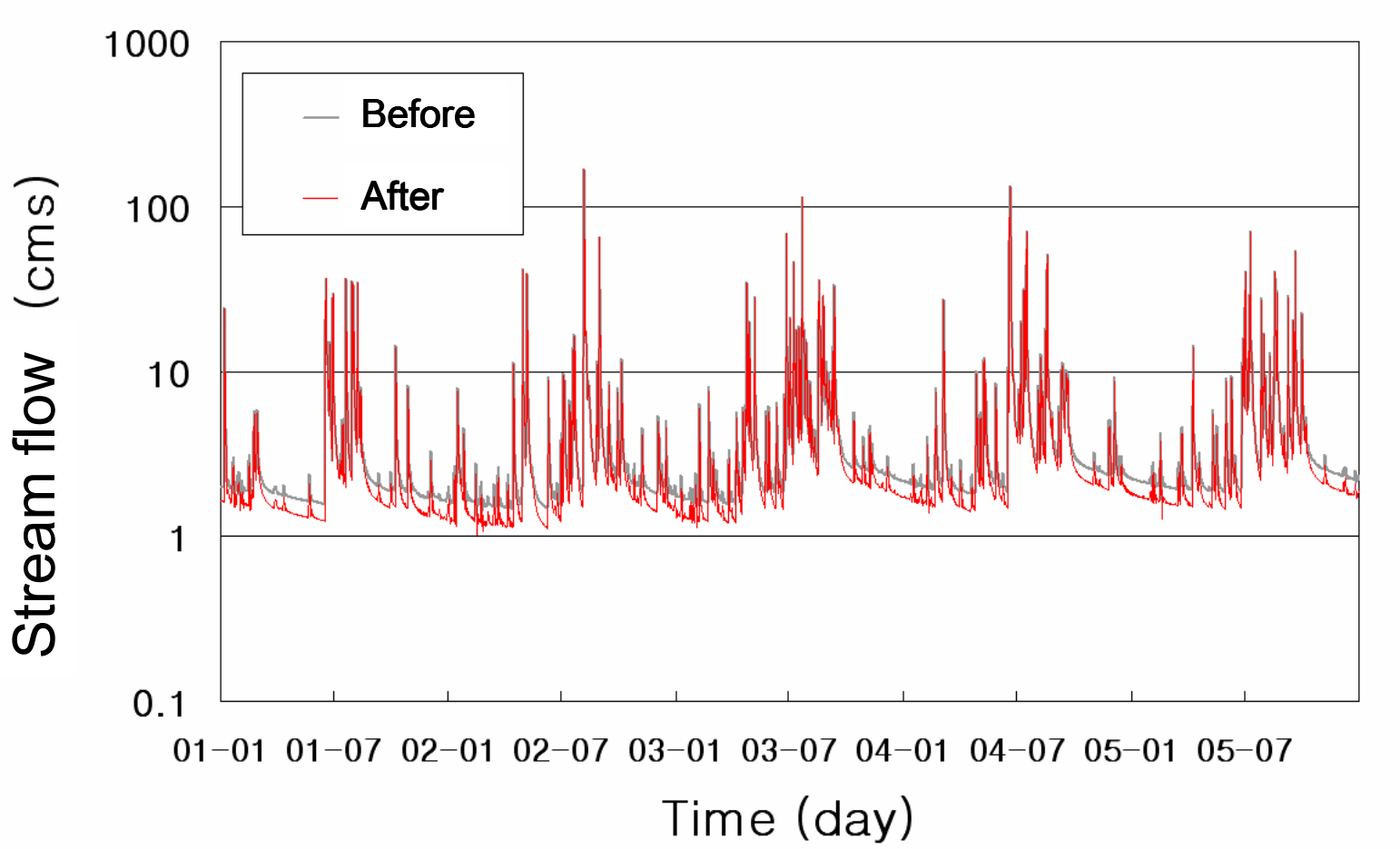
EFFECTS OF WELL PUMPING

- **Distributed drawdown by pumping (Unit: m)**



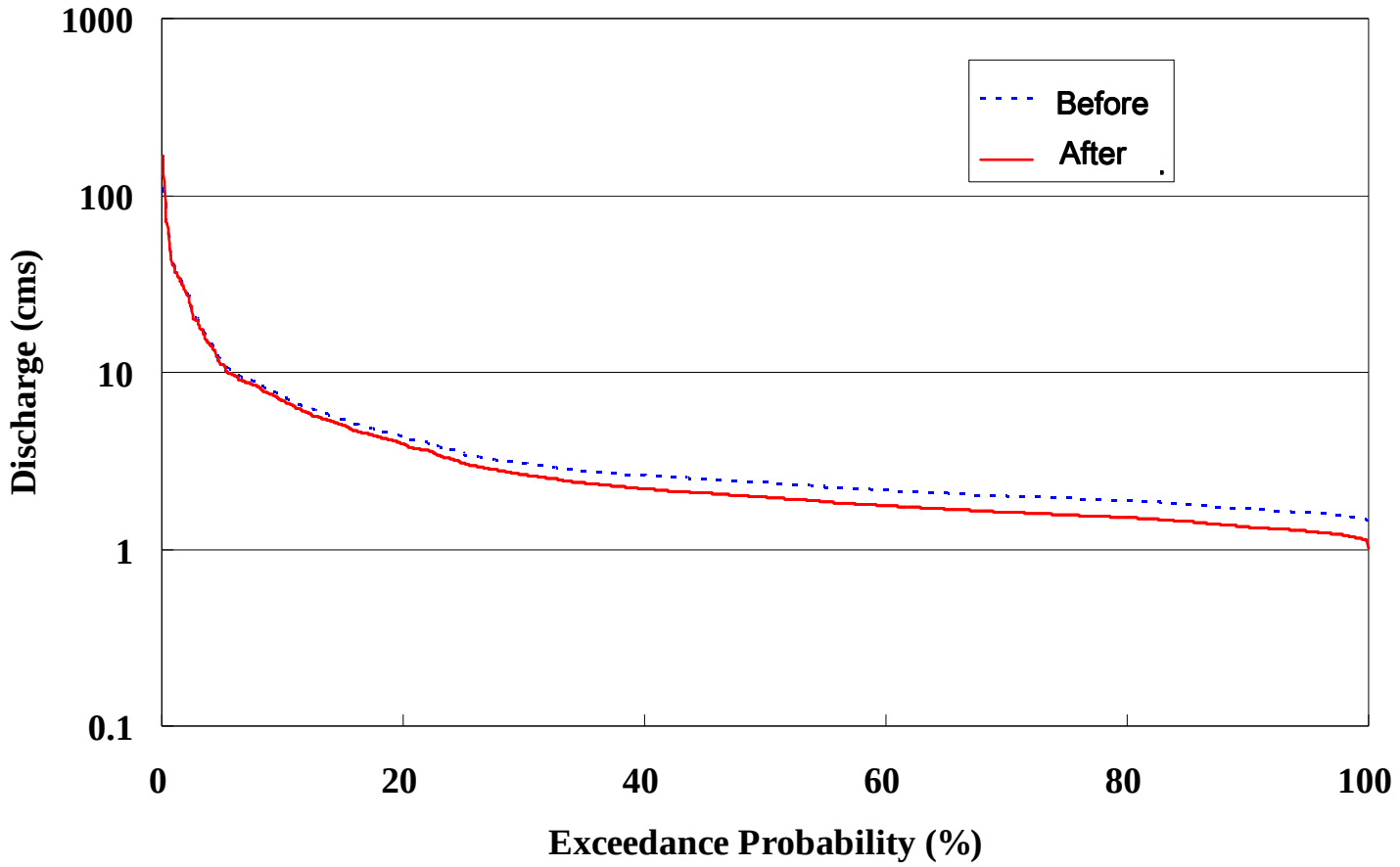
EFFECTS OF WELL PUMPING

Stream flow variation due to pumping



EFFECTS OF WELL PUMPING

Flow pattern variation by pumping

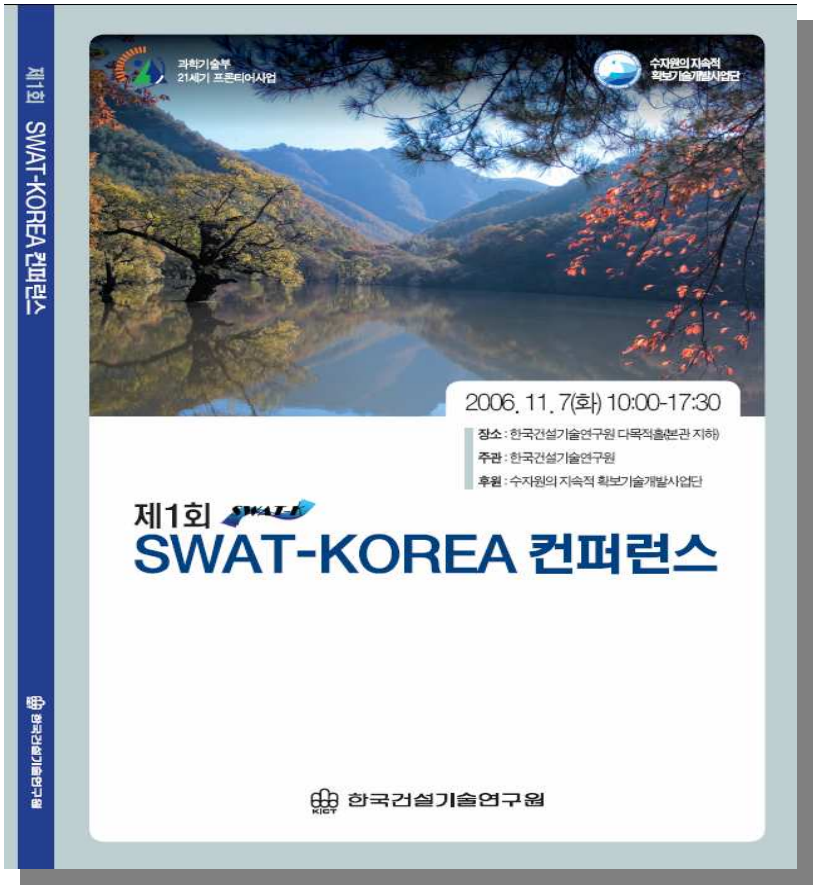


CONCLUSION

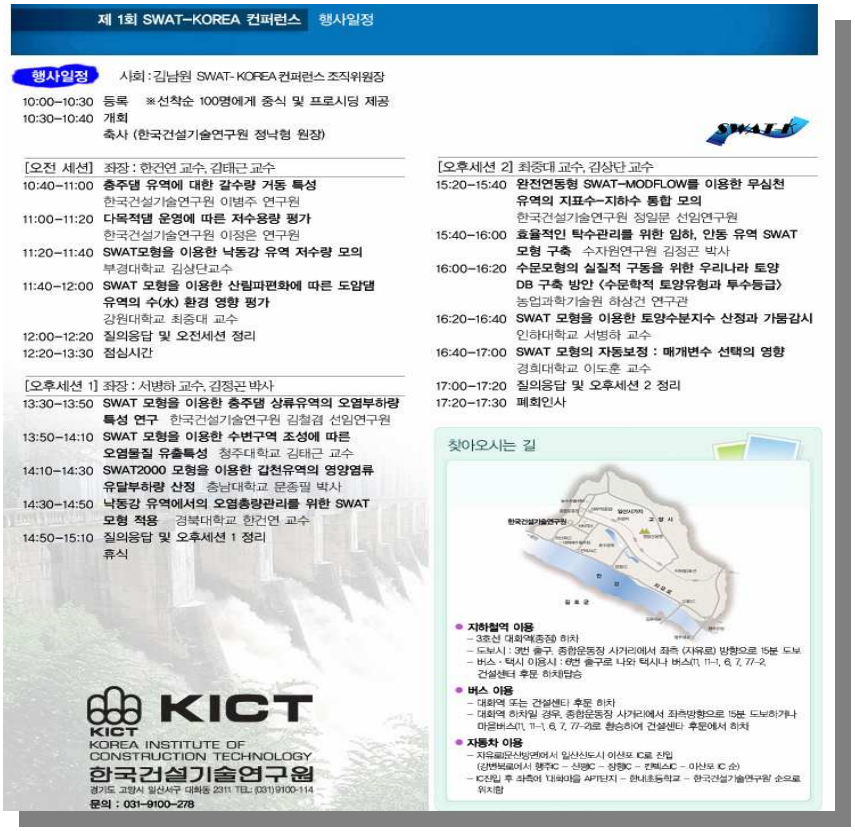
- ✓ **Potential application of combined SWAT-MODFLOW model in simulating groundwater recharge and level is demonstrated**
- ✓ **The combined models are also capable of reflecting river-aquifer exchange rate properly**
- ✓ **The reliability of groundwater discharge and total runoff of watershed is enhanced**
- ✓ **Application to planning of groundwater development / underground dam operation / river intake etc.**
- ✓ **For larger watershed, application of SWAT-MODFLOW is limited due to the limitation of MODFLOW**

1st SWAT-KOREA Conference

7 Nov. 2006 / Venue : Main hall of KICT, Ilsan



Proceeding



Program

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Staffs/Presenters

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Participants

INTERNATIONAL ACTIVITIES

: Thank you :

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