Comparison of runoff responses between SWAT and sequentially coupled SWAT-MODFLOW model

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Background

- Sustainable Water Resources Research Center
  - future water shortage problem

- Poor assessment of continuous runoff process
  - lumped model widely used in Korea

- Increased groundwater usage

- Stream depletion problem
Goals

- To develop a method for simulating water balance considering the water exchange between stream and aquifer at various scales

- To evaluate the predictive capability of SWAT with other integrated watershed models in simulating long-term runoff response in Korea
Limitations of SWAT

- Integrated model for surface and subsurface water
- Difficult to estimate stream-aquifer water exchange due to pumping
- Difficult to estimate the spatial and temporal distribution of groundwater table
- Difficult to consider the impact of deep and complex aquifer system on baseflow response
Ground water model

- MODFLOW developed by USGS
- Cell based 3D finite difference method
- Widely used public domain program
- Modular structure with various packages
SWAT-MODFLOW combined model (Perkins and Sophocleous, 1999)
Sequential coupling approach

Advantages
1. Separate simulation
2. No interface code
3. Conceptually simple

Problems
1. Scale problem
2. Lack of dynamic interaction between stream stage and groundwater level
Bocheong-chun IHP watershed

Area = 353 km²
11 rain gauges
4 water level stations

Geology
Sandstone
Granite
SWAT simulation

- **Mean precipitation**: 1018 mm

- **Wind speed**: 1.85 m/s
  - 1992: 2 m/s, 1993: 1 m/s, 1994: 2 m/s, 1995: 2 m/s, 1996: 3 m/s

- **Maximum daily temp**: 17.3°C

- **Minimum daily temp**: 4.4°C
SWAT simulation

No of HRU=97

AWC: mean=0.14, SD=0.03

Soil K: mean=21.6, SD=23

bulk density: mean=1.5, SD=0.13
MODFLOW simulation

- 100 columns, 100 rows, 1 layer
- Surface water and ground water divide coincide
- River package, Recharge package
- National Groundwater Information Management and Service Center: limited groundwater DB available
Model Calibration

- Manual calibration

- SWAT model
  - GW_DELAY, ALPHA_BF, REVAPMN
  - CN2, CH_N1, CH_N2, ESCO

- MODFLOW model
  - hydraulic conductivity
  - river bed conductance
  - aquifer depth
Annual recharge comparison

![Annual recharge comparison chart](chart.png)
Daily discharge

- **Average Discharge**
  - Observed: 7.84 CMS
  - SWAT: 6.87 CMS
  - SWAT-MODFLOW: 7.29 CMS

- **Standard Deviation**
  - Observed: 22.31 CMS
  - SWAT: 14.02 CMS
  - SWAT-MODFLOW: 10.48 CMS

- **Efficiency Index**
  - 1992: SWAT 0.43, SWAT-MODFLOW 0.50
  - 1993: SWAT 0.60, SWAT-MODFLOW 0.57
  - 1995: SWAT 0.65, SWAT-MODFLOW 0.70
  - 1996: SWAT 0.68, SWAT-MODFLOW 0.73

- **Correlation**
  - $R^2 = 0.9011$
  - $\text{SWAT-MODFLOW vs. SWAT (m}^3/\text{s})$
Periodogram for daily record
Average Annual Water Budget

- ET 43%
- Surface flow 16%
- Lateral flow 17%
- Baseflow 24%
10 day averaged discharge

![Bar charts showing discharge (CMS) for observed, SWAT, and SWAT-MODFLOW with average values of 7.9, 6.9, and 7.3, respectively.]

![Bar charts showing standard deviation for observed, SWAT, and SWAT-MODFLOW with values of 14.2, 10.9, and 6.9, respectively.]

![Efficiency Index chart with values of 0.82 for SWAT and 0.66 for SWAT-MODFLOW.]

![Scatter plot showing relationship between SWAT-MODFLOW and SWAT with a linear regression line and R² value of 0.9432.]
Monthly baseflow

![Average discharge (CMS)]

- DFM: 4.0
- SWAT: 3.3
- MODFLOW: 3.7

![Standard deviation discharge (CMS)]

- DFM: 4.0
- SWAT: 4.1
- MODFLOW: 0.4

![Efficiency Index](0.44 for SWAT, 0.15 for MODFLOW)

![Regression line] $R^2 = 0.766$
Ground water budget
Conclusions

- Performance of SWAT in predicting daily discharge is fair (EI=0.66), but that of SWAT-MODFLOW is poor (EI=0.54).

- Variance of two model outputs underestimated those of measured discharge, while average of model output agrees with measured discharge.

- Performance of two models increases as output response time scales increase.
Conclusions

- Large difference of baseflow variability between SWAT and MODFLOW

- SWAT-MODFLOW sequentially coupled model contains large uncertainty of model response due to uncertain aquifer characteristics, initial and boundary conditions, but is useful for estimating the detailed ground water balance and ground water level.
Ongoing and future research

- To test with the SWAT-MODFLOW dynamic coupling developed by KICT

- To test with other integrated models (e.g. MIKESHE, HSPF-MODFLOW)

- Over-parameterization/Non-unique problem? Need to develop rigorous calibration method using internal variables and uncertainty analysis for the coupled model
Questions or Comments?

Thank you for your attention.