SWAT vs. SWAT-MODFLOW in lowland catchments: Comparison of performance and simulation of groundwater abstraction scenarios

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INTRODUCTION

Danish drinking water supply: based entirely on groundwater

Additional abstraction for agricultural and industrial purposes

Some areas: groundwater exploitation above sustainable yield

Average GW contribution to streamflow:
- 76% continent
- 59% islands

Vital importance of good understanding of GW processes and the GW-SW interactions

GEUS (2008)
INTRODUCTION

Simple approach to represent groundwater processes

Accurate representation of GW processes is desirable.
- To know well how is the interaction with surface water
- To assess the impacts of groundwater abstraction

How to achieve it:
Coupling SWAT with a more detailed groundwater model

Walker & Mallants (2014)
INTRODUCTION: SWAT-MODFLOW

Modified from Bailey et al (2017)
STUDY AREA: ODDERBÆK CATCHMENT

MAIN CHARACTERISTICS:
- **Area**: 1142 ha
- **Elevation range**: 11 m – 58 m
- **Main land use**: Agriculture (85%)
- **Climate**: Oceanic (warm temperate, fully humid)
  - Average T (2000-2015): 12.3 °C max, 5.4 °C min

Gislum church
GOALS

Set-up a new SWAT model with the latest version of Q-SWAT

Couple the SWAT model with a MODFLOW model provided by NIRAS (SWAT-MODFLOW)

Calibrate both models (SWAT and SWAT-MODFLOW) using SWAT-CUP

Compare their performances

Evaluate models when simulating abstraction scenarios
MODELS SET-UP: Q-SWAT

A) Pasture (0.68%) → Agriculture
Water (0.14%) → Wetlands
Roads = Residential

B) Land Use
- Residential
- Agriculture 1
- Agriculture 2
- Agriculture 3
- Agriculture 4
- Evergreen forest
- Wetland

C) Soil types
- DK998
- DK999
- DK4016
- DK4018
- DK4027
- DK4048

DK4037 (0.54%) → DK4027
DK4047 (0.54%) → DK4027
MODELS SET-UP: SWAT-MODFLOW COUPLING

MODFLOW MODEL (NIRAS)
- 100 m discretization
- Two aquifers with a clay layer in-between
- Pre-calibrated (Sørensen and Jensen, 2009)

COUPLING PROCEDURE:
FIRST: Disaggregate HRUs into DHRUs (individual polygons)
SECOND: LINKAGES
- SWAT DHRUs ↔ MODFLOW grid cells
- SWAT SUBBASINS ↔ MODFLOW river cells
- Done through GIS routines (Bailey et al., 2016, 2017)
CALIBRATION AND VALIDATION

Flow data

SWAT: 24 parameters
S-M: 17 parameters

Expert knowledge

WARM-UP CALIBRATION VALIDATION

ADDITIONALLY IN SWAT-MODFLOW

BEFORE SWAT-CUP:
- Preliminary iteration of 300 simulations
- OAT manual sensitivity analysis of MODFLOW’s River Package parameters
- Manual calibration of River Package parameters.
- SWAT parameters calibration

AFTER SWAT-CUP:
- Fine-tuning of sensitive parameters in the River Package

Molina-Navarro et al. (2017)
Environmental Modelling & Software
SCENARIOS SIMULATION

3 abstraction wells, one each in subbasins 12, 14 and 15
3 abstraction wells, all in subbasin 15
- High abstraction rate (water supply, deep)
- Low abstraction rate (irrigation, shallow)

3 SCENARIOS ➔ Impacts on streamflow
RESULTS: CALIBRATION

**SWAT:**
- $R^2 = 0.69$
- $NSE = 0.64$
- $PBIAS = -4.4$

**SWAT-MODFLOW:**
- $R^2 = 0.71$
- $NSE = 0.69$
- $PBIAS = 7.0$

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<tr>
<td>PET</td>
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</table>
**RESULTS: VALIDATION**

**SWAT:**
- $R^2 = 0.64$
- $NSE = 0.59$
- $PBIAS = -2.6$

**SWAT-MODFLOW:**
- $R^2 = 0.68$
- $NSE = 0.65$
- $PBIAS = 7.6$

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<th>Parameter</th>
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<th>SWAT-MODFLOW</th>
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<td>PET (mm)</td>
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RESULTS: ABSTRACTION SCENARIOS

SWAT

A)

SWAT-MODFLOW

B)
ADDITIONAL SWAT-MODFLOW OUTPUTS

**Average daily rate of stream-aquifer water exchange (control)**

**Difference in average stream-aquifer water exchange vs. control**

SWAT-MODFLOW allows to explore the **spatial variability** of groundwater discharge at a cell level, evaluating the impacts of the scenarios.
ADDITIONAL SWAT-MODFLOW OUTPUTS

CONTROL SCENARIO

START (01/01/2000)  MID (31/12/2005)  END (31/12/2010)

THREE WELLS IN SUB-BASIN 15

START (01/01/2000)  MID (31/12/2005)  END (31/12/2010)

ONE WELL IN SUB-BASINS 12, 14 and 15

START (01/01/2000)  MID (31/12/2005)  END (31/12/2010)

SWAT-MODFLOW allows to explore the impacts of the scenarios in the water table elevation.
CONCLUSIONS

MODEL PERFORMANCE

✓ Both models showed a good statistical performance (first time this version of SWAT-MODFLOW is successfully applied in a catchment of this characteristics).
✓ SWAT-MODFLOW performs better during periods of hydrograph recession.

ABSTRACTION SCENARIOS SIMULATION

✓ SWAT-MODFLOW yielded more realistic results than SWAT, simulating a decrease in streamflow close to the abstracted water volume.
✓ In SWAT, groundwater in the “deep aquifer” was not affected, besides being numerical input limitations.
✓ SWAT-MODFLOW allows wider possibilities for groundwater analysis, e.g. spatial distribution of stream-aquifer exchange or water table elevations.

RESULTS SUPPORT THE USE OF SWAT-MODFLOW INSTEAD OF SWAT IN CATCHMENTS WHEREIN GROUNDWATER IS A DOMINANT COMPONENT OF STREAM FLOW
THANKS FOR YOUR ATTENTION

Questions?