Dynamic versus static representations of land use change in SWAT

P.D. Wagner, S. Murty B., B. Narasimhan, S. Kumar, N. Fohrer, P. Fiener
1. Motivation

Static Delta-Approach to derive impacts of land use change on water resources

Hydrologic Model

- Model run A
- Model run B

Mean water balance A
Mean water balance B

Difference of water balance components
Mean impact of land use change

Result: long-term average, dynamics are not represented

=> Integration of dynamic land use change in a hydrologic model (possible in SWAT since 2010)
1. Motivation

Integration of dynamic land use change*

Hydrologic model

Model run A

Model run B

2009-2028

Water balance without LUC

Water balance with LUC

Difference of water balance components

Temporally differentiated impacts of land use change

1. Objective

What is the impact of using dynamic land use information as compared to using static land use information?

**Static approach**
- Model run A
- Model run B
- Water balance without LUC
- Water balance with LUC
- Difference

**Dynamic approach**
- Model run A
- Model run B
- Water balance without LUC
- Water balance with LUC
- Difference

Difference of predicted impacts
2. Study area

Sub-basin 4:
Urban fringe

Kumbheri

Pune

Lavasa

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3. Materials & Methods

Land use scenario 2009 to 2028
- Land use model SLEUTH extrapolates trends from the past
- Development plan of new „hill station“ city Lavasa in the Western Ghats

Hydrologic model SWAT
- SWAT-Model-Runs from 2009 to 2028
  - with annual land use updates
  - compared to model runs with static land use information

Model Validation*
- Land use model: ROC urban 80%; deviations < 3% per land use class
- Hydrologic model: Nash-Sutcliffe efficiencies of 0.67 and 0.68

=> Both models show reasonable performance

### 3. Land Use Scenario

#### Projected Land use change between 2009 and 2028

<table>
<thead>
<tr>
<th>Land use</th>
<th>Catchment</th>
<th>Sub-basin 4 (urban fringe)</th>
<th>Sub-basin 24 (Lavasa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>-0.3%</td>
<td>-0.8%</td>
<td>-8.3%</td>
</tr>
<tr>
<td>Shrubland</td>
<td>-2.6%</td>
<td>-2.9%</td>
<td>-3.4%</td>
</tr>
<tr>
<td>Grassland</td>
<td>-1.4%</td>
<td>-5.4%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Cropland</td>
<td>-3.6%</td>
<td>-14.0%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Water</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Urban medium density</td>
<td>+6.0%</td>
<td>+15.6%</td>
<td>+9.7%</td>
</tr>
<tr>
<td>Urban high density</td>
<td>+1.9%</td>
<td>+7.5%</td>
<td>+2.5%</td>
</tr>
</tbody>
</table>
3. Land Use Scenario

Land use classification

2009/10
3. Land Use Scenario

Land use scenario

2014/15

Legend:
- Forest
- Mixed Cropland
- Bare Soil
- Shrubland
- Rice-Wheat
- Water
- Grassland
- Sugarcane
- Urban
3. Land Use Scenario

Land use scenario
2018/19

- Forest
- Mixed Cropland
- Bare Soil
- Shrubland
- Rice-Wheat
- Water
- Grassland
- Sugarcane
- Urban
3. Land Use Scenario

Land use scenario 2024/25

[Map showing various land use types such as Forest, Mixed Cropland, Bare Soil, Shrubland, Rice-Wheat, Water, Grassland, Sugarcane, and Urban.]
3. Land Use Scenario

![Land Use Scenario 2028/29](image)
3. Land Use Scenarios

**linear**

(A) Catchment Land Use (%)

- Forest
- Shrubland
- Grassland
- Mixed cropland

(B) Catchment Land Use (%)

- Rice-Wheat
- Sugarcane
- Urban
- Water
## 3. Model runs

<table>
<thead>
<tr>
<th>Land use representation</th>
<th>Land use scenario</th>
<th>Model run abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static (2009/2010)</td>
<td>-</td>
<td>LU09</td>
</tr>
<tr>
<td>Static (2028/2029)</td>
<td>-</td>
<td>LU28</td>
</tr>
<tr>
<td>Dynamic (time step 1 yr)</td>
<td>linear</td>
<td>LU1S1</td>
</tr>
<tr>
<td>Dynamic (time step 1 yr)</td>
<td>non-linear</td>
<td>LU1S2</td>
</tr>
<tr>
<td>Dynamic (time step 3 yrs)</td>
<td>non-linear</td>
<td>LU3S2</td>
</tr>
<tr>
<td>Dynamic (time step 5 yrs)</td>
<td>non-linear</td>
<td>LU5S2</td>
</tr>
<tr>
<td>Dynamic (time step 9 yrs)</td>
<td>non-linear</td>
<td>LU9S2</td>
</tr>
</tbody>
</table>
3. Land use change impact assessment

\[ \text{Delta Change} = \frac{V(LU28) - V(LU09)}{2} \]

\[ \text{Dynamic Change} = \sum_{i=2009}^{2028} [V(LUi) - V(LU09)] \]

where \( V(LU28), V(LU09), V(LUi) \) are the cumulative values of a water balance component \( V \) for the model runs \( LU28, LU09, \) and \( LUi \) (for the period between the annual land use updates \( i \)), respectively.

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4. Cumulative land use change impacts
4. Cumulative land use change impacts
5. Approximation by the Delta-Approach

- Linear Dynamic
- Non-Linear Dynamic

Sub-basin:
- $S = \text{Sub-basin}
- P = \text{Percentage Difference} (%)$
- $A = \text{Absolute Difference} (\text{mm})$

Water Yield

- Over- and Underestimation by the Delta-Approach (%)
5. Approximation by the Delta-Approach

<table>
<thead>
<tr>
<th>Difference</th>
<th>ET</th>
<th>WY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between -5% and +5%</td>
<td>5 sub-basins</td>
<td>3 sub-basins</td>
</tr>
<tr>
<td>Overestimation (&gt; +5%)</td>
<td>13 sub-basins</td>
<td>13 sub-basins</td>
</tr>
<tr>
<td>Underestimation (&lt; -5%)</td>
<td>7 sub-basins</td>
<td>9 sub-basins</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Difference</th>
<th>ET</th>
<th>WY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between -10% and +10%</td>
<td>1 sub-basin</td>
<td>1 sub-basin</td>
</tr>
<tr>
<td>Overestimation (&gt; +10%)</td>
<td>1 sub-basin</td>
<td>3 sub-basins</td>
</tr>
<tr>
<td>Underestimation (&lt; -10%)</td>
<td>23 sub-basins</td>
<td>21 sub-basins</td>
</tr>
</tbody>
</table>
5. Approximation by the Delta-Approach

### Sub-basin 4

**Dynamic linear LUC**
- Evapotranspiration: -498 mm
- Water Yield: 42 mm

**Static LUC**
- Evapotranspiration: -507 mm
- Water Yield: 51 mm

**Deviation**
- Evapotranspiration: +2%
- Water Yield: +20%

**Dynamic non-linear LUC**
- Evapotranspiration: -737 mm
- Water Yield: 89 mm

**Static LUC**
- Evapotranspiration: -507 mm
- Water Yield: 51 mm

**Deviation**
- Evapotranspiration: -31%
- Water Yield: -43%

**Maps**
- Over- and Underestimation by the Delta-Approach (%)

**Legend**
- \( S \) = Sub-basin
- \( P \) = Percentage Difference (%)
- \( A \) = Absolute Difference (mm)
6. Land use update frequency
6. Land use update frequency

Approximation of dynamically assessed sub-basin water balance changes by the delta approach and coarser land use representations as indicated by mean absolute error (MAE), root mean square error (RMSE), and Nash-Sutcliffe efficiency (NSE).

<table>
<thead>
<tr>
<th></th>
<th>Evapotranspiration</th>
<th>Water Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAE</td>
<td>RMSE</td>
</tr>
<tr>
<td>Linear Scenario approx. by Delta</td>
<td>7.6</td>
<td>10.6</td>
</tr>
<tr>
<td>Non-linear Scenario approx. by Delta</td>
<td>50.3</td>
<td>88.3</td>
</tr>
<tr>
<td>Non-linear Scenario approx. by updates every 3 yrs</td>
<td>2.7</td>
<td>5.6</td>
</tr>
<tr>
<td>Non-linear Scenario approx. by updates every 5 yrs</td>
<td>3.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Non-linear Scenario approx. by updates every 9 yrs</td>
<td>13.5</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Pronounced improvement by increasing the update frequency (5-9 years)
7. Conclusions

Dynamic land use integration yields more accurate predictions

- Water yield and ET are either underestimated or overestimated by the static delta approach in most sub-basins for both scenarios

Frequency of required land use information depends on the development rate of land use change

Non-linear land use change scenarios are hard to approximate with static land use change assessments

Land use information every five to nine years meant a pronounced improvement of prediction accuracy

- Necessity of continuous land use monitoring in rapidly developing regions
- Use the SWAT land use update function

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4. Land use change impacts

**Annual impacts of land use change**

Sub-basin 4 (urban fringe):
- Increase of water yield (surface sealing)
- Decrease of evapotranspiration (decrease of cropland)

Sub-basin 24 (Lavasa):
- Comparatively low impacts

4. Land use change impacts

Impacts of land use change on the monthly time scale