# SWAT-based simulation of climate change impact on water and sediment inflow to Lake Volta in West Africa

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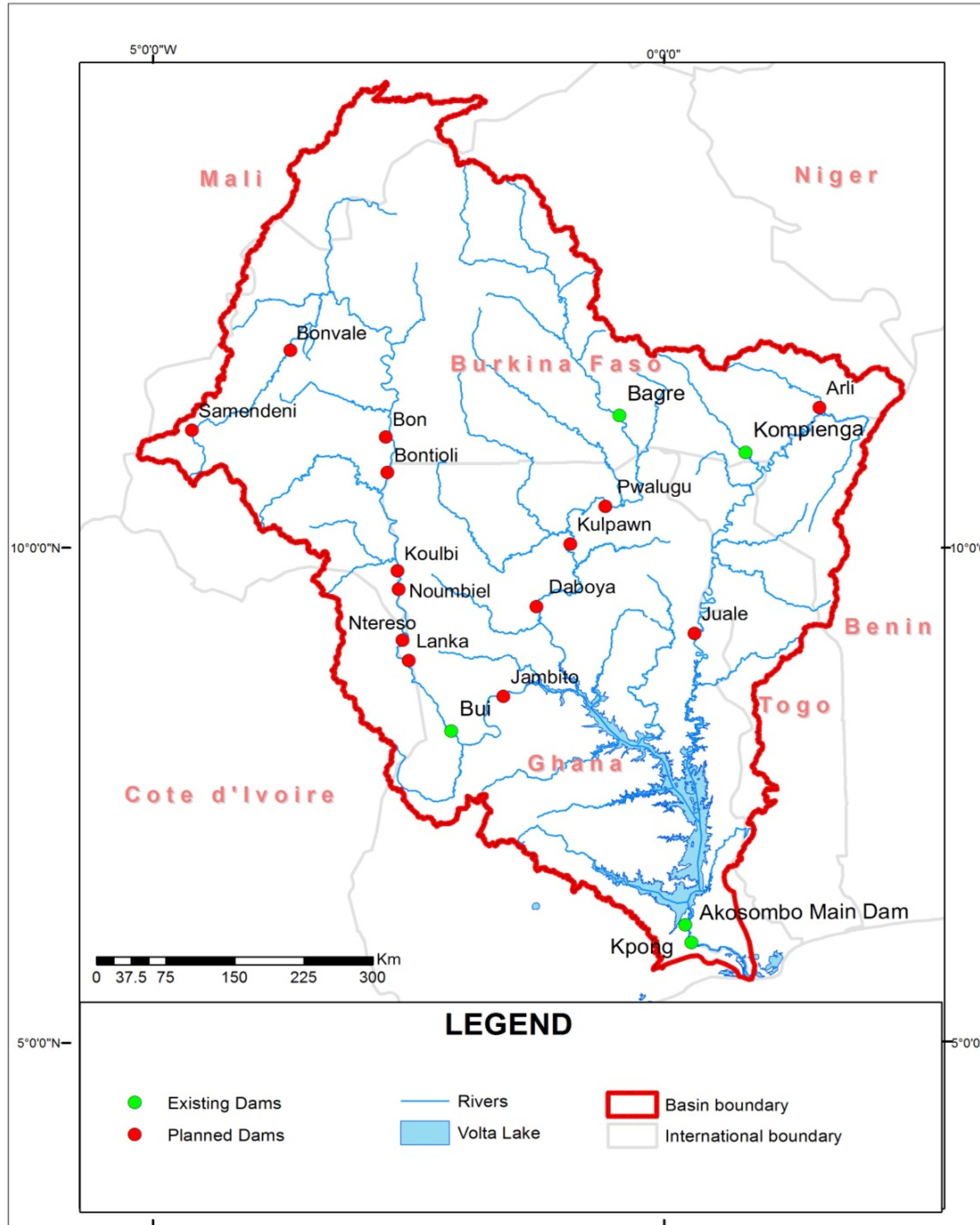
# Volta River Basin/Volta Lake

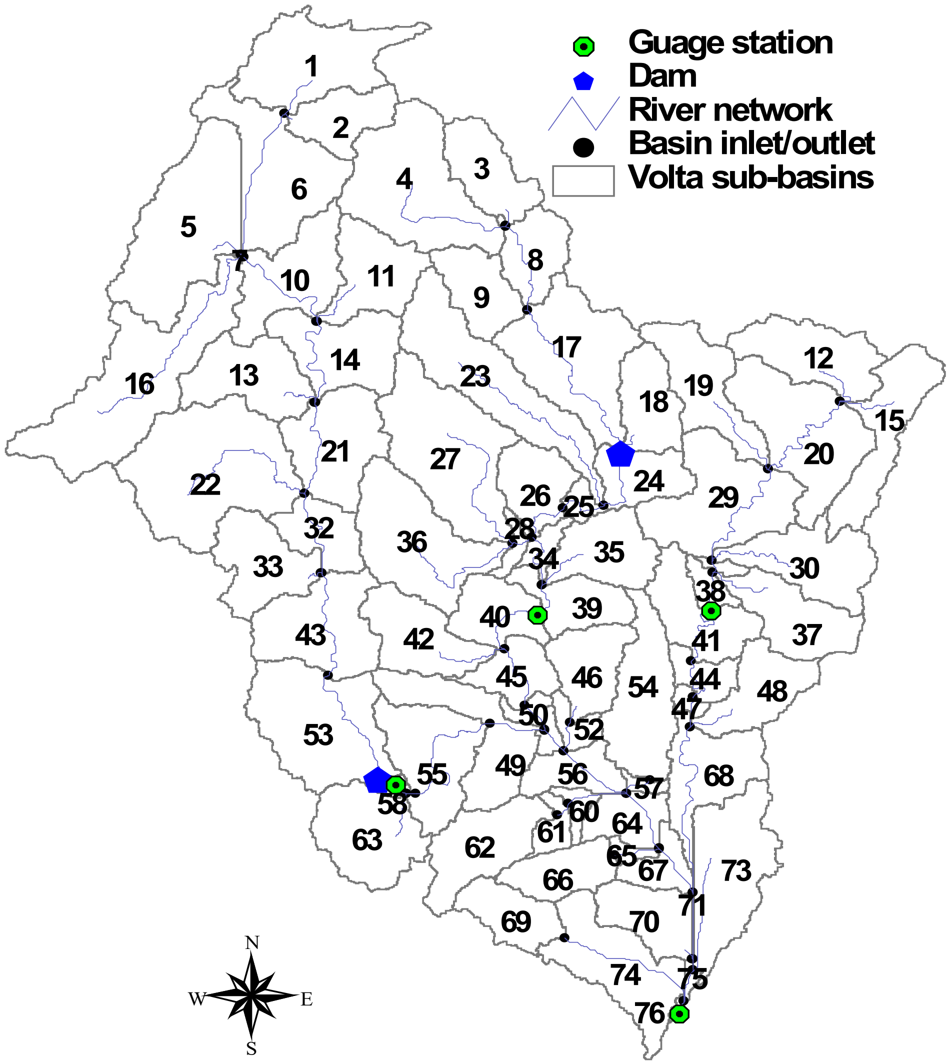
- Transboundary river basin: Ghana, Burkina Faso, Mali, Benin, Cote d'Ivoire, Togo
- Houses important hydropower plants in Ghana/Burkina Faso
- Lake: 148 $Km^3$ at FSL 84m amsl
- Lake supports 1,060 MW of HEP at Akosombo and 160 MW at Kpong
- Lake accounts for 85% of inland fish production



# Study Objectives

- Set-up and adapt the SWAT model to simulate flow, sediment and nutrients (NO2-N, NO3-N, PO4-P, T.PO4, NH4) into Lake Volta via calibration and validation processes; and
- Drive the calibrated SWAT model with climate scenarios to estimate future changes to flow, sediment and nutrients into Lake Volta

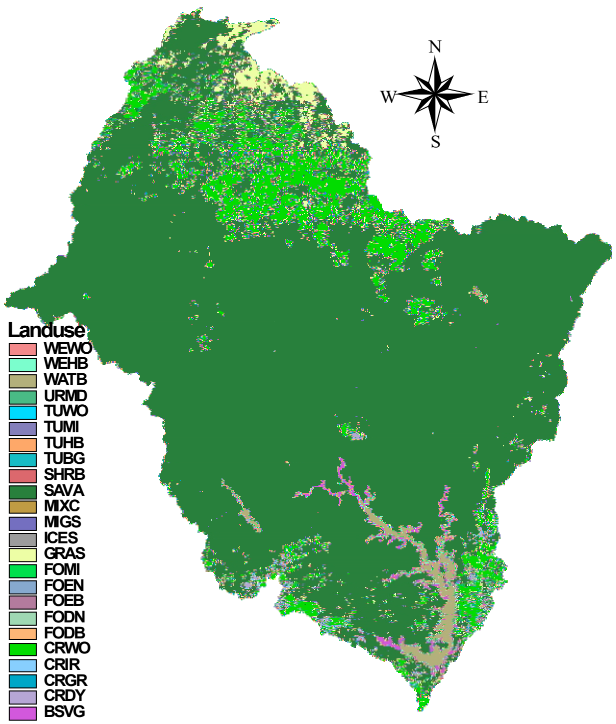
# Volta SWAT model setup



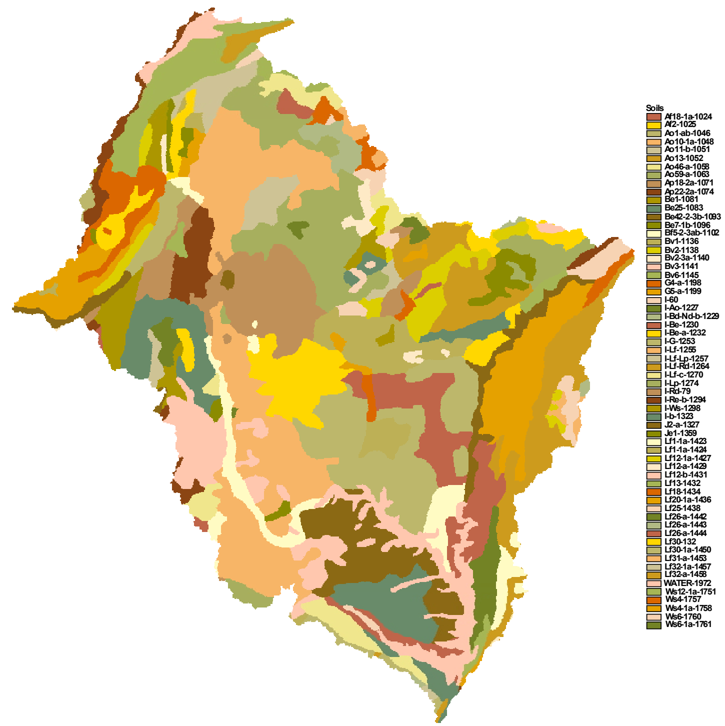

- 76 sub-basins
- 770 HRUs
- 40 climate stations
- Model calibrated at 3 flow measuring stations (Saboba on Oti, Nawuni on White Volta, Bui on Black Volta) and inlet to Akosombo dam
- 2 dams located upstream of lake were incoporated: Bui on Black Volta and Bagre on White Volta

# Land-use/-cover & soil data

- Land-use/-cover map




- Soil map




| Major landcover | Coverage (%) | Major soil types | Coverage (%) |
|---|---|---|---|
| Savanna (consists of grass and shrubs) | 84 | Luvisols (low nutrients, unstable soil structure, leading to erosion) | 70 |
| Cropland/woodland | 11 | Regosols | 14 |
| Grassland | 2 | Lithosols | 12 |

# Sensitivity analysis & calibration

## Sensitivity analysis

- Done to select parameters most sensitive to flow, sediment and nutrient to focus on for calibration
- Global sensitivity analysis done in SWAT-CUP followed by a t-test that helped to rank model parameters according to sensitivity to flow, sediment and nutrients

## SWAT model calibration/validation

- Calibration/validation done in SWAT-CUP SUFI2
- Model warm-up period: 1981-1982 (2 years)
- Calibration period: 1983-2002 (20 years)
- Validation period: 2003-2010 (8 years)

# Model performance evaluation

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O})^2} \qquad R^2 = \frac{\sum_{i=1}^{N}\left[(O_i - \overline{O})\,(O_i - \overline{O})\right]^2}{\sum_{i=1}^{N}(O_i - \overline{O})^2 \sum_{i=1}^{N}(O_i - \overline{O})^2} \qquad PBIAS = \frac{\sum_{i=1}^{N}(O_i - P_i)*(100)}{\sum_{i=1}^{N}(O_i)} \qquad RSR = \frac{RMSE}{STDEV} = \frac{\sqrt{\sum_{i=1}^{N}(O_i - P_i)^2}}{\sqrt{\sum_{i=1}^{N}(O_i - \overline{O})^2}}$$

where $O_i$ is the measured data; $P_i$ is the simulated data;

$\overline{O}$ is the mean of the measured data;

$\overline{P}$ is the mean of the simulated data; and $N$ is the number of compared values

**Model performance criterion (Moriasi et al., 2007)**

| Performance rating | RSR | NSE | $R^2$ | PBIAS (%) | |
|---|---|---|---|---|---|
| | | | | Streamflow | Sediment |
| **Very good** | 0.00 ≤ RSR ≤ 0.50 | 0.75 < NSE ≤ 1.00 | | PBIAS < ±10 | PBIAS < ±15 |
| **Good** | 0.50 < RSR ≤ 0.60 | 0.65 < NSE ≤ 0.75 | | ±10 ≤ PBIAS < ±15 | ±15 ≤ PBIAS < ±30 |
| **Satisfactory** | 0.60 < RSR ≤ 0.70 | 0.50 < NSE ≤ 0.65 | >0.6 | ±15 ≤ PBIAS < ±25 | ±30 ≤ PBIAS < ±55 |
| **Unsatisfactory** | RSR > 0.70 | NSE ≤ 0.50 | <0.6 | PBIAS ≥ ±25 | PBIAS ≥ ±55 |

# Uncertainty Analysis

- Parameter uncertainty analysis conducted in SUFI2 of SWAT-CUP to account for all uncertainty
- Two factors, *R* & *P* proposed by Abasspour et al, 2004 were calculated as a measure of the uncertainty
- P-factor denotes the percentage of measured data enveloped by a 95% prediction uncertainty (95 PPU); ideal value is 1
- R-factor gives the thickness of the 95PPU, a measure of the quality of the calibration; ideal value is zero

# Results on discharge/sediment

# Sensitivity Analysis

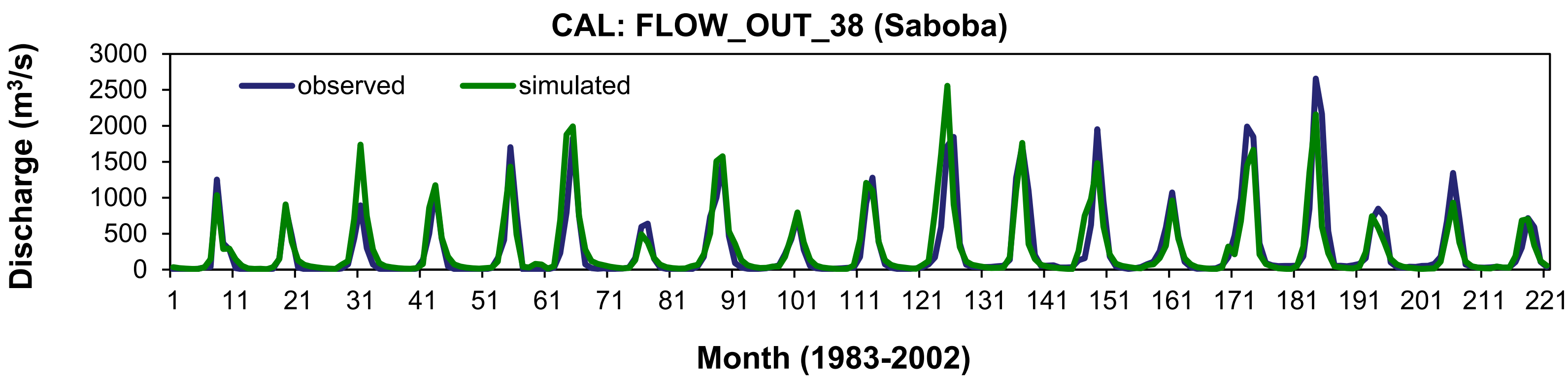
**Flow sensitive parameters**

| Rank | Parameter Name | t-Stat[1] | P-Value[2] |
|---|---|---|---|
| 1 | r_CN2.mgt | -13.57 | 0.05 |
| 2 | v_GWQMN.gw | 13.01 | 0.05 |
| 3 | v_ALPHA_BNK.rte | -11.44 | 0.06 |
| 4 | v_ REVAPMN.gw | 10.68 | 0.06 |
| 5 | v_GW_DELAY.gw | 8.89 | 0.07 |
| 6 | v _RCHRG_DP.gw | -7.22 | 0.09 |
| 7 | v_CH_N2.rte | -6.85 | 0.09 |
| 8 | v_ESCO.hru | -6.33 | 0.10 |
| 9 | r __SOL_AWC.sol | 5.00 | 0.13 |
| 10 | v_ALPHA_BF.gw | 3.98 | 0.16 |
| 11 | v_CH_K2.rte | 3.11 | 0.20 |
| | | | |

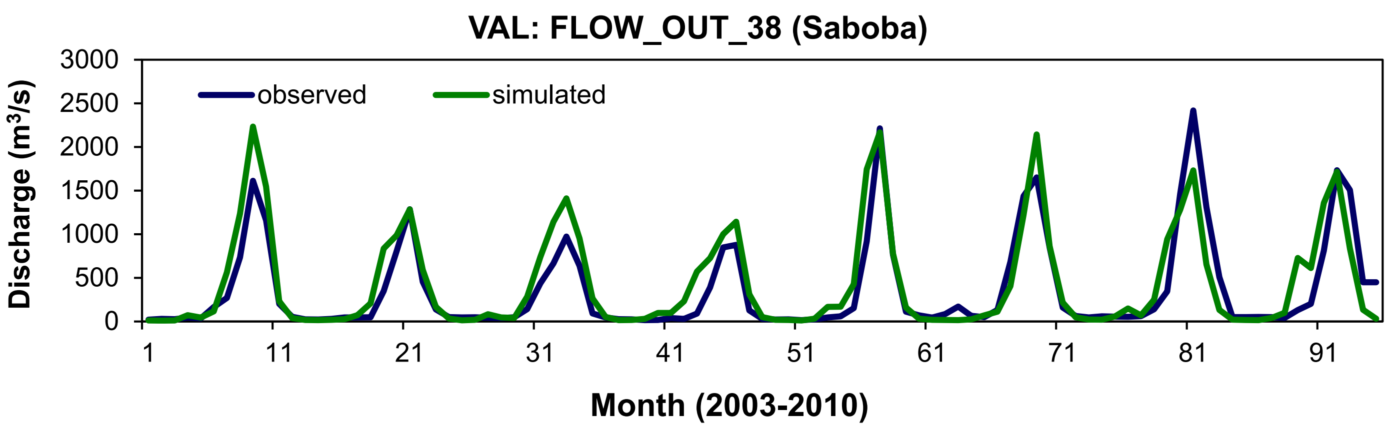
**Sediment sensitive parameters**

| Rank | Parameter Name | t-Stat[1] | P-Value[2] |
|---|---|---|---|
| 1 | v_PRF.bsn | 9.34 | 0.08 |
| 2 | v_SPCON.bsn | -8.05 | 0.09 |
| 3 | v_ SPEXP.bsn | 7.47 | 0.12 |
| 4 | v_CH_EROD.rte | -6.91 | 0.12 |
| 5 | v _CH_COV.rte | -5.43 | 0.13 |
| 6 | r_USLE_P.mgt | 3.88 | 0.15 |
| 7 | r_USLE_K.sol | 2.26 | 0.19 |

# Calibration/validation of discharge

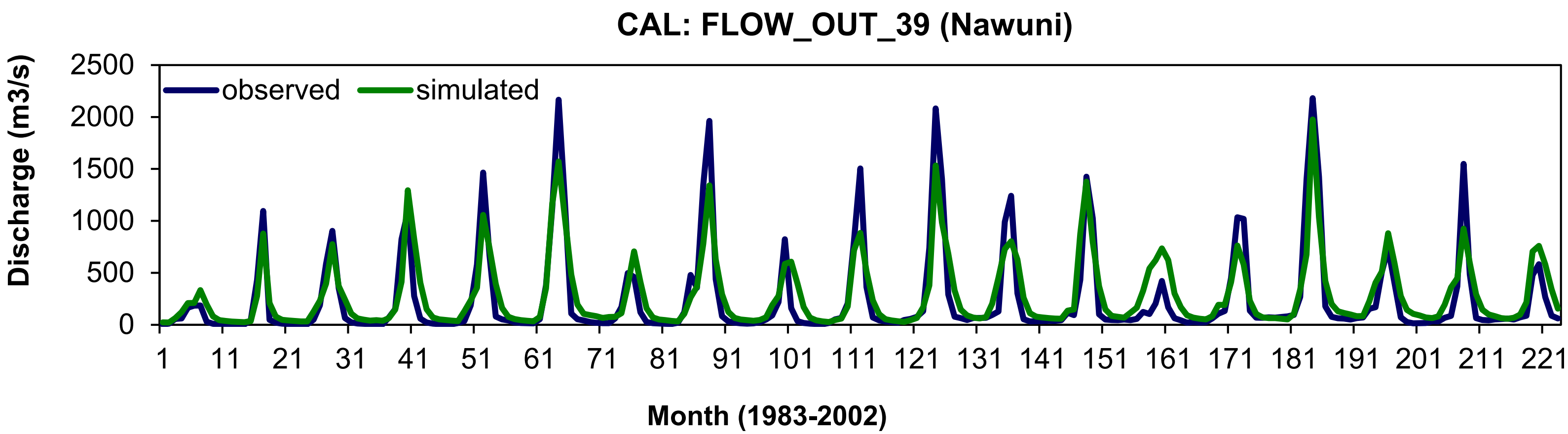



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.86 | 0.83 | 2.7 | 0.21 | 0.83 | 0.88 |

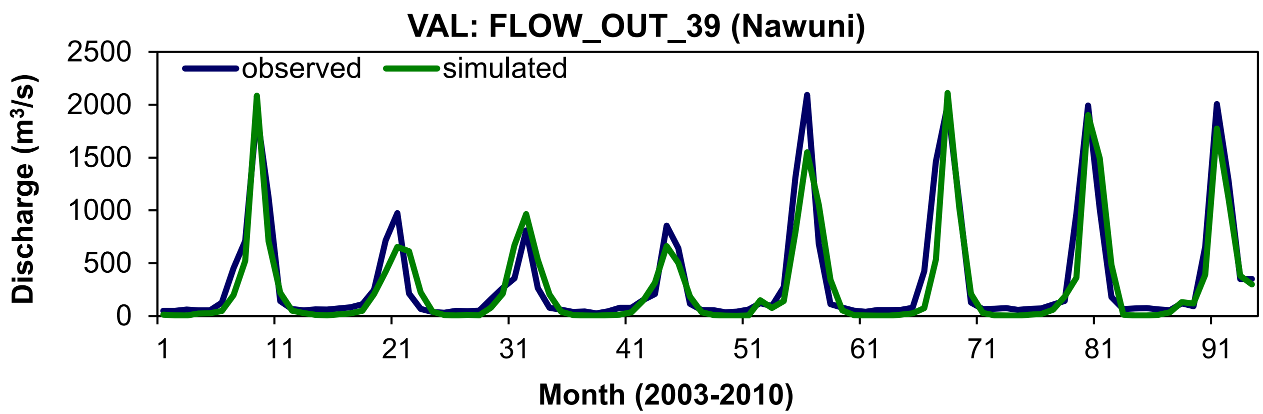



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.81 | 0.78 | -5.2 | 0.39 | 0.37 | 0.26 |

# Calibration/validation of discharge - Cont.

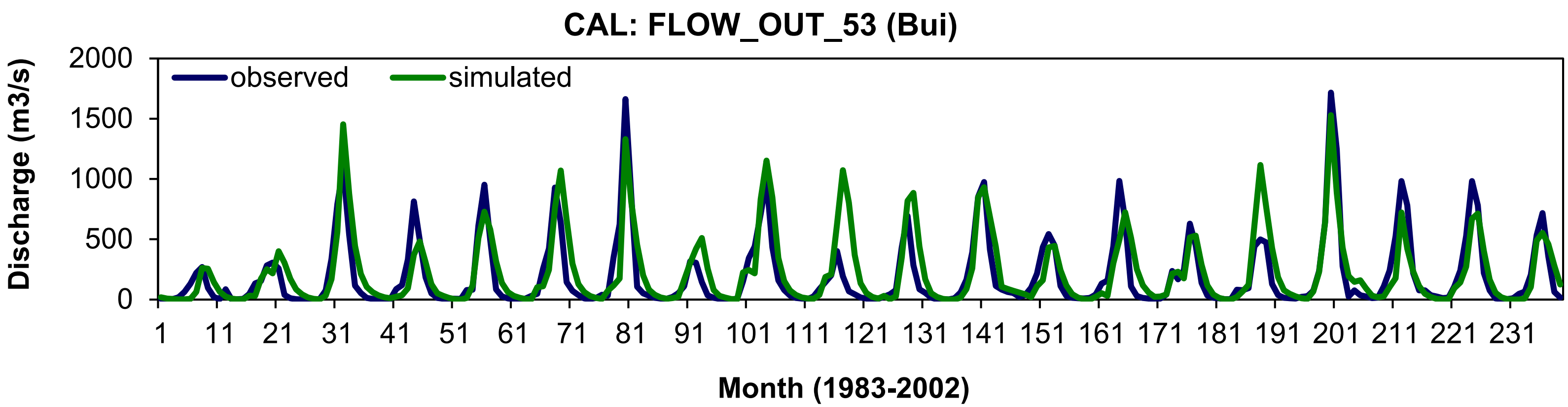



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.83 | 0.79 | 6.8 | 0.23 | 0.95 | 1.22 |

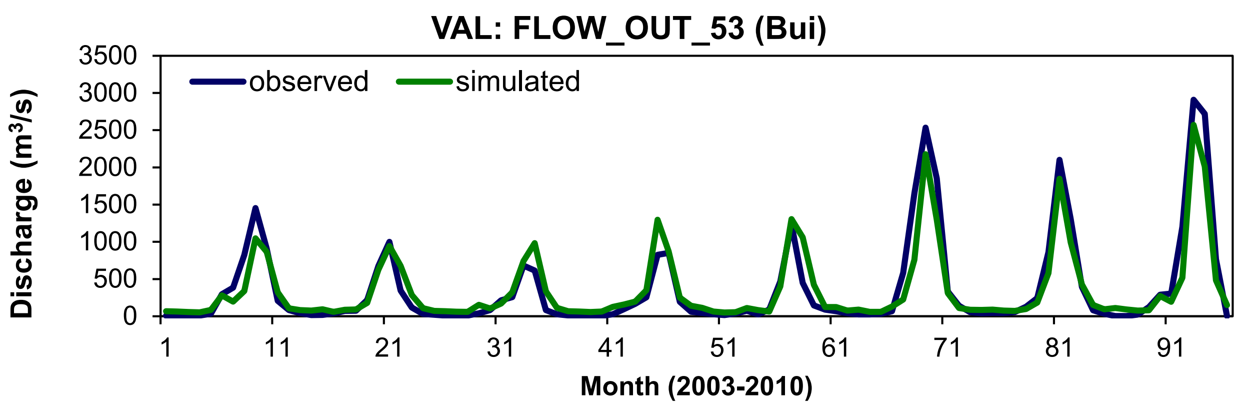



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.79 | 0.75 | 9.1 | 0.28 | 0.74 | 0.26 |

# Calibration/validation of discharge - Cont.

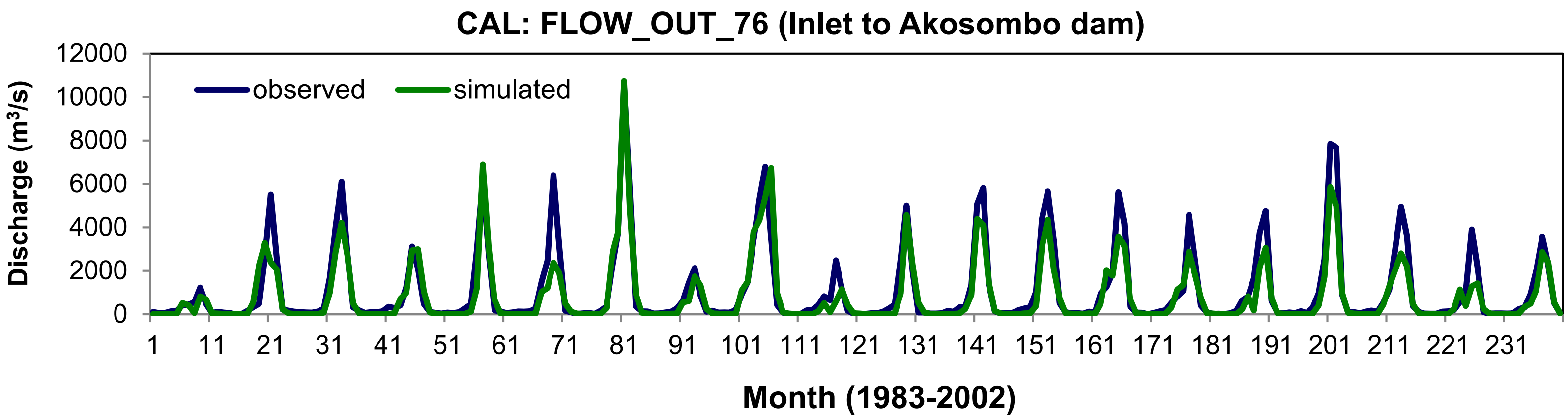



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.81 | 0.78 | -5.8 | 0.34 | 0.92 | 1.78 |

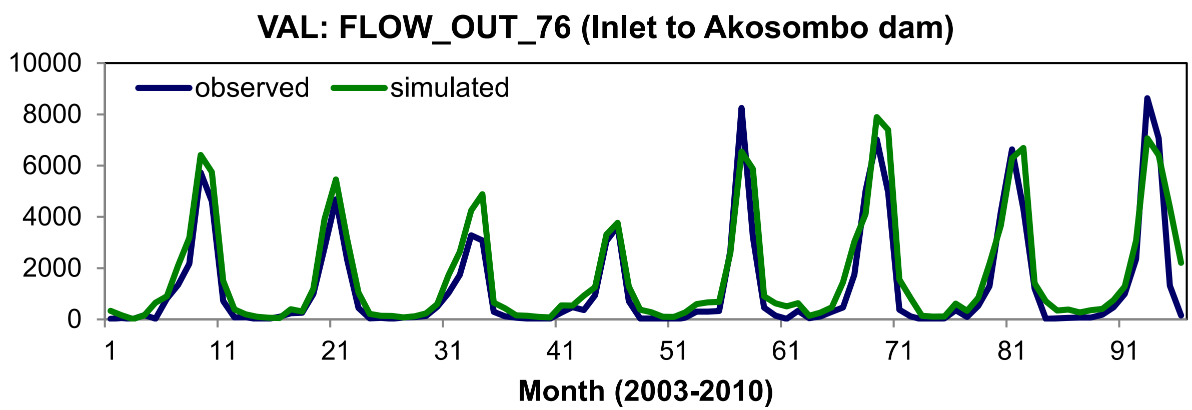



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.71 | 0.70 | -9.3 | 0.38 | 0.68 | 0.30 |

# Calibration/validation of discharge - Cont.

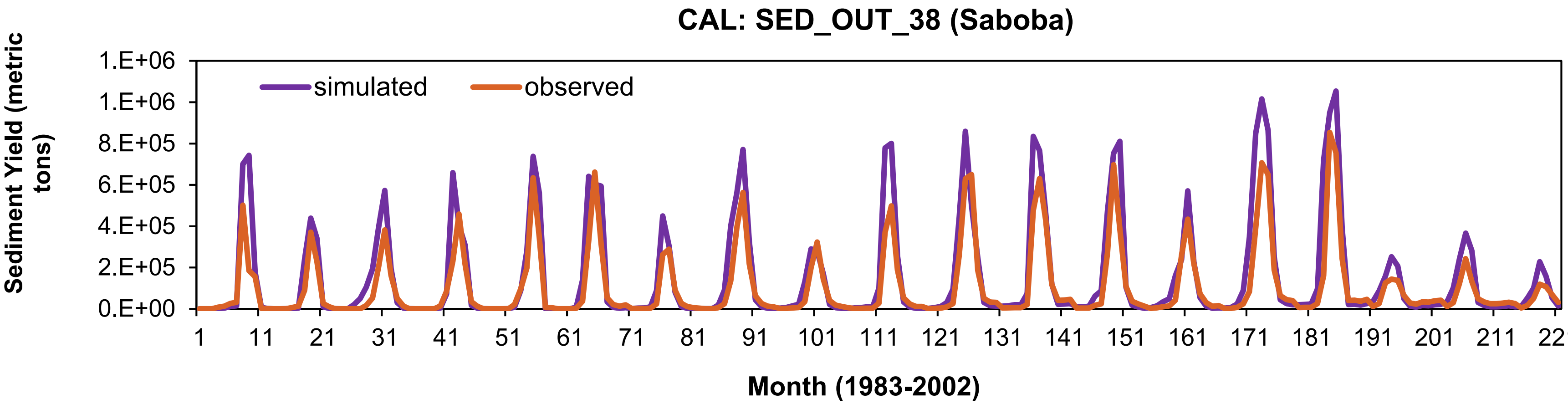



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.86 | 0.83 | 11.5 | 0.41 | 0.91 | 1.66 |

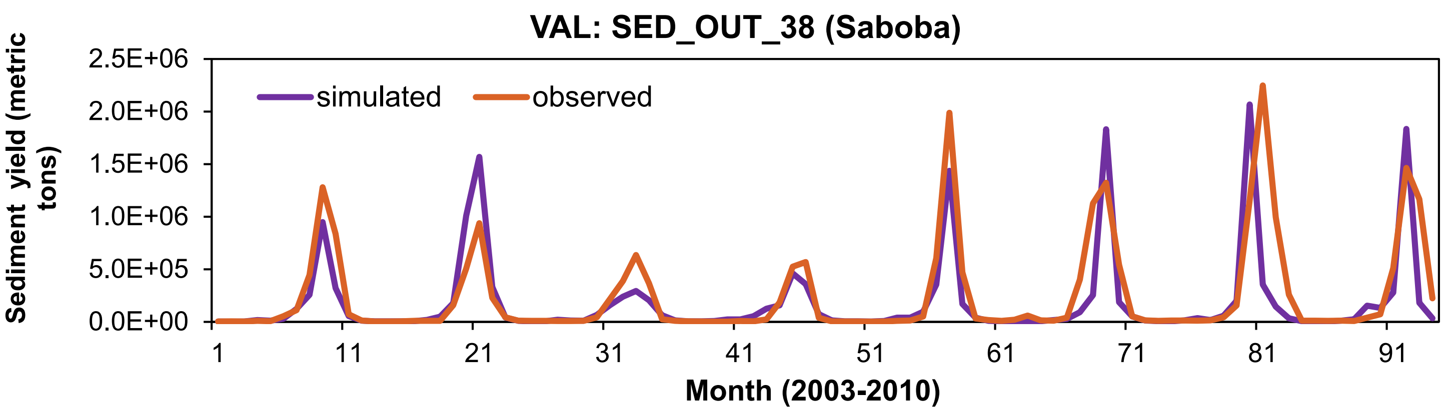



| R2 | NSE | PBIAS | RSR | P-factor | R-factor |
|---|---|---|---|---|---|
| 0.68 | 0.62 | -11.8 | 0.41 | 0.71 | 1.55 |

# Calibration/validation of sediment

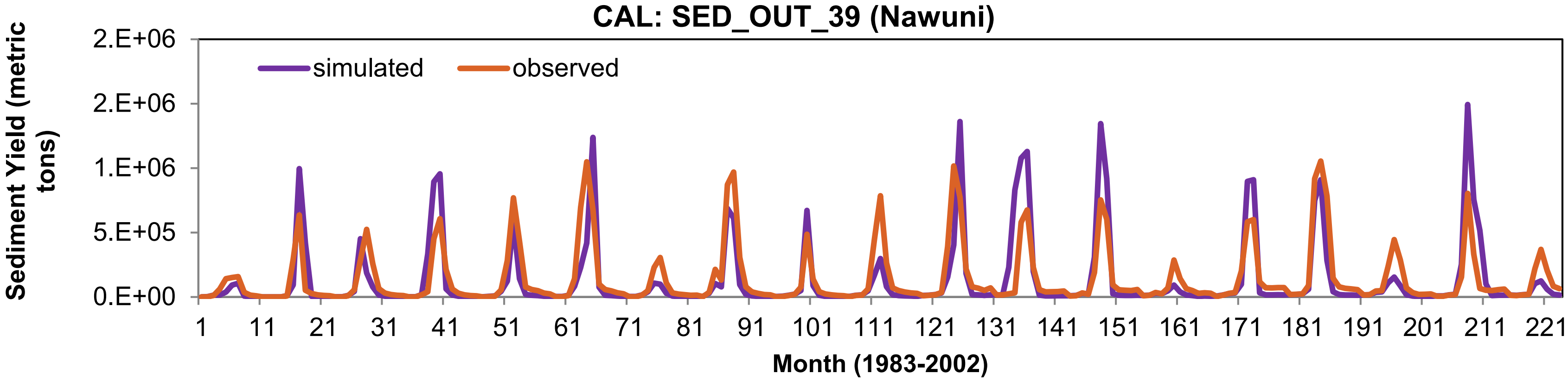



| R2 | NSE | PBIAS | P-factor | R-factor |
|---|---|---|---|---|
| 0.72 | 0.67 | -13.3 | 0.64 | 1.65 |

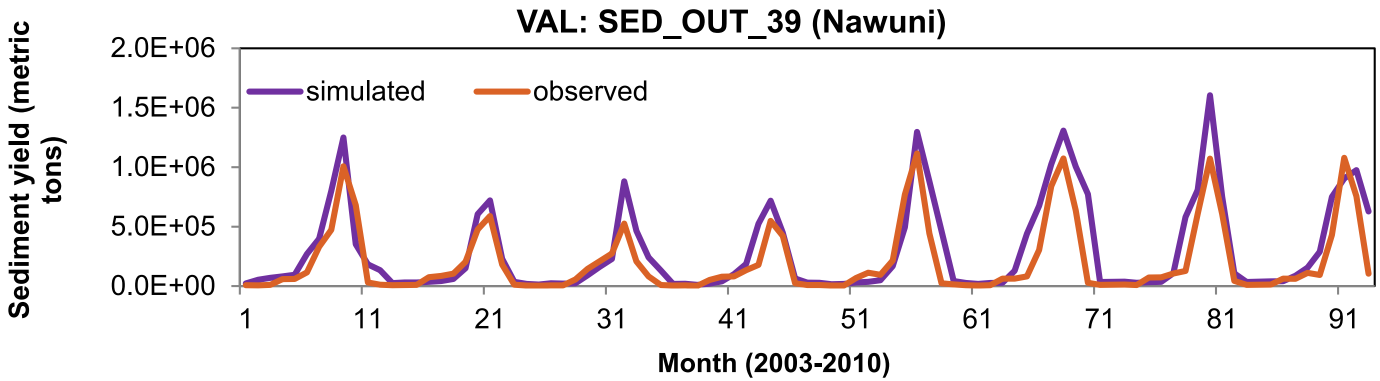



| R2 | NSE | PBIAS | P-factor | R-factor |
|---|---|---|---|---|
| 0.69 | 0.64 | -3.7 | 0.54 | 1.05 |

# Calibration/validation of sediment - Cont.

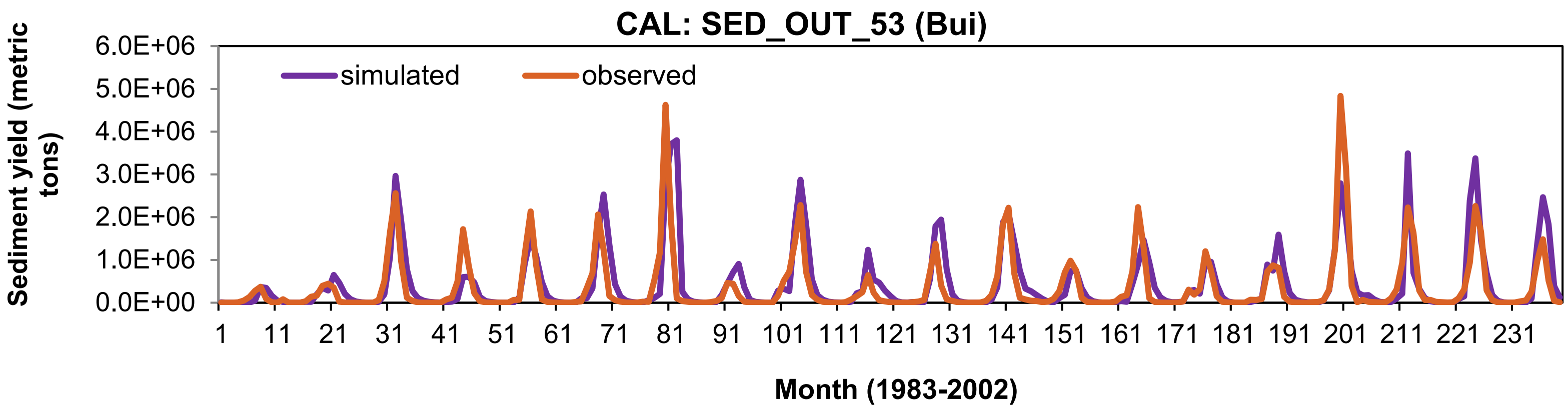



| R2 | NSE | PBIAS | P-factor | R-factor |
|---|---|---|---|---|
| 0.79 | 0.69 | -9.4 | 0.61 | 1.72 |

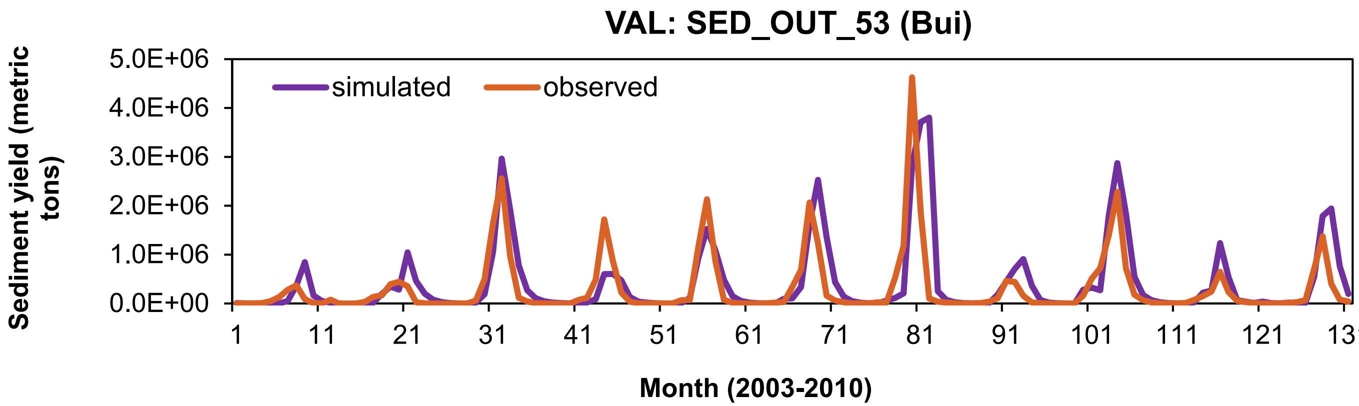



| R2 | NSE | PBIAS | P-factor | R-factor |
|---|---|---|---|---|
| 0.70 | 0.63 | -11.9 | 0.64 | 2.1 |

# Calibration/validation of sediment - Cont.




| R2 | NSE | PBIAS | P-factor | R-factor |
|---|---|---|---|---|
| 0.68 | 0.61 | -7.2 | 0.52 | 1.45 |



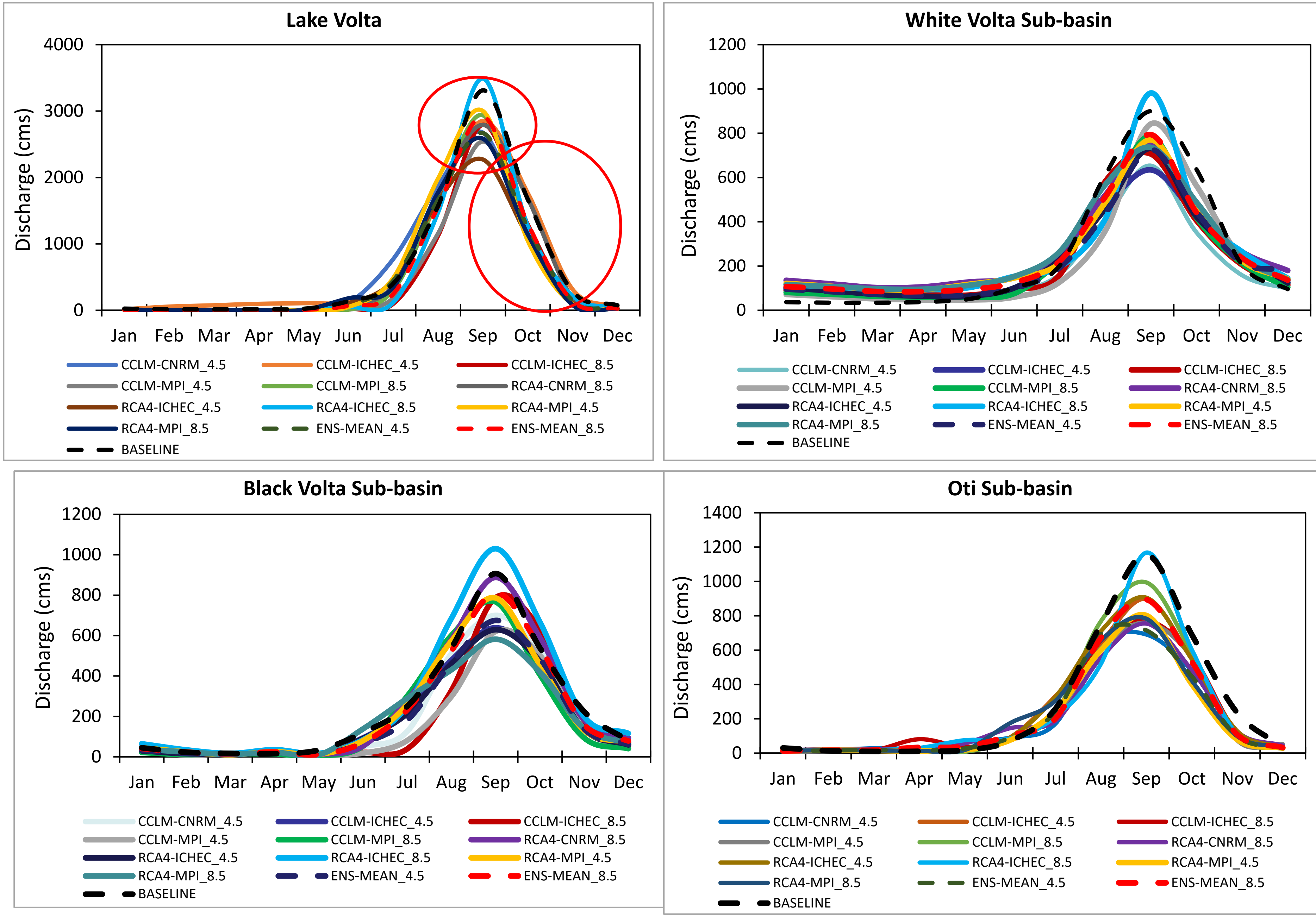

| R2 | NSE | PBIAS | P-factor | R-factor |
|---|---|---|---|---|
| 0.63 | 0.53 | -14.7 | 0.43 | 1.56 |

# Projected changes in annual discharge/sediment

**Projected changes in water /sediment flows into Lake Volta for the future (2051-2080), relative to the baseline (1983-2010) based on ensemble of 10 climate projections for RCP4.5 and RCP8.5**

| | | **Discharge** | | **Sediment** | |
|---|---|---|---|---|---|
| | **Scenario** | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| **Lake Volta** | Range | -21.7 to -31.6 | -13.2 to -23.8 | -29.4 to +3.2 | -15.1 to +6.3 |
| | **Ens. mean** | **-27** | **-21** | **-15** | **-4** |
| **Black Volta** | Range | -9.4 to -21.3 | +11.5 to -12.8 | -3.4 to -9.7 | -1.7 to -5.6 |
| | **Ens. mean** | **-11** | **-8** | **-9** | **-2** |
| **White Volta** | Range | -19.9 to -27.3 | +2.2 to -21.3 | +11.7 to -23.9 | -7.6 to -18.5 |
| | **Ens. mean** | **-25** | **-16** | **-19** | **-10** |
| **Oti** | Range | -26.1 to -48.6 | -24.0 to -39.5 | -8.2 to -27.9 | -7.2 to -23.7 |
| | **Ens. mean** | **-45** | **-32** | **-18** | **-13** |

# Projected changes in monthly discharge



# Conclusions

- The SWAT model was successfully adapted to the Volta basin to simulate water and sediment flows into the Volta Lake
- Discharge into the lake is projected to reduce, on average, between 20% and 27% in the future (2051-2080), relative to the baseline (1983-2010), with negative consequences for hydropower power generation
- Discharge reductions will occur mostly in the peak months of August-October, which will negatively impact on spawning of some species of fish in the Lake (e.g. Tilapia, Aletes, Synodontis)
- Sediment inflow to the lake is projected to decrease, on average between 4% and 15% in the future (2051-2080), relative to the baseline (1983-2010)
- Alternative energy sources (e.g. solar) will be required; also, aquaculture may have to be intensified to make up for any loss