Integration of remote sensing data into a watershed-scale wetland modeling for an improved model prediction

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Wetland hydrology

- Wetland ecosystem functions
  - Mitigating flood damage
  - Improving water quality by reducing pollution loads
  - Serving as natural habitats to support biodiversity

- This ecosystem functioning highly relies on the hydrological characteristics of wetlands (e.g., hydro-period).
  - Hydro-period: duration and frequency of inundation and soil saturation at a specified depth

A watershed model

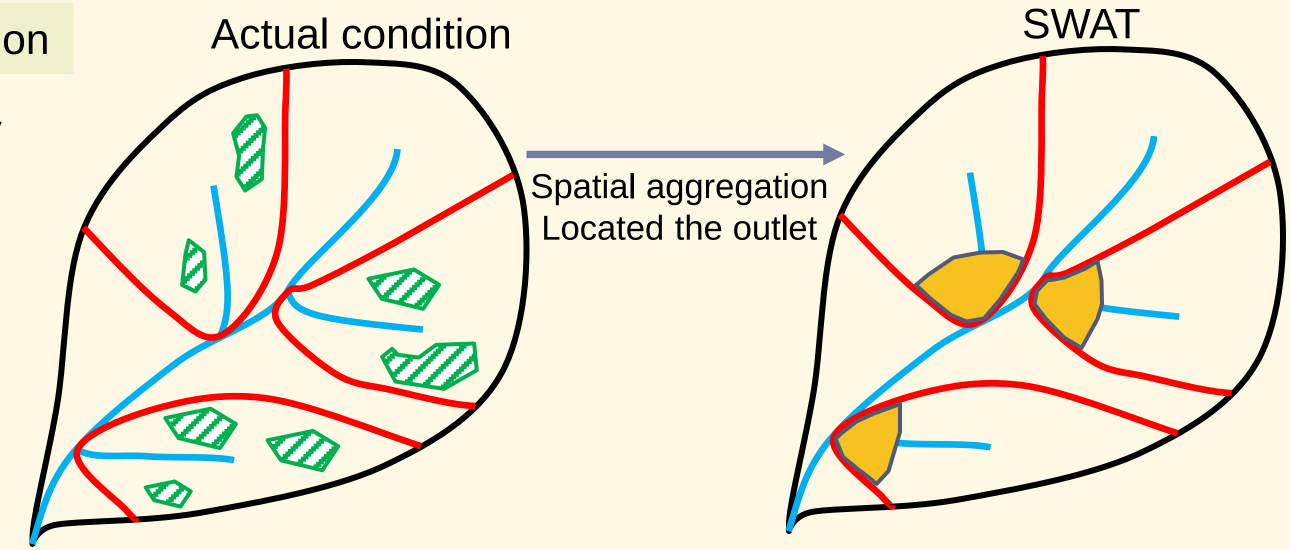
- Soil and Water Assessment Tool (SWAT)
  - One of watershed models to predict the cumulative impacts of multiple wetlands in the watershed.
  - Previous application
    - Simulating wetland loss and restoration scenarios (Yang et al., 2010; Records et al., 2014)
    - Identifying the optimal locations for wetland restoration (Babbar-Sebens et al., 2013)
    - Investigating wetland effects on streamflow during dry and wet periods (Wu and Johnston, 2008)

Limits in a wetland module of SWAT

Wetland representation

Watershed boundary
Sub-watershed boundary
Stream
wetland
Aggregated wetland

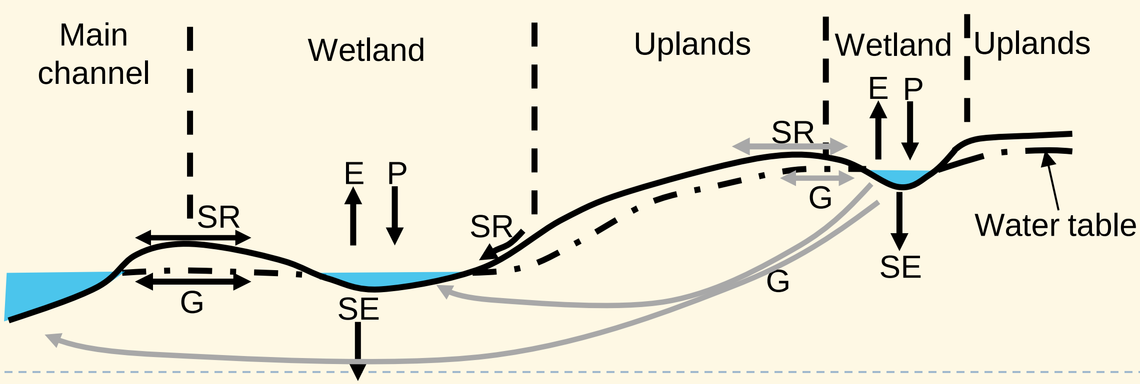
Wetlands within a sub-watershed are aggregated into one wetland.



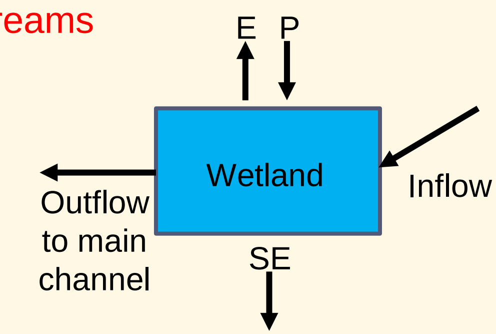
Physical processes

SR: Surface runoff, G: Ground water,
SE: Seepage, E: Evaporation, P: Precipitation

Unidirectional flow from wetlands to streams



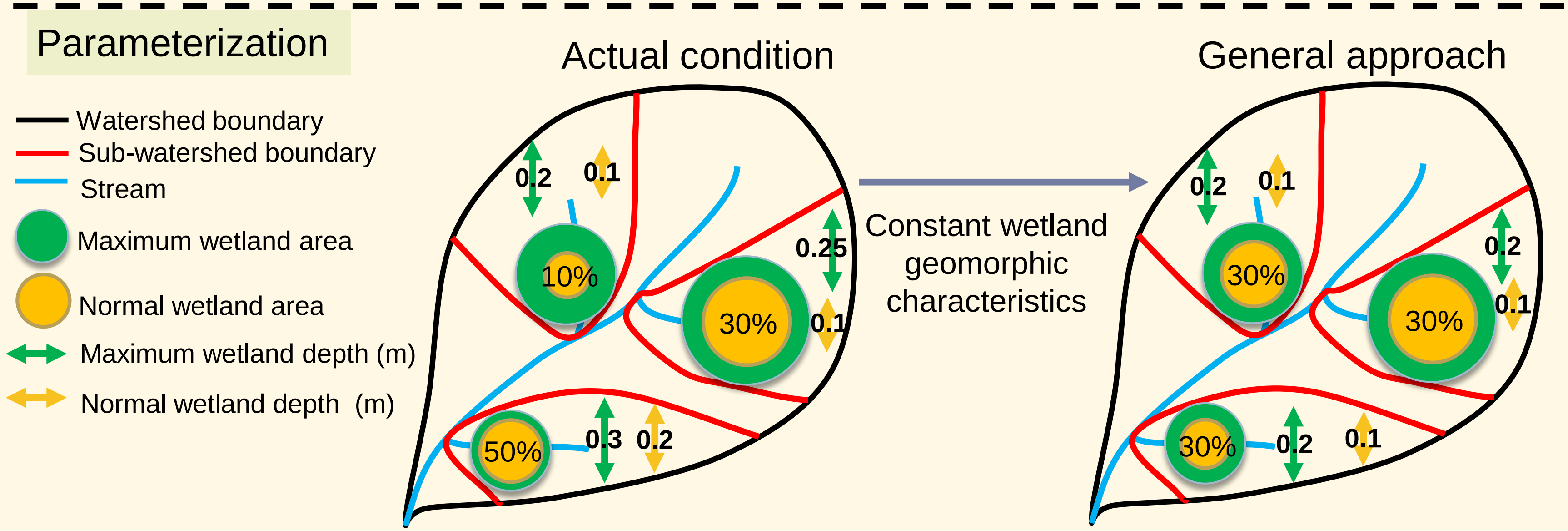
Actual condition



SWAT

Necessity of spatially-distributed inundation information #1

- Limited in wetland parameterization
  - Surface area and volume of a wetland at normal and maximum water levels
  - Uniform characteristics for all wetlands



Necessity of spatially-distributed inundation information #2

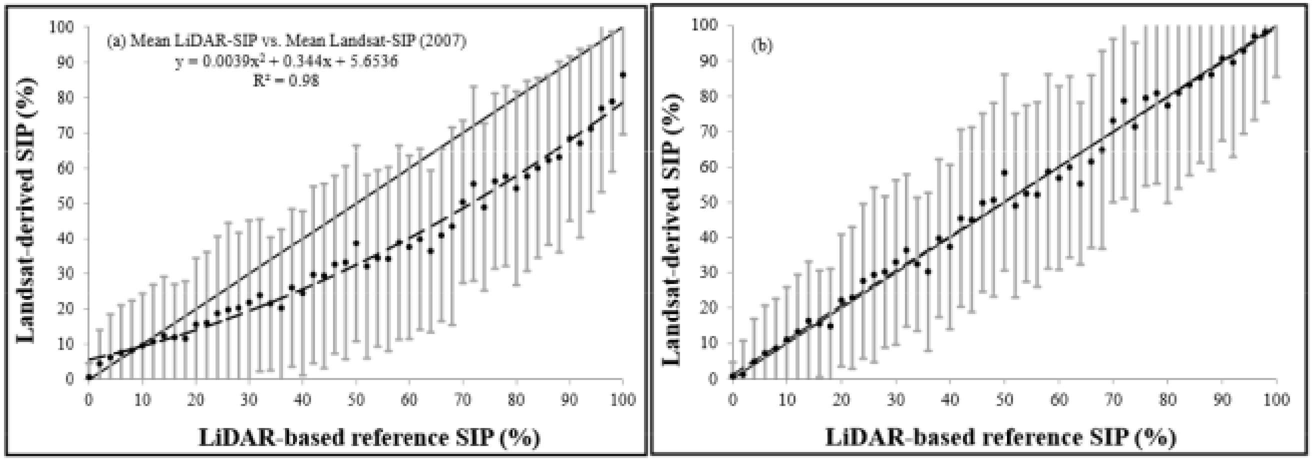
- Limited in assessing the wetland module performance
  - Observed streamflow - an aggregate response of the watershed
  - The wetland module has an insignificant impact on model performance - if SWAT is well calibrated without the wetland module, the model performance is evaluated as "satisfactory" regardless of the wetland module.
  - Model uncertainty in wetland parameters
    - "Equifinality" : multiple parameter sets produce similar or acceptable model outputs

Remote sensing data #1

- Inundation maps (Huang et al., 2014)
  - Inundation percentage at 30-meter pixel based on the statistical relationship between Light Detection and Ranging (LiDAR) and time series Landsat records.

Relationship between Landsat and Validation Data Before Correction

Relationship between Landsat and Validation Data After Correction



Mean SIP values of the initial 2007 RT prediction were lower than the mean reference SIP within 2% bins

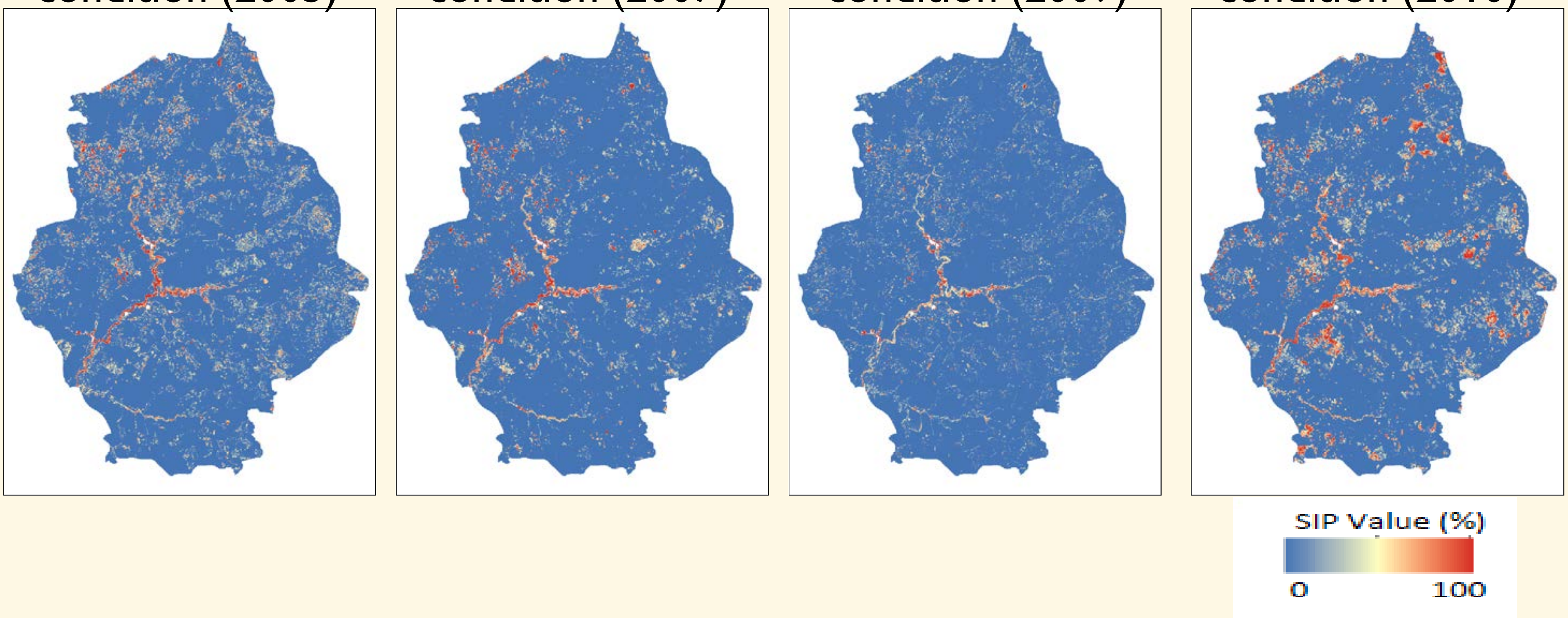
Biases were corrected by fitting a 2nd order polynomial function between mean reference values and mean predictions.

SIP: Sub-pixel Inundation Percentage

Remote sensing data #2

- Inundation maps under different climate conditions
  (Huang et al., 2014)

Average condition (2005) | Average condition (2007) | Dry condition (2009) | Wet condition (2010)



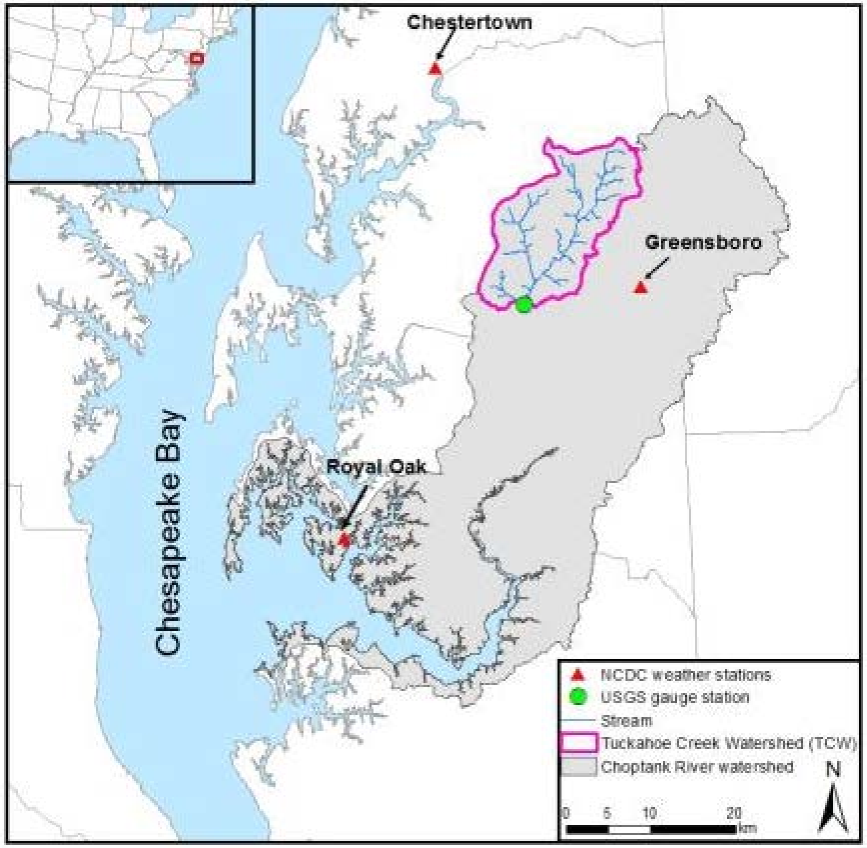
SIP: Sub-pixel Inundation Percentage

Objective

- To integrate remote sensing data into SWAT for an improved prediction on inundated areas within riparian wetlands
- To assess the capacity of wetlands to regulate downstream water

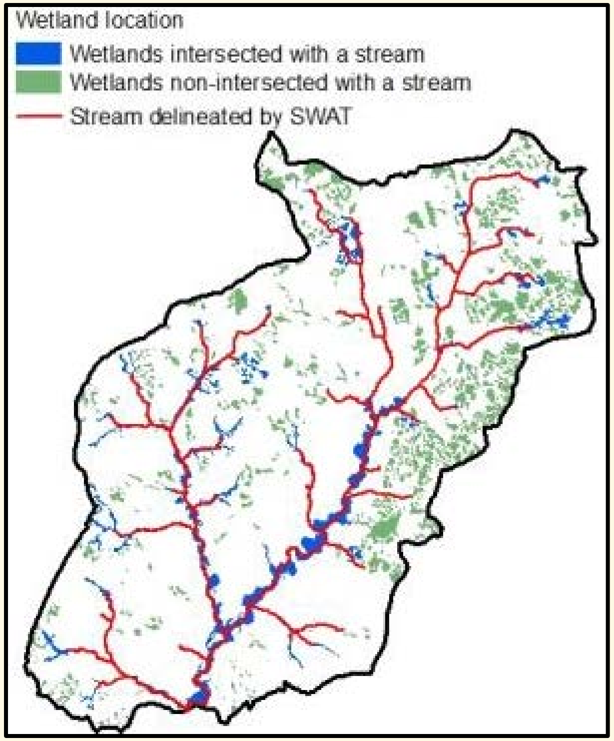
Study Area

- Headwater forested wetlands in the Choptank River Watershed
  - Coastal Plain of the Chesapeake Bay Watershed
  - Wetlands are mostly depressional.
  - NWI distribution: 34.5 km^2 (15.5% of the watershed)
  - Land use: Agriculture (51.3%) and forest (38.4 %)



Wetland modeling

- Riparian Wetlands (RWs)
  - Wetland polygons intersect with the stream map
  - Simulated using Riparian wetland module, a SWAT extension - water exchange between a stream and RW at the sub-water scale (Liu et al., 2008)
- Non-Riparian Wetlands (NRWs)
  - Wetland polygons away from the stream map
  - Simulated using a wetland module of SWAT
- Aggregated RW and NRW at the sub-watershed scale



<NWI wetland polygon>

Type	Area
RW	13.4 km^2
NRW	21.1 km^2

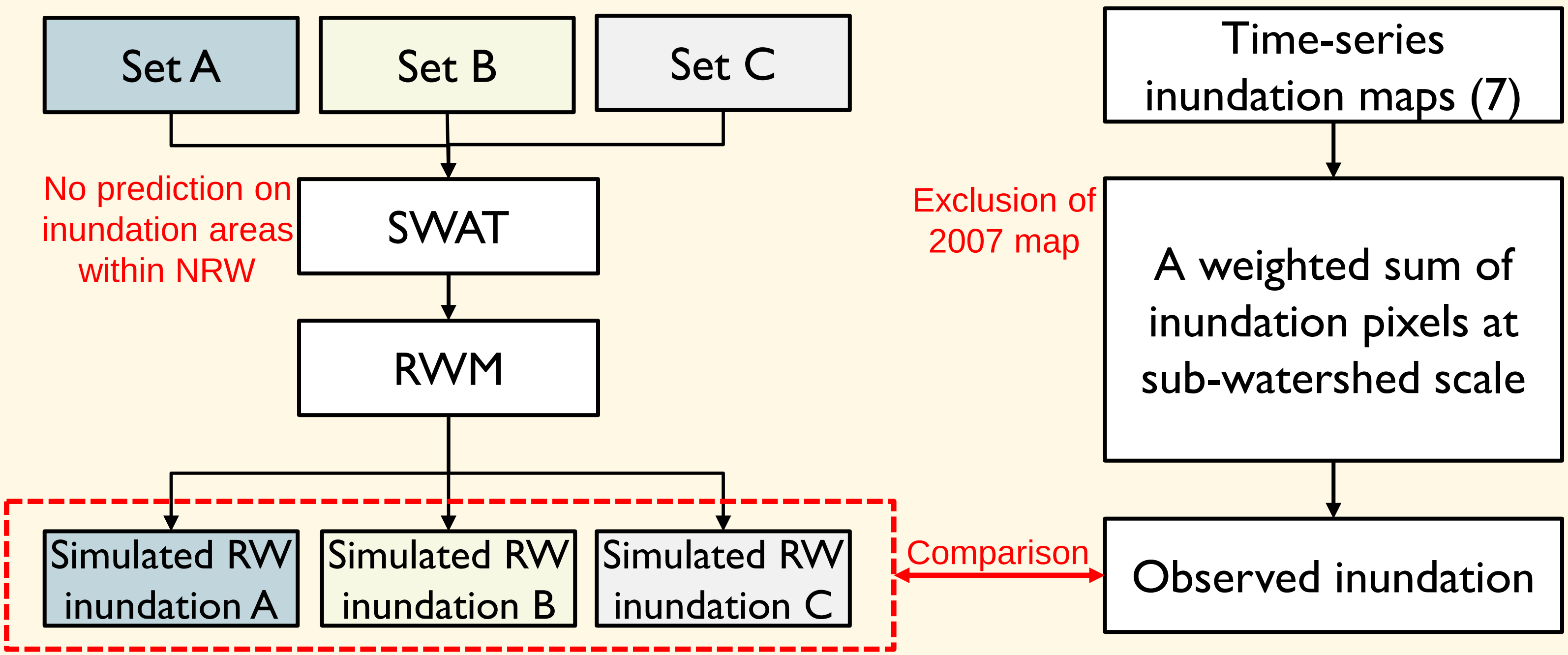
Wetland parameterization #1

- Using NWI and inundation map, spatially-varying wetland geomorphic parameters were estimated.
- Maximum wetland area and depth (NWI map)
  - Aggregated surface area of wetlands within a sub-watershed
  - Aggregated volume of wetlands derived from the method of Lane and D'Amico (2010)
  - Depth = Volume / Surface Area (assuming the geometry of a wetland as a cubic)
  - Separately calculated for RWs and NRWs at the sub-watershed scale

Wetland parameterization #2

- Normal wetland area and depth (Inundation map)
  - Selection of the inundation map taken at the weather condition most likely depicts the normal inundation pattern based on streamflow and Palmer drought index.
  - Normal surface area was estimated by calculating a weighted sum of inundation pixels (using inundation percentage as a weight), separately for RWs and NRWs at the sub-watershed scale (Huiran et al., 2016).
  - The normal depth is calculated using the same method used for the maximum depth.
  - Low normal volume for upland wetlands and great normal volume for downstream wetlands

Inundation pattern evaluation



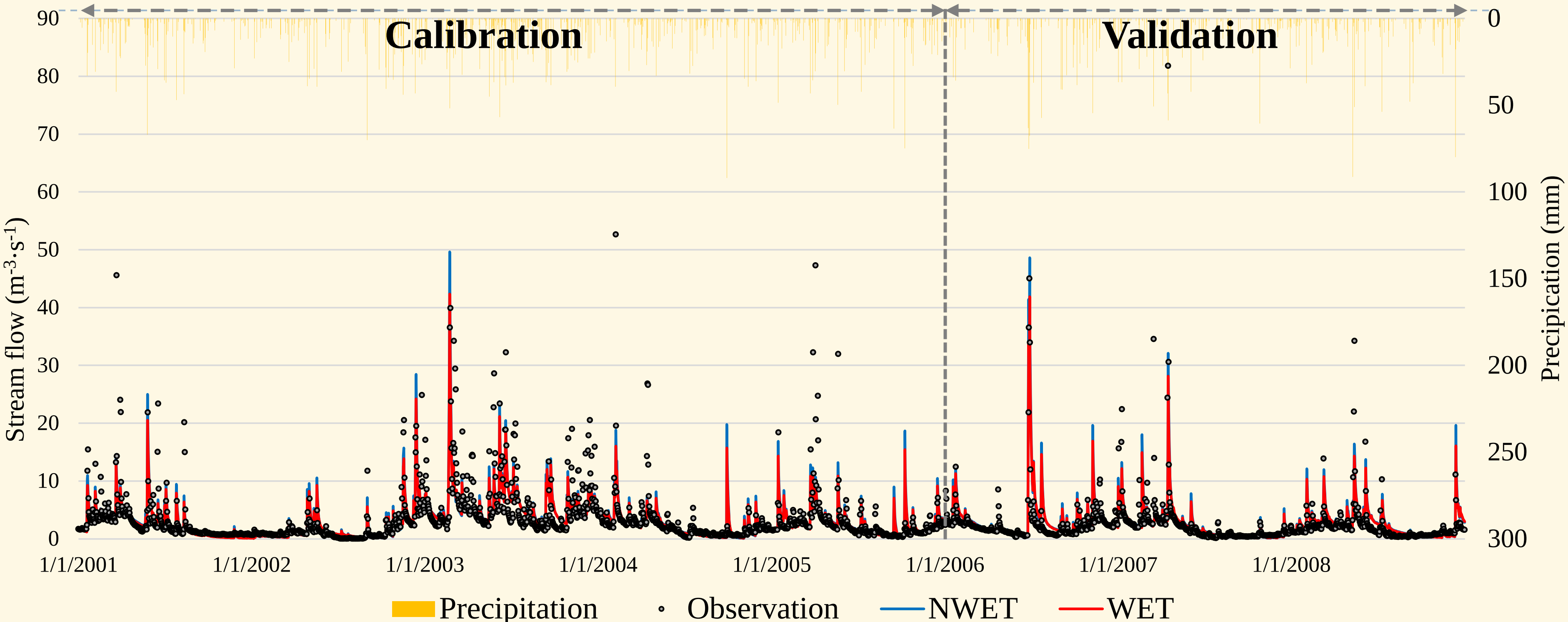
	Description	Note
Set A	Spatially-varying wetland parameters	2007 inundation map
Set B	Average of Set A	Uniform for all sub-watersheds
Set C	Parameters used in Liu et al. (2008)	

Wetland function evaluation

- Comparing wetland effects on streamflow between two sub-watersheds with different land use distribution

- The effect of wetland characteristics on peak flow reduction at a large storm event (when the greatest precipitation occurred during the simulation period)

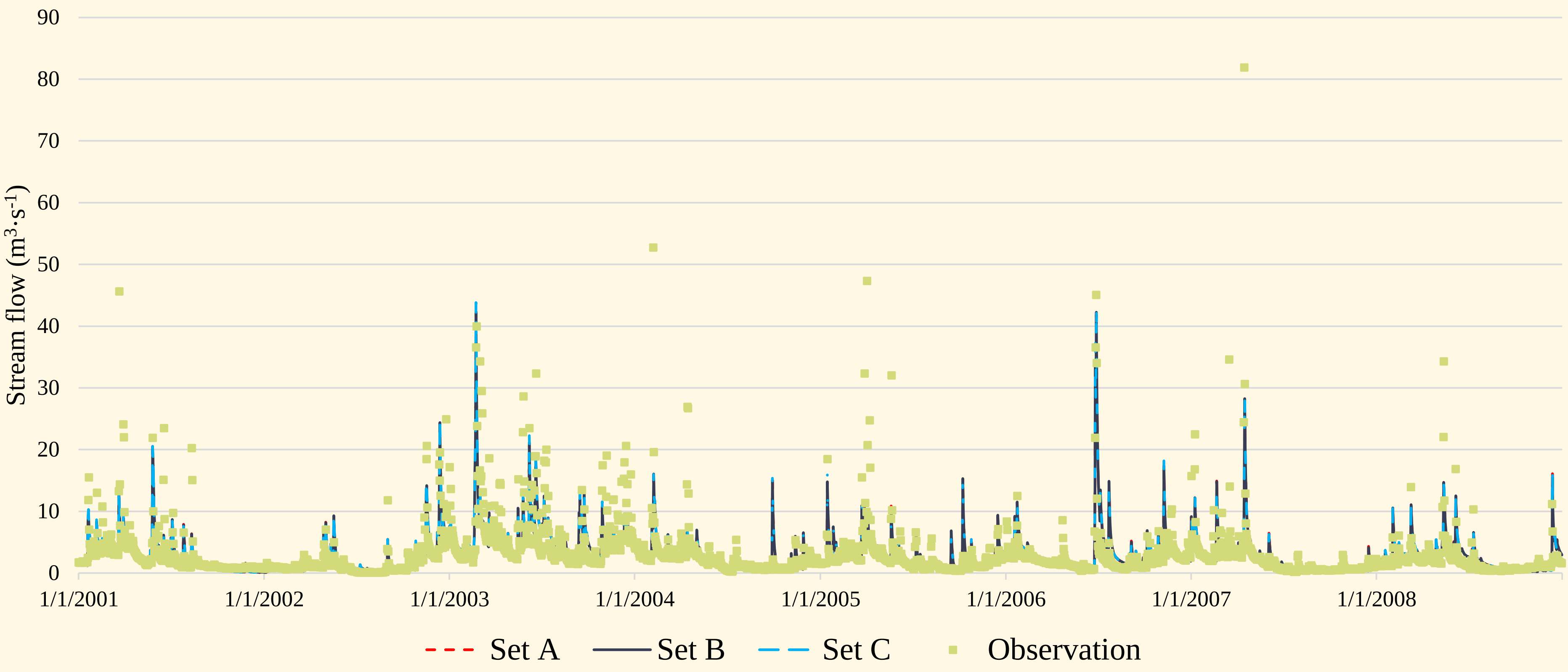
Model calibration and validation



Daily simulation	Period	NSE	RSR	PBIAS
NWET (Simulated streamflow without wetland module)	Calibration	0.424	0.758	- 0.3
	Validation	0.534	0.682	23.5
WET (Simulated streamflow with wetland module)	Calibration	0.461	0.733	-5.1
	Validation	0.553	0.668	17

- Spatially-varying wetland parameters were used for WET.

Wetland module uncertainty



✓ Three sets of wetland parameters produce similar streamflow.

Inundation map vs Simulated inundation #1

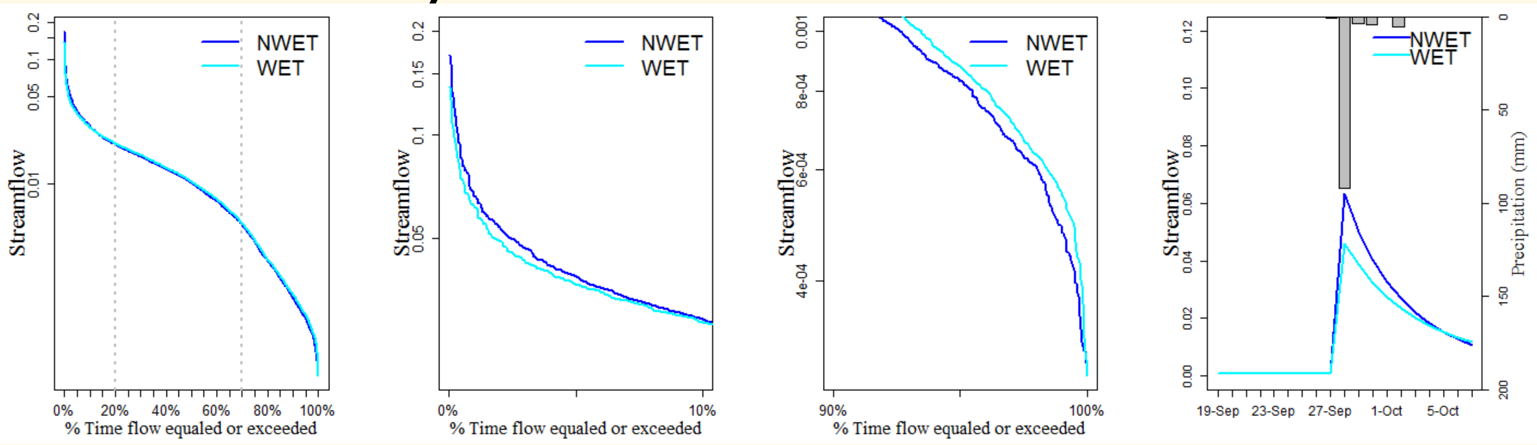
Inundation map vs Simulated inundation #2

Inundation map vs Simulated inundation #3

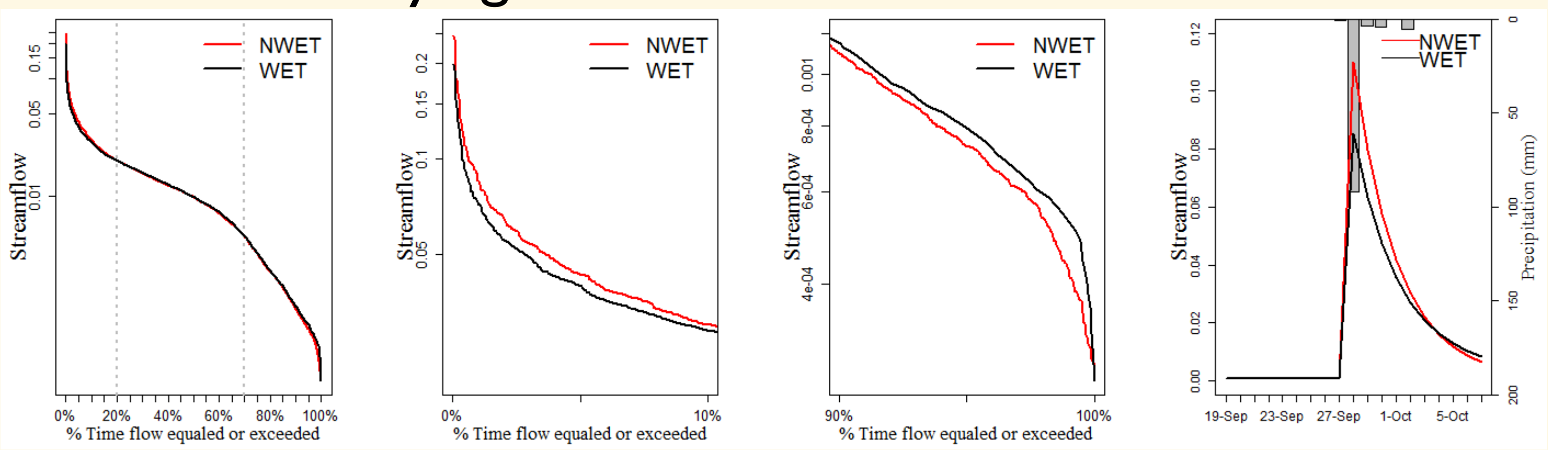
Inundation map vs Simulated inundation #4

Land use effects on wetland

✓ Sub #1 dominated by forest



✓ Sub #4 dominated by agriculture

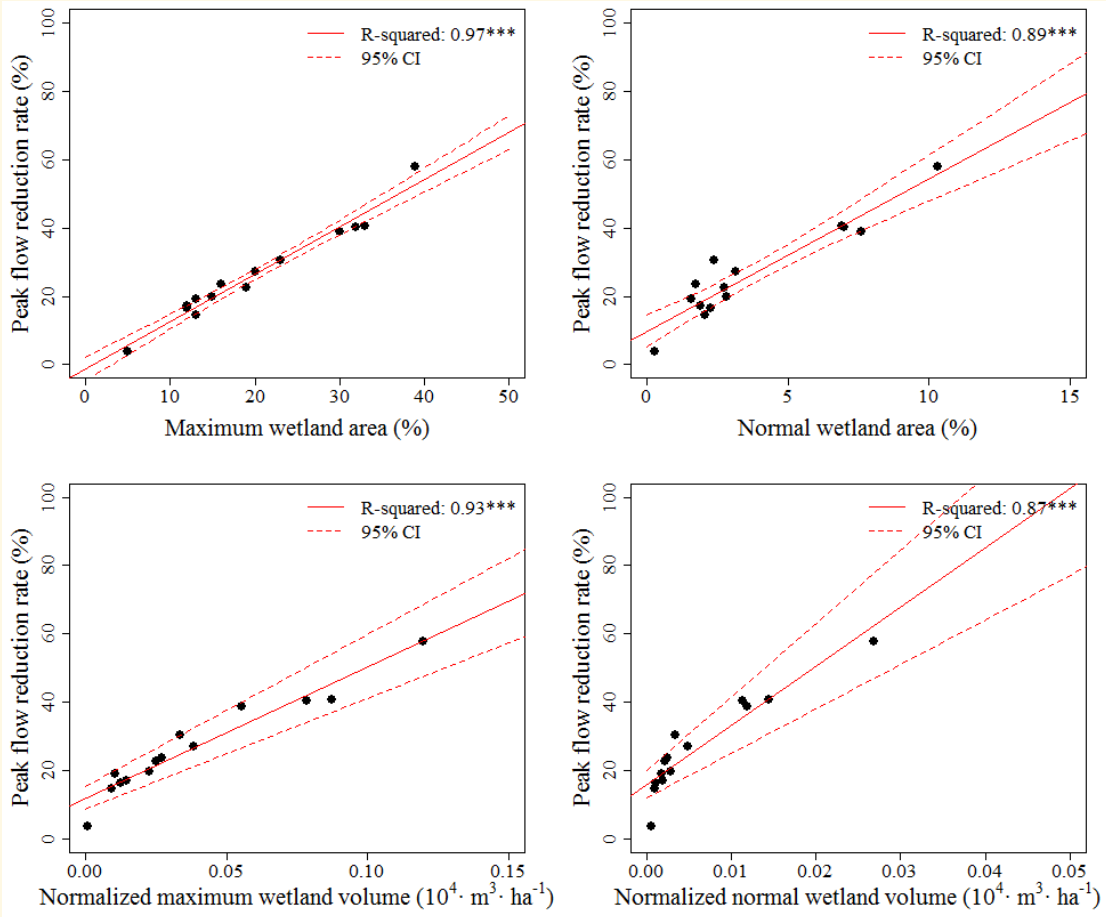


<High-flow period> <Low-flow period> <At storm event>

NWET: Simulation without wetland modules & WET: Simulation with wetland modules

Wetland effects on peak flow

✓ Comparing the relationship between peak flow reduction rate and wetland characteristics at 17 upstream sub-watersheds



- Peak flow reduction rate (%) = (NWET - WET) / NWET ×100
- CI: Confidence Interval & *** : statistical significance at the level of 0.01.

Conclusion

- Remote sensing data helped to set wetland parameters and evaluate wetland module performance.

- Integration of remote sensing data into a watershed model contributed to enhancing the model prediction on wetland hydrology and reducing model uncertainty.

- Wetlands were shown to be effective at regulating streamflow and mitigating peak flow.

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