Implementing generalized methods for simulating lakes and reservoirs on the Community SWAT+ Global Model

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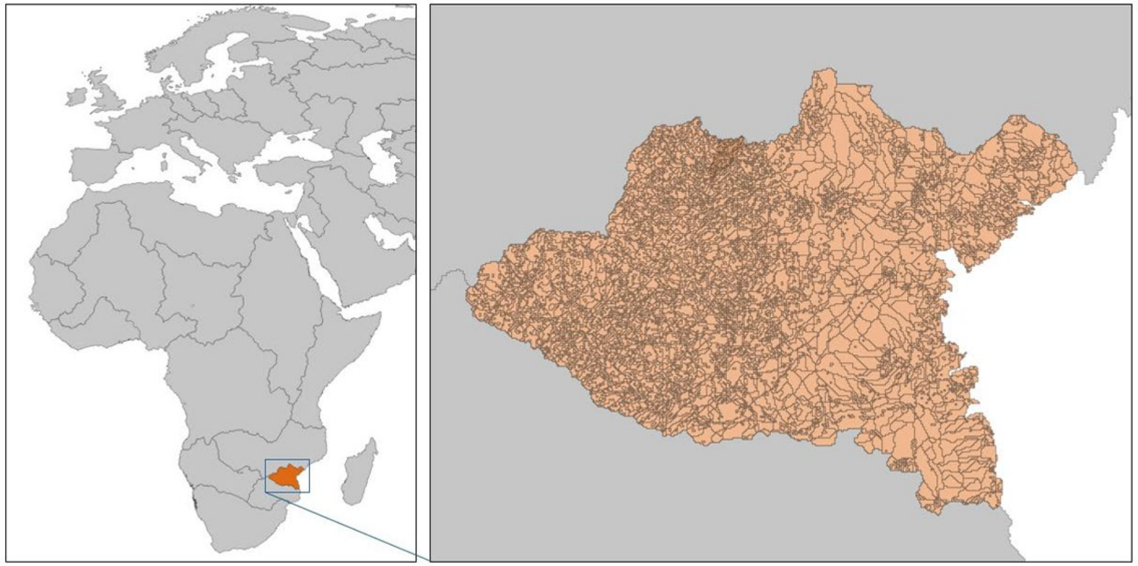
Background: CoSWAT & CoSWAT-WQ

- Global Coverage (90 basins)
- 2.63 million HRUs / 2 km resolution

Model Basins

Example of HRU distribution



Figures taken from Chawanda et al., 2025

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Background: CoSWAT & CoSWAT-WQ

- Global Coverage (90 basins)
- 2.63 million HRUs / 2 km resolution

Limitations or missing components:

- Lakes and reservoirs are not included
- No irrigation and other water management practices
- Representation of pollution sources
- Water temperature estimations
- Static land use
- …

More details (COSWAT)

More details (COSWAT -WQ)

Background: Lakes & Reservoirs in SWAT+

Reservoir Water Balance:

$$\frac{\mathrm{d}S}{\mathrm{d}t} = P - E \pm G + Q_{in} - Q_{\text{out}}$$

- S = Storage
- P = Precipitation
- Q_{in} = Surface water inflow
- E = Evaporation from lake surface
- Q_{out} = **Surface water outflow** → Decision Tables (res-rel.dtl)
- G = Groundwater exchange (positive for inflow, negative for outflow)

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Background: Lakes & Reservoirs in SWAT+

Limitations for Global Applications:

Need to have information about operation rules of the reservoir	→	Not possible to know at a global scale
There are natural, unregulated Lakes	→	Operation rules do not apply

Need for generalized schemes that can be set up using global datasets

Objectives

1. Identify simple, parametric methods that can be used to implement reservoirs on the CoSWAT GHM.
2. Implement these methods on the SWAT+ source code. Make them available through decision tables.
3. Re-structure the GHM considering lakes and reservoirs in the hydrographic network and apply implementations.
4. Run simulations with the re-structure GHM and validate against streamflow observations and reservoir/lake storage observations.

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Time-Invariant Parametric Lake scheme

Natural Lakes (Doll et al, 2003)

$$Q_{out} = K_r \cdot S \cdot \left(\frac{S}{S_{max}}\right)^{\alpha}$$

Release coefficient
($0.01 day^{-1}$)

Exponential
Coefficient (1.5)

S = Si – So : Current storage – Dead storage
Dead storage: Below this, not outflow
Smax = Principal Volume (Pvol)

What do we specify in the decision table?

- Release rate
- Inactive storage (as % of Pvol)

On CoSWAT

- Release rate: 0.01
- Inactive storage: To which depth is 5 m (GLOBathy)

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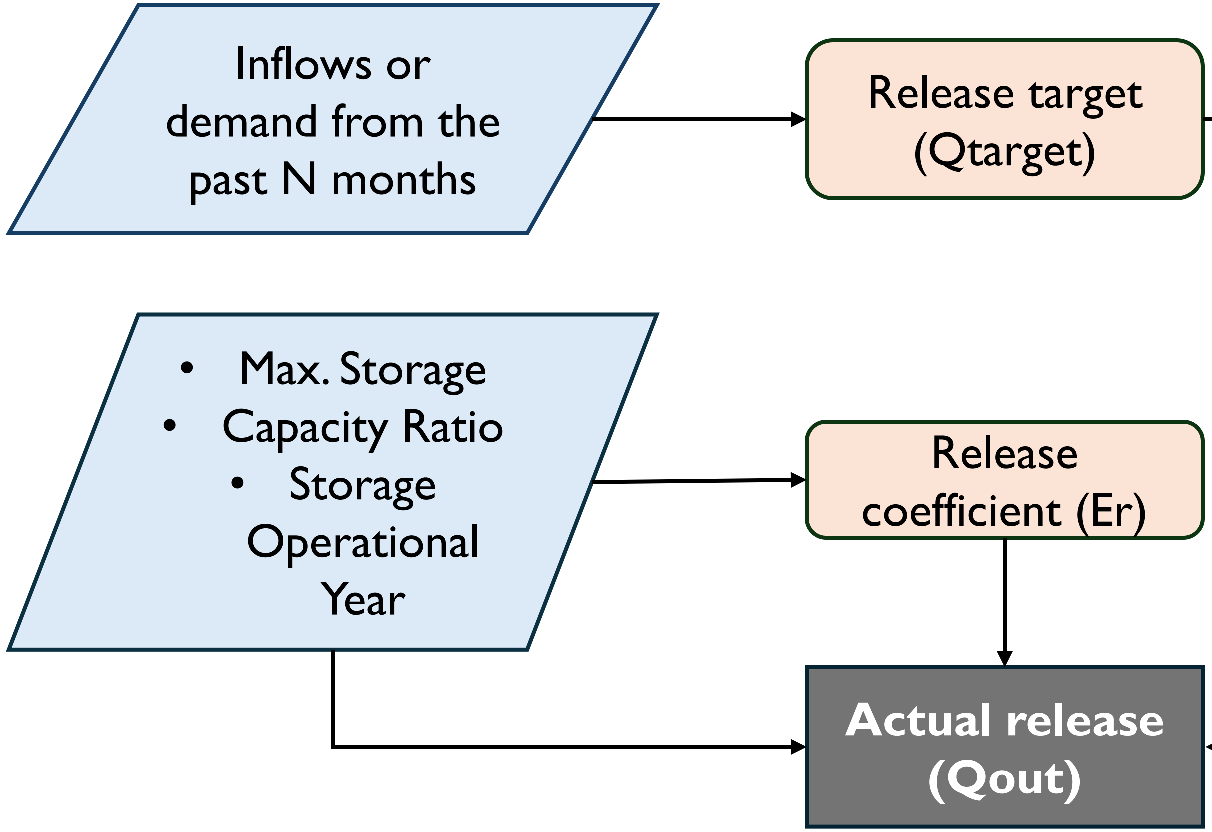
Time-variant Parametric Reservoir schemes

Reservoirs General Purpose & Irrigation (Hanazaki et al, 2006)



What do we specify in the decision table?

- Irrigation or not
- α: (1- α) = Dead storage (%)
- β: Ecological flow demand (%)

On CoSWAT

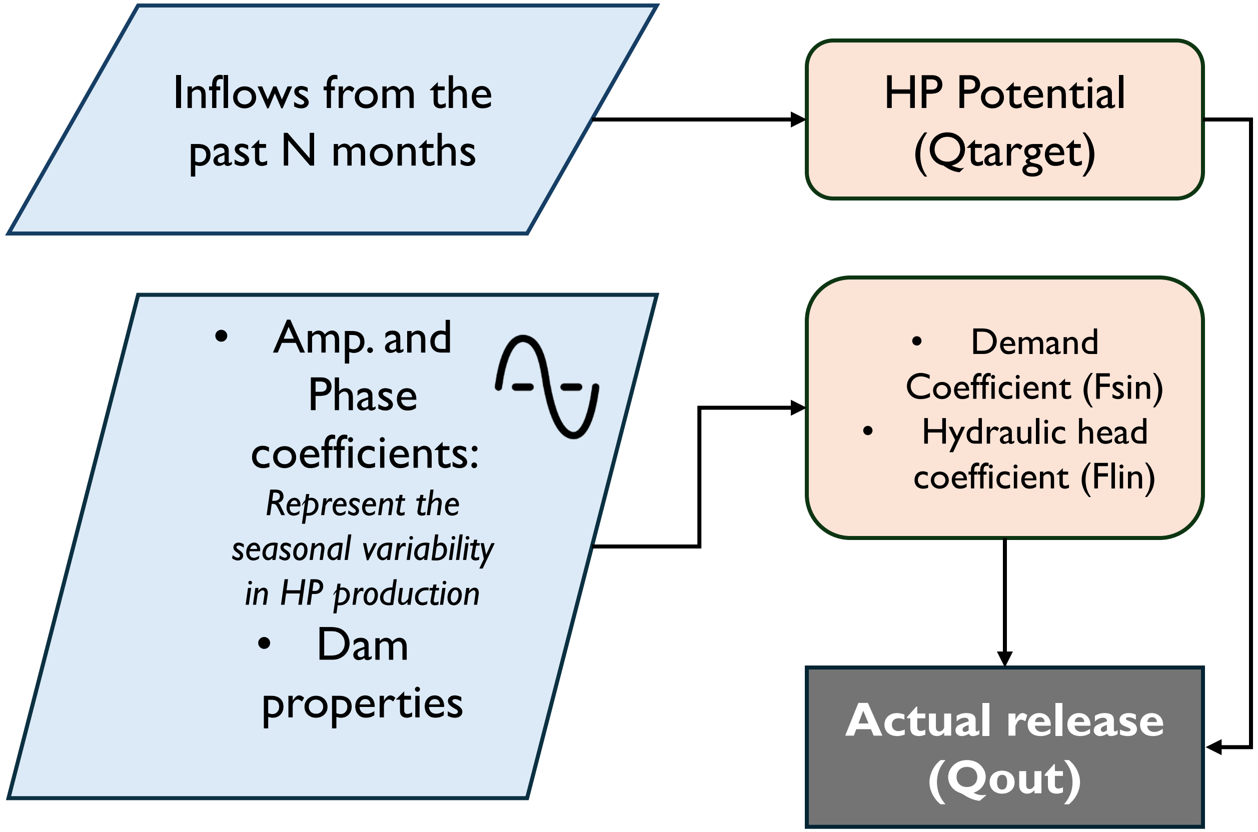
- α : 0.85
- β : 0.1 (10%)
- N: 12 * 5 (Looks at the last 5 years)

Example of dtl

```
name        conds     alts      acts
res_19      3         4         3
var         obj       obj_num   lim_var   lim_op   lim_const        alt1   alt2   alt3   alt4
vol         res       0         pvol      *        1-α 0.15000      <      >      <      >
vol         res       0         pvol      *        % 0.82922        <      >      -      -
year_seq    res       0         null      *        5.00000          <      <      >      >
act_typ     obj       obj_num   name      option               const         const2         fp
release     res       0         no_rel    rate                 0.00000       0.00000        null
release     res       0         nat_rel   doell                % 0.82922     Kr 0.01000     null
release     res       0         res hana  hanazaki 06 irr      α 0.85000     β 0.10000      null
```

Time-variant Parametric Reservoir schemes

Reservoirs Hydropower (Arheimer et al, 2020 – HYPE model)



What do we specify in the decision table?

- Amplitude and Phase Coefficients
- Dead storage

On CoSWAT

- Amplitude 0.70
- Phase: Depends on the region (Latitude)
- N: 12 * 5 (Looks at the last 5 years)
- Hydraulic head assumed to be limited to 20% of storage

Implementation in SWAT+ source code

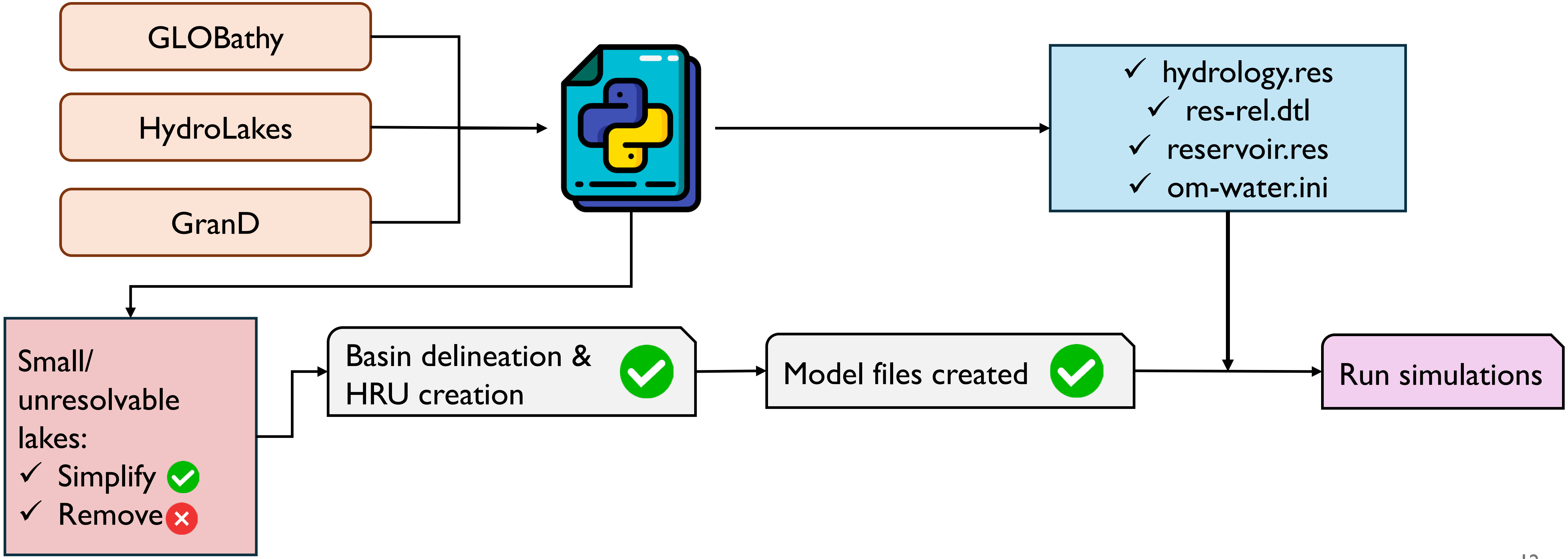
Add release options for decision tables (res-hydro.f90)

Adjust reservoir objects to account for additional necessary information (reservoir_module.f90)

Adjust water balance calculations to consider GLOBathy coefficients provided in model files (res_control.f90)

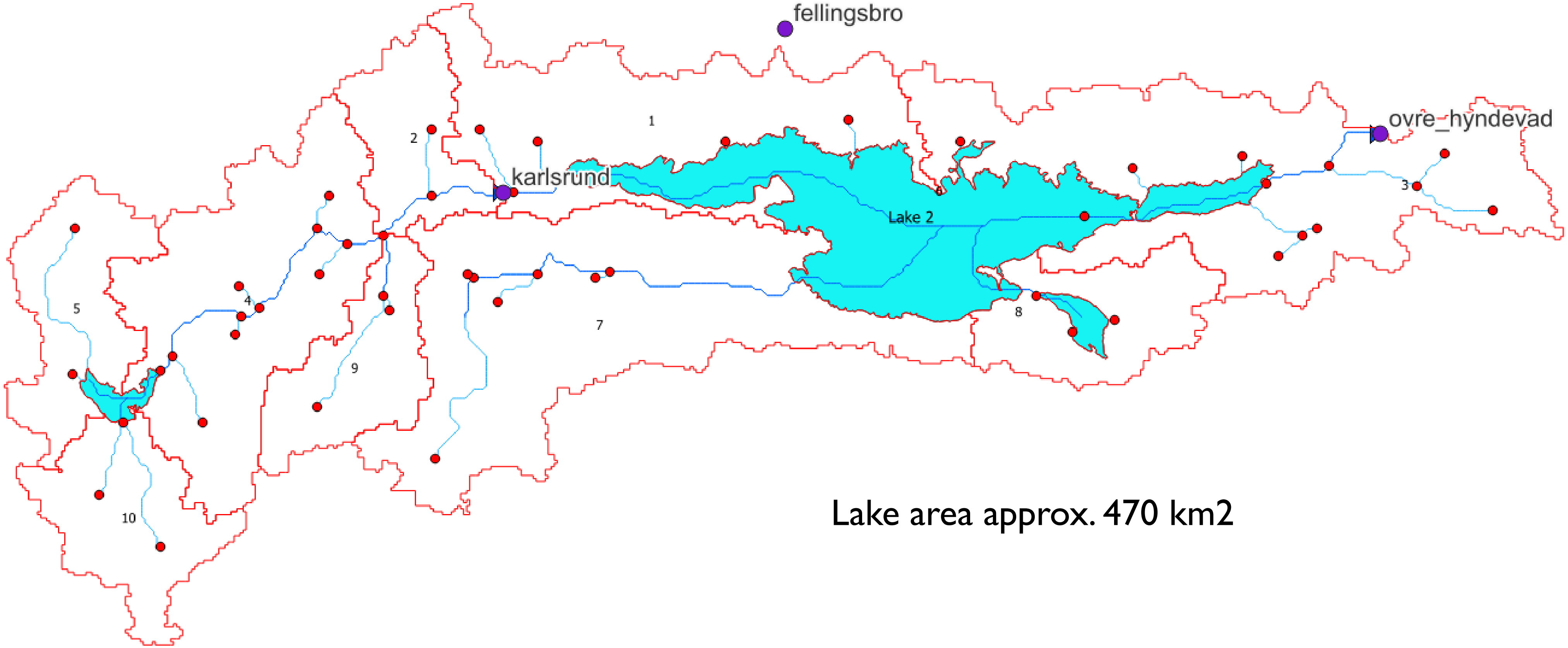
The implementation was done testing on a local model with 2 small lakes (Lake Hjalmaren Basin, Sweden).

Additions to the CoSWAT Framework



Preliminary results: Local case – Natural lake

Hjalmaren Basin



Lake area approx. 470 km2

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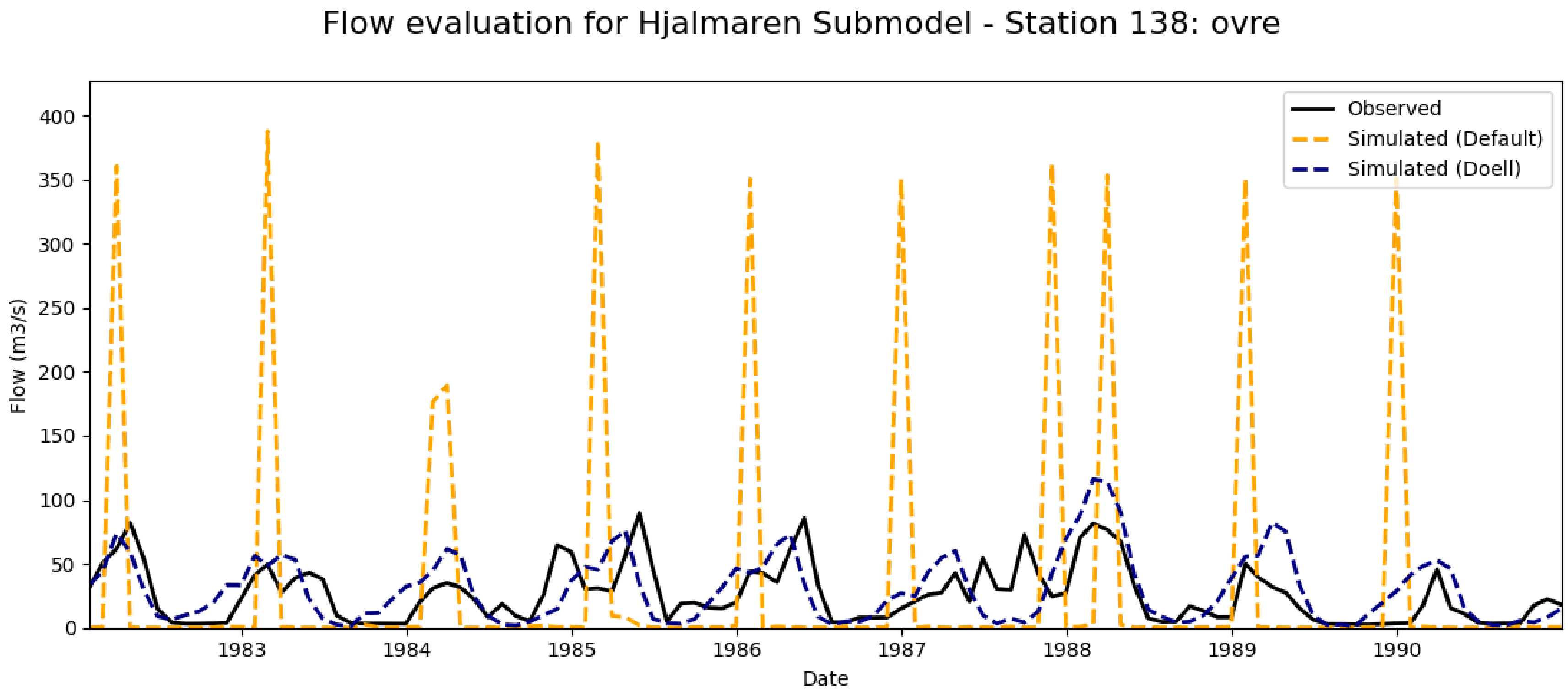
Preliminary results: Local case – Natural lake

* Default: Drawdown days

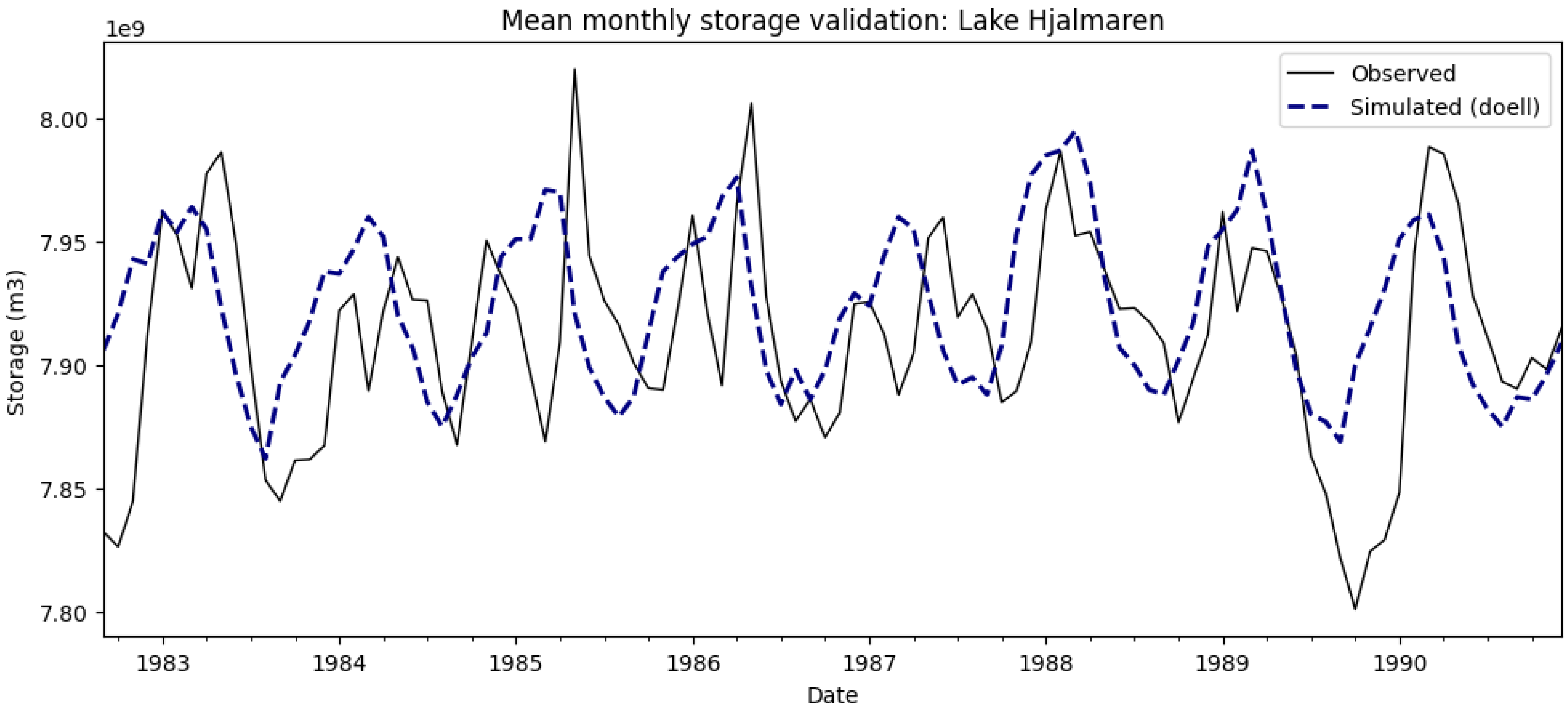
Hjalmaren Basin: Flow after lake



	PBIAS	KGE
Default	-30.60	-2.67
Doell	-18.90	0.58

Preliminary results: Local case – Natural lake

Hjalmaren Basin: Storage



KGE = 0.34 PBIAS = -0.15%

Preliminary results: CoSWAT Validation

WORK IN PROGRESS

- Restructure CoSWAT (1km resolution)
- Weather Forcings: GWSP3-EWEMBI
- Using dataset from Yasin et al (2018) About 36 reservoirs
  - Monthly storage, inflow outflow
- Using GRDC
  - Mean monthly streamflow

Observations (Yasin et al., 2018)	CoSWAT Regions
Flood Control	Africa-Nile
Hydropower	America-bravo
Irrigation	America-colorado
Water Supply	America-columbia
	America-mississippi
	America-Nelson
	Asia-Aral
	Asia-Mekong

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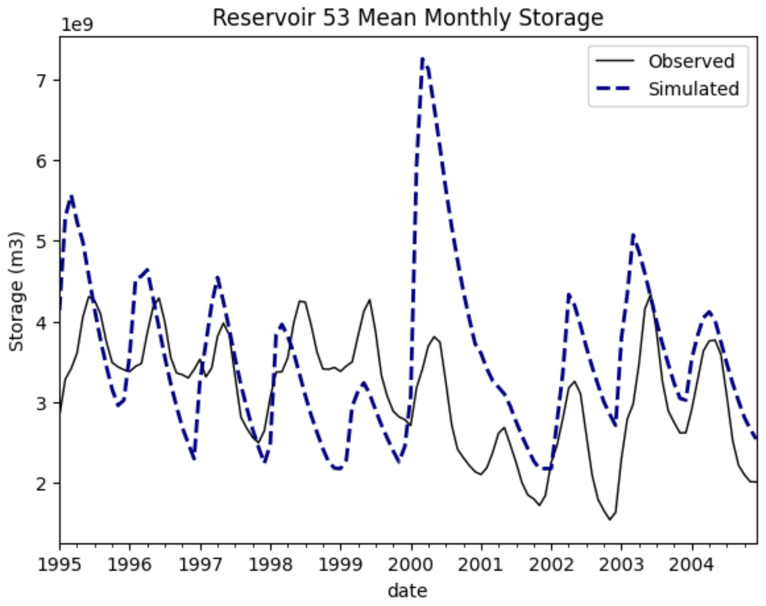
Preliminary results: CoSWAT Validation

WORK IN PROGRESS

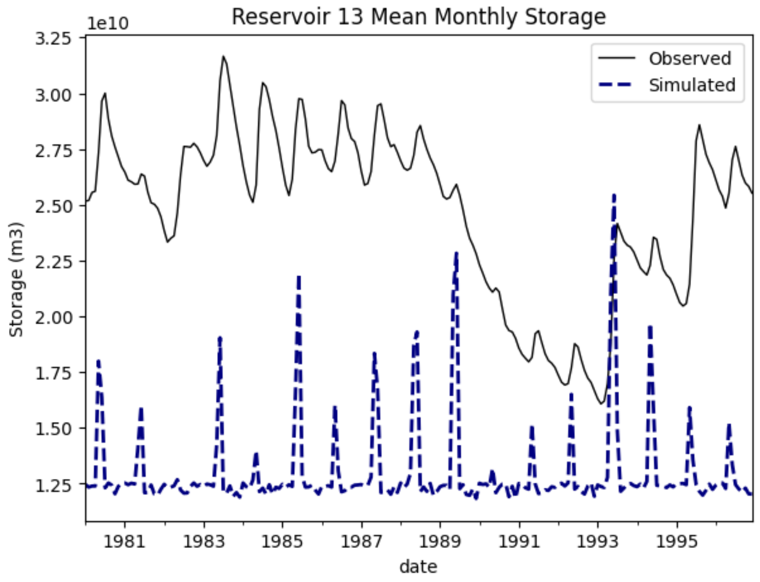
The good…

Lake Oroville
(Flood Control)



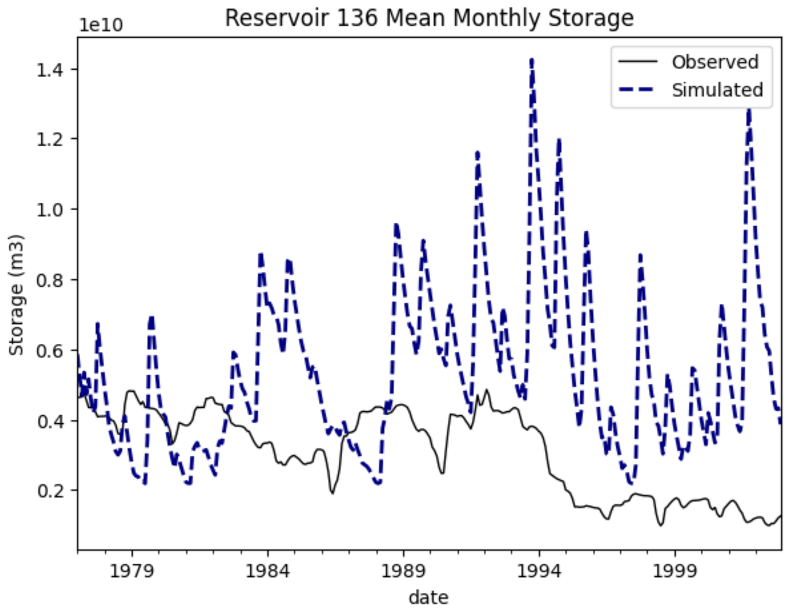
The bad…

Glen Canyon Dam
(Hydropower)



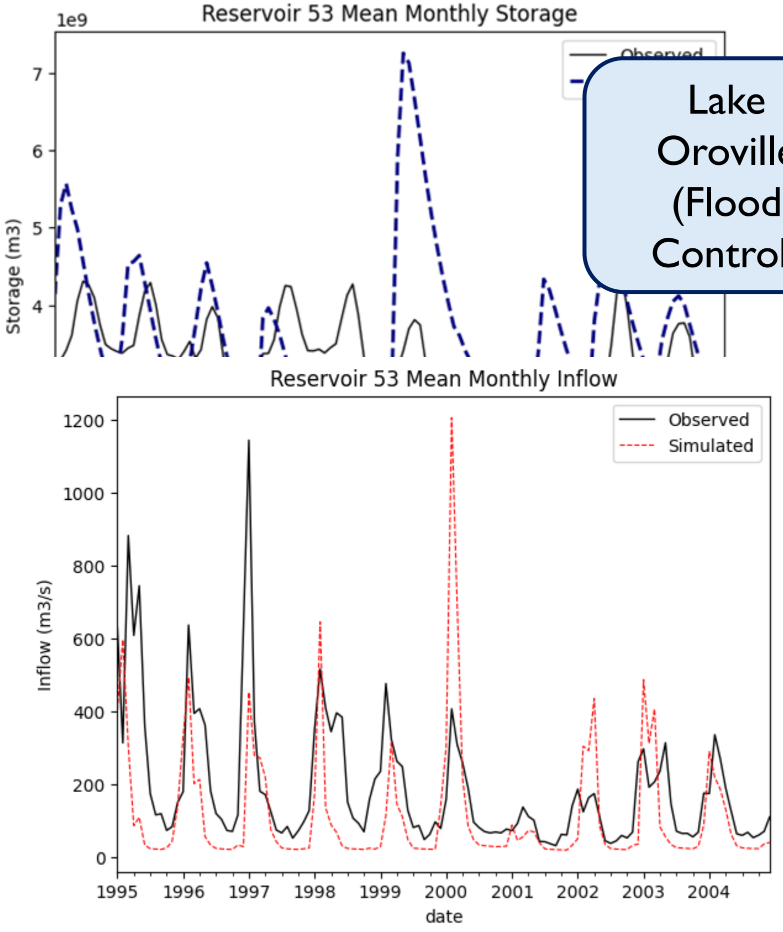
The ugly….

Amistad Reservoir
(Irrigation)

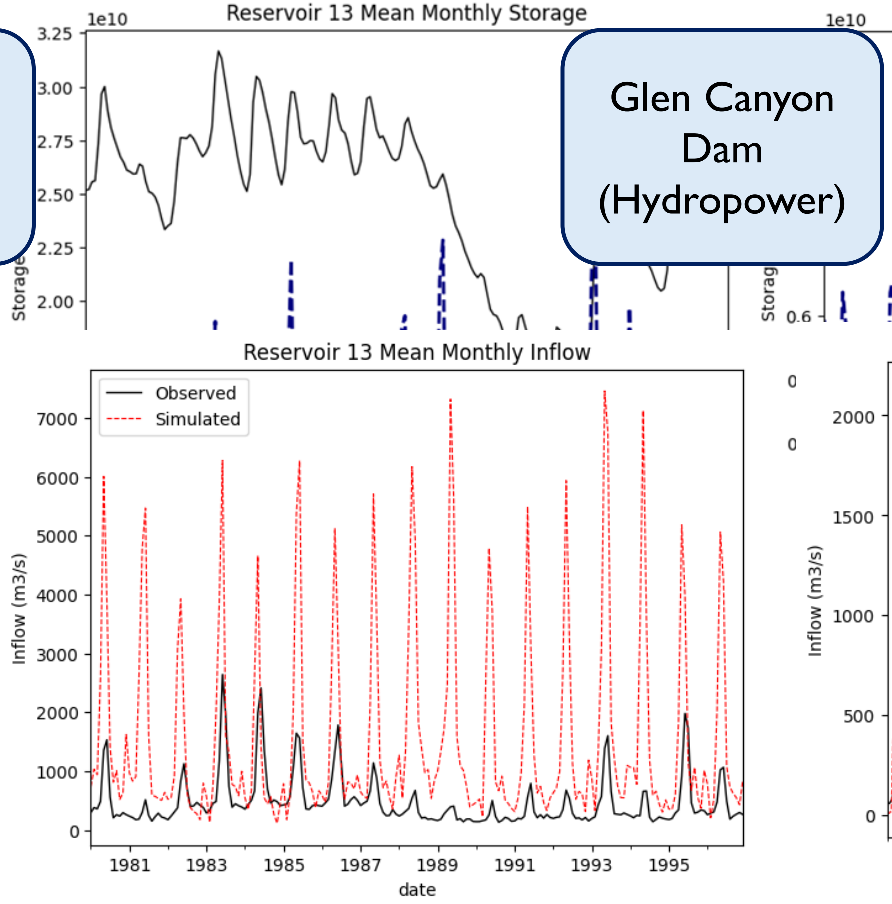


Preliminary results: CoSWAT Validation

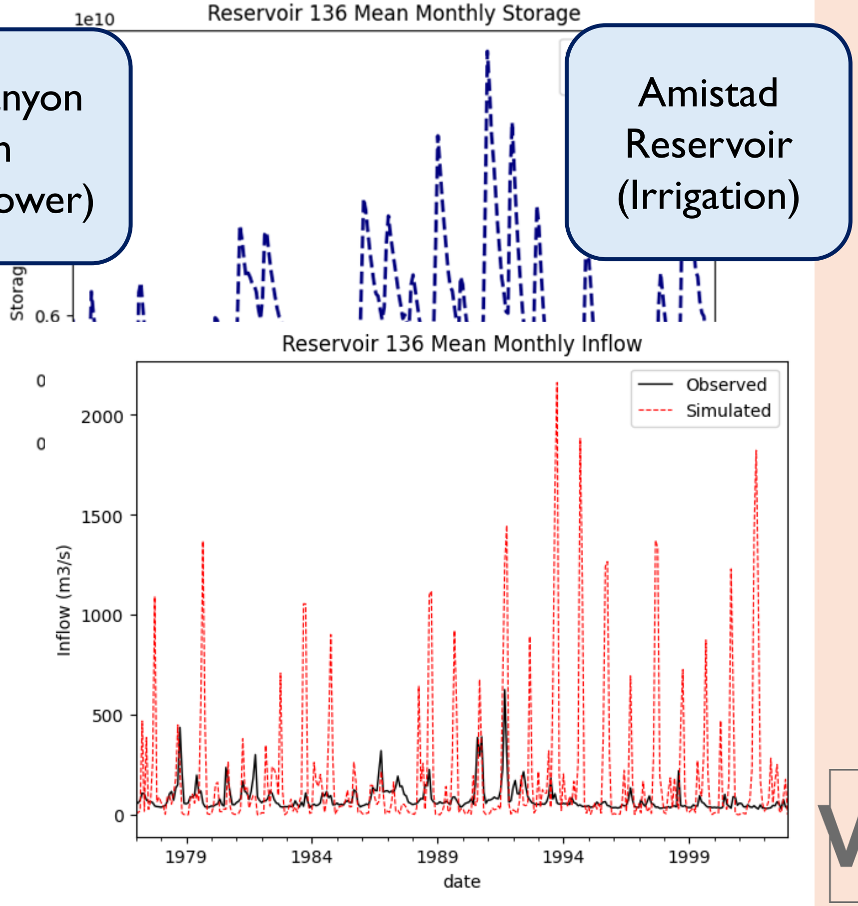
The good…



The bad…



The ugly….



Current challenges & next steps

- Delineation issues → Need to adjust QSWAT algorithms
- HYPE scheme revision
- Missing other types of demands?
- Spillway release when storage surpasses emergency volume

Next steps…

- Include irrigation
- Extend validation to all regions
- Look at influence on WQ (Sediment and Nutrient retention)

Thank you!

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