Adaptive Reservoir Operation under the Challenges of Transboundary Dams: Example from the Nile River Basin Using Satellite Remote Sensing

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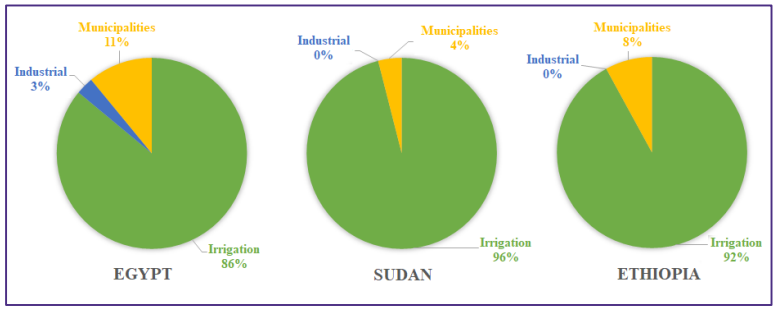
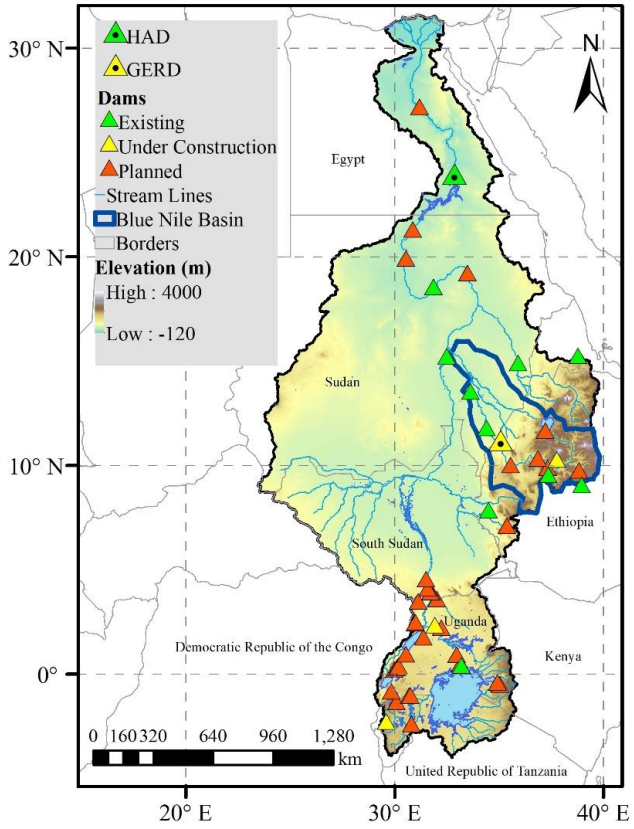
UNIVERSITY *of* WASHINGTON

Background & Motivation

- World's longest river (6,650 km)
- 11 countries
- Home to more than 200 million people



Nile River Basin



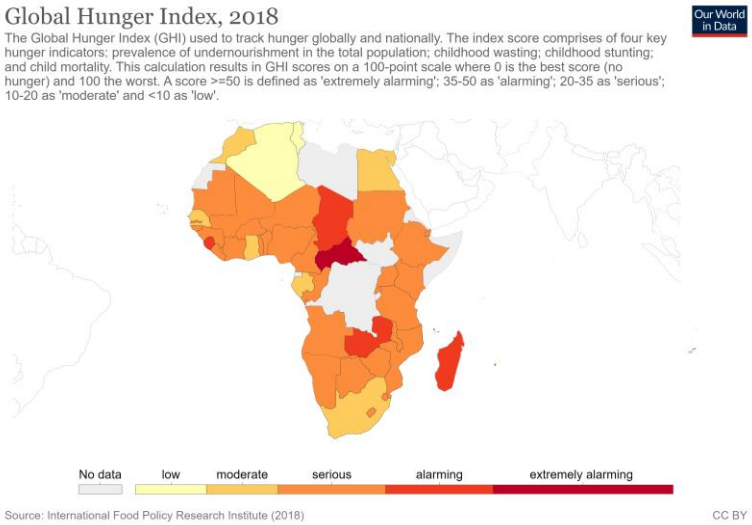
GRanD Database (Lehner et al., 2011) and Zarfl et al. (2015)

Grand Ethiopian Renaissance Dam (GERD)

- **currently under construction in Ethiopia**
- **Largest hydropower dam in Africa**
- **74 km^3 of reservoir storage**

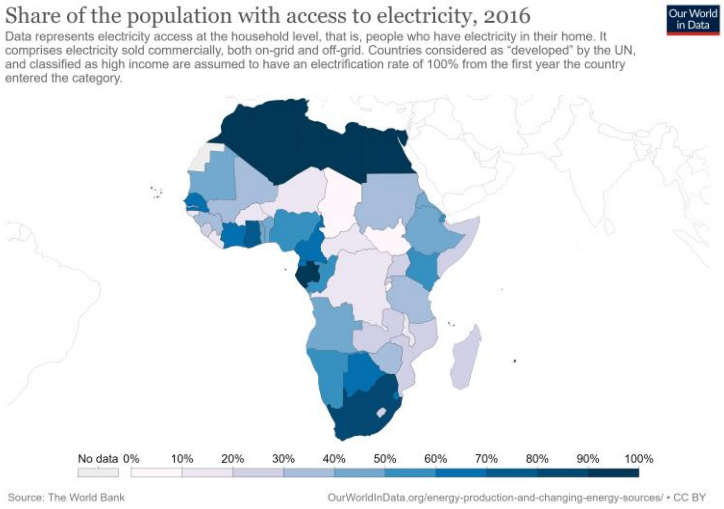
Background & Motivation

Food Security in NRB



- 34% of the population of the basin are undernourished
- Serious alarming (20-35%) in Nile Basin countries

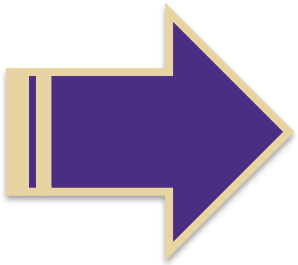
Energy Security in NRB

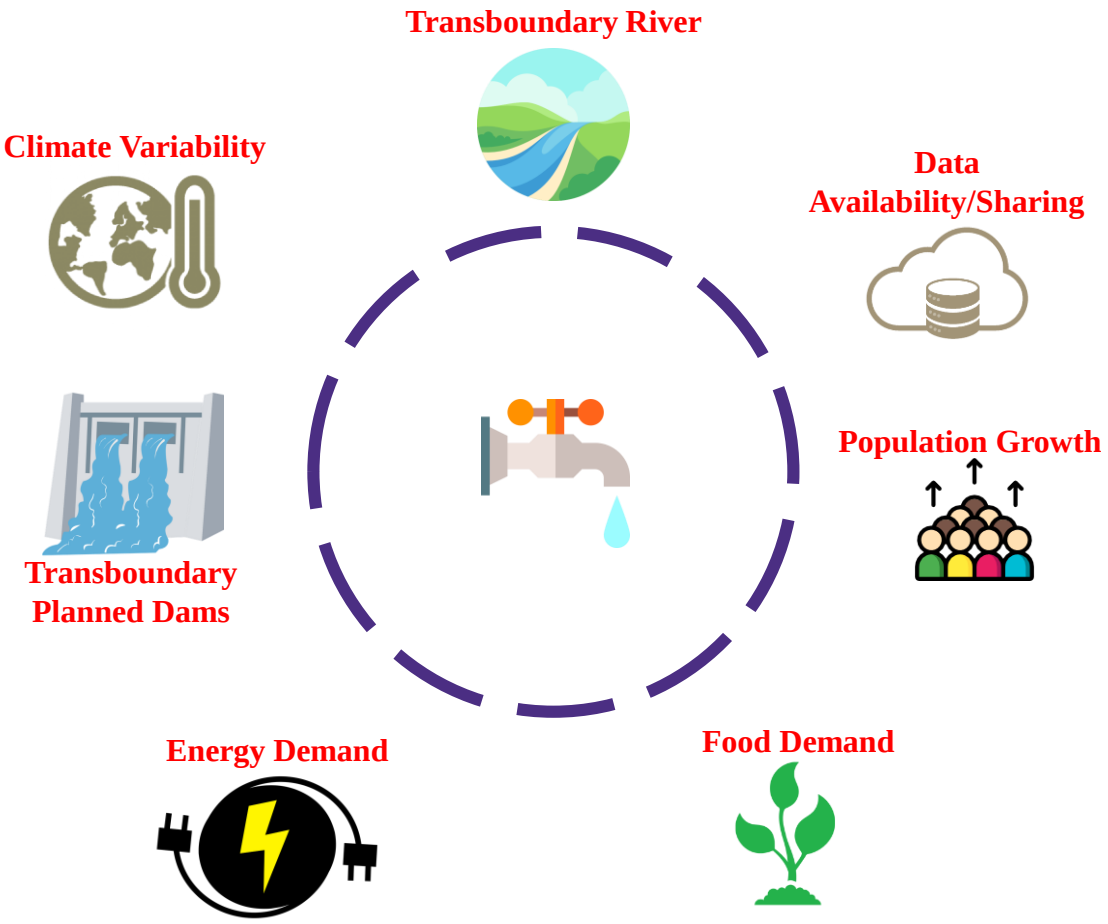


- 620 million people in Africa without electricity.

Challenges in NRB

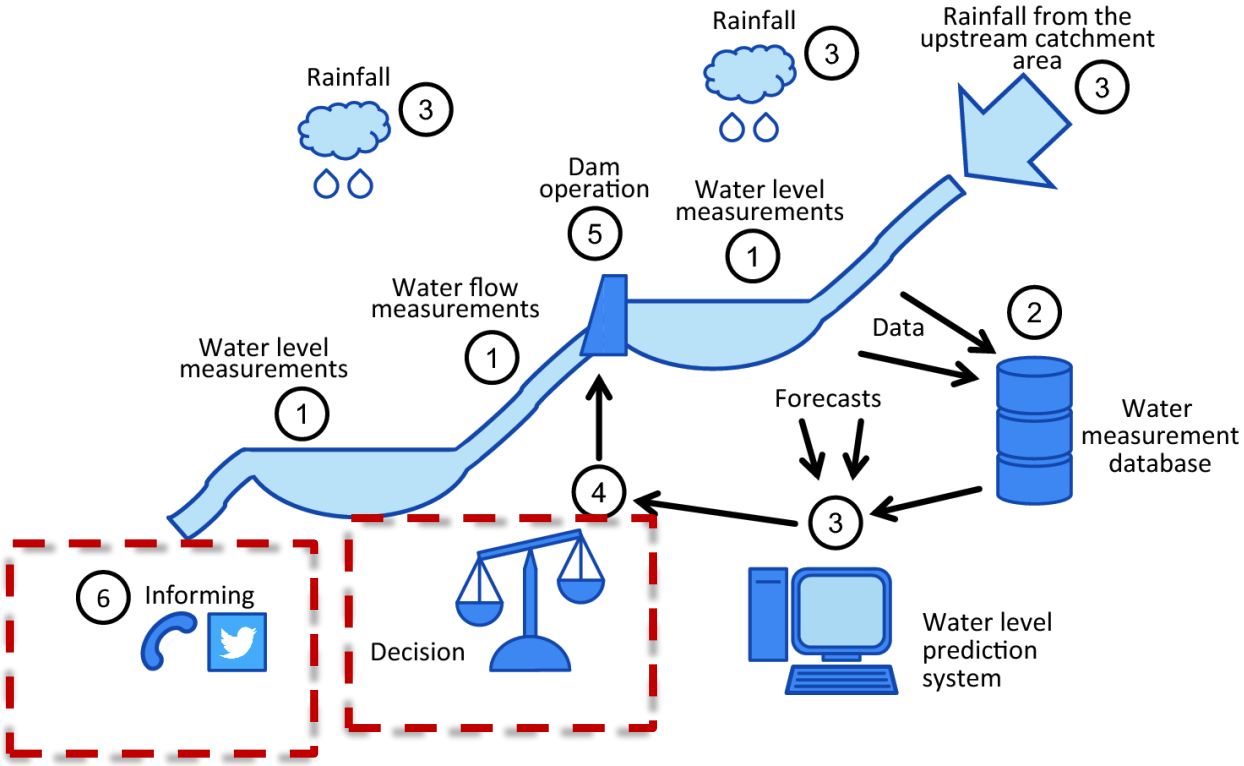
Recap the Challenges in NRB





Adaptive Reservoir Operation (ARO)

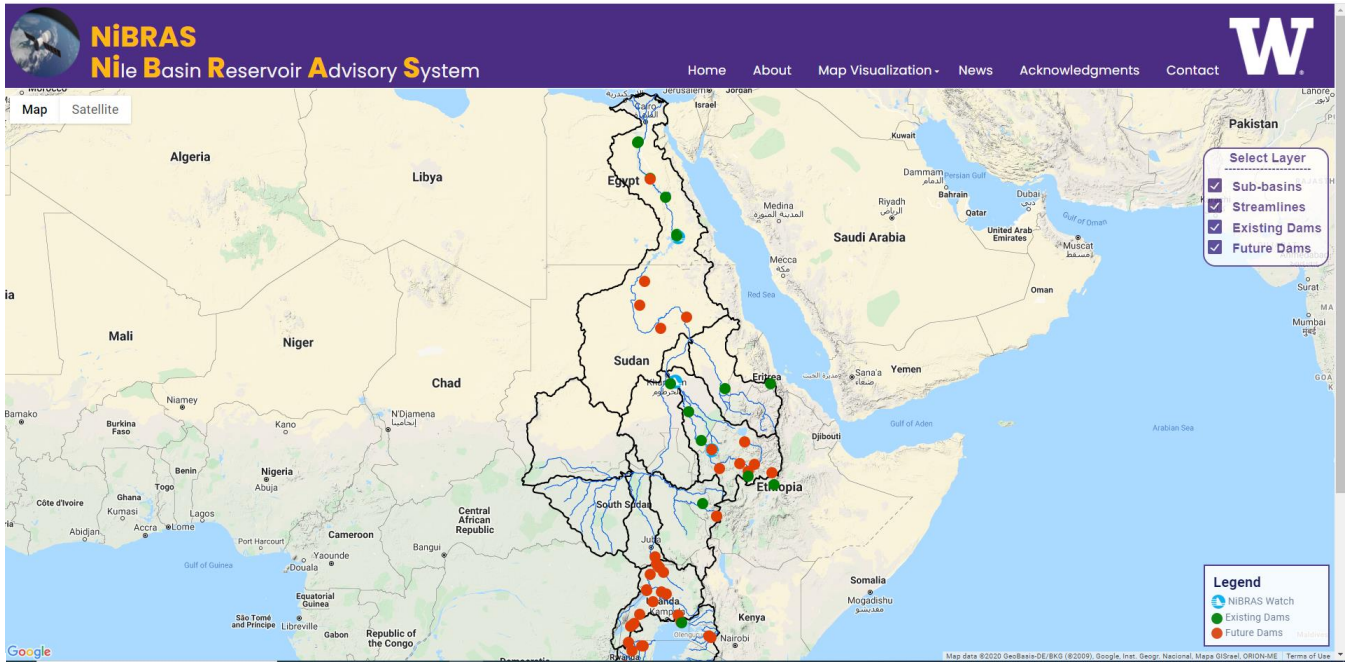
- Adapting reservoir operation to impacts from expected challenges.



Source: Mustajoki, J., & Marttunen, M. (2019). Improving resilience of reservoir operation in the context of watercourse regulation in Finland. *EURO Journal on Decision Processes*, 1-28.

Informing Decisions for ARO

- **Vision:** *Building a satellite-based decision support system for advising reservoir operation in the Nile river basin*
- **Ni**le **B**asin **R**eservoir **A**dvisory **S**ystem or **NiBRAS**

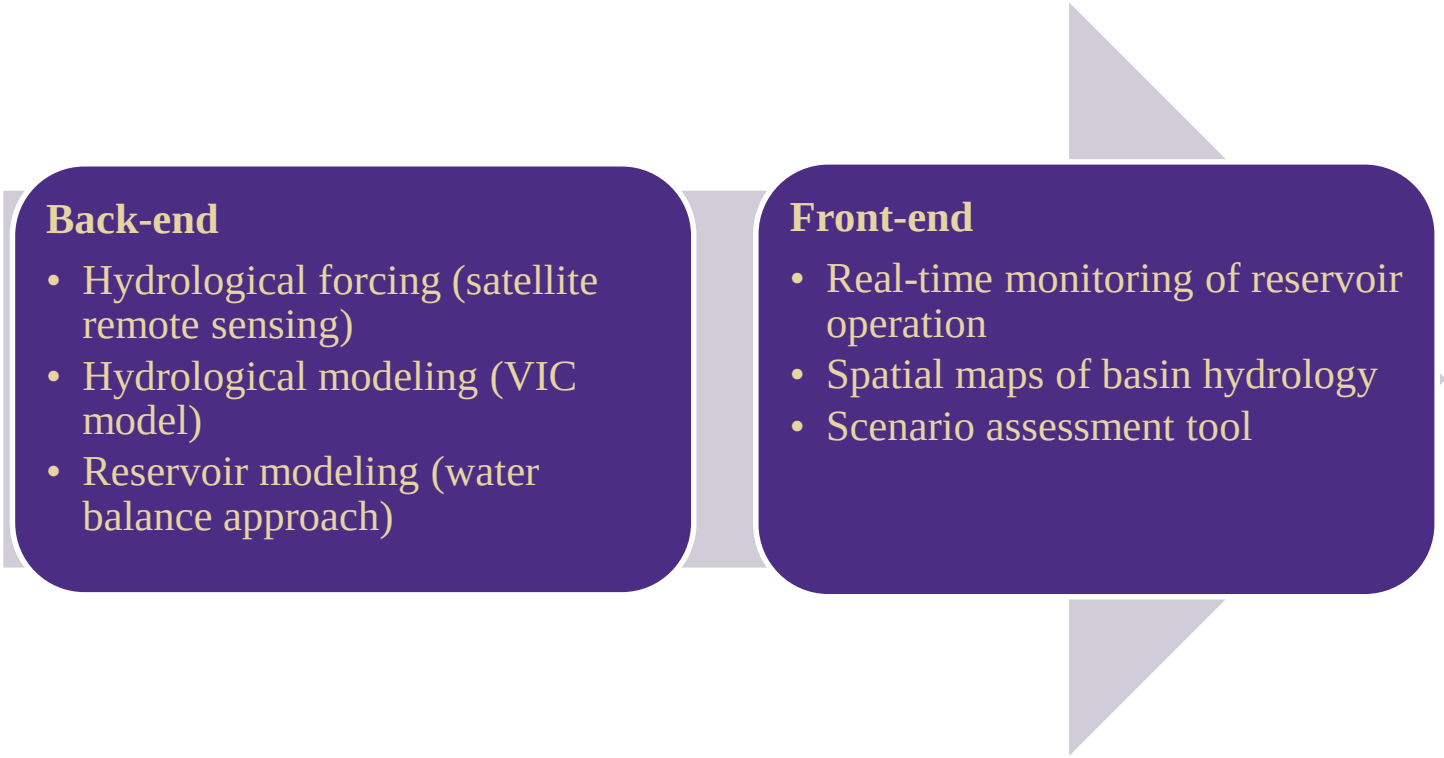


http://students.washington.edu/dardiry/nibras

NiBRAS means Light in Arabic

Nile **B**asin **R**eservoir **A**dvisory **S**ystem **(NiBRAS)**

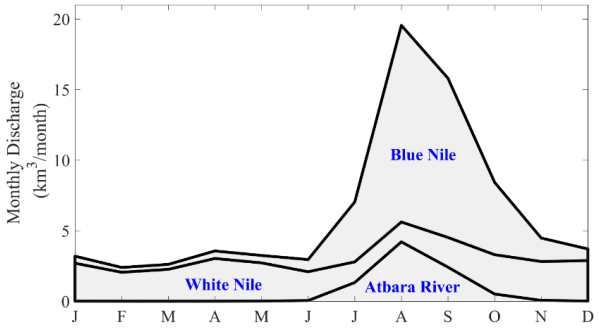
- NiBRAS integrates complex physical land surface and reservoir models in the back end with a front-end user interface to facilitate decision making

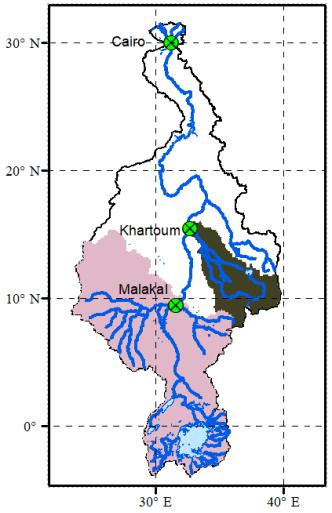


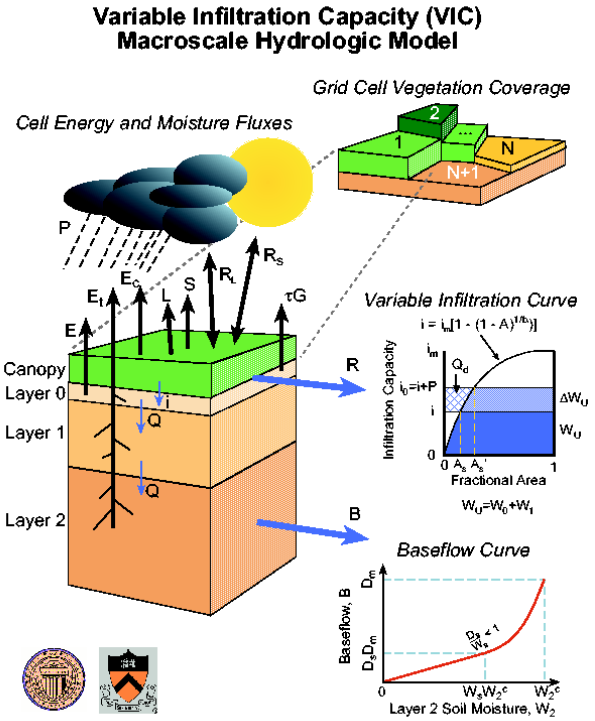
NiBRAS Back-end

Hydrological Modeling (VIC)

- Spatially distributed grid cells
- Spatial Scale: 0.1° (~10 km)
- Temporal Scale: Daily
- Forcing: IMERG-NCDC-MODIS



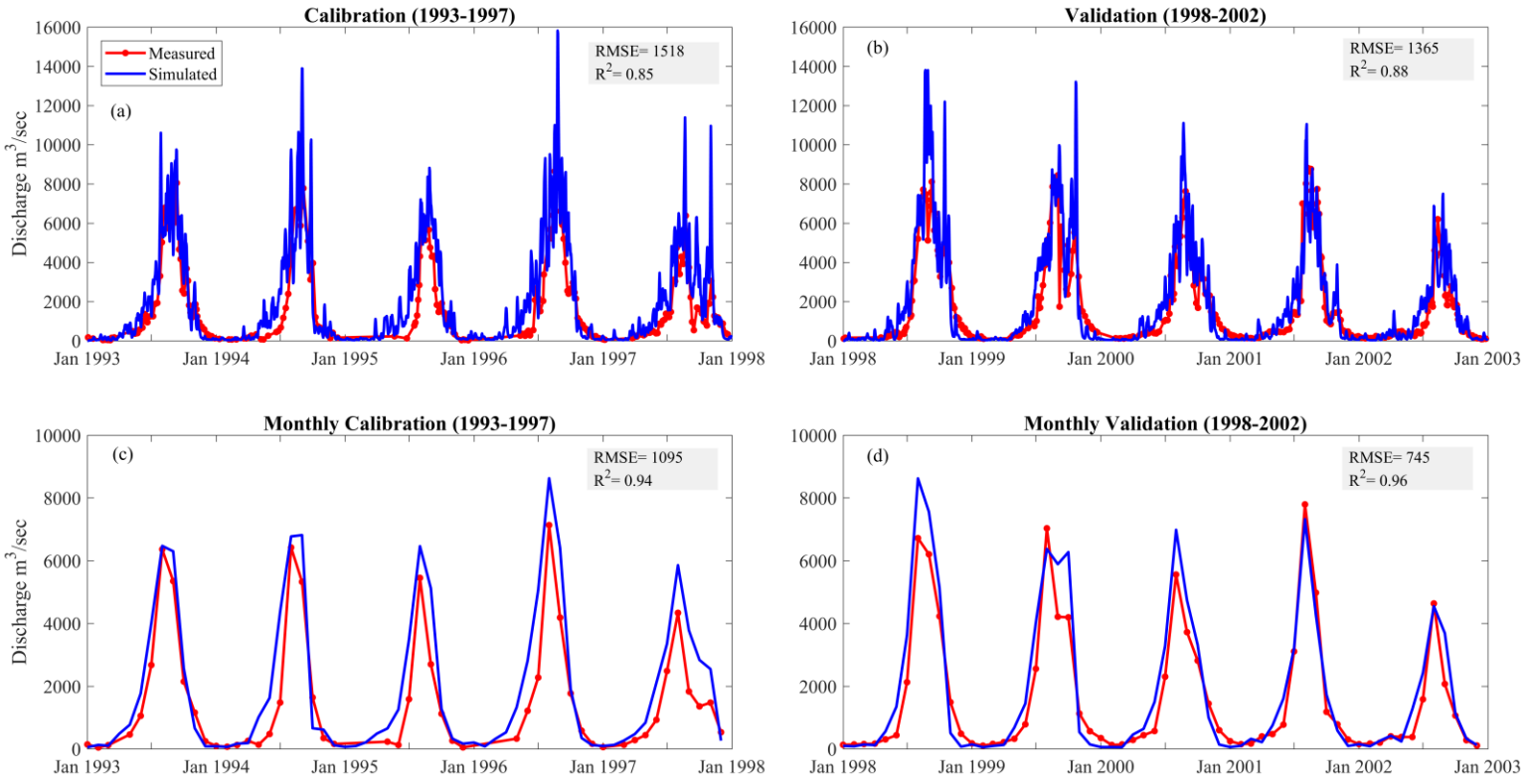




Source: Liang, X., Lettenmaier, D. P., Wood, E. F., & Burges, S. J. (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research: Atmospheres, 99(D7), 14415-14428.

NiBRAS Back-end

VIC Calibration at Khartoum Station

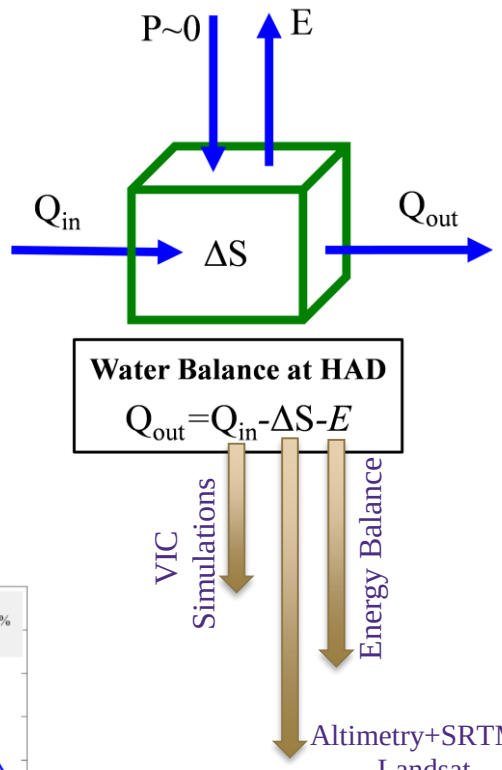


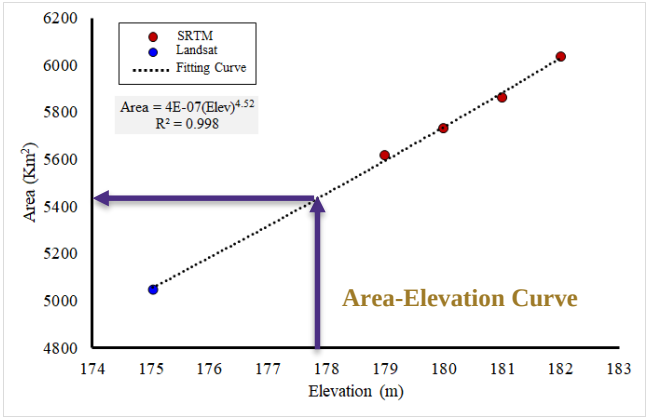
* *Eldardiry, H., & Hossain, F. (2019). Understanding Reservoir Operating Rules in the Transboundary Nile River Basin Using Macroscale Hydrologic Modeling with Satellite Measurements. Journal of Hydrometeorology, 20(11), 2253-2269.*

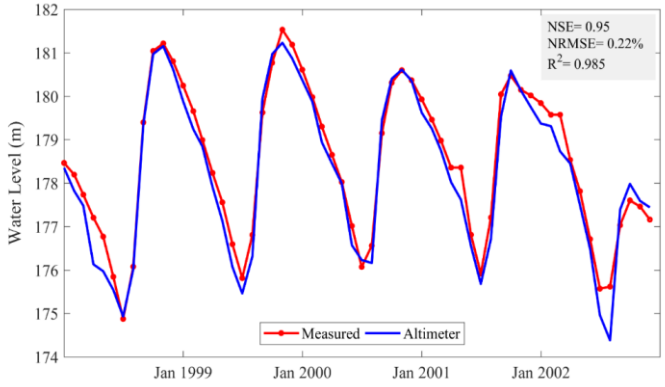
NiBRAS Back-end

Reservoir Modeling

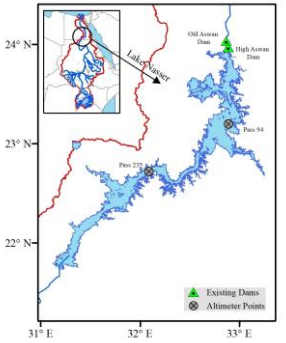
- How is the HAD being operated?
- What is the water level in the HAD lake?
- How much water being released/stored every month?







Water Level in HAD Lake from radar altimetry

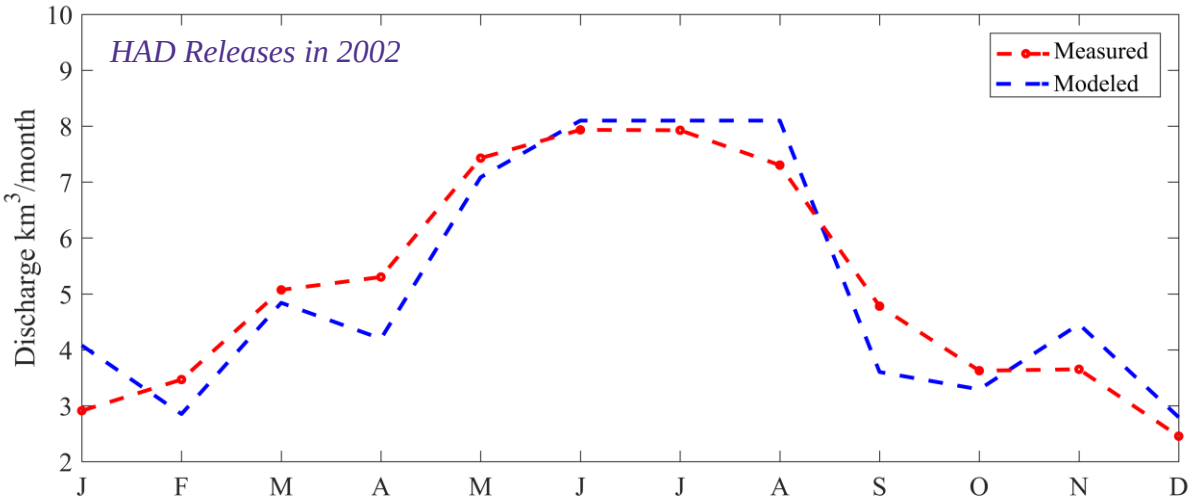


HAD Operation

Outflow=Inflow-Volume Change

Inflow=Blue Nile (VIC)+White Nile (Mon. average)+ Atbara (Mon. average)- Losses (Energy Balance).

Volume =Altimeter water level change*Area (using Area-Elevation curve).



- For five years (1998-2002) → R^2= *0.67*
- For only 2002 → R^2= *0.94*
- Sources of Uncertainties:
  - *VIC Simulations*
  - *Altimetry water levels*

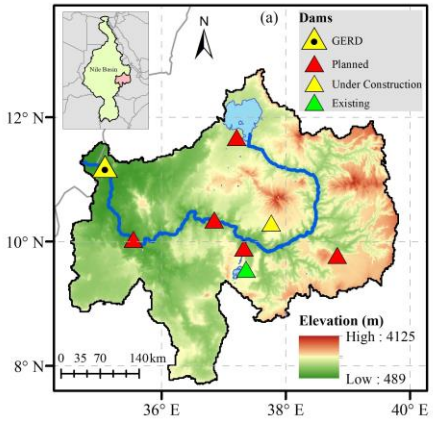
Google Earth Engine

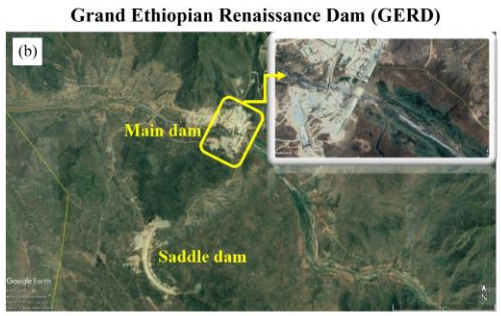
Credit: *In-situ data were obtained from reports published by the Ministry of Water Resources and Irrigation (MWRI) in Egypt*

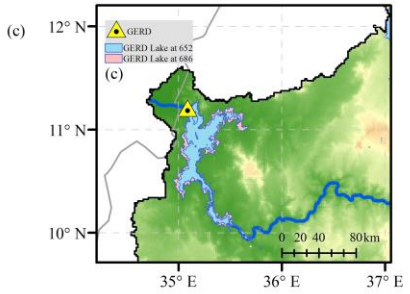
NiBRAS Back-end

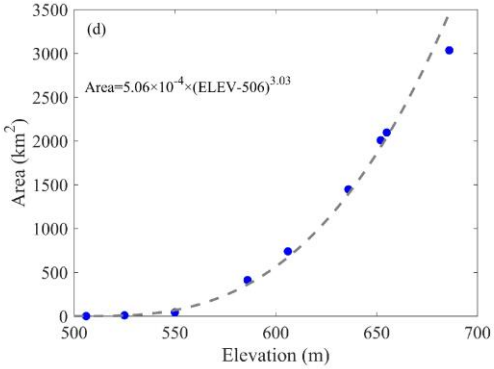
GERD Filling/Operation

- Hydropower capacity= 6,450 MW
- Impounding capacity= 74 km^3
- Median Flow=47.5 km^3/year

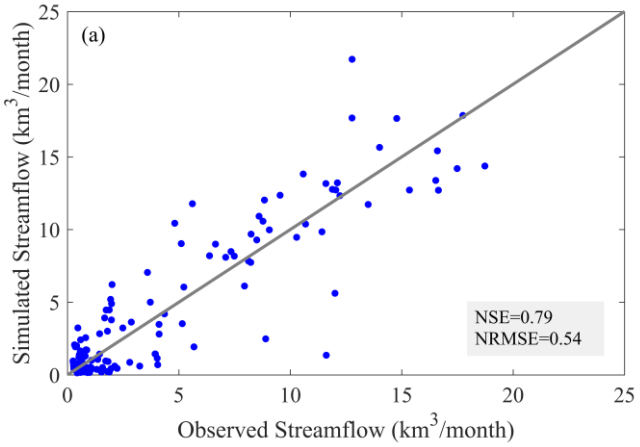


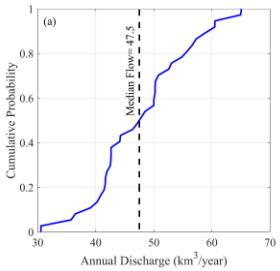


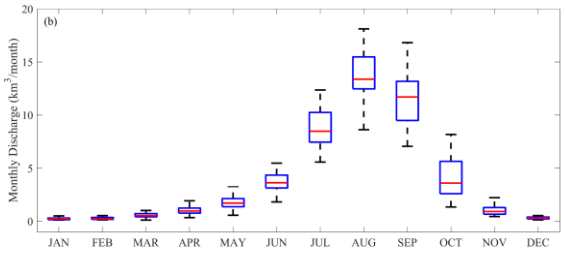




VIC Simulations at Eldiem Station

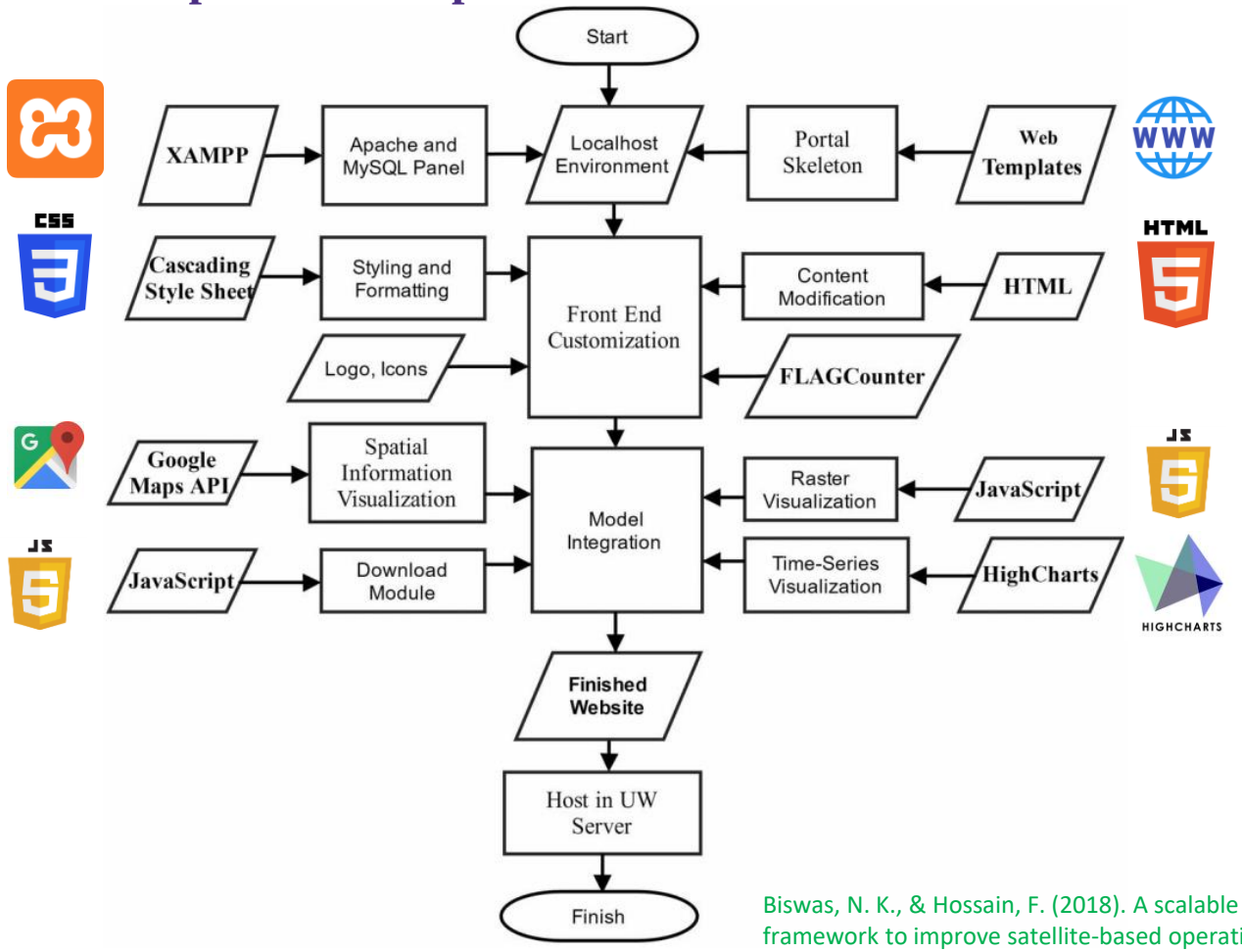






NiBRAS Front-end

Open-source web portal development

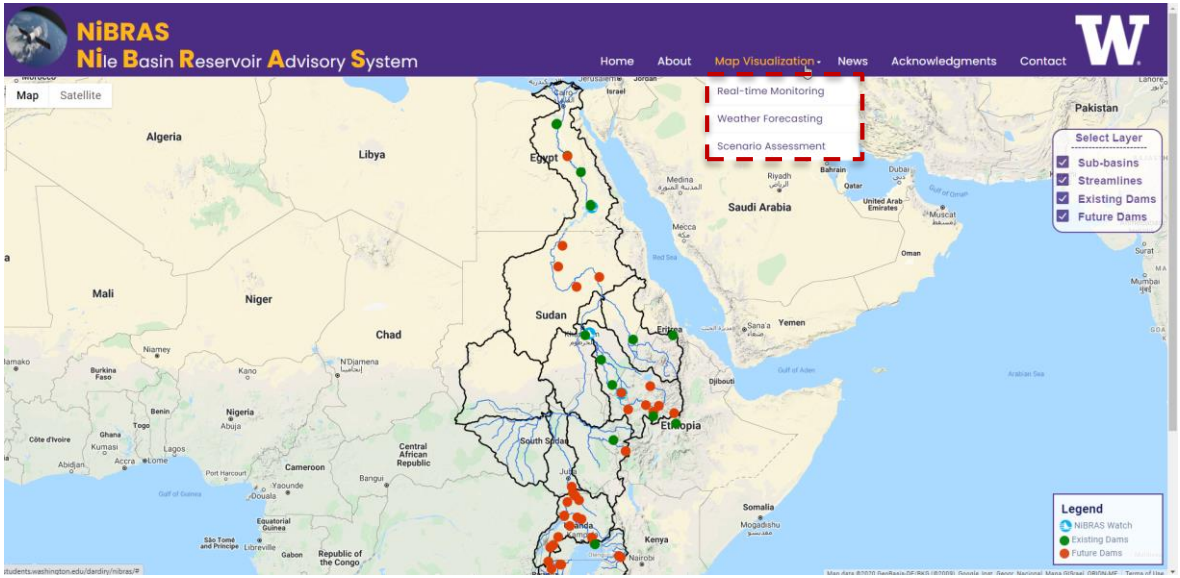


Biswas, N. K., & Hossain, F. (2018). A scalable open-source web-analytic framework to improve satellite-based operational water management in developing countries. Journal of Hydroinformatics, 20(1), 49-68.

NiBRAS Front-end

Tools

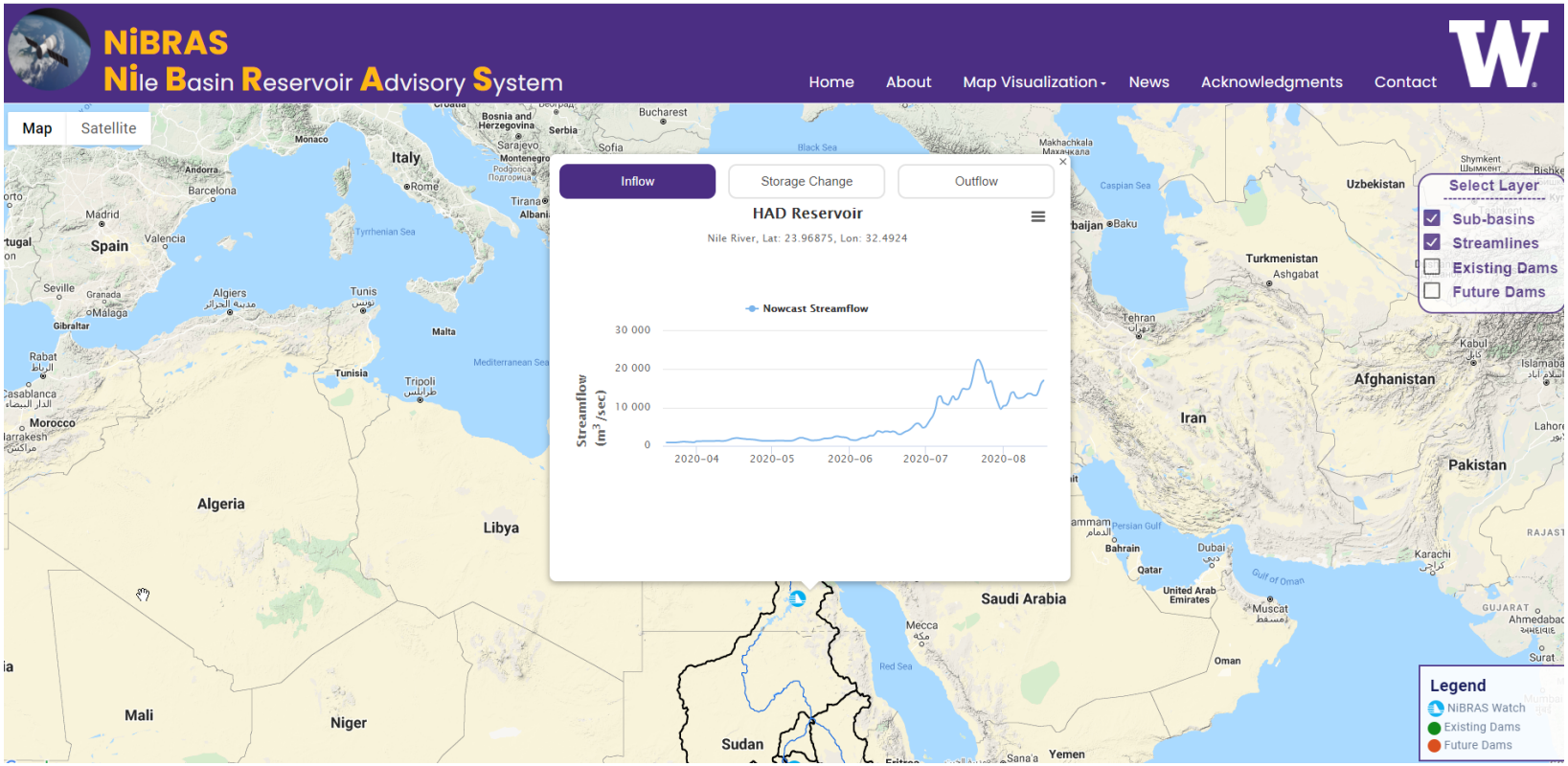
- Real-time monitoring.
- Scenario Assessment Tool (SAT) [In Progress]
- Forecast-based Adaptive Reservoir Operation (FARO) [In Progress]
- Monitoring Reservoir Initial Impoundment (MRI2) [In Progress]



NiBRAS Front-end

Tools

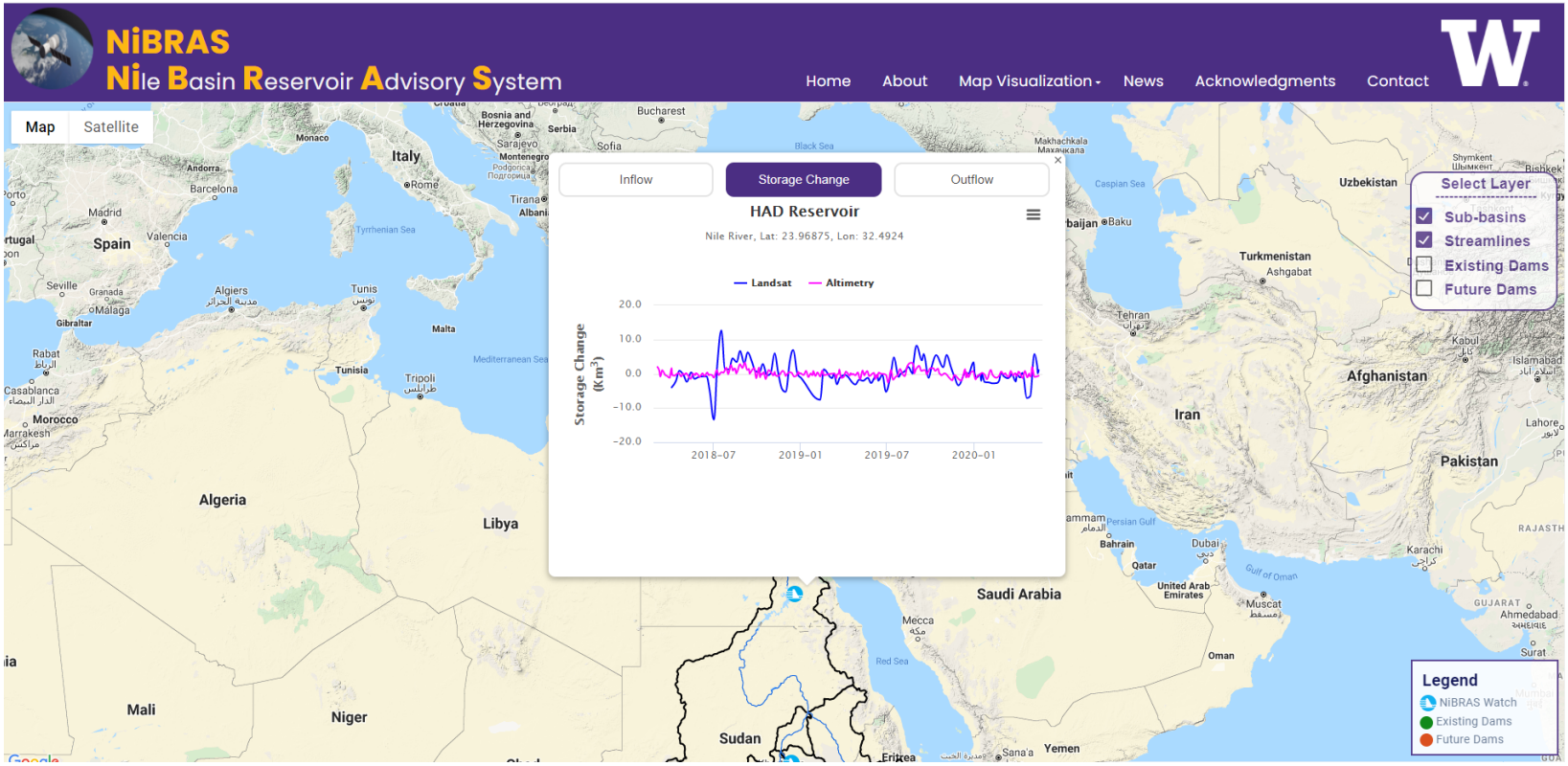
- Real-time monitoring for HAD Operation (Inflow)



NiBRAS Front-end

Tools

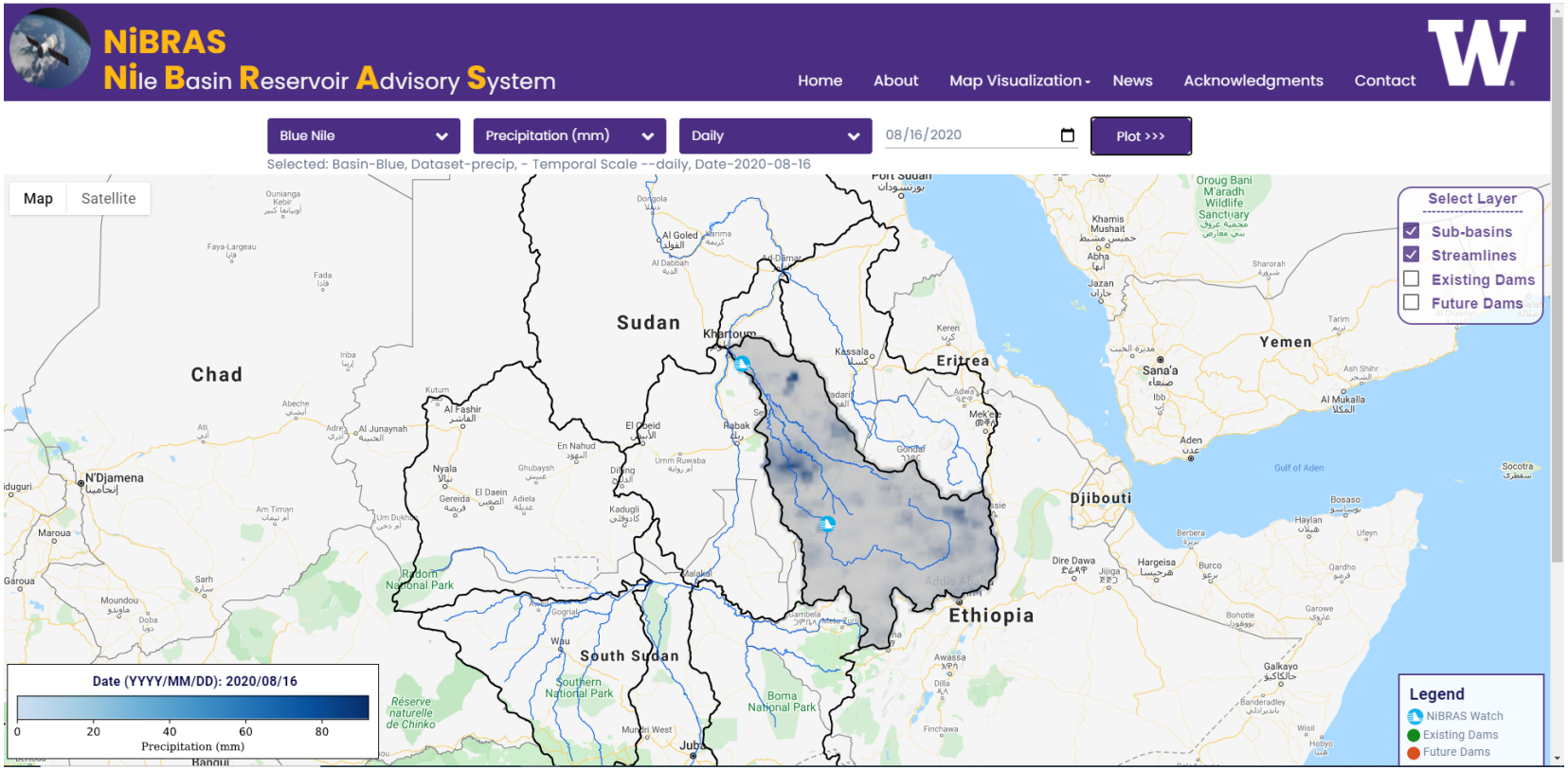
- Real-time monitoring for HAD Operation (Storage Change)



NiBRAS Front-end

Tools

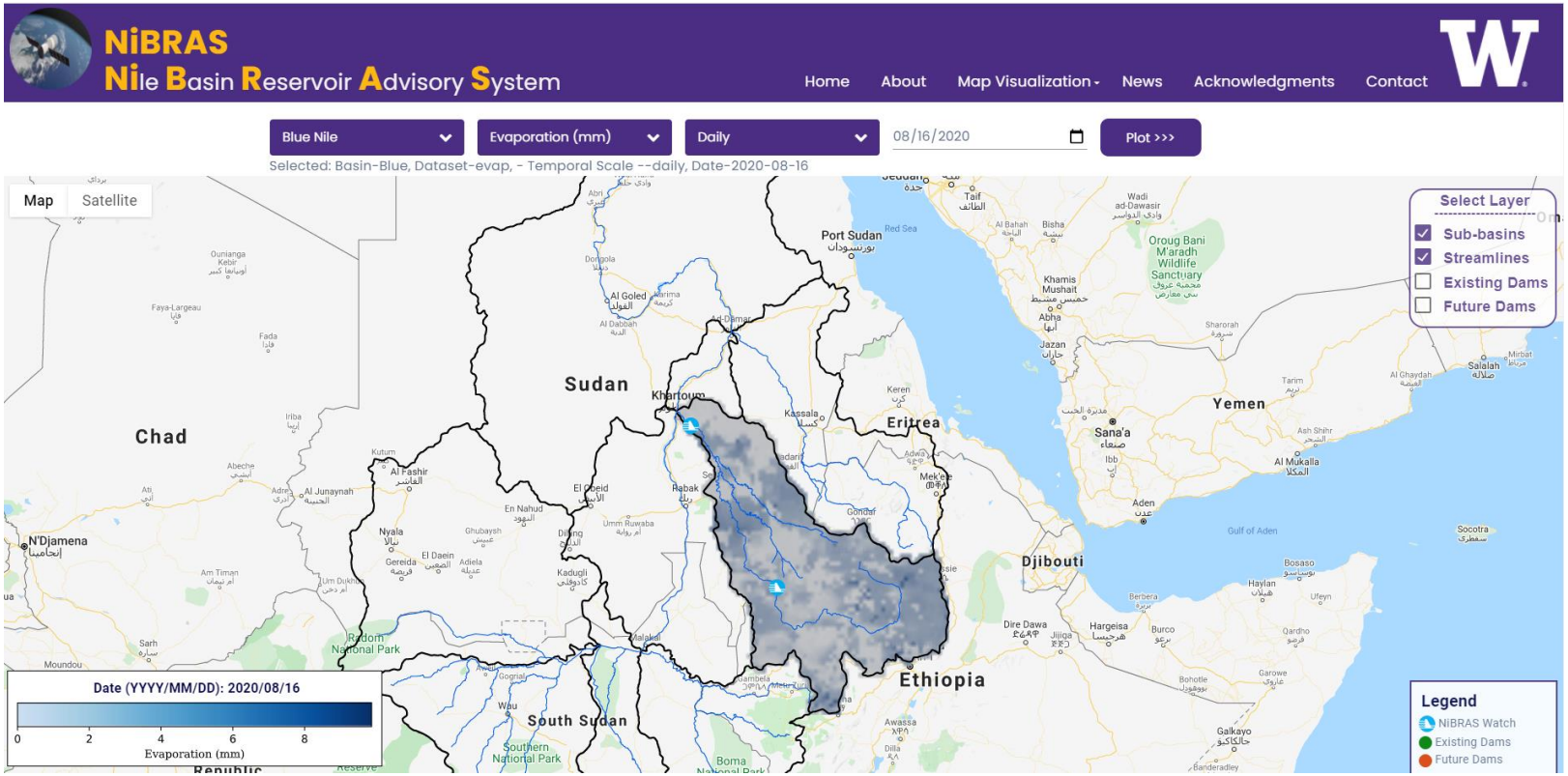
- Hydrology of Blue Nile Basin (Precipitation)



NiBRAS Front-end

Tools

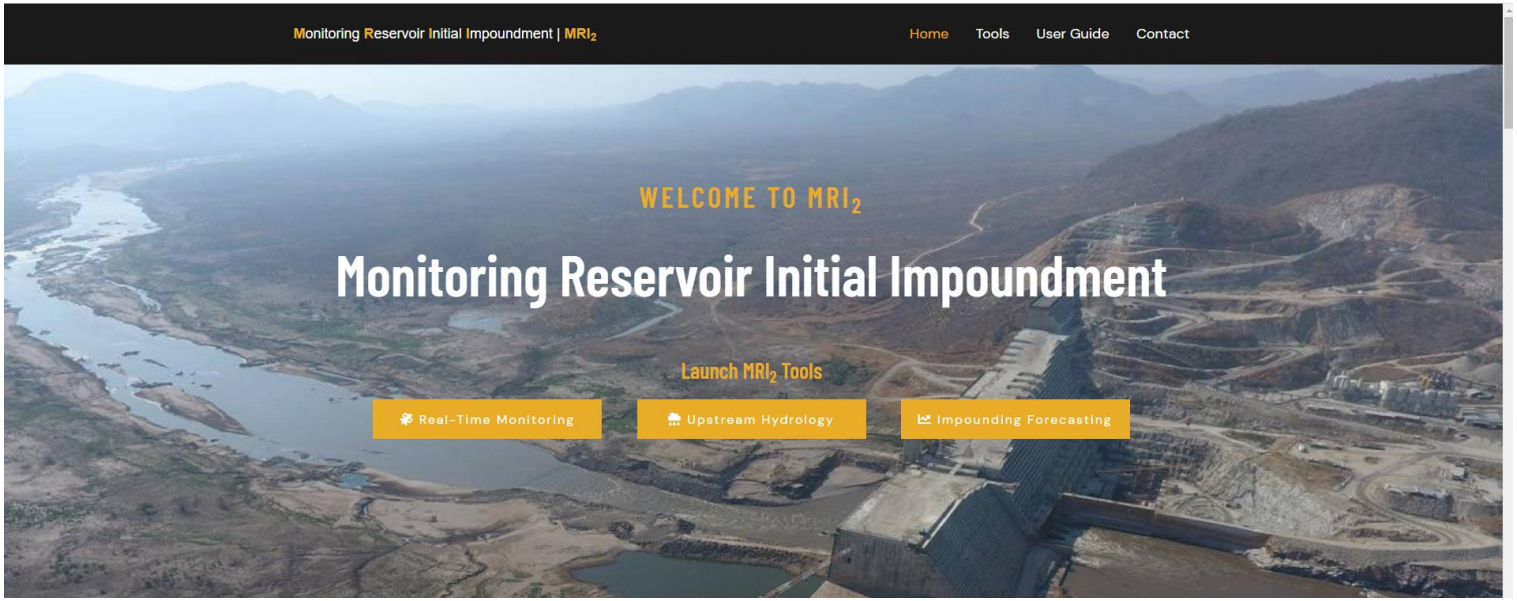
- Hydrology of Blue Nile Basin (Evaporation)



NiBRAS Front-end

Tools (In Progress)

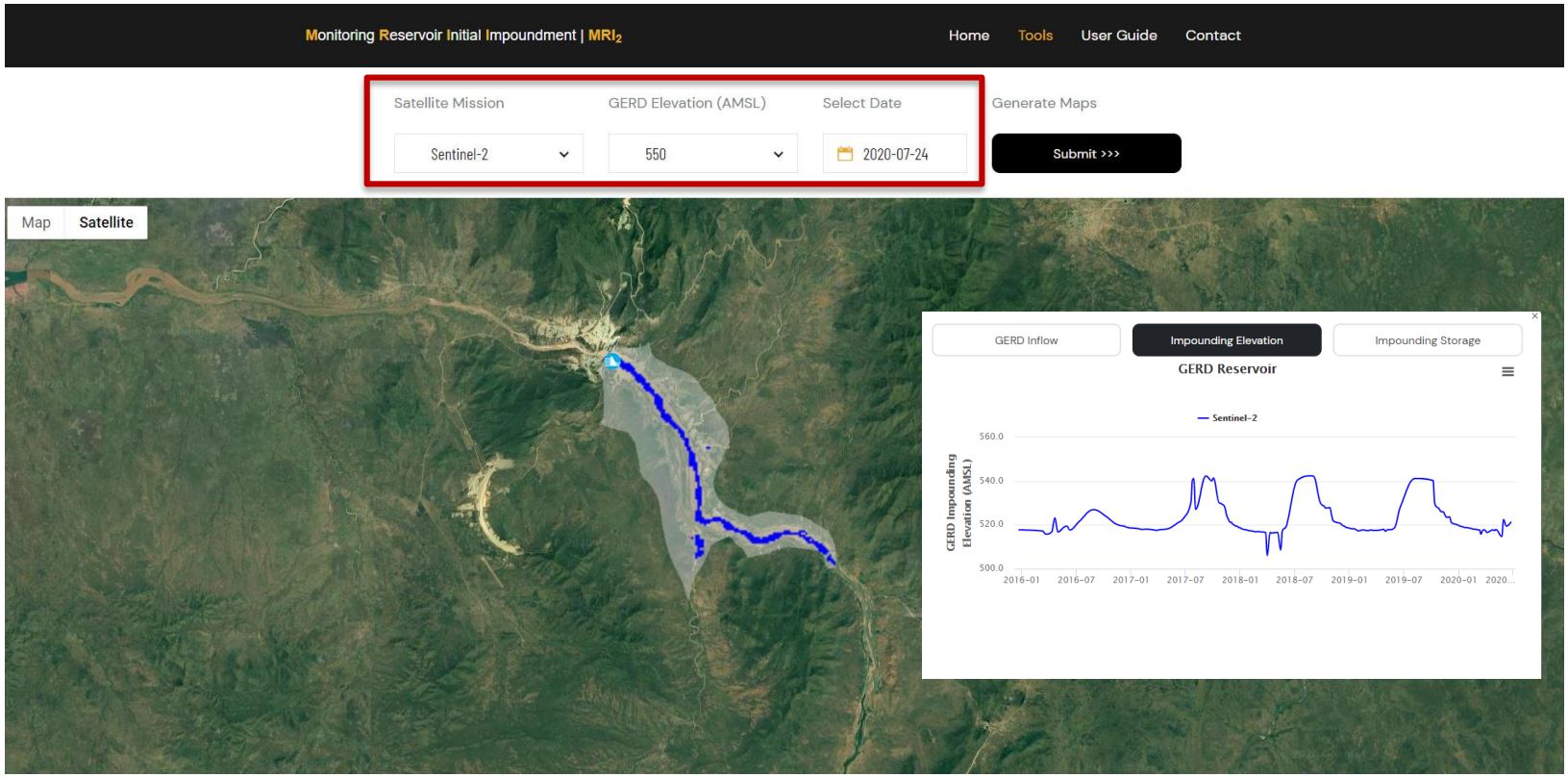
- Monitoring Reservoir Initial Impoundment (MRI_2)



NiBRAS Front-end

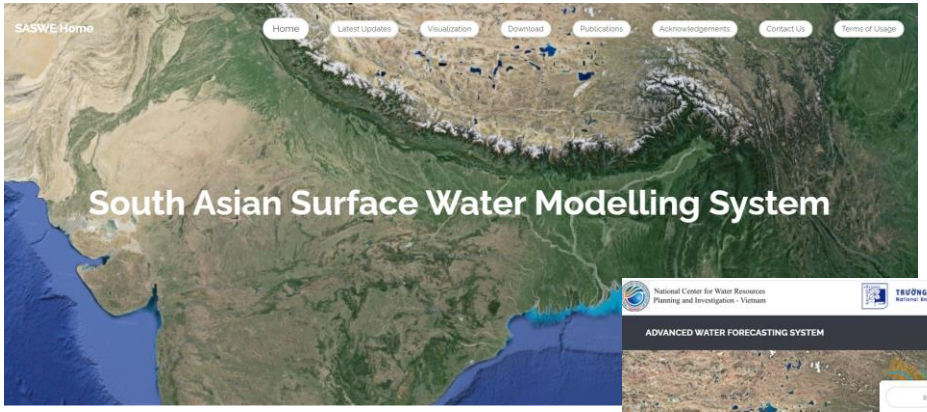
Tools (In Progress)

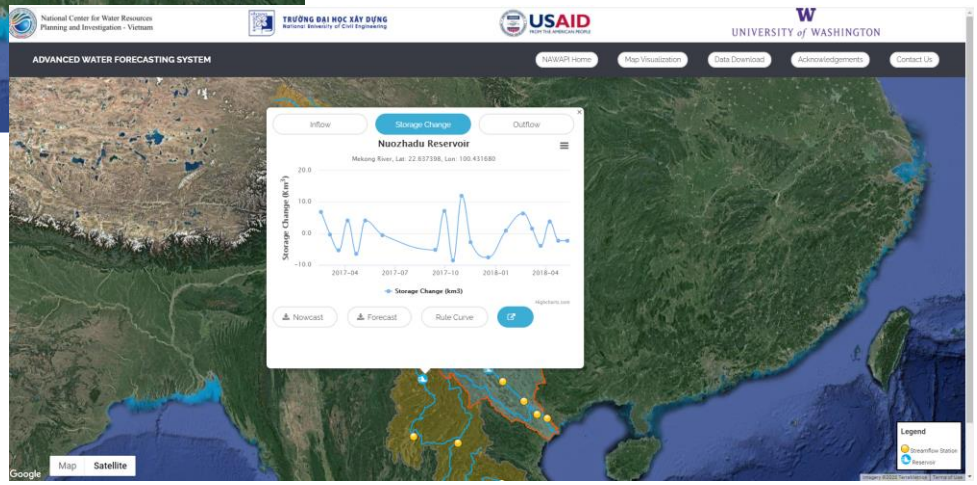
- Monitoring Reservoir Initial Impoundment (MRI_2)



Scaling Up to Global Applications

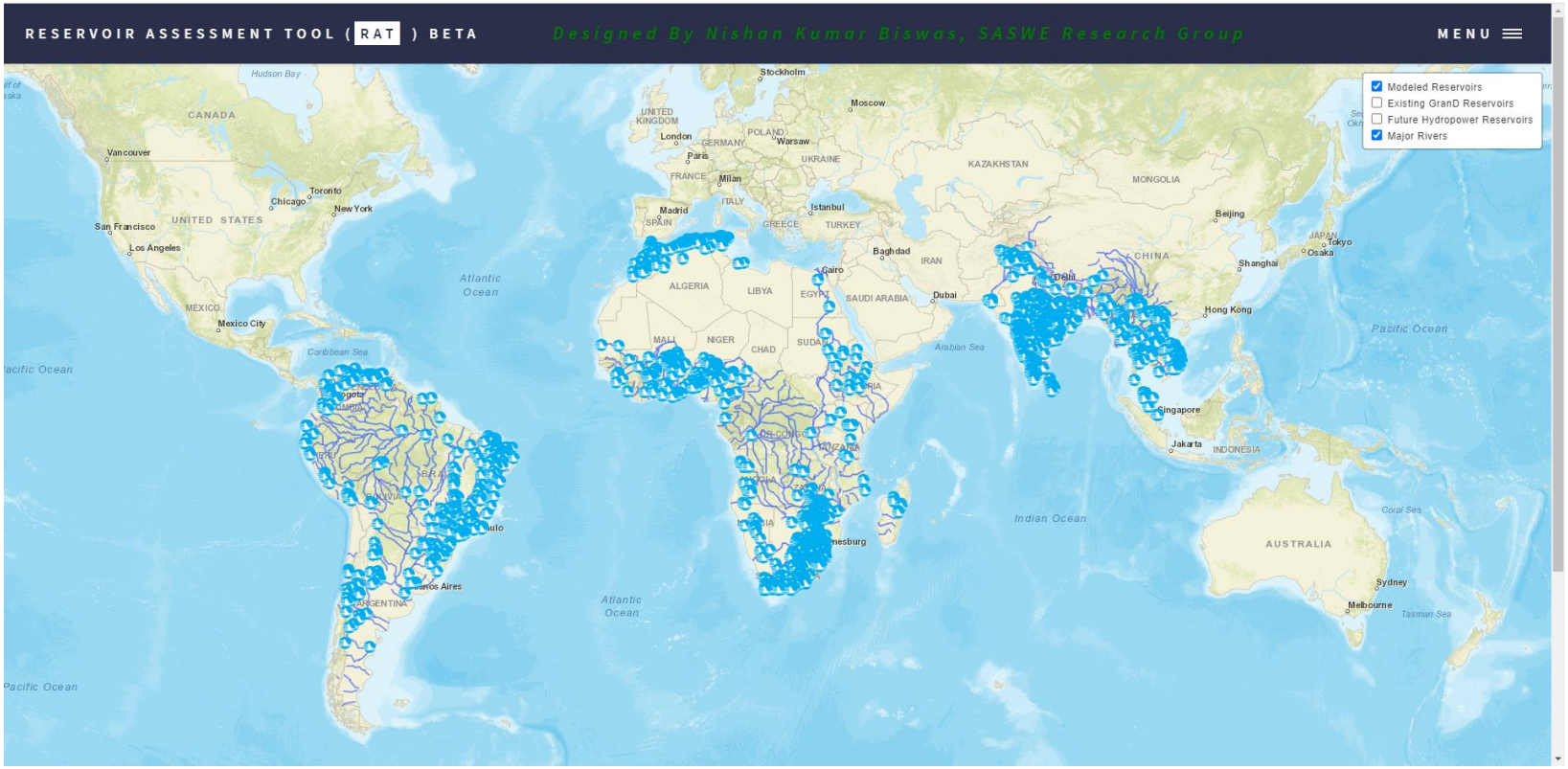
- South Asian Operational Systems
- Learn more about SASWE Research group operational systems (http://depts.washington.edu/saswe/)





Scaling Up to Global Applications

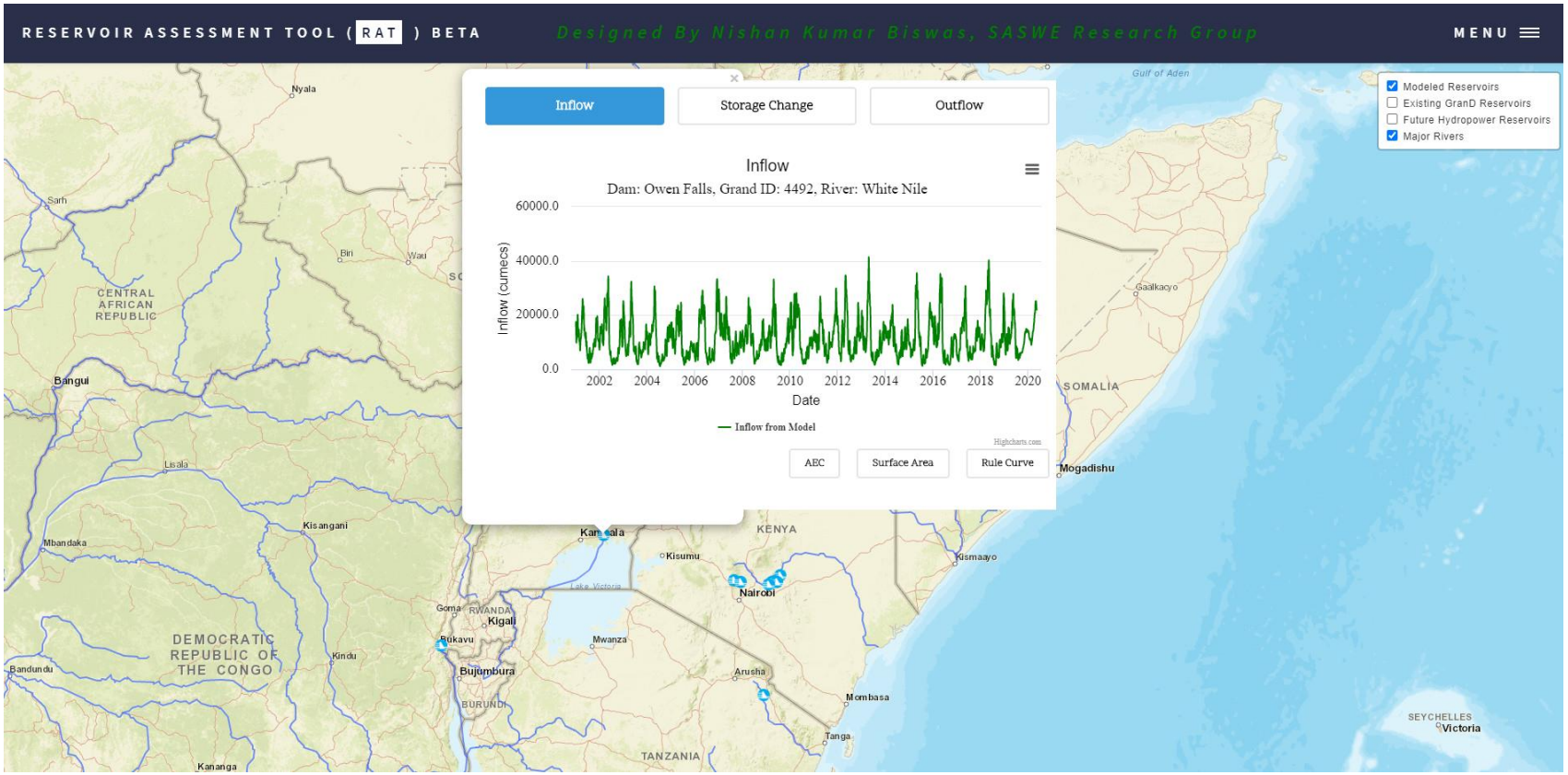
- Reservoir Assessment Tool (RAT)
- Africa, South East Asia, and South America



Source: Biswas, N., F. Hossain, M. Bonnema, H. Lee, F. Chishtie (2020). A Global Reservoir Assessment Tool for Predicting Hydrologic Impact and Operating Pattern of Existing and Planned Reservoirs, Environmental Modeling and Software

Scaling Up to Global Applications

- Owen Falls (Lake Victoria)



Thank You!

If interested

3-day workshop on using satellite remote sensing in the Nile River Basin