Evaluating the Benefits Provided by SWOT Data Towards Estimating Reservoir Residence Time in the Mekong River Basin

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Abstract
The Mekong river basin is undergoing rapid hydropower development. Sixteen dams are planned on the main stem of the Mekong river and many more on the east tributaries. Understanding the effects current and future dams have on the river impacts is reservoir residence time, the amount of time water spends stored in a reservoir. The forthcoming Surface Water and Ocean Topography (SWOT) mission is poised to provide unprecedented amount of surface water observations, which when augmented by currently flying satellite missions, can provide the necessary information to estimate the residence time of water across the entire basin in a more comprehensive way than ever before. In this study, we combine observations from current satellite missions (Landsat spectral data, altimetry, spectral imaging, precipitation) to estimate the residence time of all reservoirs. We then use this information to project how much future reservoirs will increase the residence time of the river system. Next, we explore how SWOT observations can be used to improve residence time estimation by examining the accuracy of reservoir surface area and elevation observations as well as accuracy of river discharge observations. The temporal frequency of SWOT observations are also considered in the investigation of reservoir residence time estimation.

1. The Mekong River Basin
- World’s 12th largest river, draining area from 6 South East Asian nations
- Current, basin streamflow is relatively unregulated by dams
- Primarily hydropower development
- 18 main stem dams planned or under construction, only 5 currently built
- It is critical for the millions of people living in the basin to better understand the effects reservoirs have on: Fish migration, nutrient and sediment transport, streamflow timing, and magnitude
- Important metric: Reservoir Residence Time
- Ground-based measurements of streamflow, reservoir storage non-existent or difficult to obtain
- Satellite remote sensing is essential to understand reservoir behavior

Goals:
1. Utilize current array of satellite observations to estimate residence time of 20 existing reservoirs in the Mekong Basin
2. Develop method for incorporating observations from the forthcoming Surface Water and Ocean Topography (SWOT) mission into residence time estimation and evaluation performance

2. Reservoir Residence Time
Definition: Length of time a parcel of water remains in reservoir (8)
- Traditionally calculated from average streamflow and reservoir storage assuming steady state and inflow = outflow:
  \[ \theta = \frac{\Delta S}{\bar{Q}} \]
- However, reservoir storage, inflow, and outflow are variable 
  Need to understand a reservoir’s dynamics to estimate it’s residence time

Plug Flow: Water parcels do not mix with each other
- Water parcels exit reservoir in same order they entered
- Residence time of each parcel calculated individually as the time it takes for parcel to exit reservoir

3. Mass Balance
\[ O = I - \Delta S \]

4. Storage Change from Satellite Data

5. Residence Time Estimates
- Residence time ranged from 0.09 to 4.04 years
- Reservoirs only increased basin residence time by only 3 weeks
- When considering only regulated flow (17% of total flow), these reservoirs increased residence time by 4 months
- If the two largest and lowest residence time reservoirs are excluded, the residence time of the remaining 3.5% of total basin flow is increased by 1.3 years
- Overall, residence time decreased with stream order
- Mekong reservoirs fell below global average residence time
- When compared to the traditional residence time V/O approach (labeled as Degree of Regulation from Lehner et al. 2011), the residence time of many reservoirs was similar, but others deviated significantly

6. Temporal Patterns of Residence Time
- Average annual residence time across all reservoirs appears to vary inversely with basin precipitation
- This trend is less prevalent in reservoirs with lower residence time
- Monthly residence time follows a clear trend, decreasing through the dry season and early wet season, and increasing through the later half of the wet season
- This trend is predominant in reservoirs with lower residence time

7. Incorporation of SWOT Observations
Research Questions:
1. How accurately can reservoir height and surface area be estimated from SWOT observations?
2. How does this accuracy compare to existing methods?
3. How often will SWOT observe reservoirs?
4. How does the observational frequency fit with other missions that will be available when SWOT launches?

With the combination of accuracy and observational frequency, how much more information about reservoirs will we have and how best to use it along side information from other missions?

References

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Appendix A: Residence Time Data for 20 Mekong basin reservoirs (in progress)

Appendix B: Monthly residence time for 20 Mekong basin reservoirs (in progress)