SUSTAINABLE SURFACE WATER STORAGE DEVELOPMENT SCENARIOS FOR RIVER BASINS WITH EXAMPLES FROM SRI LANKA

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Abstract

A key question in sustainable development is how much alteration in natural systems, such as river basins, is acceptable? One of the ways by which humans alter a river basin is by building water storage infrastructure. While storage reservoirs deliver numerous benefits, they can also induce social and environmental costs by displacing people, fragmenting river networks and altering downstream flow regimes. In such a context, merely capping total water withdrawal from rivers for human consumption is not sufficient. River basin plans should also identify optimal (acceptable) limits to surface storage capacities, and optimal numbers, degrees of distribution and locations of storage infrastructure. It remains largely unclear, however, whether it is possible to define a hydrologically, ecologically, and socially justified 'surface water storage boundary' for a river basin, or what would be the 'best arrangement' of this bounding storage capacity in the basin's river network to maximize storage benefits and minimize environmental and social costs. The main objective of this research is to develop a suite of tools that may help to answer the above questions of a 'surface water storage boundary' and its 'optimum arrangement' for a river basin. In this context, the research introduces two novel concepts: the 'storage scale' and the 'sustainable storage development framework.' The 'storage scale' has four elements – capacity, number, distribution, and location – individual scales that help visualize a 'surface water storage boundary' and its 'optimum arrangement' for a typical river basin. The 'sustainable storage development framework' consists of three dimensions – economic benefits, ecosystems, and society – and a set of indicators quantifying each dimension.

This research demonstrates the use of the concepts 'storage scale' and 'sustainable storage development framework' in investigating a 'surface water storage boundary' and its 'optimum arrangement' by taking as examples two contrasting river basins in Sri Lanka - Malwatu Oya in the Dry Zone and Kalu Ganga in the Wet Zone, assuming storage is developed for multi-purpose water supply. The research first characterizes water scarcity issues in Malwatu Oya and water surplus (flooding) issues in Kalu Ganga. Next, the research illustrates a generic methodology in which storage-yield curves are used to design "sustainable surface water storage development pathways" and "acceptable limits" to storage development and water withdrawals for entire river basins, under a range of environmental flow (EF) release scenarios. The methodology allows the estimation of corresponding storage capacity distribution and withdrawal thresholds at sub basin level. This ensures that the river continues to stay on an identified overarching sustainable storage development pathway, even when the configuration of a reservoir system changes. The research introduces the indices "Water Supply Sustainability" and "Environmental Flow Sustainability" which facilitate the decision on which pathway and management strategy would be most appropriate for a particular river. The study illustrates "average" pathways, and "conservative" and "maximum" limits to storage development and water withdrawals by taking the two study basins as examples. Results of the research may be used to identify how the current level of storage development in a river basin compares with an identified sustainable storage development pathway, and which parts of a river basin are currently over-exploited or under-exploited, thereby enabling better planning for the future.

The results also indicate that four of the 15 major sub basins of Malwatu Oya are over exploited while five others are under exploited when compared with an average storage development pathway in which water supply and environmental flow needs are afforded equal priority. The current cumulative storage capacity of the entire

Malwatu Oya basin is about 43% of the Mean Annual Runoff (MAR), but its gross annual withdrawals (including losses) are about 55% of the MAR – an 'unsustainable' yield at this storage capacity. Consequently, current water supply (irrigation) and EF demands of the basin can only be satisfied about 75-80% of the time. The research highlights that potential yield gains from storage in water surplus Kalu Ganga are approximately ten times those of Malwatu Oya. Individual sub basins of Kalu Ganga, which show the highest potential gains from storage, are also identified.

The research also presents novel methods that measure flow regulation, river connectivity and social equity implications of surface storage development and illustrates their use in assessing different reservoir system configurations (different storage capacities, numbers, and modes of siting / spatial distribution of reservoirs) in the study basins. The Modified River Regulation Index (MRRI) measures the overall degree of regulation of a river by reservoirs, taking into account not only the volume of flow that is captured by them, but also their placement and type (centralized large or distributed small) – two aspects that are not considered in previous indices. River connectivity indices formulated in the research illustrate that the lowest connectivity in a river basin results from a single new reservoir placed on a main stem of a previously unregulated river, between the two locations that command 50% and 75% of the basin area, respectively. The indices illustrate that the current level of connectivity of Malwatu Oya is extremely low due to the presence of a large number of reservoirs in the river network. Approximations to estimate Normalized Externality (NE), a measure of how equitable a storage project is, show that the ratio of the total affected population to the total number of beneficiaries of a storage project increases as reservoir sizes increase.

This research also demonstrates an integrated index, which combines indicators on economic benefits, ecosystems, and society to identify "best performing" reservoir

system configurations for each river. The results show that while lower cumulative storage capacities score higher on the integrated index than higher cumulative storage capacities irrespective of the reservoir arrangement, the "optimum arrangement" is unique to each river. Other research outputs include (i) Regional storage – yield curves for Malwatu Oya and Kalu Ganga basins; (ii) Linear area-discharge relationships for the Malwatu Oya and Kalu Ganga basins, and (iii) Indices based on storage-yield curves, supporting the identification of dry zone tank cascades with higher potential returns for investment (higher gains in yield) in restoration efforts.

Keywords: surface water storage; sustainable development; reservoirs; dams; storage benefits; ecological integrity; ecological impacts; social impacts; sustainability; environmental flows; acceptable limits; pathways; flow regulation; river connectivity; equity.