Effects of reservoir storage on streamflow in Western Cape, South Africa

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Introduction

Cape Town, in the Western Cape Province, South Africa relies heavily on reservoirs for water supply. Reservoirs are on relatively small rivers due to topographic controls on drainage basin size. Precipitation is seasonal, which makes reservoirs essential for water supply; water from rainy seasons is stored for water use during dry months. A severe drought (2015-2018) caused serious depletions in the water supply, leading to a crisis in 2018. As urban populations continue to grow, the demand for water will also grow. Water supply is stressed by climate variability, climate change and population growth. Therefore, there is a need to both evaluate water supply and the consequences of water retention on streamflow and river habitats. This research seeks to evaluate these issues by comparing streamflow in undammed and dammed rivers in the Western Cape Province.

Western Cape Precipitation Regime

- Rainfall is seasonal, with most of the rain falling in the S. Hemisphere winter months (May-August).
- Precipitation is spatially heterogeneous, with the highest rainfall occurring along the east coast.

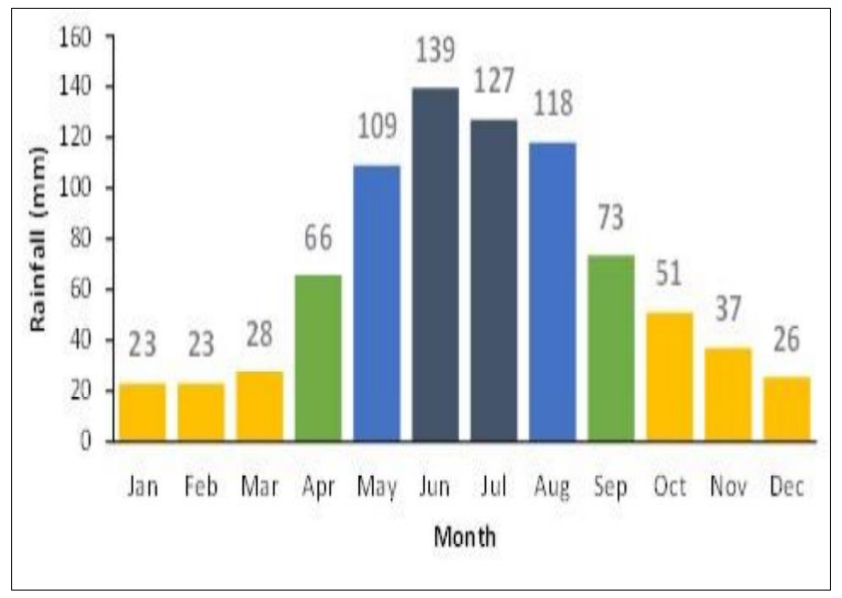

Fig. 1: Mean monthly rainfall in Cape Town, South Africa (South African Weather Service, 2018).

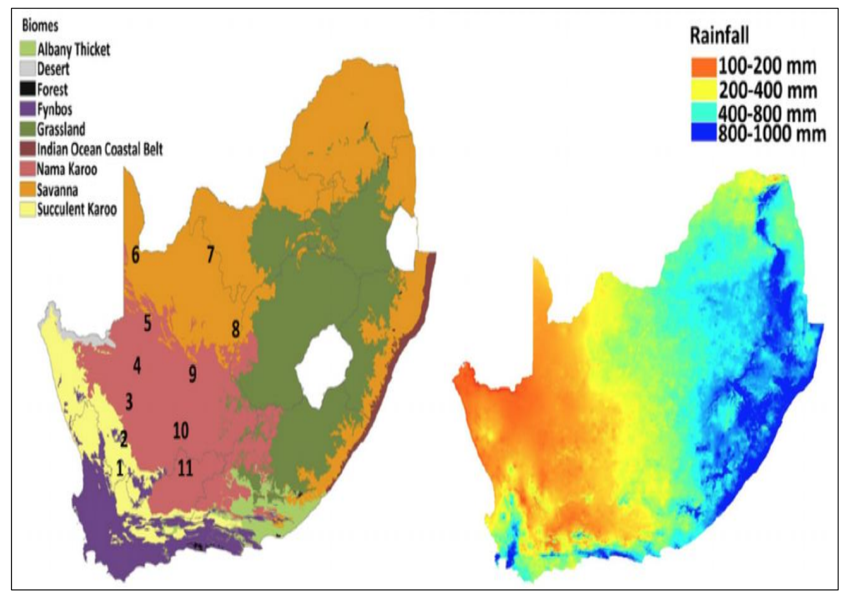

Fig. 2: Spatial heterogeneity in South African precipitation (Shackelton et al., 2015).

Hypothesis

H_1: Reservoir storage significantly reduces river discharge (*Q*) and annual runoff compared to similar undammed rivers

H_2: Reservoir storage shifts the probability distribution of wetted widths towards smaller widths and causes greater inter-annual variability in riparian water supply.

H_3: Annual precipitation has significantly changed in the past 40 years, reflecting climate change.

Paired Watershed Approach

- Selected 2 unregulated/3 regulated rivers based on longest recorded periods of data and similar gauged catchment areas (fig. 3).

Experimental Design

Study Site & Data Acquisition

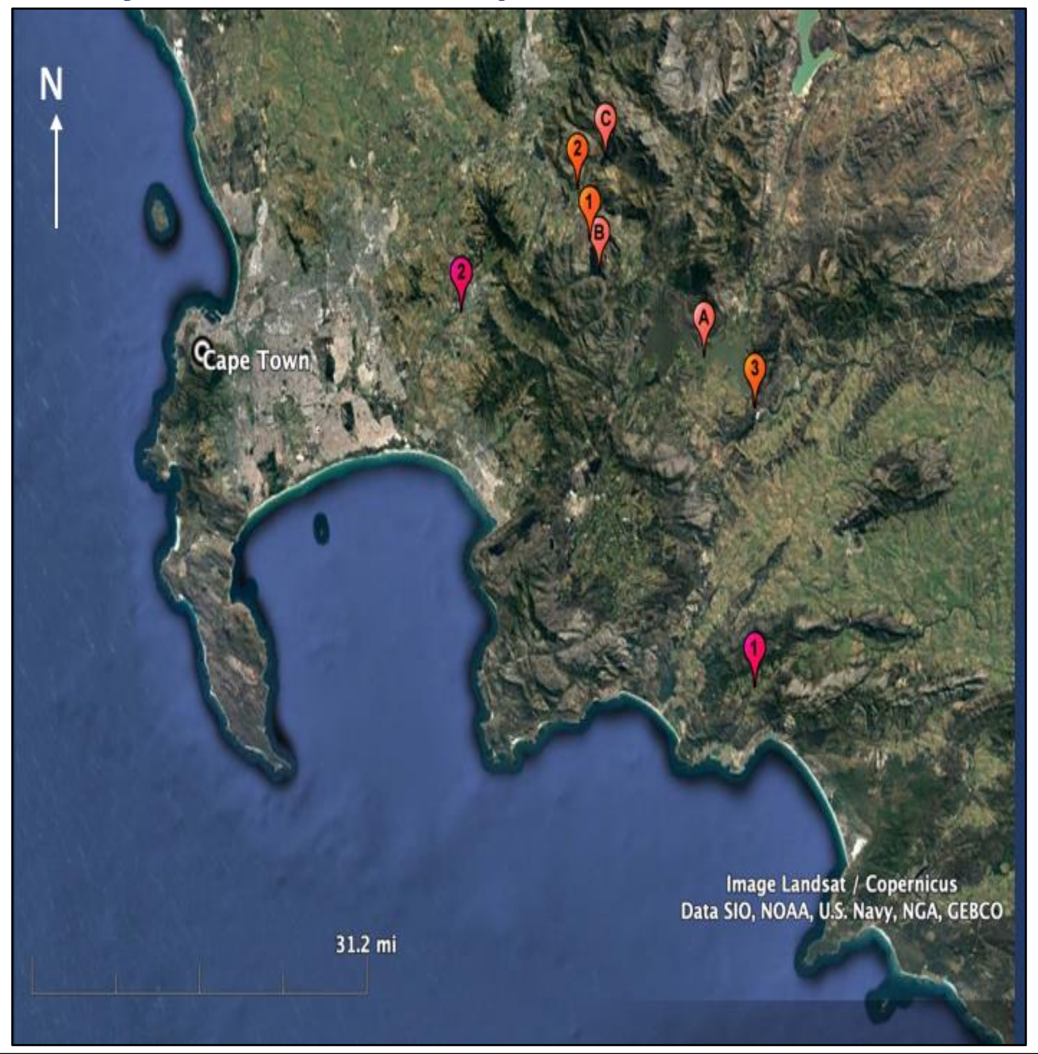

Fig. 3: Study site locations. Red markers represent sites of dammed rivers: (A) The Waterskloof Dam, (B) Berg River Dam, (C) Wemmershoek Dam. The markers are placed at the site of gauges, located at dam outlets. Orange markers represent sites of dammed rivers directly downstream of a dam where gauged data was obtained: (1) Berg River, (2) Wemmershoek River, (3) Sonderend River. Pink markers represent sites of undammed rivers where gauged data was obtained: (1) Onrus River, (2) Eerst River.

River name	Onrus	Berg	Wemmershoek	Eerst	*Sonderend
Dam name		Berg	Wemmershoek		Waterskloof
Catchment Area (km^2)	23	83	118	183	516
Available data period	1996-2018	2008-2018	2009-2018; 2014 absent	1980-2018	1974-2018

Results

Precipitation time series

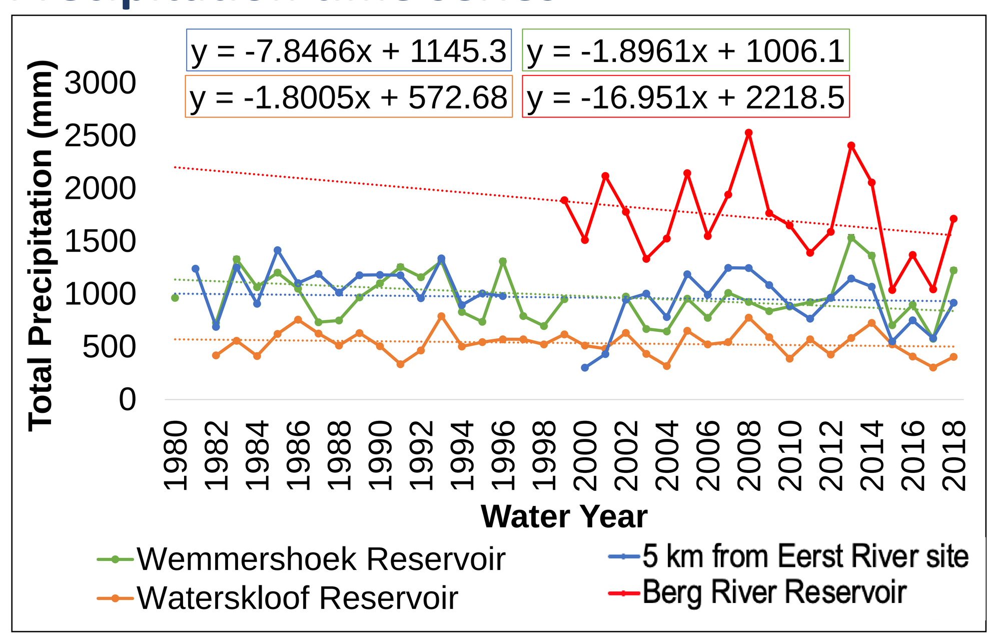

Fig. 4: Annual precipitation from gauge data located at or near stream sites. Note: large inter-annual variation, no significant long-term trend, and low annual precipitation during the recent drought (2015-early 2018).

Mean Annual Runoff (MAR) Comparisons

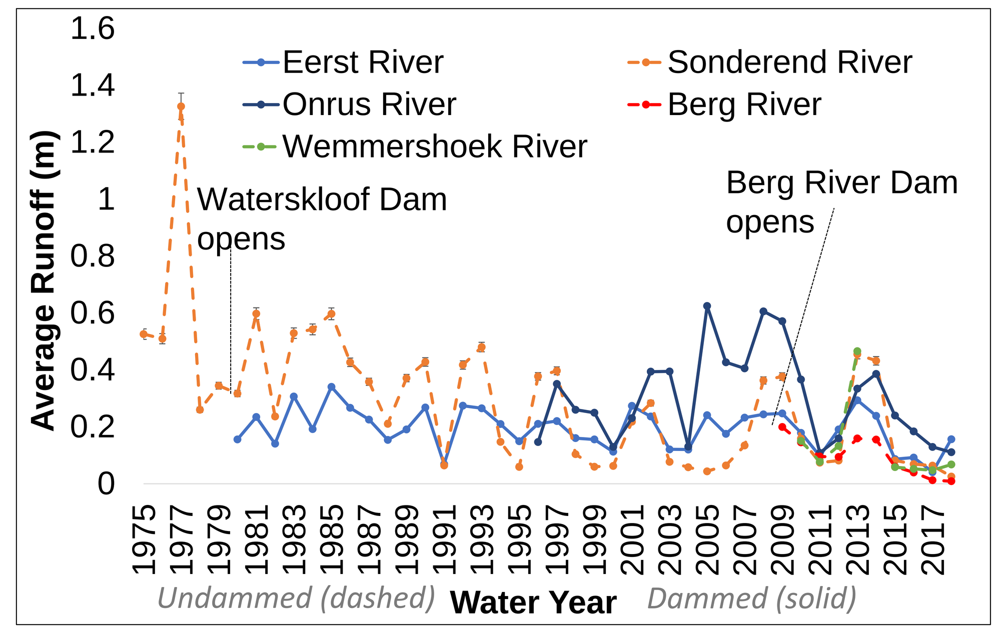

Fig. 5: Annual runoff from gauge data at stream sites. Runoff downstream likely reflects water storage, export, use, and increased evapotranspiration (due to evaporation from impounded water).

Flow Duration Analysis (probability analysis of daily runoff)

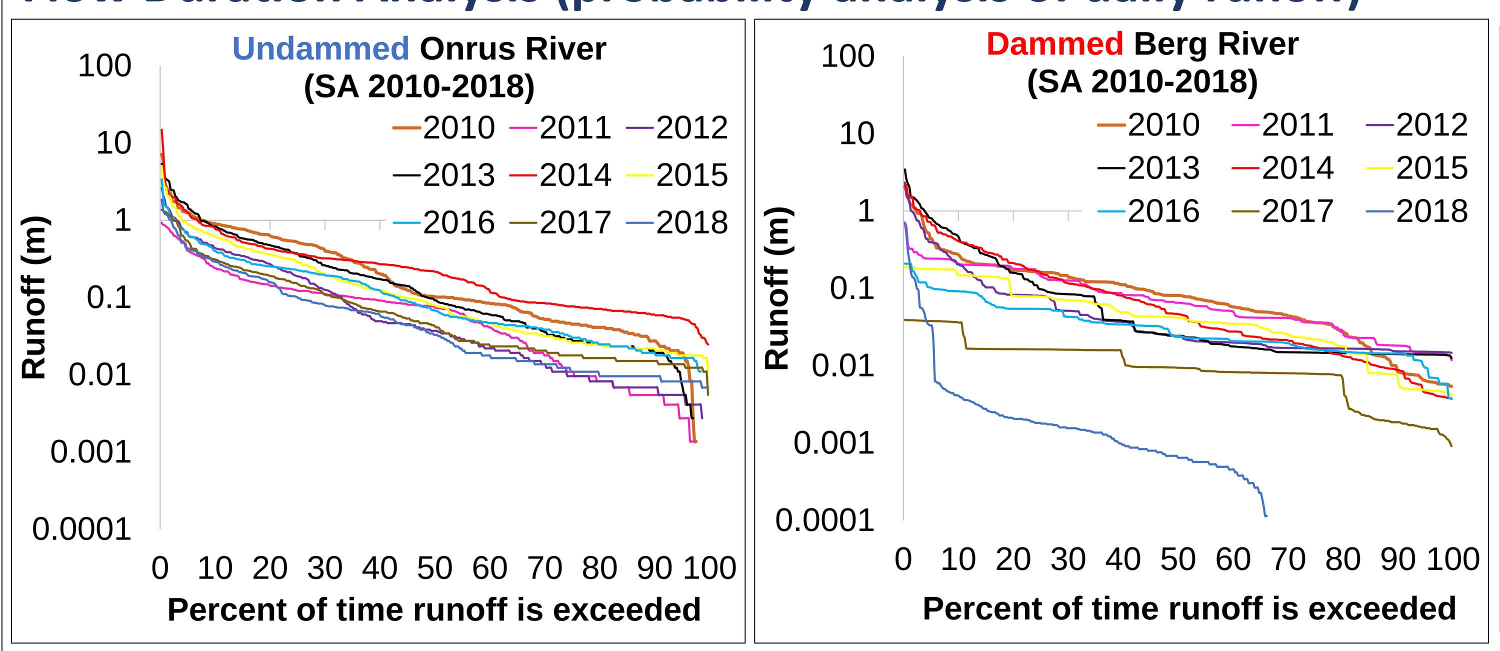

Fig. 6: Comparison of daily runoff for 2 of the paired watersheds. The dammed river has similar runoff distribution during wet years, but significantly reduced runoff during dry years (lowest is 2018 for both).

Results: Riparian Zone Recharge

Width-discharge relationships and width probability distribution relationships: wetted width

Fig. 7: River width was measured near the gauge on air photos. Gauge data from the same dates were used to develop discharge-width relationships.

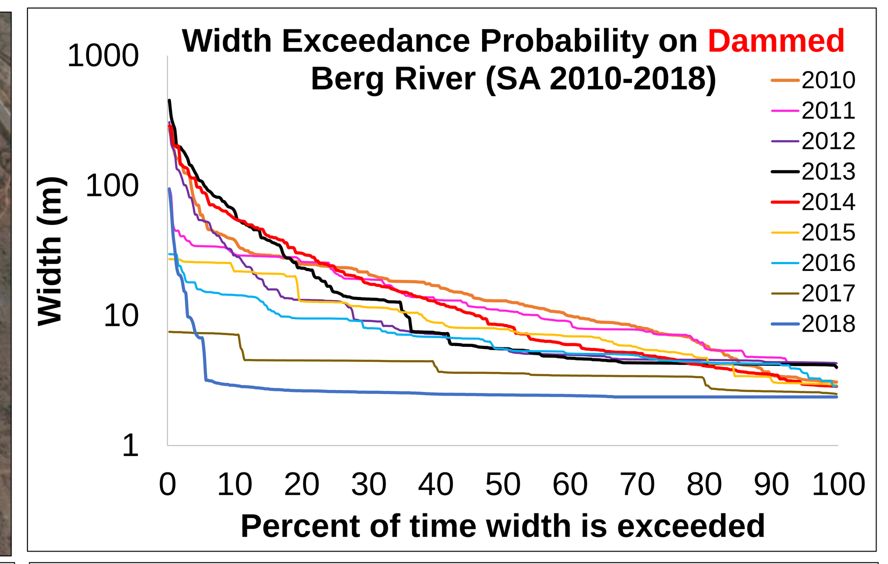

Fig. 8: Similar to daily runoff, wetted width exhibits significant inter-annual and within year variability, with reduced width during dry years & seasons.

Discussion

Mean Annual Runoff and daily runoff (H_1)

Streams with reservoir storage exhibited reduced annual and daily runoff compared to similar undammed rivers supporting the hypothesis. This reduction is most evident in dry years, generating large inter-annual variations in runoff. Flow duration analysis indicate that reservoirs decrease daily runoff significantly during both dry seasons and dry years compared to similar rivers without reservoirs. Some dammed rivers had significant periods of no or very low flow during dry years. Although undammed rivers have very low flow during drought periods, these small amounts of flow might be sufficient enough to allow aquatic life to survive during dry periods.

Width (H_2)

The dammed Berg River exhibited a simple relationship between wetted width and discharge. This relationship was used to estimate the probability distribution of daily wetted width using the flow duration analysis for the discharge probability distribution. These data indicate significant reduction in river or floodplain width during dry years and dry season, as predicted by the flow duration analysis and supporting the hypothesis.

Precipitation (H_3)

Statistical tests indicate that annual precipitation exhibits inter-annual variability, but mean precipitation has not changed significantly over the past 40 years, except for the recent decade with a prolonged drought (2010-2018). A stationarity test (Sun et al., 2018), indicates this stationary behavior. These data do not support the hypothesis of climate change in this region.

References and Acknowledgments

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