Developing Flow Policies to balance the Water Needs of Humans and Wetlands Requires a Landscape Scale Approach In Future Scenarios and Multiple Timescales

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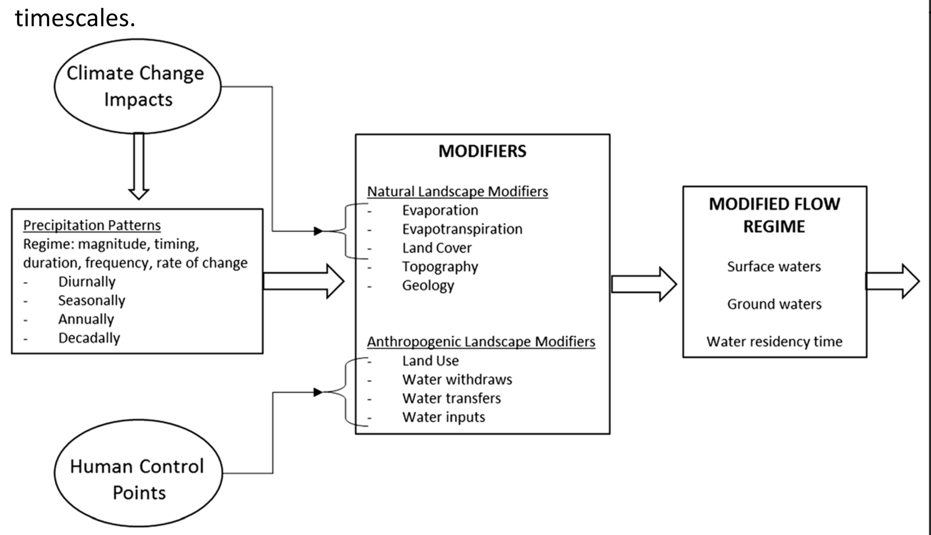
Introduction

Maintenance of the natural flow regime is essential for continued wetland integrity; however, the flow regime is greatly influenced by both natural and anthropogenic forces (Fig. 1). Wetlands may be particularly susceptible to altered flow regimes as they are directly impacted by terrestrial freshwater flows and marine sea level rise at a variety of time scales.

Figure 1. Climate change and anthropogenic forces modify the natural flow regime of water across the landscape impacting wetland ecosystems at a variety of timescales.



ECOLOGICAL IMPACTS TO WETLAND ECOSYSTEMS

Ecological Attribute	Diurnal	Seasonal	Annual	Decadal
Organism survival	X			
Organism reproduction	X	X	X	
Organism migration	X	X		
Plant seed dispersal	X	X		
Plant establishment	X	X	X	
Longitudinal and lateral connectivity and nutrient cycling	X	X	X	X
Invasive species establishment	X	X	X	X
Habitat structure	X	X	X	X
Biodiversity maintenance			X	X
Habitat succession			X	X
Habitat migration			X	X
Extinction and speciation				X

The type and distribution of wetlands across the landscape are largely determined by the seasonality, magnitude, and duration of both ground and surface water availability (Fig. 1). Similarly, the biodiversity of wetlands depends on predictable seasonal flooding periods and rates of water level change to assure the completion of life cycles and the maintenance of natural processes. Collectively the system should maintain resilience so long as components of the natural flow regime maintain regular variation within historic bounds. The obvious problem is that human land and water use alters the natural flow regime. Water withdrawals and inter-basin water transfers (IBWT) are seen as a threat to natural flow regimes and local environmental integrity and impact wetlands across many time scales (Fig. 1). IBWTs are infrastructure systems that move water from water-abundant to water-deficient areas to support urban and agricultural development (Fig. 2). IBWTs impact hydrological, physical, chemical, and biological characteristics of surface water, linked riparian wetlands, ground-water systems, and socio-economic conditions at source and receiving areas.

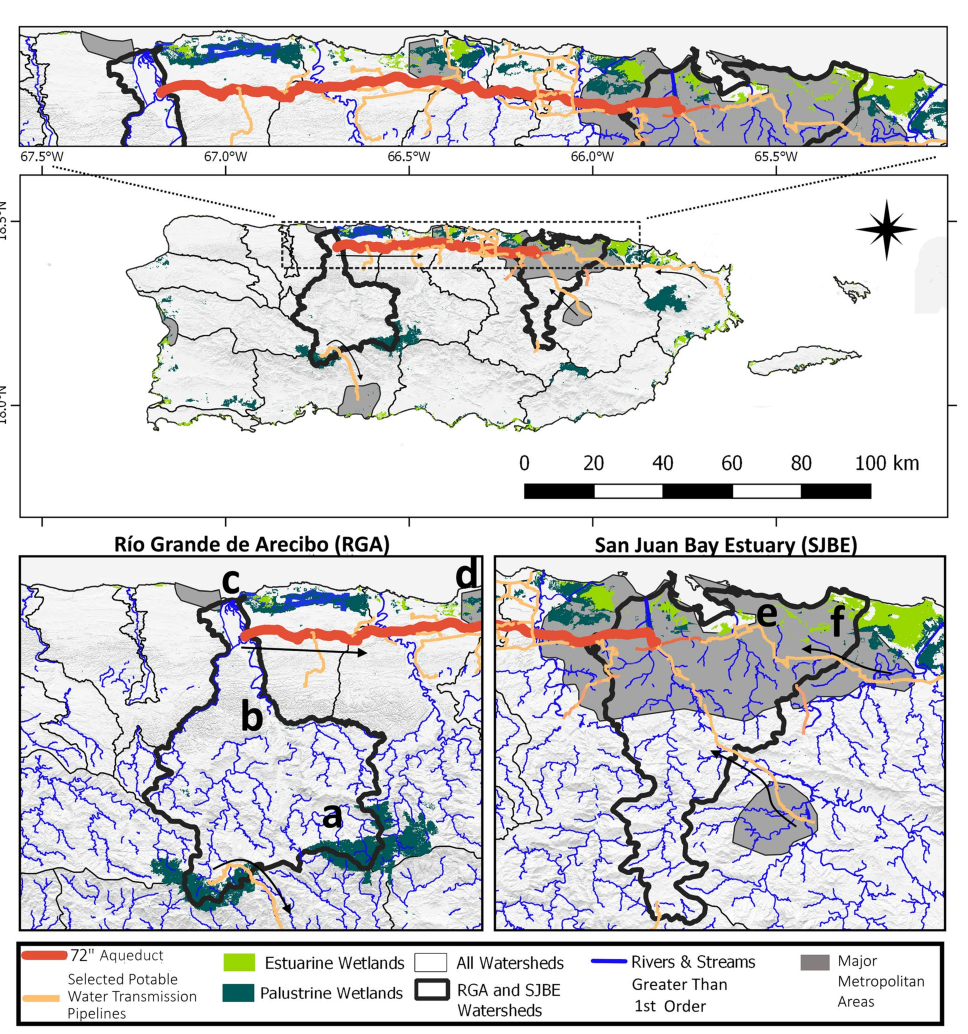


Figure 2. Wetland types and distributions in Puerto Rico including a major inter-basin water transfer tube (red line) and other key water infrastructure

In addition to water management, climate change is expected to magnify droughts which are likely to deepen and broaden the suite of subsequent impacts to water supplies and natural systems. Finally, sea level rise will increase the risk of salinization of coastal wetlands and endanger freshwater resources for human and ecological use.

Because of the scale of these stressors, we argue that ensuring the continued long-term provision of water and wetland derived services will require consideration of broader spatial and temporal scales in water resource planning. More effective management can happen with attention to in the larger spatial context including watershed scale to larger, multi-watershed and multi-jurisdictional geographic regions. In the temporal context, water use and allocation policies need to take into account the full spectrum of time scales of ecological processes (e.g. fish days to months and habitat migration years to decades). Finally, we stress the importance of utilizing future modeled climate projections to consider the future consequences of these stressors for water resources at broader spatiotemporal scales.

Results

In Puerto Rico, contemporary water management is decreasing freshwater delivery to wetlands and contributes to the salinization of important coastal wetlands as sea levels rise. Further, downscaled climate models predict an increase in drought frequency, intensity, and duration by mid-century (Fig. 3) as well as changes in rain seasonality (Fig. 4). Conflicts over water allocation seem imminent between human and ecological needs (Table 1).

Water deficits are expected in Puerto Rico in the **future** due to **inter-basin water use** and **precipitation decline -** current **water flow policies** are likely inadequate to protect future **wetland integrity** - a **landscape perspective** could help address this issue

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Figure 3

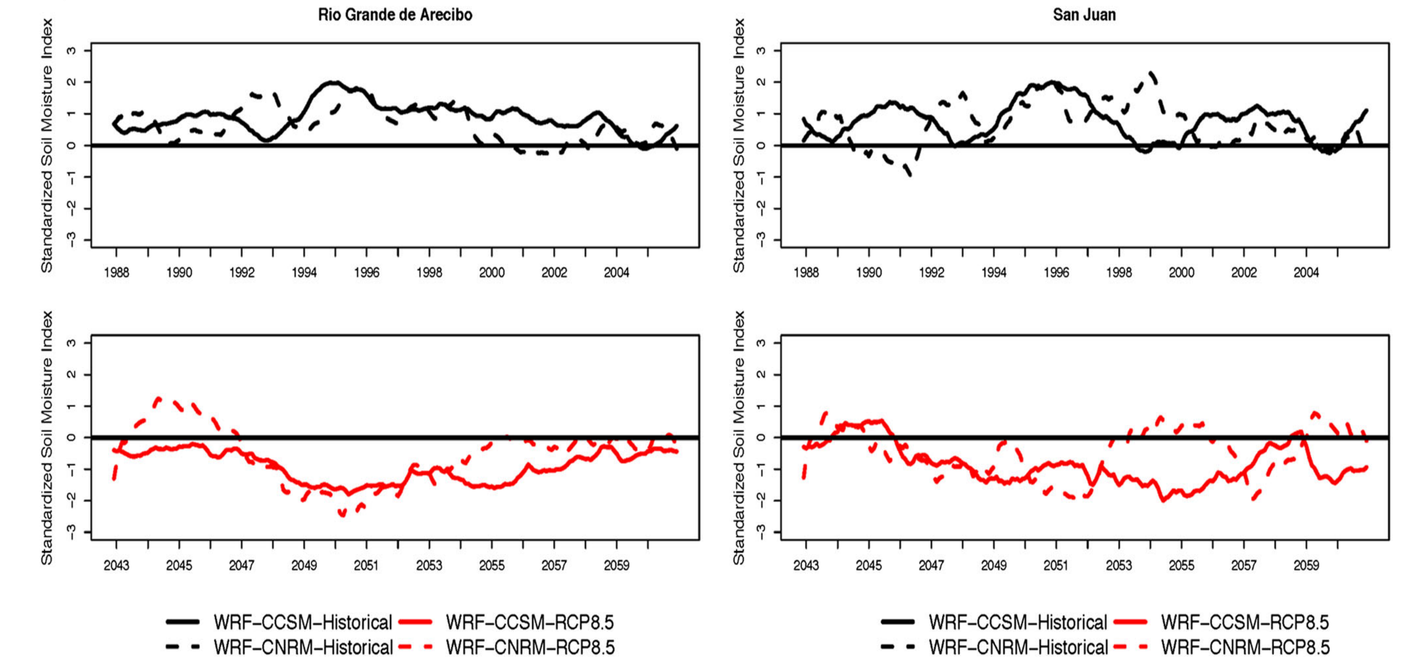

Figure 3 (above). 24-month Soil Moisture Index (SSI) for Rio Grande de Arecibo (left) and San Juan (right) watersheds for a historical (1988–2005, top) and future time slice (2041–2060, bottom RCP8.5). Two global climate models, CCSM and CNRM, are downscaled using the WRF model and shown as WRF-CCSM and WRF-CNRM.

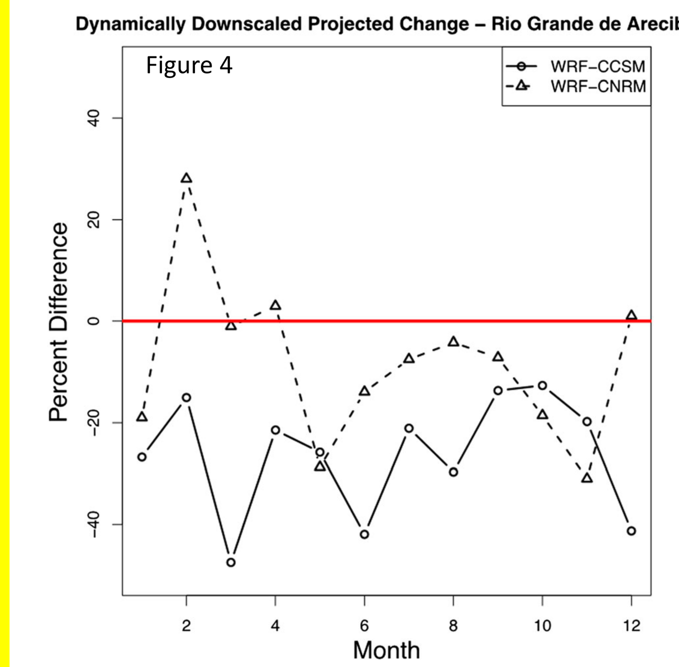

Figure 4 (left). Percent change in monthly precipitation for the Rio Grande de Arecibo watershed from the dynamical downscaled simulations, WRF-CCSM and WRF-CNRM. Projected percent change is centered on mid-century (2041-2060).

Table 1. Rio Grande de Arecibo water balance 2002 (Source: Puerto Rico Inventory of Aquatic Resources, 2004) and generalized future scenarios described in the text. *30% decrease based rough annual average from the dynamically downscaled climate projection (Figure 4). #Current physical capacity of the Superaquaducto infrastructure limits transfers to San Juan (not including water to the south) to 3.79 x10^5 m^3/d.

Component	Observed (2002) (m^3/d)	Potential future scenario (m^3/d)
Precipitation	3.50 x10^6	2.45 x10^6*
Evapotranspiration	2.18 x10^6	increase
Groundwater storage	1.01 x10^5	Decrease
Groundwater withdraw	2.8 x10^4	Increase
PRASA intake	3.18 x10^5	>4.54 x10^5 (>50% increase)
Inter-basin water transfer	2.96 x10^5 (up to 100)	3.79 x10^5#
Wastewater stream discharge	4.92 x10^3	---
Wastewater discharge to the ocean	2.20 x10^4	---
Groundwater discharge to the ocean	3.37 x10^4	---
Average run-off	1.18x10^6	< 0 DEFICIT
Unaccounted flow	-3.88 x10^5	

Conclusions: Management and Science Needs

Current minimum flow policies are insufficient given the complexities of ecosystem processes and the changes in precipitation patterns and sea level rise that are expected in the future. Improved flow policies need to be established that reflect the functional relationships between specific representative ecological resources and components of the natural flow regime across all relevant time scales. Similarly, flow policies need to be developed within a landscape scale to implicitly address the socio-ecological trade-offs as well as the complexities of water management (Table 2).

Table 2. Science and operational needs toward developing more holistic regional flow policies for Puerto Rico consolidated from DNER 2016a,b and personal communications of authors with regional water managers and ecologists.

Infrastructure

- Approaches to identify leaking infrastructure
- Approaches to increase water use efficiency among all sectors
- Science to support green infrastructure best practices to increase water residency time, reduce the negative impacts of flooding, and maintain biodiversity
- Enhanced infrastructure planning and financing to interconnect diverse water sources to communities that will maximize opportunities to distribute human water demands across multiple water sources reducing the risk of conflict

Social

- Development of environmental flows working group that integrates policy-makers, decision-makers, science providers (e.g., ecologists, hydrologists, landscape ecologists, climate scientists), and decision support specialists
- Collaboratively develop shared science priorities and business plan to fulfil them

Hydrologic

- Greater understanding (reduced uncertainty) in relationships between ground and surface waters and flows relative to changing climate and land use across multiple timescales
- Understanding the flooding and drought cycles and how these cycles effect ecological end points
- Improved subwatershed water budgets including daily times steps and interaction of water infrastructure, including specifically IBWTs and ocean disposal of treated water

Ecological

- Greater mechanistic understanding (reduced uncertainty) of how alterations in flow regimes, across multiple time and spatial scales incur ecological responses among habitats, e.g. wetlands, species, and ecosystem services
- Prioritizing representative ecological end-points for species, habitats, processes (e.g., migration or growth, maintenance of habitat heterogeneity)
- Identifying specific components of the flow regime that limit ecological end points and then identifying response thresholds

Climate

- Greater understanding (reduced uncertainty) of future drought dynamics
- Evaluation of how soil moisture is impacted by anthropogenic water withdraws and additions (i.e., transfers) and how this may impact future predictions of drought
- Reduce uncertainty in spatially-explicit changes in rainfall and evapotranspiration among watersheds

Interactive

- Interdisciplinary collaboration including hydrologists, biologists, engineers, climate scientists, social scientists, land and water use managers, and community leaders needed to develop and balance flow regimes to meet the diversity of goals recognizing multiple timeframes and ecological and human desired end points