Water and Vegetation Interactions at Ecosystem Scales: A Two-Way Highway with High Traffic

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Abstract
This paper describes a series of ongoing investigations focused on ecohydrology and the fundamental principles of how water and the water cycle interact with vegetation, the transport of nutrients and energy in ecosystems. A summary is presented of these ongoing research projects in the Florida Everglades, Brazil, and a startup initiative in Iraq.

Keywords
Water, Vegetation, Ecosystems, Ecohydrology, Modeling

1. Introduction
Water-controlled ecosystems, i.e., systems in which either excess and/or deficit of water, nutrients and energy are determinants of its structure and function, have complex dynamic characteristics that depend on many interrelated links between climate, soil and vegetation. For instance, vegetation exerts important controls on the water and nutrient balances of ecosystems and is responsible for many feedbacks to the atmosphere. At the same time, climate and soil have a key influence on patterns of vegetation distribution. Vegetation plays a special role in water-controlled ecosystems: plant physiological processes condition the water and nutrient balances of the system. At the same time, plants are also impacted by the climate and hydrologic conditions they contribute to produce. The links between water and nutrient availability in the soil, i.e., soil moisture and nutrient concentrations, and vegetation, pose interactions of direct and indirect natures. Soil moisture and nutrient availability have direct impacts on the essential physiological processes of individual plants: transpiration, photosynthesis and biomass production. They also indirectly control many other vital aspects for vegetation such as absorption of nutrients and soil temperature. The availability of water and nutrients is also a driver for competition mechanisms.
2. Biocomplexity of the Everglades (Florida) and Cerrado (Brazil) Ecosystems

The primary objective of this project, funded by the National Science Foundation in the United States is to develop a quantitative model of the spatial structure and temporal changes of heterogeneous vegetative ecosystems. This model is being developed at a systems level, i.e., seeking the quantification of stocks and fluxes of water and nutrients, as they couple and aggregate into the spatial and temporal organization and adaptation mechanisms of vegetation at the ecosystems level. The team of researchers assembled for this project has done work on two hydrologically-controlled ecosystems that have similar spatiotemporal structures: a similar field scale heterogeneity in vegetation characterized by the dynamic coexistence of sparse woody and graminaceous species. This convergent vegetation structure however, interacts/feedbacks with potentially different hydrologic flows and nutrient transport mechanisms. We seek here to quantitatively and comparatively evaluate this interactive feedback on these two hydrologically-controlled ecosystems in the proposed research and education activities: the Everglades of South Florida and the central savannas of Brazil (Cerrado). Both of them are subjected to strong
seasonal fluctuations in rainfall, have an extended dry season, receive similar amounts of annual rainfall, and are located in the tropical/subtropical belt. Undoubtedly, differences in the hydrologic and vegetative forcings are significant. While the Everglades are very close to sea level and horizontal movement of water is a major controlling factor of vegetation distribution, the Cerrado is also relatively flat but the soils are very well drained with a deep groundwater table and negligible horizontal/lateral flow. The basic ecohydrological interactions are illustrated in Figure 1 and Figure 2.

Figure 1: Conceptual Model for Vegetation-Hydrology-Nutrient Interactions in the Everglades Ecosystem. Solid and dashed lines represent water and nutrient fluxes, respectively.

Figure 2: Conceptual Model for Vegetation-Hydrology-Nutrient Interactions in the Cerrado Ecosystem. Solid and dashed lines represent water and nutrient fluxes, respectively.
3. Remote Sensing of Ecohydrologic Interactions in Coastal Wetlands

Coastal wetlands provide critical habitat for a wide variety of plant and animal species, and form a natural boundary of transition between terrestrial and marine environments. Globally, most such regions are under severe environmental stress, mainly from urban development, pollution, and rising sea level. However, there is increasing recognition of the importance of these habitats, and mitigation and restoration activities have begun in a few regions. A key element of wetland restoration involves monitoring and modeling wetland hydrologic water stages and flow rates, in order to understand the underlying flow dynamics, assess potential restoration strategies, mitigate effects of past anthropogenic intervention, and predict the effects of future changes to water resources management infrastructure, such as dams, levees, locks and canal flow control structures.

The study by Wdowinski et al. (2004) introduces new space-based hydrologic observations of South Florida, revealing spatially detailed, quantitative images of water levels in the Everglades. Their observations capture dynamic water level topography, providing the first three-dimensional regional-scale picture of wetland sheet flow.

The Everglades region in south Florida is a unique ecological environment (see Figure 3). It is known also as "River of Grass", following the classic work of Marjorie Stoneman Douglas, which first called attention to the environmental importance of the Everglades. The hydrologic regime of the Everglades is primarily a sloping surface sheet flow that drains Lake Okeechobee southwards into the Gulf of Mexico. The combination of abundant water and sub-tropical climate results in a wide diversity of flora and fauna. The Everglades contains both temperate and tropical plant communities, including sawgrass prairies, mangrove and cypress swamps, pinelands, and hardwood hammocks, as well as marine and estuarine environments.

Anthropogenic changes in the past 50 years, mainly for water supply, agricultural development and flood control purposes, have disrupted natural water flow and severely impacted the regional ecosystem. Currently, Everglades flow is controlled by a series of hydraulic control structures to prevent flooding and regulate flow rates, but which also suppress natural water level fluctuations, essential for supporting the fragile wetland ecosystem. This controlled Everglades environment provides a large-scale laboratory for monitoring and modeling wetland surface flow. Enhanced modeling capabilities and understanding of the Everglades hydrological system are essential for the Everglades restoration project, which is the largest and most expensive (multi-billion dollar) wetland restoration project yet attempted worldwide.
Figure 3: (a) RADARSAT-1 ScanSAR image of Florida showing location of study area (RADARSAT data © Canadian Space Agency / Agence spatiale canadienne 2002. Processed by CSTARS and distributed by RADARSAT International). (b) Cartoon illustrating the double-bounce radar signal return in vegetated aquatic environments. The red ray bounces twice and returns to the satellite, whereas the black ray bounces once and scattered away. (c) JERS L-band interferogram of the eastern south Florida area showing phase differences occurring during 44 days (1994/6/26-1994/8/9). Each color cycle represents 15.1 cm of elevation change (See color scale in inset Figure 4).
4. Ecohydrology of the Southern Iraqi Marshlands

The Mesopotamian Marshlands (Ahwar in Arabic), associated with the Tigris and Euphrates rivers, once inundated 20,000 square kilometers in southern Iraq and Iran. These complex ecosystems consisted of marshes and lakes that provided habitat for diverse populations of fish and wildfowl as well as the homeland of the ancient wetlands-dependent people known as the "Ma'dan", or "Marsh Arabs". Some consider this vast marsh the site of the biblical "Eden". Water management during the later years of the Baathist regime was based on water diversion actions directed towards punishing the resistance movement that sought refuge in the Ahwar in the early 1990s. As a result of such actions, the marshes have dried up to less than 5% of their former extent (see Figure 3), causing extensive salination of the soils and an extensive unsaturated zone in this arid climate. Endangered species of birds are threatened by the marshland loss along major flyways. Salt water has also intruded into waterways, adversely affecting local freshwater commercial fisheries. The Ma'dan culture has essentially been destroyed, in violation of its members’ human rights.

These changes in water management in the Tigris-Euphrates watershed have had, and will continue to have, profound political, economic, environmental and cultural/ethnical consequences in the countries composing the watershed: Turkey, Syria, Kuwait and Iraq. In light of the ongoing reconstruction efforts in Iraq, it is important to recognize that a new approach is needed to prevent the catastrophic collapse of this ecosystem; one that is comprehensive and integrated, one that includes larger-scale restoration projects, and one that will require a substantial and sustained level of funding over the next 20 years.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Water Potential</th>
<th>Consumption Targets</th>
<th>Water Potential</th>
<th>Consumption Targets</th>
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</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>25.24 (51.8%)</td>
<td>6.87 (13.0%)</td>
<td>31.58 (88.7%)</td>
<td>18.42 (35.0%)</td>
</tr>
<tr>
<td>Syria</td>
<td>0.00 (0.0%)</td>
<td>2.60 (4.0%)</td>
<td>4.00 (11.5%)</td>
<td>11.30 (22.0%)</td>
</tr>
<tr>
<td>Iraq</td>
<td>23.43 (48.1%)</td>
<td>45.00 (83.0%)</td>
<td>0.00 (0.0%)</td>
<td>23.00 (43.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>48.67 (100.0%)</td>
<td>54.47 (100.0%)</td>
<td>35.58 (100.0%)</td>
<td>52.92 (100.0%)</td>
</tr>
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A joint planning and ecohydrological restoration effort has been launched working in collaboration with in-country agencies and potential stakeholders. The purpose of the proposed study is to develop a comprehensive framework for a long-term program to address the competing problems of water supply, energy generation, wetland loss and ecosystem degradation in the Tigris-Euphrates watershed. This framework may include a suite of viable alternative restoration plans, presented at a programmatic level, and recommended processes and procedures for further evaluation and implementation of specific restoration projects.
Figure 3: Analysis of Landsat satellite imagery shows that the surviving Mesopotamian marshlands declined by 30% from 1,084 square kilometers in 2000 (left) to 759 square kilometers in 2002. At this rate of loss, the marshes are likely to totally vanish within the next five years. (Maps Copyright © 2002 UNEP/DEWA/GRID-Geneva).

A research team will be assembled to work jointly with in-country team members in Iraq and Kuwait to build the human, scientific, technological and policy making capacity that will enable a follow up comprehensive restoration plan for the Ahwar. This capacity building will be developed and sustained through an in-country knowledge base seeded at the higher education level through a carefully designed research and education plan. It is anticipated that this plan will be similar to other experiences of our team, including the restoration of the Florida Everglades (our team’s “backyard”), the largest ecosystem restoration program ever funded worldwide. The proposed research and education capacity and infrastructure building plan will include a suite of viable alternative restoration approaches, developed at a programmatic level, and recommended processes and procedures for further evaluation and implementation of specific restoration projects.
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