A synthesis on modern methods in rangeland ecohydrology I

Uma síntese sobre métodos modernos de ecohidrologia de pastagens I

Síntesis sobre métodos modernos de ecohidrología de pastizales I

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ABSTRACT
Rangeland ecohydrology is an emerging and developing field that primarily deals with the nexus of rangeland ecosystems and the hydrologic processes that affect them. In the arid and semiarid rangelands of the American Southwest, capturing and retaining water is crucial to the overall health and functionality of floodplain grasslands. In the Southwestern U.S., the native grasses Big sacaton (*Sporobolus wrightii*) and Alkali sacaton (*Sporobolus airoides*) have historically dominated riparian floodplains, including those on the Altar Valley's Buenos Aires National Wildlife Refuge (BANWR) near Tucson, AZ. However, issues of hydrologic connectivity have grown prevalent on the Refuge due to advancement of altered drainage pathways via channel incision and arroyo formation. Some of these incised channels likely developed due to failed (breached, scoured, or flanked) water retention and diversion structures put in by the U.S. Soil Conservation Service (SCS) in the early 1900's as part of water infrastructure improvement efforts. Other considerations include land cover erosion due to overgrazing. As these channels further gully after sufficient rainfall the sacaton floodplain disconnects from available runoff via incised channels where ideal rainfall would once inundate floodplain grasslands.

RESUMO
A ecohidrologia de pastagens é um campo emergente e em desenvolvimento que trata principalmente do nexo entre os ecossistemas de pastagens e os processos hidrológicos que os afetam. Nas pastagens áridas e semiáridas do sudoeste americano, a captação e a retenção de água são cruciais para a saúde e a funcionalidade gerais das pastagens de várzea. No sudoeste dos EUA, as gramíneas nativas Big sacaton (Sporobolus wrightii) e Alkali sacaton (Sporobolus airoides) dominaram historicamente as planícies de inundação ribeirinhas, inclusive as do Altar Valley's Buenos Aires National Wildlife Refuge (BANWR), próximo a Tucson, AZ. No entanto, os problemas de conectividade hidrológica se tornaram predominantes no Refúgio devido ao avanço das vias de drenagem alteradas por meio da incisão do canal e da formação de arroyo. Alguns desses canais incisos provavelmente se desenvolveram devido a estruturas de retenção e desvio de água que falharam (rompidas, desgastadas ou flanqueadas), instaladas pelo Serviço de Conservação do Solo dos EUA (SCS) no início do século XX como parte dos esforços de melhoria da infraestrutura hídrica. Outras considerações incluem a erosão da cobertura da terra devido ao pastoreio excessivo.

À medida que esses canais se tornam mais irregulares após uma chuva suficiente, a planície de inundação do Sacaton se desconecta do escoamento disponível por meio de canais incisos onde a chuva ideal inundaria as pastagens da planície de inundação.

RESUMEN

La ecohidrología de pastizales es un campo emergente y en desarrollo que se ocupa principalmente del nexo entre los ecosistemas de pastizales y los procesos hidrológicos que los afectan. En los pastizales áridos y semiáridos del suroeste estadounidense, la captación y retención de agua es crucial para la salud y funcionalidad generales de las praderas inundables. En el suroeste de EE.UU., las gramíneas autóctonas Big sacaton (Sporobolus wrightii) y Alkali sacaton (Sporobolus airoides) han dominado históricamente las llanuras aluviales ribereñas, incluidas las del Refugio Nacional de Vida Silvestre Buenos Aires (BANWR) del Valle de Altar, cerca de Tucson, AZ. Sin embargo, los problemas de conectividad hidrológica son cada vez más frecuentes en el Refugio debido al avance de las vías de drenaje alteradas por la incisión de los canales y la formación de arroyos. Algunos de estos canales incisos probablemente se desarrollaron debido a estructuras de retención y desvío de agua fallidas (rotas, socavadas o flanqueadas) colocadas por el Servicio de Conservación del Suelo de EE.UU. (SCS) a principios del siglo XX como parte de los esfuerzos de mejora de la infraestructura hídrica. Otras consideraciones incluyen la erosión de la cubierta vegetal debida al sobrepastoreo. A medida que estos canales se desbordan más después de lluvias suficientes, la llanura aluvial del Sacatón se desconecta de la escorrentía disponible a través de canales incisos en los que las lluvias ideales inundarían antaño los pastizales de la llanura aluvial.

1 INTRODUCTION

The history of the BANWR in the Altar Valley provides valuable context to the issue of hydrologic connectivity. Originally settled in the late 1880's, the area that is presently the Refuge was once a working cattle ranch that changed ownership several times until purchased in 1985 by the U.S. Fish and Wildlife Service to establish a wildlife refuge. The U.S. Fish and Wildlife Service removed cattle grazing from the land with the aim of restoring grasslands in the Valley to their original state as well as hoping to restore declining populations of the masked bobwhite quail (Sayre, 2002).

Apart from the history of land ownership in the Altar Valley, the history of sacaton grass prevalence and vegetation change in the region of Southeastern Arizona is also of note. It is clear from literature that vegetation change, arroyo formation, and rangeland degradation are nothing new to Southeastern Arizona. However, there is still much argument as to the leading cause of these phenomena (i.e. humans, climatic factors, etc.) (Reeves, 1991) (Bahre, 1991). Nevertheless, sacaton stand distribution is declining in Southeastern Arizona and informed land management remains vital (Tiller, Hughes, & Bodner, 2013).

The proposed synthesis aims to explore concepts in rangeland ecohydrology and management techniques for sacaton grasslands in order to better understand the hydrology on the BANWR. By studying hydrologic connectivity, strategies can be developed to restore ecosystem

and floodplain health. Through mapping and quantifying drainage patterns, a maintenance and/or removal plan of existing failed retention and diversion structures can be developed. Watershed scale implications include improved soil moisture distribution, greater forage availability for wildlife, and enhanced ecosystem services for inhabitants of the Altar Valley. Other important land management concerns involve woody plant encroachment such as Mesquite Bosque and the efficacy of shrub removal efforts in increasing the water budget. Technological advances such as remote sensing are also reviewed in better understanding hydrologic connectivity and floodplain health.

Sacaton Grasses

The bunchgrasses Big sacaton (*Sporobolus wrightii*) and Alkali sacaton (*Sporobolus airoides*) are historically native to floodplains in the American Southwest. These grasses have trapped sediment, spread water like a dam, and leveled valley bottoms in the past (Cox J. R., 1988). The decline in prevalence of these grasses may be attributed to past grazing methods, agricultural crop conversion, channelization for irrigation, or residential development (Cox J. R., 1984). Though no longer relevant to the former working cattle ranch, it is recommended that land and cattle managers only graze big sacaton grasslands in the spring months for optimal plant production (Cox, Gillen, & Ruyle, 1989).

Common ways to assess the ecological state of riparian sacaton stands and grasslands include the use of state-and-transition models (STMs or S&T), remote sensing, field verification, and consultation of expert opinion (Gori & Enquist, 2003) (Gori & Enquist, 2005) (Tiller, Hughes, & Bodner, 2013). STMs are defined as, “synthetic descriptions of the dynamics of the vegetation and surface soils occurring within specific ecological sites,” (Bestelmeyer, et al., 2010). For example, Tiller et al., utilized Natural Resource Conservation Service (NRCS) STMs to distinguish sacaton and other present shrubs in the Upper Cienega Creek Watershed of Southeastern Arizona. The NRCS STMs serve to classify vegetation by type, state, and canopy cover (Table 1).

Table 1. STM/S&T for sacaton classification in Upper Cienega Creek watershed (Tiller, Hughes, & Bodner, 2013)

Table 2—Combined Loamy Bottom Ecological Sites (rangeland and forestland), 12-16 inch precipitation zone, in tabular format for quick field reference. Letters represent original models' states; numbers represent revised model's sub-state distinctions. An asterisk (*) denotes naming convention differs from Mesquite-Sacaton state described in Loamy Bottom rangeland S&T model.

Rangeland								Forestland			
State	Sacaton Grassland (HCPC)	Sacaton Grassland	*Sacaton-Mesquite	Exotics	Eroded Sacaton	Annuals	Eroded Mesquite	Mesquite Bosque-native annuals (HCPC)	Mesquite Bosque - exotic annuals	Mesquite Thornscrub	Mesquite Scrubland
Original state	A	B	C	D	E	F	G	H	I	J	K
Refined sub-state		B1,B2,B3	C1,C2		E1,E2		[not observed]				
	Canopy cover (%)							Canopy cover (%)			
Sacaton	25-80	25-65	5-40		20-50	trace					
Mesquite		1-15	5-20	0-15			20-80	25-65; large	20-80; large	5-20; shrubby	5-20; shrubby
Other shrubs, succulents			yes			0-10	0-10	0-5		5-15	5-15
Exotics (johnsongrass, bermuda)				yes							
Annuals	0-20					yes			yes; dominate	yes; fluctuate	yes; fluctuate
Gully erosion					severe		severe	yes	yes	yes	yes
Flooding					reduced	reduced	no flooding	no flooding	no flooding	no flooding	no flooding
Water table (ft)	<20	<20	<20	<20	>20	>20	25-50	25-50	25-50	25-50	>60
Causal Mechanisms			lack of fire	plowing, cultivation, burning low SM	gully erosion	plowing, cultivation, burning low SM				clearing, cultivation	lowered water table

This information was used to form a better understanding of the ecological conditions of sacaton stands in the region. Furthermore, the S&T information was paired with data from remote sensing imagery to implement within Geographic Information System (GIS) analysis software. The GIS outputs show a map of the delineated Upper Cienega Creek Watershed with color-coded classifications of vegetation distribution and soil type within the watershed (Figure 1). Field verification is always performed to test the accuracy of aerial imagery and map development.

Figure 1. Sacaton distribution and classification in GIS (Tiller, Hughes, & Bodner, 2013)

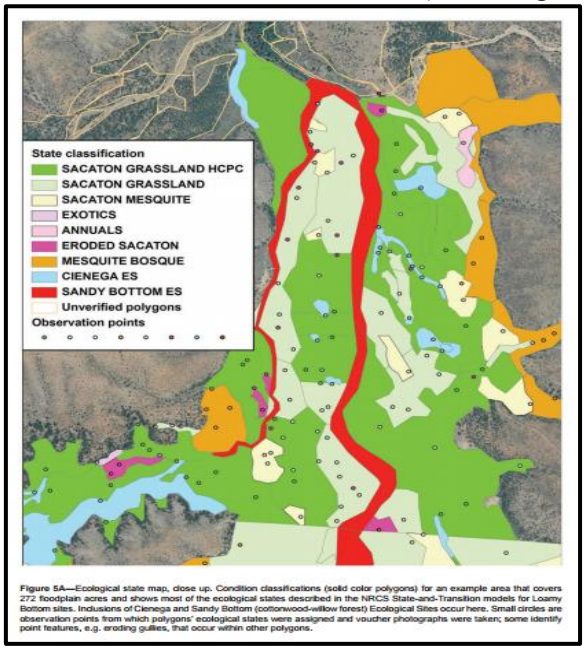


Figure 5A—Ecological state map, close up. Condition classifications (solid color polygons) for an example area that covers 272 floodplain acres and shows most of the ecological states described in the NRCS State-and-Transition models for Loamy Bottom sites. Inclusions of Cienega and Sandy Bottom (cottonwood-willow forest) Ecological Sites occur here. Small circles are observation points from which polygons' ecological states were assigned and voucher photographs were taken; some identify point features, e.g. eroding gullies, that occur within other polygons.

The aforementioned Gori and Enquist study in the Apache Highlands (encompassing Southern Arizona, Southwestern New Mexico, and Northern Mexico) utilized GIS to map and classify grassland conditions as well as expert consultation and field verification to estimate canopy cover and shrub conversion. The study found that, over a century, 36% of these grasslands have transitioned to shrubland during half a century of grazing rest. Results indicate that sacaton riparian grasslands now constitute but 0.7% of total grasslands in the region.

The studies and methods described above cover the use of remote sensing and GIS for grassland ecological state and condition analysis. While most of these studies were conducted in areas within the general region of Southeastern Arizona, a similar approach has not been conducted on the BANWR. A modern approach including mapping, quantifying, and classifying sacaton stand and soil distributions on the Refuge could prove useful to floodplain restoration efforts in the Altar Valley.

Rangeland Ecohydrology

"Rangeland hydrology, or rangeland watershed management, is the study of hydrologic principles as applied to range ecosystems" (Branson, Gifford, Renard, & Hadley, 1981). This is a concise, yet useful, description of rangeland ecohydrology. In other words, rangeland ecohydrology melds many disciplines including ecology, range and watershed management, soil sciences, geomorphology, etc. with the overall goal of better understanding the interconnections between vegetation change, the water cycle, and provision of ecosystem services (Wilcox, Le Maitre, Jobbagy, & Breshears, 2017). This "… subdiscipline shared by the ecological and hydrological sciences that is concerned with the effects of hydrological processes on the distribution, structure, and function of ecosystems, and on the effects of the biotic processes on the elements of the water cycle…" is especially relevant to the BANWR where sacaton floodplain health is of biotic concern (Nuttle, 2002). And further, the arid and semiarid environment of Southern Arizona lends itself to water scarcity, "… where water is an important limiting resource not only for its scarcity but also for its intermittency and unpredictable presence," (Porporato & Rodriguez-Iturbe, 2002) (D'Odorico & Porporato, 2006).

While ecohydrology is a relatively new interdisciplinary field, it is now in its second decade of use. In fact, King and Caylor conducted a study by comparing all scientific research studies from 1996 to 2010 that have the word 'ecohydrology' in its title and/or abstract. Their results showed that, out of 309 total studies, 104 studies or 34% were modeling based (Figure 2) (King & Caylor, 2011).

Figure 2. Results of literature review research on ecohydrology (King & Caylor, 2011)

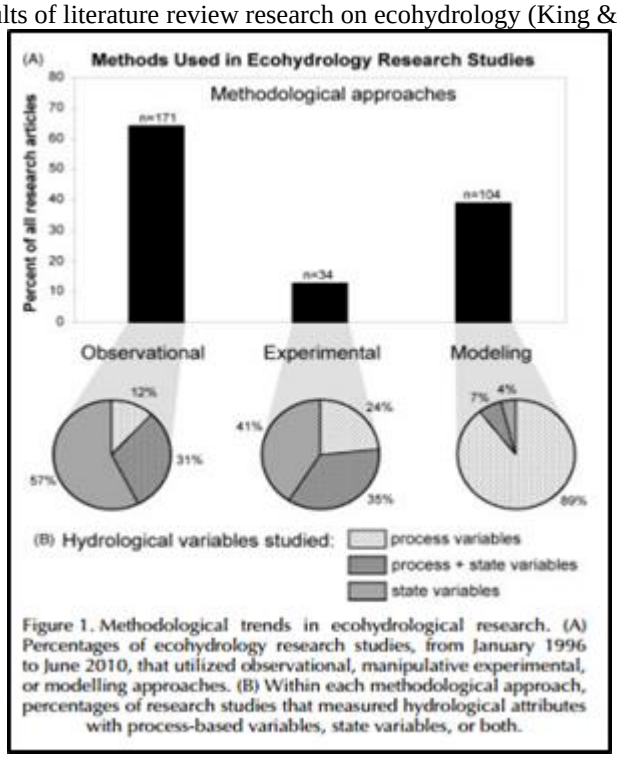


Figure 1. Methodological trends in ecohydrological research. (A) Percentages of ecohydrology research studies, from January 1996 to June 2010, that utilized observational, manipulative experimental, or modelling approaches. (B) Within each methodological approach, percentages of research studies that measured hydrological attributes with process-based variables, state variables, or both.

The use of hydrologic modeling provides, "a way to transfer knowledge from a measured or study area to an unmeasured area where management decisions are needed," (Branson, Gifford, Renard, & Hadley, 1981). With the current situation on the BANWR, hydrologic modeling is a useful method to inform rangeland management via mapping and quantifying drainage flow patterns and erosion processes. Available modeling tools include the Automated Geospatial Watershed Assessment tool (AGWA), the Rangeland Hydrology and Erosion Model (RHEM), KINEROS2, the Soil and Water Assessment Tool (SWAT), and GIS (Figure 3).

Figure 3. AGWA, KINEROS, SWAT model creation for watershed analysis (Goodrich, et al., 2011)

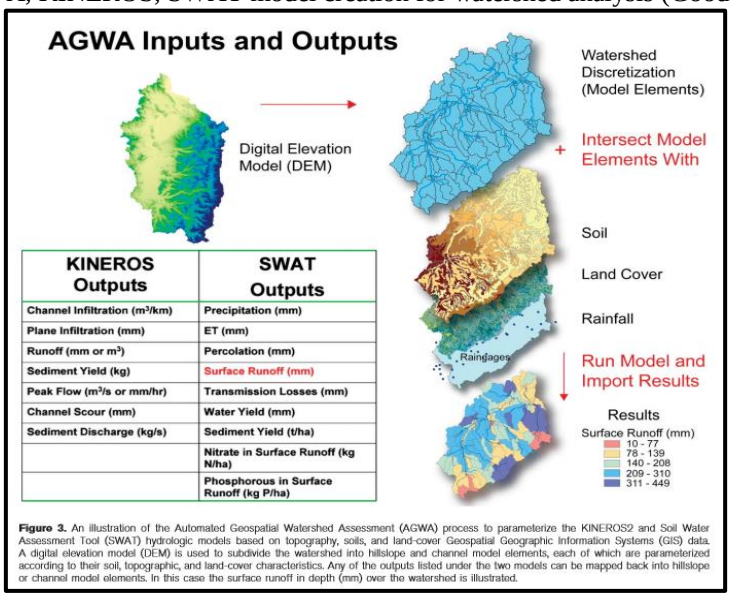


Figure 3. An illustration of the Automated Geospatial Watershed Assessment (AGWA) process to parameterize the KINEROS2 and Soil Water Assessment Tool (SWAT) hydrologic models based on topography, soils, and land-cover Geospatial Geographic Information Systems (GIS) data. A digital elevation model (DEM) is used to subdivide the watershed into hillslope and channel model elements, each of which are parameterized according to their soil, topographic, and land-cover characteristics. Any of the outputs listed under the two models can be mapped back into hillslope or channel model elements. In this case the surface runoff in depth (mm) over the watershed is illustrated.

These models require spatially explicit land cover, soil type, and precipitation datasets, among others—usually found available from the United States Department of Agriculture (USDA) NRCS and other research entities (Goodrich, et al., 2011). Land cover and vegetation datasets are often developed using a Digital Elevation Model (DEM) or remote sensing like Light Detection and Ranging (LiDAR) (Wilcox, Le Maitre, Jobbagy, & Breshears, 2017).

Another ecological concern is that of woody plant encroachment and the subsequent effects on the ecosystem water budget. In fact, over the last century or more, woody plant encroachment of shrubs on grassland savannas has increased (Archer, Schimel, & Holland, 1995). Because water is so vital to grassland health, what is the efficacy of large-scale shrub removal in increasing the ecosystem water budget? More knowledge regarding the effects of shrub encroachment on hydrologic processes is needed. This is another area where remote sensing is of value. Remote sensing bridges the gap of large spatiality in investigating water budget changes over periods of time. It also helps to estimate variables of soil moisture, precipitation, vegetation, and water stress through data extrapolation (Wang, et al., 2012). Because woody plant encroachment has the potential to affect many of the components of the water budget, continued extensive research is needed going forward for managers (Archer, et al., 2017). Finally, the concept of woody plant encroachment and its effects on water budget is not without controversy as it is highly variable. For example, in semiarid rangelands, shrub removal as a means of improving the water budget has not proven significant on a meaningful scale (Wilcox, 2002). Furthermore, there are studies that have shown that shrub encroachment may not be all bad. A study conducted in Spain has shown that shrub encroachment may be helpful in reversing desertification and creating “islands of fertility” with an enhanced water budget (Maestre, et al., 2009) (Archer, et al., 2017).

2 DISCUSSION & CONCLUSION

Ecological state assessments of vegetation, hydrologic modeling using remote sensing data, field work and consultation with experts are all modern ecohydrological methods that can help rangeland managers understand the relationships between biota, water yield, and erosion processes (Wilcox & Thurow, 2006) (Jones, 2012). Methods such as those described in this paper, “that link field-based measurements of plant water use with modeling efforts that incorporate larger scale constraints on water fluxes offer particularly promising opportunities to advance understanding of the role of plant–water relations in ecohydrological processes,” (Asbjornsen, et al., 2011). Much of the research described in this paper is focused on the Southwestern U.S., and more specifically Southeastern Arizona, the Altar Valley, and the Buenos Aires National Wildlife Refuge. Of concern in this water-limited region of the world, are the plant-water relations between sacaton floodplain

grasses, large-scale rainfall events, and channelized landscapes. Future research is needed using many of the modern methods previously discussed in furthering the partnership between ecologists and hydrologists and in pursuing a better understanding of the, “linkages among water, vegetation, and nutrients and the effects of management and land use on the processes that govern their interactions,” (Newman, et al., 2006).

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