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HYDROLOGIC LANDSCAPE UNITS AND ADAPTIVE MANAGEMENT OF INTERMOUNTAIN WETLANDS

Stephan G. Custer and Richard S. Sojda*

ABSTRACT: Adaptive management is often proposed to assist in the management of national wildlife refuges and allows the exploration of alternatives as well as the addition of new knowledge as it becomes available. The hydrological landscape unit can be a good foundation for such efforts. Red Rock Lakes National Wildlife Refuge (NWR) is in an intermountain basin dominated by vertical tectonics in the Northern Rocky Mountains. A geographic information system was used to define the boundaries for the hydrologic landscape units there. Units identified include alluvial fan, interfan, stream alluvium and basin flat. Management alternatives can be informed by examination of processes that occur on the units. For example, an ancient alluvial fan unit related to Red Rock Creek appears to be isolated from stream flow today, with recharge dominated by precipitation and bedrock springs; while other alluvial fan units in the area have shallow ground water recharged from mountain streams and precipitation. The scale of hydrologic processes in interfan units differs from that in alluvial fan hydrologic landscape units. These differences are important when the refuge is evaluating habitat management activities. Hydrologic landscape units provide scientific underpinnings for the refuge's comprehensive planning process. New geologic, hydrologic, and biologic knowledge can be integrated into the hydrologic landscape unit definition and improve adaptive management.

INTRODUCTION

National wildlife refuge management is complex, and refuge managers are progressively more interested in ways to apply scientific knowledge to help attain management objectives. Adaptive management can provide a way to empirically examine existing management actions and evaluate alternative ones. In this paper, we first provide definitions for the terms adaptive management and hydrologic landscape unit. We then describe the process by which units were identified at Red Rock Lakes NWR. Finally, we show how hydrologic landscape units can be applied as a scientific framework for adaptive management. We hasten to point out that the two are not synonymous. It would seem that hydrologic landscape units might also be applied in the development of conceptual ecosystem models. The resultant management simulations commonly associated with the use of such models share many commonalities with certain aspects of adaptive management (Walters and Holling 1990), and we encourage exploration of this area.

What Are Adaptive Management and Hydrologic Landscape Units?

Adaptive management is a process for informed decision making. Our characterization follows from many authors in the past 28 years, including Holling (1978); Walters (1986); Lee and Lawrence (1986); Walters and Holling (1990); Nichols et al. (1995); Lee (1999); and Kendall (2001). Adaptive management involves developing objectives and a corresponding quantitative or symbolic logic function used to assess them. A set of feasible management actions must be identified. Model(s) must be developed that can predict the reaction of the natural resource system to those management actions based on the objectives. Such models are often mathematical or statistical, but could also be mechanistic, symbolic, or rule based. In its simplest sense, an underlying model for adaptive management could be merely conceptual. In any case, there should be some measure of our confidence in the ability of the model(s) to assess our objectives. Finally, some monitoring program must be in place to assess realization of the objectives. These elements of adaptive management are dependent on sound experimental design, and we contend that hydrologic landscape units can be the underpinning of that design.

*Respectively, Associate Professor, Department of Earth Sciences, Montana State University, Bozeman MT, 59717-3480, Phone: 406-994-6906, E-Mail: scuster@montana.edu. Wildlife Biologist, Northern Rocky Mountain Science Center, USDI-Geological Survey, Montana State University, Bozeman, MT, 59717-3492, Phone: 406-994-1820, E-Mail: sojda@usgs.gov.

Hydrologic landscape units are a conceptual way to describe how a portion of some geographical place functions with respect to atmospheric water, surface water and ground water relations. "The basic land-surface form of a fundamental hydrologic landscape unit is an upland separated from a lowland by an intervening steeper slope" (Winter 2001; Wolock et al. 2004). The hydrologic functioning of such a unit is a multivariate concept. It consists of precipitation and snow melt, surface water flow which is primarily controlled by topography and surface permeability, ground water flow from a recharge area to a discharge area which is controlled by infiltration and topography as well as the hydraulic conductivity of the subsurface materials, and evapotranspiration which is controlled by climate and vegetation. The concept is independent of spatial scale. Small hydrologic landscape units can be superimposed on larger units (Winter 2001). The conceptual framework provided by hydrologic landscape units is particularly relevant to adaptive management because it can "be the foundation for design of studies and data networks, syntheses of information on local to national scales and the comparison of process research across small study units in a variety of settings" (Winter 2001, p. 335).

Study Area

The Red Rock Lakes NWR is in Montana, near the Idaho border, west of Yellowstone National Park and in the Centennial Valley (Figure 1). Upper Red Rock Lake is the eastern-most lake (elevation 6610 feet). Lower Red Rock Lake is the western-most lake (elevation 6608 feet). The two lakes are connected by a shallow river locally known as the River Marsh and are surrounded by wetland complexes which were mapped as part of the National Wetland Inventory (United States Fish and Wildlife Service 2005). The level of Lower Red Rock Lake is controlled by a water control structure. Geologic mapping for the area has been compiled at a scale of 1:100,000 (O'Neill and Christiansen 2002). The refuge is in an intermountain tectonic basin on the northern margin of the Yellowstone hotspot (Pierce and Morgan 1992). Generally, rocks exposed at the surface include Archean metamorphic rocks, Paleozoic and Mesozoic limestones mudstones and sandstones, and Cenozoic deposits that include basalts and rhyolites from the Snake River Plain and the Yellowstone Caldera, as well as sedimentary materials including glacial, alluvial, lacustrine, eolian dune and mass-movement deposits (Sonderegger et al. 1982). There are numerous faults in the area but most are older than the Quaternary sediments in the valley (Sonderegger et al. 1982; Amend et al. 1986). The east-west Quaternary listric-normal fault along the Centennial Mountain front drops the Centennial Valley to the north and raises the Centennial Range to the south. The Centennial fault has an estimated 10,000 feet of total offset that has occurred in the past 10 ma (Sonderegger et al. 1982) and has segments that display fault scarps of approximately 30 feet (Kenneth L. Pierce, Personal Communication, United States Geological Survey, Bozeman, Montana, 2006).

The climate in the study area is severe with a short growing season (National Oceanic and Atmospheric Administration Western Regional Climate Center 2005). At Lake View, the annual average maximum temperature is 48.9 ^{o}F (75.2 ^{o}F in August and 22.5 ^{o}F in January); the annual average minimum temperature is 21.1 ^{o}F (40.8 ^{o}F in July and -0.1 ^{o}F in January. The average annual precipitation in the study area ranges from approximately 50 inches in the Centennial Range to 15 inches on the valley floor (United States Soil Conservation Service 1977; Amend et al. 1986; Montana Natural Resources Information System 2005). Class A pan evaporation is approximately 35 inches per year (Dingman 1994). Soils in the study area include poorly developed Entisols and Inceptisols, Alfisols, well drained Mollisols, poorly drained Mollisols, Histosols, sand dune soils, and poorly drained soils which often have salts (thenardite) at the surface (Amend et al. 1986, Nielson and Farnsworth 1966, Tippy et al, 1978). Much of the Red Rock Lakes NWR is a designated wilderness area so detailed climatic, hydrologic, and soil data are rare.

METHODS AND RESULTS

The hydrologic landscape units were mapped using a geographic information system. Base maps include 14 1:24,000 topographic maps tiled together into a single georeferenced image. The contour interval varies from 40 foot spacing with 20 foot supplemental lines to 20 foot spacing with 10 foot supplemental lines. The contour interval is irregular even on a single quadrangle. United States Geological Survey Digital OrthoPhoto Quadrangles (1:24,000 scale) provided important photographic information about the landscape. Categories in a GIS coverage of the National Wetland Inventory (U.S. Fish and Wildlife Service 2005) for the area were condensed. Periodically and permanently flooded areas were distinguished from areas that are saturated but not flooded.

A key idea of Winter (2001) and Wolock et al. (2004) that we attempted to carry forward in our identification of hydrologic landscape units was to group pieces of the landscape that function similarly. Detailed empirical climatic, hydrologic, and soil data are unavailable, so we relied heavily on topography, vegetation, and near surface materials that could be discerned visually from aerial photos and imagery, topographic maps, National Wetland Inventory maps, and field observations. The amalgamation, synthesis, and interpretation of such information was done manually and mapped in a GIS; the ideas we present can be thought of as a multivariate representation of the hydrologic landscape unit. Figure 1 shows the four types of hydrologic landscape units identified in the study area: alluvial fan, interfan, stream alluvium, and basin flat.

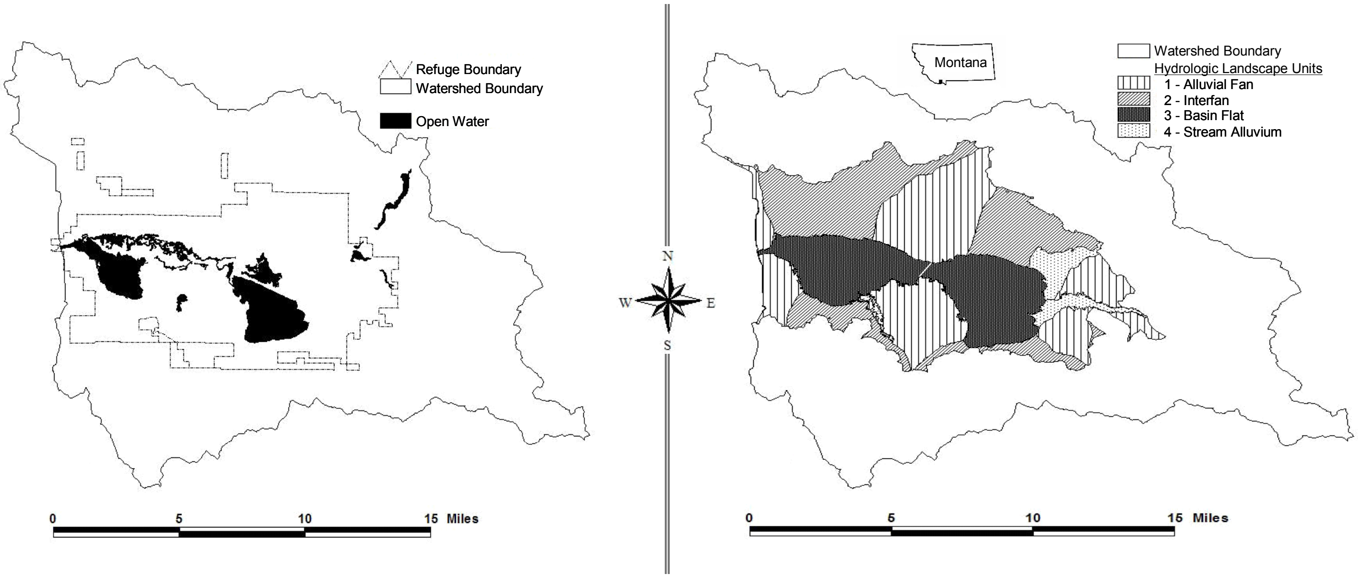

Figure 1. Left, location map for Red Rock Lakes NWR. Right, map of hydrologic landscape units for the Centennial Valley in southwest Montana.

Identification of Individual Units

Alluvial fan hydrologic landscape units impinge on the basin flat units and were identified based upon arcuate contours identified on 1:24,000 scale topographic maps. The lateral margins of the alluvial fan hydrologic landscape units were drawn to coincide with the up-slope "V" in the contour lines that separate the arcuate contours that represent the alluvial fan hydrologic landscape unite and the adjacent unit. The distal alluvial-fan-hydrologic-landscape-unit edge was generalized to the crenulate lowest arcuate contour. The details of the distal boundary were also controlled by the upper edge of continuous periodically flooded wetlands. The word continuous in this context refers areas with no interspersed uplands. Only alluvial fans large enough to impinge on a lake or stream were individually mapped and labeled as alluvial fan hydrologic landscape units.

Between the alluvial fan units are interfan units (Figure 1). These interfan units often have small alluvial fans similar to the alluvial fan hydrologic landscape units, but the arcuate contours do not extend to nor impinge upon Upper or Lower Red Rock Lakes, the River Marsh area, or Red Rock Creek. The boundaries between the interfan and the alluvial fan units were drawn based upon the "V" shaped contours that interrupt the arcuate contours of the alluvial fan unit. The same criterion for the boundary between the basin flat unit and the alluvial unit was used for the interfan hydrologic landscape unit.

Stream alluvium hydrologic landscape units were also distinguished (Figure 1). These areas were mapped as stream alluvium by O'Neill and Christiansen (2002) and showed a clear topographic incision that distinguishes them from alluvial fan units. These areas are not characterized by arcuate contours that are typical of alluvial fan units.

The basin flat unit has very little relief and lies below the alluvial fan, interfan and stream alluvial units. The basin flat contains spatially continuous, periodically-flooded palustrine wetland NWI units dominated by *Carex utriculata, Carex aquatilis,* and *Juncus balticus* and the associated organic soils as well as lacustrine and riverine wetlands (U.S. Fish and Wildlife Service 2005). The topography rises subtly above the basin flat unit to periodically flooded areas, but these periodically flooded areas are interspersed with upland areas and the wetland areas are saturated but not flooded. These discontinuous areas were included in the alluvial fan and interfan hydrologic landscape units. On the south margin of Upper Red Rock Lake there are wetland areas between ice-thrust features and the steep eroded face of alluvial fan and interfan units that were included in the basin flat unit.

DISCUSSION

Two examples illustrate how the hydrologic landscape units provide insights into hydrologic processes at Red Rock Lakes NWR. The first is the hydrologic difference between interfan and alluvial fan units (Figure 1). The drainage areas that deliver water to the interfan units are smaller. The alluvial fan unit and the interfan unit would be expected to show different responses to management activities because there is a difference in the magnitude and timing of hydrologic processes transferring water across the unit to the wetlands.

A second example of hydrologic insight is the alluvial fan unit north of Red Rock Creek (northwest side of hydrologic units map in Figure 1, north of the stream alluvium unit). Red Rock Creek has incised through the fan unit. Modern alluvium associated with the creek displays no alluvial fan characteristics and is mapped as a stream alluvium unit. Red Rock Creek may receive water from the upland on the fan unit, but can not deliver recharge water onto the fan unit and so can not recharge the alluvial fan unit. Despite the lack of perennial stream recharge on this alluvial fan unit, there are artificial impoundments and surface water flowing on the alluvial fan unit (left side of Figure 1). This water arises not from streams, but rather from bedrock springs and perhaps from infiltration of snow melt and rainfall on the alluvial fan unit itself. In this situation, management actions in the watersheds above the alluvial fan unit would not be expected to have large impacts on the surface water flow on this fan unit unless those actions changed the ground-water flow to the springs. This situation contrasts with that on other alluvial fan units in the study area where management activities that influenced stream flow might change stream losses and gains on that alluvial fan unit.

Examples of Linkage To Adaptive Management

Hydrologic landscape units are a good foundation for application of adaptive management to mountain basin wetlands, although we are not aware of such units having been so used in any wetland management, nor in aspects of national wildlife refuge management. One example of applying adaptive management to wetlands would be to set an objective based on desired submergent communities and examine how well different water level regimes result in achieving the desired community structure. A second could be to set emergent plant community objectives and assess the effects of grazing or burning or water diversion into irrigation ditches on different hydrologic landscape units. In both cases, hydrologic landscape units can be used as a management and monitoring framework because such units are spatial entities with common, identified, multivariate ecological properties. Even a 50:50 probability of achieving an objective is acceptable. One can begin without any confidence in the model and then, with appropriate monitoring, that confidence can be refined as experiments are implemented over time. The hydrologic landscape unit can also be used to help direct a sampling program which will reduce the uncertainty. A manager might even consider management that would proffer the reduction of uncertainty in the model at the expense of short term achievement of management objectives. The latter case would assume that a more effective model would help improve understanding and reach long term objectives.

Kendall (2001) states that the first premise of adaptive management is understanding the uncertainty in the system, and then working to reduce that uncertainty. The very nature of the similarity within hydrologic-landscape-unit types is the basis for considering them as a framework for adaptive management. Like units can be expected to have similar responses to the same management actions. Because adaptive management is, essentially, conducting management as an empirical experiment, an experimental control at a second spatial location is critical to evaluation of the effects of management actions. Hydrologic landscape units provide a framework for that control. The hydrologic landscape units can be used to guide monitoring efforts and allows the manager to select experimental and control areas. In the example of the Red Rock Creek alluvial fan unit, insights that might reduce uncertainty emerged from the recognition that no blue-line streams cross onto the alluvial fan unit, but that a spring supplies significant water to the surface water features on the alluvial fan unit. In the scheme presented by Kendall (2001) such units help reduce the uncertainty associated with environmental variation and that associated with the spatial component of partial observability. Proper identification of hydrologic landscape units would prevent management experiments from being applied to different sets of abiotic casual factors and therefore avoid the corresponding confounding statistical effects.

An additional way in which hydrologic landscape units can be integrated into adaptive management includes the assignment of the way a hydrologic landscape unit currently functions as an objective. In this way, current function becomes a basis for assessment of management actions. To assess whether the objective is achieved requires the manager to empirically evaluate progress. The hydrologic landscape unit provides a sound basis for monitoring design. This approach is not restricted to the current condition and can be applied to some other desired condition of interest to the manager.

The hydrologic landscape unit is also a good basis to assess whether an abiotic factor such as loss of water through the stream bed is important to the biotic properties in the case where little is known about the interactions. Hydrologic landscape units can inform the manager where to concentrate monitoring efforts for optimum effectiveness and to prevent over and under sampling of specific areas. If monitoring suggests hydrologic landscape units should be revised or refined such changes should be implemented. Our initial identification of units should not be viewed as definitive and can be modified as more detailed information is developed.

CONCLUSIONS

Hydrologic landscape units were developed for Red Rock Lakes National Wildlife Refuge where refuge staff have just begun the development of a comprehensive conservation plan. We have similarly begun to suggest that hydrologic landscape units might be useful in that development, but we are not yet proceeding beyond the current conceptual stage. Four types of hydrologic landscape units were identified in the study area: alluvial fan, interfan, stream alluvium, and basin flat. The units could provide the structure for study of impacts of irrigation diversion on wetlands. Hydrologic landscape units can be used as a management and monitoring framework because such units are spatial entities with common, identified multivariate ecological properties. Because data are sparse, so far we have relied heavily on topography, vegetation, and near surface materials that could be discerned visually from aerial photos and imagery, topographic maps, National Wetland Inventory maps, and field observations. The amalgamation, synthesis, and interpretation of such information can be thought of as a multivariate representation of the landscape, and it is difficult to visualize the all the underlying processes. As such depictions become conceptualized in computer models, hydrologic landscape units can be more effectively used in watershed management simulations. Similarly, we believe that ecosystem models could potentially benefit from the integration of hydrologic landscape units.

Hydrologic landscape units are a conceptual way to describe how a portion of an area functions with respect to atmospheric water, surface water and ground water relations. Hydrologic landscape units provide a useful scientific framework in which to monitor and assess the effects of current or proposed management objectives. This framework produces useful insights into hydrologic system interactions, a basis for monitoring activities to assess management impacts on the wetland system as well as a basis for making informed management decisions by reducing the uncertainty associated with wetland management. This stems from the inherent similarity among units of the same type, and the differences between different units. The conceptual framework provided by hydrologic landscape units is particularly relevant to adaptive management because they are a good foundation for monitoring networks, selection of experimental areas and study controls which are used to test management actions and alternatives. The hydrologic landscape units can be used to guide monitoring efforts. The units can be modified as more detailed information is developed.

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