Challenges in wetland restoration of the western Great Basin

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Western Great Basin wetlands are recharged by surface and underground runoff from mountains. Evapotranspiration is the only mechanism that drains Basin wetlands. Surface modifications to intercept runoff and ground water are the greatest impact to the Basin's wetlands. Restoration of wetlands in the Basin should start with a clear understanding of the site's hydrology, soil, and topography. Wetland managers should have goals and objectives for each restoration project and should ensure that adequate water is available to achieve those goals. Restoration techniques used in the Basin are summarized, including the creation of diked wetlands, excavation strategies, nest island creation, restoration of moist-meadow habitats, and control of alien organisms such as tamarix (*Tamarix* spp.), loosestrife (*Lythrum salicaria*), and carp (*Cyprinus carpio*).

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Introduction

The geologic setting of the Great Basin accounts for the many terms used to describe the region: Intermountain Basins, Basin and Range Country, Sagebrush Desert, High Mountain Desert, and "The Rest of the West." All conjure images of a desolate open expanse with little human habitation. Wetlands are rarely mentioned as an attribute of the western Great Basin (Basin), yet the Basin supports a diverse system of pluvial lakes, playas, marshes, and riparian habitats. Forty-five modern valley lakes occur in the western and central Great Basin, covering 1,001,345 ha (Grayson 1993). These lakes support over 640,000 ha of marshes, playas, and riparian habitats, many critical to the life history needs of North American shorebirds.

Although the Basin's wetland acreage seems high, particularly for an arid region, it is more important to examine where wetlands are located in relation to ongoing efforts to protect and restore them. Characterized as a high-altitude, cold desert, the diversity of Basin habitats makes the region one of the world's most biologically diverse desert ecosystems. Numerous north-south oriented mountain ranges divide the western Great Basin into a series of smaller, isolated basins fed by over 200 drainages. The longest drainage is the Humboldt River, Nevada, which begins in the eastern Basin and terminates in the Humboldt Sink. Other large drainages and basins occur along the eastern flank of the Sierra Nevada-Cascade range.

The western Great Basin is sparsely settled relative to other interior regions of the United States. Nevertheless the Basin's wetlands are under numerous threats from development, ground and surface water diversions, and hydroelectric projects. In this paper we summarize the hydrologic uniqueness of the western Great Basin, past and modern impacts to the wetlands, and offer techniques to restore, protect, and manage this critical continental resource. To understand wetland restoration, it is important to first comprehend the dynamics of the regional hydrology.

Hydrology of western Great Basin wetlands

How western Great Basin wetlands function is critical to understanding what techniques might be employed for restoration and protection. Three factors, 1) location and size of mountains, 2) precipitation rates, and 3) evapotranspitration rates account for the high number of lakes and wetlands north of the 40th parallel, and lack of wetlands to the south (Figure 1).

Effects of mountains

The western Great Basin is dissected by numerous north-south mountain ranges, 33 of which have peaks that exceed 3,000 meters elevation (Grayson 1993). The importance of these peaks in driving the Basin's hydrology and location of wetlands is underscored by the occurrence of the Humboldt River system. The Humboldt River is the largest watershed within the Basin. Its headwaters are in high mountain ranges where rainfall exceeds 40 cm annually (Figure 2).

Elsewhere in the watershed, annual rainfall averages 20 cm. The size of these ranges are small by comparison with the Sierra Nevada and Rocky

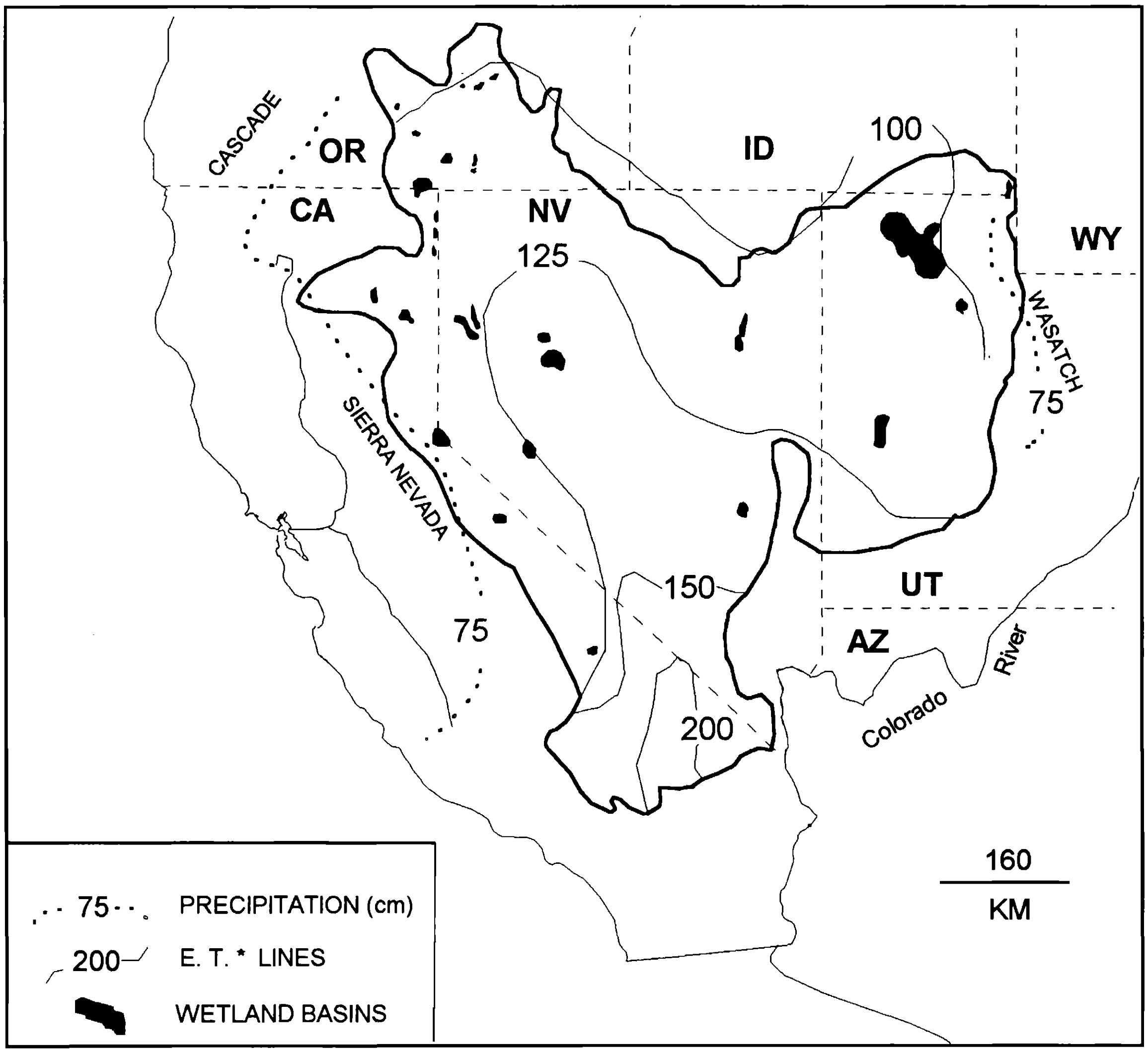


Figure 1. Terminal wetland habitats of the western Great Basin in relation to precipitation and evapotranspiration (E.T.).

Mountains, but combined, they dominate the Basin as geologic features. The front ranges that rim the Basin are associated with the largest wetland complexes (Figure 1). The eastern drainages of the Sierra Nevada support 229,764 ha of lakes (dominated by Mono, Tahoe, Pyramid, and Honey lakes), and the eastern drainages of the Cascades support 415,536 ha (dominated by Abert, Klamath, Goose, and Summer lakes). At 20,000 ha, Malheur Lake (actually a marsh) is the largest inland lake not connected to the three front ranges that rim the Basin (Duebbert 1969). Although lake valleys are more permanent in their water features, numerous playas and sinks also provide important waterbird habitat, particularly for nesting shorebirds. Some of these playas flood and dry on annual cycles (Humboldt and Carson, Nevada), while others only periodically flood (Railroad Valley, Nevada).

Precipitation patterns

The position of mountain ranges and how they intercept and deflect Pacific and Continental generated storms drive the hydrology of the western Great Basin. Pacific storms dominate weather patterns of the western and northern Basin between October and April. Continental and Gulf storms impact the mountains of the eastern Basin and account for 50% of total regional rainfall (Grayson 1993). In between these large storm systems, rainfall totals range from 10 cm to 30 cm (Figure 2). Patterns of rainfall within the western Great Basin are greatly affected by orthography, with ranges creating rain shadows on their lees. The front ranges intercept the majority of precipitation. The Sierra Nevada intercepts most rainfall from westerly low-pressure systems creating a gradient of 150 cm per year in the Desolation Wilderness, California to 20 cm per year in Carson City, Nevada, a distance of 40 km (Durrenberg & Johnson 1976). Typically the crest of front ranges often exceed 75 cm of precipitation per year (Figure 1). This precipitation generally falls as snow and the resulting melt waters account for the majority of wetlands along the front ranges (Figure 1).

Another characteristic of Basin wetlands and lakes is that all are terminal, with no drainage to the ocean. In general, these sinks are fed by surface runoff, which can account for up to 80% of the lake and wetland recharge in a given system (Hoffman 1994). However, many of the Basin marshes are equally impacted by groundwater recharge and not surface runoff. For example, Ruby Marsh, in the eastern Great Basin of Nevada, is annually dependent upon ground water, flowing from at least 25 artesian springs that surface along the eastern base of the Ruby Mountains (Wilson 1986).

Evapotranspiration

Since basins have no outlets, evapotranspiration is the only mechanism (other than diversions by humans) that "drains" its marshes. Evapotranspiration rates in the Basin are among the highest in North America, but vary greatly from north to south. Average evapotranspiration rates in the north are between 86 - 112 cm per year, and in the south between 140 - 215 cm per year (U.S. Dept. of Commerce 1983). Higher temperatures account for the higher rates in the south. Most of the Basin's wetlands and lakes occur north and west of an evapotranspiration rate of the 125 cm per year evapotranspiration line (Figure 1).

Basin lakes and marshes experience hydrologic fluctuations during an annual cycle and among years. Variability is directly associated with the degree of precipitation from the previous snow season. In wet years, numerous shallow basins flood, but in drought years, relatively large playas might dry. These patterns of wet and dry periods are dramatic and unpredictable. For example, since hydrologic records were started in 1938, Malheur Lake, Oregon has ranged in size from 26,800 ha (1952) to 2,800 ha (1962). In 1934, Malheur Lake was dry and farmed. By 1938 the lake had reached 17,200 ha (Duebbert 1969). Even more permanent lakes such as Lake Abert (14,600 ha) and Goose Lake (38,960 ha) have been dry in the recent past (Grayson 1993). In the mid-1980s numerous lakes in the Basin flooded to their highest levels recorded. By the early 1990s, drought greatly impacted many Basin lakes.

Shorebird habitat in western Great Basin wetlands

The importance of Basin wetlands to shorebirds has been discussed in previous chapters. In addition to the high diversity of shorebirds, Basin wetlands account for one of the world's most unique systems of biota. During the late Pleistocene, Basin wetlands

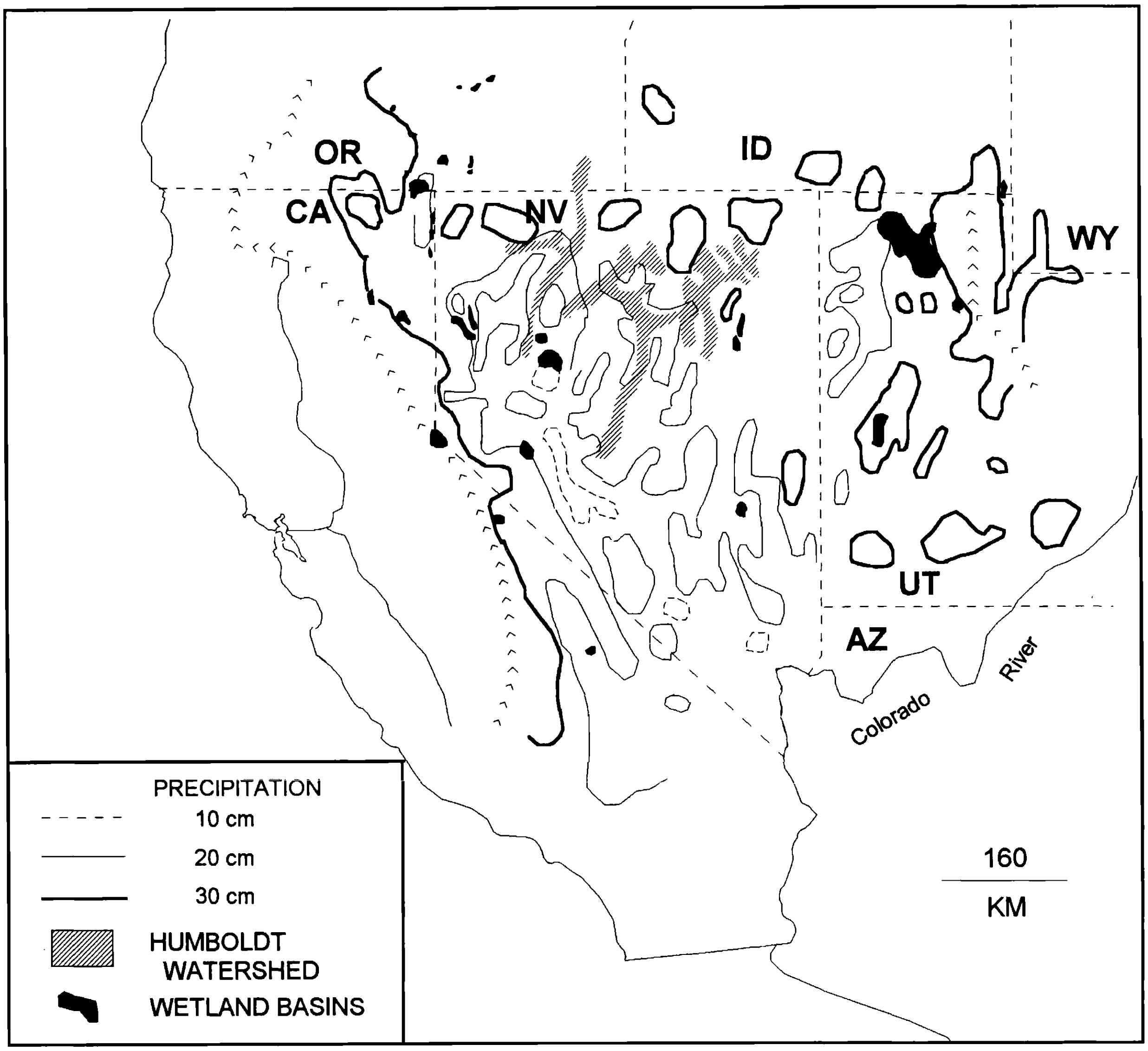


Figure 2. Location of Humboldt River system in relation to rainfall patterns.

were part of a large system of pluvial lakes. During its peak, the Basin held 11,120,000 ha of lakes and wetlands; however, climatic changes have reduced this acreage 90% (Grayson 1993). Inhabited by numerous invertebrates, fishes, amphibians, and other terrestrial vertebrates, major radiations of species resulted from recurrent isolation events that were created by sequential drying periods. There are no bird species endemic to the Basin, although there are numerous species associated primarily with this region (Ryser 1985). Most avian species are associated with the sagebrush and sagebrush-steppe communities of the basin floors and pinyon-juniper woodlands of the mountains.

Basin wetlands are of primary importance to numerous species of waterbirds. For example, the Lahontan Valley provides habitat for the widest diversity and largest populations of migratory and wetland dependent waterbirds in Nevada (USFWS 1994; Jehl 1994; Page & Gill 1994). Although the Basin wetlands have been recognized as important to numerous species of nesting waterbirds, dominated by ducks and shorebirds, they are also a critical staging and migratory area for continental resources of shorebirds and waterfowl (Kadlec & Smith 1989; Ratti & Kadlec 1992; Jehl 1994). This region is of global importance for numerous nesting shorebirds (Oring & Reed, this volume), including: Black-necked Stilt (*Himantopus mexicanus*), Snowy Plover (*Charadrius alexandrinus*), Long-billed Curlew (*Numenius americanus*), and Willet (*Catoptrophorus semipalmatus*). Basin wetlands are also of continental importance for numerous other waterbirds (Table 1). The importance of Basin wetlands thus cannot be overlooked as a critical link among continental resources. Restoration and management of remaining wetland landscapes should be a priority.

Impacts to western Great Basin wetlands

Understanding the threats and degradations that impact these wetlands are critical prior to initiating restoration efforts. Several authors have summarized the impacts on Great Basin wetlands (Kadlec & Smith 1989; Ratti & Kadlec 1992; Jehl 1994; Ducks Unlimited 1994). Many of the modern land uses in the Basin are inconsistent with historic hydrologic patterns of flooding and drought, and so degradation has occurred rapidly. The Reclamation Act of 1902 was the primary vehicle for the beginning of modifications to Basin wetlands. Attempts to harness water resources, both surface runoff and groundwater, were carried out in order to minimize flooding and drought impacts, particularly during periods of climatic extremes (Hoffman 1994). These modifications have resulted in systems that often need human-induced management of wetlands in certain key marsh habitats within the Basin (Kadlec & Smith 1989).

Surface modifications to intercept precipitation and snow-melt runoff have resulted in the single greatest impact to Basin marshes. Water diversion for agriculture accounts for 84% of diversions in Nevada (Hoffman 1994). The water area of the Carson Basin, Nevada was nearly permanent during the 1800s, encompassing 80,000 ha (Hoffman 1994). Water was diverted in 1902 to manage 5,600 ha of irrigated agricultural lands, and by 1990, 23,200 ha were under management (Hoffman 1994). During the drought of 1986 - 1992, water was diverted for agriculture and urban use at the expense of wetlands. Stillwater National Wildlife Refuge, Carson Lake, and Carson Sink were nearly dry, accounting for only 240 ha of

Table 1. Breeding waterbirds of western Great Basin (Sources: AOU 1983, Ryser 1985, Page and Gill 1994).

Primary Importance *Large portion of continental breeding population within the Basin*	***Secondary Importance*** *More widespread, but Basin marshes important to western U.S. populations*	***Minor Importance*** *Present as breeding species, but widespread across the continent*
White-faced Ibis *Plegadis chihi*	Eared Grebe *Podoceps nigricollis*	Pied-billed Grebe *Podilymbus podiceps*
Canada Goose *Branta canadensis*	Snowy Egret *Egretta thula*	Double-crested Cormorant *Phalacrocorax auritus*
Cinnamon Teal *Anas cyanoptera*	Sandhill Crane *Grus canadensis*	American Bittern *Botaurus lentiginosus*
American Avocet *Recurvirostra americana*	Gadwall *Anas strepera*	Black-crowned Night-Heron *Nycticorax nycticorax*
Black-necked Stilt	Trumpeter Swan *Cygnus buccinator*	Green Heron *Butorides striatus*
Snowy Plover	Ruddy Duck *Oxyura jamaicensis*	Great Blue Heron *Ardea herodias*
Long-billed Curlew	Canvasback *Aythya valisineria*	Mallard *Anas platyrhynchos*
California Gull *Larus californicus*	Redhead *A. american*	Green-winged Teal *A. crecca*
	Willet	American Wigeon *A. americana*
	Wilson's Phalarope *Phalaropus tricolor*	Northern Pintail *A. acuta*
	Franklin's Gull *Larus pipixcan*	Northern Shoveler *A. clypeata*
	Ring-billed Gull *L. delawarensis*	Blue-winged Teal *A. discors*
	Forster's Tern *Sterna forsteri*	Ring-necked Duck *Aythya collaris*
	Black Tern *Chlidonias niger*	Lesser Scaup *A. affinis*
	Caspian Tern, *S. caspia*	Virginia Rail *Rallus limicola*
		Sora *Porzana carolina*
		American Coot *Fulica american*
		Killdeer *Charadrius vociferus*
		Spotted Sandpiper *Actitis macularia*
		Common Snipe *Gallinago gallinago*
		Belted Kingfisher *Ceryle alcyon*

wetlands in 1992 (Alberico 1993; Hoffman 1994). In the Klamath Basin of Oregon/California, diversions prior to 1900 to control flooding resulted in a decline from 140,000 ha of wetland to 14,000 ha in the late 1980's (USFWS 1989).

In addition to water diversions, water quality degradations continue in the Great Basin. Dams on the Carson, Walker, Humboldt, and Bear rivers have greatly impacted wetlands in terminal basins. Livestock management is of paramount concern because of traditional grazing on public lands. Livestock are attracted to streams and marshes, contributing to lower water quality and habitat degradation (Heitmeyer 1991). Bank erosion caused by livestock along smaller streams can be severe. Water quality issues in marshes are further complicated as most terminal basins today receive return water from agricultural lands that can lead to nutrient loading, increases in salt concentrations and trace metals, and decreases in water clarity.

Diversion of freshwater tributaries can lead to dramatic degradation of lacustrine wetlands, as seen in Los Angeles' diversion of tributary waters from Owens and Mono Lakes. These diversions over 50 years led to a decline from nearly 1,000,000 waterfowl to about 10,000. Ground water aquifers are impacted by increased urban growth in Las Vegas and Reno-Sparks. Railroad Valley's marshes are currently fed by numerous free-flowing springs. Las Vegas has targeted Railroad Valley's large aquifer as a potential urban source (M. Biddlecomb, Ducks Unlimited, Inc., pers. comm.). Lowering the aquifer of this valley could result in the drying of the area's marshes, including those inhabited by the endangered Railroad Valley Springfish (*Crenichthys nevadae*).

The Basin has long been exploited for its mineral riches to the detriment of ground water aquifers. Massive dewatering efforts associated with modern gold mining operations continue to degrade ground water sources. In addition, milling and leaching operations generate toxic liquid wastes. These waste products are piped to evaporation ponds that attract migrating waterbirds. Several mines have been fined for the adverse impact of these toxic evaporation ponds on migratory birds.

The introduction of the common carp (*Cyprinus carpio*) has presented unique problems for Basin marshes. Carp occur in most major wetlands in the west, can tolerate extreme water temperatures and low oxygen levels, and are responsible for numerous problems in wetlands. Their bottom foraging activities dislodge aquatic plant beds, impact invertebrate masses, and increase turbidity, thus reducing photosynthetic activity by submerged plants (Robel 1961; Ivey 1990). In some western marshes, carp populations account for 90% of the fish biomass (pers. comm. J. Morgan, Portand Metro Department).

Tamarisk (*Tamarix* spp.), a tree native to Eurasia and Africa, was brought to the southwestern U.S. for windbreaks and shade (Kearny & Peebles 1959). This fast growing tree can survive in wetland and alkali habitats and has spread throughout warmer areas in the western United States. Tamarisk can reproduce quickly and completely choke out shallow wetlands and rivers. Once established in waterways, the tree's dispersal strategy, which is to send out numerous, tiny seeds, quickly infests ponds and streamside riparian habitats. Managers are often forced to forgo certain water sources or completely dry out ponds in an attempt to control tamarisk. Unfortunately, the conditions for shorebird spring migration are low water levels and tacky mudflats, a condition suited for tamarisk regeneration. As such, areas that are managed for shorebirds are usually the first to become overgrown.

Restoration of western Great Basin wetlands

Water availability is the limiting factor for most wetland managers in the Basin. Wetland management therefore has become a commonly accepted practice (Kadlec & Smith 1989). In order to mimic the natural hydrologic cycle of spring runoff and progressive drying through the summer, managers must have adjudicated water rights. Even then, access is not guaranteed as water rights often exceed availability.

The critical need for wetland management in the Basin received new interest and focus with creation of the Intermountain West Joint Venture (IMJV). The IMJV targeted 161,000 ha for primary protection and restoration (Ratti & Kadlec 1992). Restoration goals range from creation of impoundments and water control projects to reestablishing natural hydrologic connections between basins and creeks.

Already efforts to restore and create wetlands at river and spring inlets have met with some success, including a portion of the 400 ha Railroad Valley Wetlands, Nevada, the 1,560 ha River's End project at Lake Abert, Oregon, and the 3,160 ha Warner Lakes Project, Oregon. These projects are being accomplished through multi-partner efforts involving state, federal, and non-profit organizations. Because of this success, wildlife agencies and non-profit organizations, like Ducks Unlimited, Inc. (DU), have developed policies to cluster refuges around viable river and stream inlets to terminal basins, not within basin bottoms alone.

The largest, most complex, and perhaps the most important restoration project in the Basin involves the Lahontan Valley, Nevada. This massive area includes Stillwater National Wildlife Refuge, Carson Lake, which is managed by the Nevada Division of Wildlife, and various other federal, state, and private lands. For a history of this critical area, a summary of its wildlife, and further discussion of efforts to purchase water for it, see Neel & Henry, this volume.

Wetland construction: levees, dikes, and spillways

Before creating impoundments, managers should consider soils, hydrology, topography of the restoration site, water circulation, water control, and pond bottom elevations (Charney *et al.* 1995).

Certain dike and levee designs can provide excellent habitat for shorebirds. Levees should have gentle side-slopes. In most Basin marshes, levees needed to impound water for shorebirds need not exceed 90 cm in height. The required height would be predicated on the area's topography. Side slopes of levees should be designed for a 5:1 to 10:1 slope. A 90 cm high levee, with a 3.6 m top width, then would have a width of 13 m (5 m+3 m+5 m) for 5:1 slope and 21 m (9 m+3 m+9 m) for a 10:1 slope. Gradual slopes provide suitable foraging habitat in a linear band around the impoundment.

The areas of the impoundment that can provide the dirt necessary for levee construction (borrow sites) should be selected with care. Two strategies can be employed (Figure 3). A borrow site on the high elevations of the pond should be identified. Borrowing from the high elevations will lower that area accordingly. It is important that finished elevations produce desired water depths when flooded. Another strategy is to borrow along the length of the levee. Here a set-back of 15 to 30 m allows marsh vegetation to grow between levee and borrow channel. The borrow should have shallow slopes (15:1) and should not exceed the desired depths for shorebird use. Borrow channels should also be wide enough to allow access of conventional farm equipment for disking or other physical manipulations.

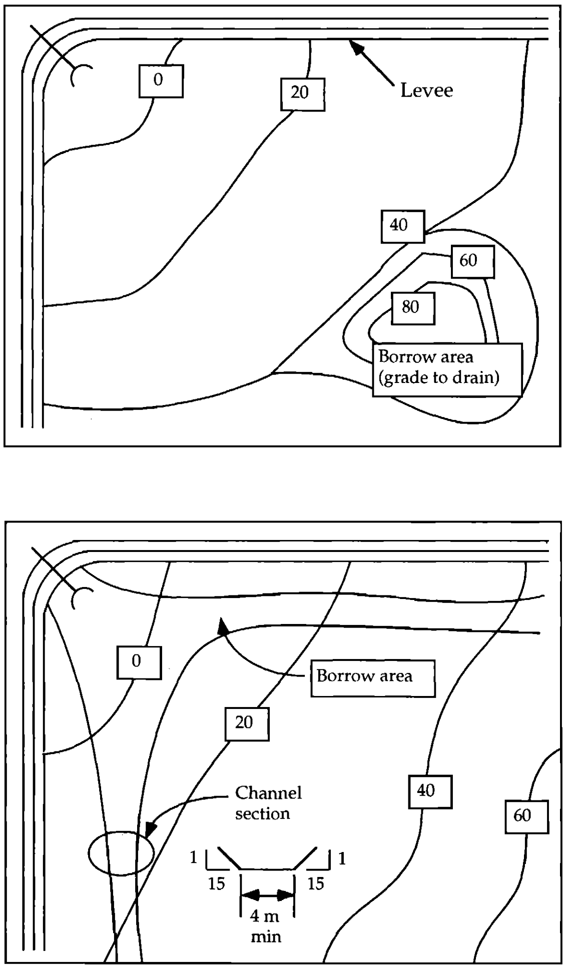


Figure 3. Dirt borrow strategies for diked wetland construction. Boxed numbers are relative units of elevation.

The soils must be characterized to determine if, when innundated, they will seal since soil types vary enormously in their water holding capacity (Figure 4). Auger boring tests can determine the extent of the confining clay layer and characterize soil horizons. Where clay is to be used for levee construction or is to be excavated, thickness of the clay layer must be determined. A clay content of 10% is essential for levee construction while clay content greater than 30% is considered ideal. If sand forms a lens underlying the confining clay layer, it is imperative that the clay layer not be breached. If it is, a drain is created and the water holding capacity of the impoundment is compromised. The adequacy of the site's soils for levee construction should be tested by an engineer prior to construction.

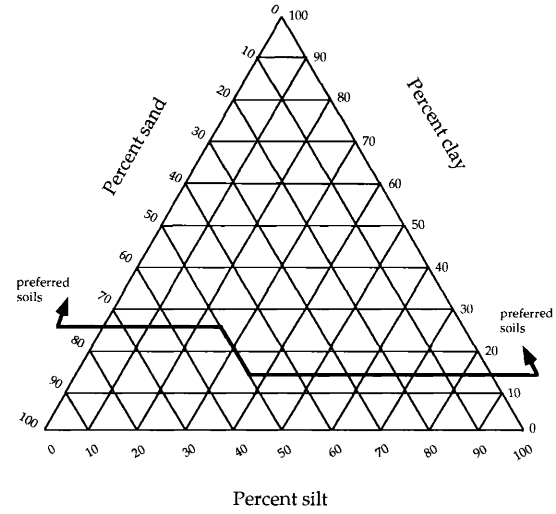


Figure 4. U. S. Department of Agriculture soil triangle chart.

Though lack of water is the most important problem facing Basin wetlands, periodic flooding wreaks havoc with management efforts. In the mid 1980s, floods obliterated many ponds, levees, and control structures. The key to survival of these facilities is spillway design that can relieve flood water pressure. Spillways vary from low, earthen areas on dikes to geoweb-lined dikes and concrete structures. Spillways should be designed by engineers based on hydrologic data of inflowing streams. Spillways in the Basin generally are sized to accomodate a 50 to 70 year flood event, but some larger ones accomodate a 100 year event.

Wetland construction: vegetation removal

One of the primary goals of managed wetlands is to create a set of conditions to manage water levels and control marsh vegetation. In systems where the ground remains saturated, levees may not be a cost effective alternative for restoration and control. Numerous techniques have been employed in Basin refuges (Kadlec & Smith 1989, Fredrickson & Dugger 1993). Blasting to provide openings should not be employed in playas and marshes, because blasting can compromise the clay layer and drain the site. Also, usable habitat is reduced due to the coneshaped profile of blast holes (Fredrickson & Dugger 1993). Removal of vegetation using herbicides followed by burning can be effective. The success of herbicide applications varies with plant species, time and methods of application, and concentrations. The manufacturer of the selected herbicide should be contacted to determine these variables.

Excavation of overgrown vegetation to re-open a marsh can be expensive, but is logistically possible, even in wet conditions. As with blasting, great care in not breaching the clay layer must be taken. Equipment operating on specially designed mats to allow for access into marshes can be used to reopen channels, ponds, and create a diverse shoreline. Excavation of vegetation mats and root balls may be all that can be accomplished without compromising the clay layer. If the marsh is too deep for mats, several floating machines can be employed. Aquamogs and cookie-cutters can be used when water depths are 30 cm. These machines have variable attachments to allow for the mulching of root masses, vegetative materials, and woody plants. All the above techniques can maintain desired interspersion for years after application, the result of shortened growing seasons in the Basin (Kadlec & Smith 1989; Fredrickson & Dugger 1993).

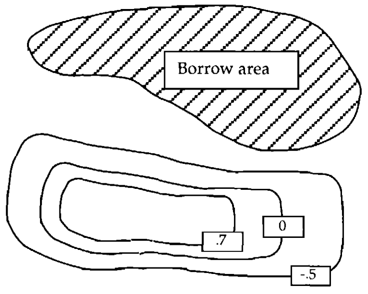
Wetland construction: upland habitat

The creation and management of moist-meadow habitat and other grassy wetlands to provide upland nesting habitat for shorebirds remains a challenge in the Basin. Several techniques have been employed to provide permanent water for waterfowl and other deep water nesting species, but few have attempted shallow habitat or moist-meadow management. Several shorebirds prefer to forage and nest in moist meadow or shallow emergent marsh. Moist meadows can be managed to provide for flooded spring conditions benefiting shorebirds, cranes, rails, and Black Terns. The completion of the waterbird breeding season can then allow managers to dry and mow or graze the meadows to provide for upland foraging species such as geese, cranes, and curlews. Key to any moist-meadow restoration is the flexibility to use water when needed. Wells are often employed, but stream diversions can be utilized for at least portions of the summer. A similar infrastructure used by ranchers to flood pastures can be employed on refuges. Parallel checks can send water down the meadow, and small levees can impound the water to accommodate depths to 15 cm. Most areas use a delivery ditch with 15 - 30 cm wide culverts with slide gates to allow for water control. In higher elevations, *Juncus*, *Eleocharis*, and graminae species dominate moist-meadow habitats as at Modoc NWR, California and Ruby Lake NWR, Nevada. Lower elevation areas with poorer soils can be dominated by salt grass (*Distichlis*) and sedges (*Carex* and *Scirpus*) as in Railroad Valley, Nevada and Honey Lake State Wildlife Area, California. Areas with better soils can provide excellent upland grass and legume mixtures. Ogden Bay State Wildlife Area, Utah has experimented with various mixtures and has found native bunchgrass and western wheatgrass (*Agropyron smithii*) mixtures inter-seeded with legumes provides excellent upland cover. Great Basin wild rye (*Elymus cinereus*) has shown great success in meadow management areas.

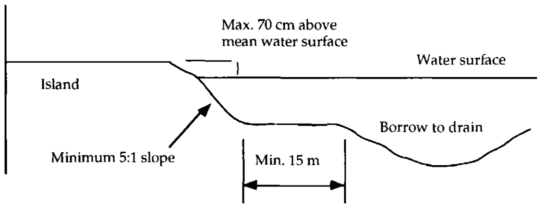
Braided meadows have been restored in the Basin, created by establishing a network of small spillways within a drainage way. Two areas where braided meadows have been restored are Wanakut Wildlife Area, Oregon (managed by the Umatilla Indian Reservation) and at DeChambeau Ponds, Mono Lake, California. At Wanakut, area managers breached several irrigation channels to spread water across a meadow. The water sought its own channels, creating swells and flooded grassy habitat. Common Snipe and Wilson's Phalaropes nest as well as Cinnamon Teal, Mallard, Sora, and Long-billed Curlew.

Wetland construction: nesting islands

Also of importance for shorebirds has been the management of nesting islands within units. Again several configurations can be utilized, but those most successful for shorebirds are shallowly sloped and low. The shoreline, if terraced to create shallows, can provide excellent foraging habitat for adult and young shorebirds. Past efforts to build islands have involved pushing material into a mound and creating a deeper "trench" around the island. A more effective technique would be to build the island utilizing strippings or excess soil from borrow areas. If this cannot be accomplished, then select a borrow area off one side of the island allowing a 15 m minimum buffer between the island and the borrow area. The result is a shallower base habitat near the island and a sloping shoreline (Figure 5).



Plain view of island



Section view of island and borrow

Figure 5. Typical nest island profile showing preferred dirt borrow location. Boxed numbers are relative units of elevation.

Managing islands for shorebirds requires periodic vegetation manipulation. Usually a pond has a complex of islands, including densely vegetated islands for species such as waterfowl, and open islands, where vegetation is removed for nesting Killdeer, stilts, and avocets. Management plans can be developed that allow for fall burning of island vegetation. Burnt islands will green-up in spring, providing short grassy habitat for shorebird nesting. The only Basin wildlife area to employ a shorebird nesting island management program has been the Jay Dow, Sr. Wetlands, at Honey Lake, California. The University of Nevada, Reno has continued to rotate island cover from open to dense vegetation and shorebird nesting has been maintained for five years. Even Greater Sandhill Cranes have nested on these islands.

Most nesting islands are surrounded by permanent water which limits land predators, but predation by gulls, harriers, owls, and herons can limit reproductive success. To combat this, islands should not be too small to behaviorally limit predator avoidance displays used by shorebirds. Quantitative data to show when island size becomes limiting to successful shorebird reproduction are not available. Numerous shapes of nesting islands have been employed, but there are no shapes that work best. The creation of nesting islands should have three basic parameters driving their final configuration: optimal shoreline, distance to other islands and shore, and slope. For these reasons, several wildlife areas use a sinuous or hourglass shape for islands, limit their height from 30 cm to 60 cm above maximum water levels, and establish a slope with a minimum 5:1 ratio (Figure 5).

Alien organisms

The control of alien animals and plants has become a paramount issue for wetland managers. Managers at Malheur NWR and Lahonton Valley are concerned about carp. Waterfowl production at Malheur NWR prior to carp invasion peaked at 147,000 birds in 1948. Since then, annual production of ducks has declined to 30,000; the decline was attributed to carp increases (Ivey 1990). Nationally, losses of aquatic vegetation beds to carp have resulted in declining waterbird production rivaling bird loss due to diseases such as botulism (Ratti & Kadlec 1992).

Carp can be controlled using rotenone poisoning, draw-downs (if possible), and eliminating re-invasion pathways, *e.g.*, via fish screens. Rotenone provides short-term benefits, but its use must be accompanied by eliminating re-invasion routes. Rotenone treatments at Malheur NWR resulted in a temporary increase of sago pond weed (*Potamogeton pectinatus*) from 830 ha to 4,930 ha, with an increase of diving duck use days from 807,000 to 3,000,000 (Ivey 1990).

Tamarisk poses a great threat to shallow wetland management in the Basin. Variable water levels, a common occurrence in the Basin, provide ideal conditions for tamarisk. The ability to maintain water levels is essential for successful control. However, as with carp, the re-invasion route must be dealt with. Here is where tamarisk control has met its biggest challenge, and no solutions have been offered to date.

A similar threat, purple loosestrife (*Lythrum salicaria*), is invading the Basin from the north. This plant is already a problem in the Columbia Basin, and efforts by the state and federal government to contain it have had limited success. Control of loosestrife has centered around eradication of the plant through herbicide applications and physical manipulation coupled with water control. The minute and profusely produced seeds of purple loosestrife make re-invasion control a real challenge because seeds stick to the bodies of migratory birds and are widely dispersed. In the mid 1990s biological control showed some promise in the war against purple loosestrife (D. Kraege, Washington Department of Fish and Wildlife, pers. comm.).

Diseases

The incidence of disease, especially avian cholera and botulism Type C, in the Basin has been well documented for waterfowl (Kadlec & Smith 1989). At one Great Basin site, the Great Salt Lake, the 1994 cholera outbreak killed tens of thousands of birds, including shorebirds. The control of both diseases lies with adequate water control and removal of carcasses. Adequate water control and flow are needed to reduce the threat of disease outbreaks. When designing impoundments three conditions must be met in order to minimize stagnant water and associated disease outbreaks: 1) adequate water must be available to allow for replenishment through the long, hot summer and falls, 2) adequate drains and control structure should be provided to maximize circulation, and 3) inflow areas should not be too close to outflow structures, thus minimizing "dead areas" in a pond.

Conclusion

Wetlands of the Basin are a biologically valuable, but often overlooked, continental resource. Continued protection and ongoing efforts to restore some of these wetlands will be a fluid process. As scientists and managers increase their understanding of Basin marshes, new techniques for restoration can be developed. It is critical that managers outline project goals and coordinate efforts with other Basin managers. The IMJV provides a dynamic network for managers across the Basin, particularly when dealing with shorebirds. Some practices widely used for waterfowl can be employed for shorebirds. These include moist-meadow management, nesting island management, and modified impoundment development. The project goals should be met by examining the variables critical to a successful restoration project including: historic and current hydrology (ground and surface), soils, and water management capabilities.

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References

Alberico, J. A. 1993. Drought and predation cause avocet and stilt breeding failure in Nevada. *Western Birds* 24: 43-51.

American Ornithologists' Union. 1983. *Check-list of North American birds, 6th edition*. American Ornithologists' Union. Washington, D. C.

Anglin, A., & Shellhorn G. 1992. *Great Basin wetlands, a concept paper.* Unpub. U. S. Fish and Wildlife Service document, Fallon, Nevada.

Charney, R. L, Well, J. R., Engilis, A., Jr., Reid, F. A., & Goebel, P. 1995. *A guide to wetland restoration on private land. Valley habitats: A tech. guide.* Series no. 4. Ducks Unlimited, Inc., Sacramento, California.

Dahl, T. E. 1990. *Wetland losses in the United States, 1780s to 1980s.* U. S. Department of the Interior, Fish and Wildlife Service, Washington, D. C.

Ducks Unlimited, Inc. 1994. *Ducks Unlimited continental conservation plan: An analysis of North American waterfowl populations and habitats, Part II*, pp. 135-314. Ducks Unlimited, Inc., Memphis, Tennessee.

Duebbert, H. F. 1969. *The ecology of Malheur Lake and management implications.* Bureau of Sports Fisheries and Wildlife, U. S. Fish and Wildlife Service. Washington, D. C.

Durrenberger, R. W., &. Johnson, R. B. 1976. *California: Patterns on the land*, 5th ed. Mayfield Publ. Co., Palo Alto, California.

Fredrickson, L. H., &. Dugger, B. D. 1993. *Management of wetlands at high altitudes in the Southwest.* U. S. Department of Agriculture, Forest Service, Southwest Region, Washington, D. C.

Fredrickson, L. H., & Reid, F. A. 1990. Impacts of hydrologic alteration on management of freshwater wetlands. In: *Static wetland management symposium*, pp. 71-90. 51st Midwest Fish and Wildlife Conf., West Lafayette, Indiana.

Grayson, D. K. 1993. *The desert's past: A natural prehistory of the Great Basin.* Smithsonian Inst. Press, Washington, D.C.

Hayward, C. L., Cottam, C., Woodbury, A. M., & Frost, H. H. 1976. Birds of Utah. *Great Basin Naturalist Memoirs.* No. 1.

Heitmeyer, M. E. 1991. Wetlands and cattle grazing: Impacts and management considerations for waterfowl. In: F. M. Byers (ed.), *Cattle on the land: A conference.* Texas A&M University Press, College Station.

Helmers, D. L. 1992. *Shorebird management manual.* Western Hemisphere Shorebird Reserve Network, Manomet, Massachusetts.

Hoffman, R. J. 1994. *Detailed study of irrigation drainage in and near wildlife management areas, West-Central Nevada, 1987-90. Part C. Summary of irrigation-drainage effects on water quality, bottom sediment, and biota.* U. S. Geological Survey Rep. No. 92-4024-C.

Ivey, G. 1990. The need for carp eradication on Malheur NWR. *Issue Paper, Feb. 7, 1990, Malheur National Wildlife Refuge.* Princeton, Oregon.

Jehl, Jr., J. R. 1994. Changes in saline and alkaline lake avifaunas in western North America in the past 150 years. *Stud. Avian Biol.* 15: 258-272.

Kadlec, J. A., & Smith, L. M. 1989. The Great Basin marshes. In: L. M. Smith, R. L. Pederson, and R. M. Kaminski (eds.), *Habitat management for migrating and wintering waterfowl in North America*, pp. 451-474. Texas Tech. University Press, Lubbock.

Kearney, T. H., & Peebles, R. H. 1959. *Arizona flora.* University of California Press, Berkeley.

Page, W. P., & Gill, R. E., Jr. 1994. Shorebirds in western North America: Late 1800's to late 1900's. *Stud. Avian Biol.* 15: 147-160.

Ratti, J. T., & Kadlec, J. A. 1992. *Concept plan for the preservation of wetland habitat of the Intermountain West.* U. S. Fish and Wildlife Service, Portland, Oregon.

Robel, R. J. 1961. The effects of carp populations on the production of waterfowl food plants on a western waterfowl marsh. *Trans. North Amer. Widl. and Nat. Resour. Conf.* 26: 147-159.

Ryser, Jr., F. A. 1985. *Birds of the Great Basin: A natural history.* University of Nevada Press, Reno.

U. S. Department of Commerce. 1983. *Climatic atlas of the United States.* Environ. Data Serv., U. S. Dept. of Commerce, Washington, D. C.

U. S. Fish and Wildlife Service. 1989. *Concept plan for waterfowl habitat protection Klamath Basin, Oregon and California.* Portland, Oregon.

U. S. Fish and Wildlife Service. 1994. Stillwater Marsh National Wildlife Refuge management plan: Provisional draft. Portland, Oregon.

Wilson, J. L. 1986. *Ruby Lake National Wildlife Refuge, Ruby Valley, Nevada: Management plan.* U. S. Fish and Wildlife Service, Portland, Oregon.