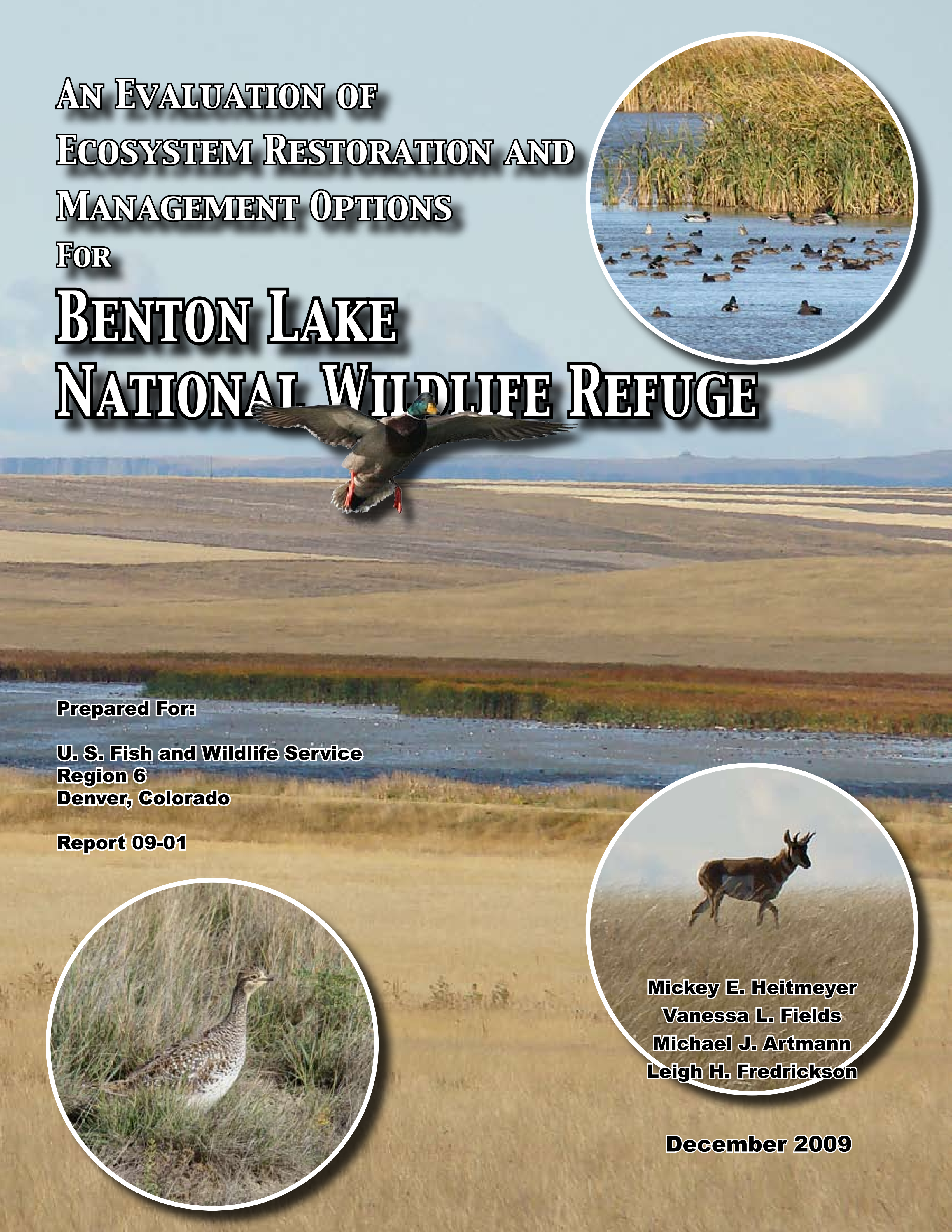

AN EVALUATION OF ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS FOR

BENTON LAKE NATIONAL WILDLIFE REFUGE

Prepared For:

U. S. Fish and Wildlife Service
Region 6
Denver, Colorado

Report 09-01

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Mike Artmann

EXECUTIVE SUMMARY

Benton Lake National Wildlife Refuge (NWR) contains 12,383 acres on the western edge of the Northern Great Plains about 12 miles north of Great Falls, Montana. The dominant feature on the NWR is the 5,600 acre shallow lake bed, known as Benton Lake, created during the last Pleistocene glacial period. This large wetland is hydrologically closed; most natural runoff in the Benton Lake Basin drains to Benton Lake proper and the basin has no natural outlet.

Although established in 1929, Benton Lake NWR was not developed or staffed until the early 1960s. Prior to development, water levels in Benton Lake historically fluctuated seasonally and annually depending on annual patterns of precipitation and runoff. During wet years Benton Lake contained more extensive surface water area and supported large numbers of breeding and migrating waterbirds, especially dabbling ducks. In contrast, during dry years, less water was present and fewer birds were present. Because of a desire to support more predictable and frequent flooding, and waterbird abundance, during summer, Benton Lake NWR constructed extensive water source, conveyance, and management systems. These developments and other hydrological and topographic alterations on Benton Lake NWR and surrounding lands have gradually altered this ecosystem by increasing concentrations of contaminants, especially selenium; siltation and alteration of the topography of the historic lake bed, altered vegetation communities and increased presence of invasive species;

periodic outbreaks of botulism; and decreased presence and productivity of waterbirds.

In 2009, the U.S. Fish and Wildlife Service began preparation of a Comprehensive Conservation Plan for Benton Lake NWR. This planning process is being facilitated by a contemporary evaluation of ecosystem restoration and management options using Hydrogeomorphological Methodology (HGM). This report uses the HGM approach to obtain and use historic and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) plant and animal communities, and 6) physical anthropogenic features of NWRs and surrounding landscapes with the following objectives:

1. Identify the pre-European settlement ecosystem condition and ecological processes.

2. Evaluate changes in the Benton Lake ecosystem from the pre-settlement period.

3. Identify restoration and management options and ecological attributes needed to successfully restore specific habitats and conditions in the area.

The Benton Lake Basin, including the Benton Lake bed depression, was formed during the last Pleistocene glacial period when ice sheets dammed the ancestral Missouri River and formed glacial Lake Great Falls. Glacial drift associated with this ice sheet was deposited northeast of Benton Lake and created a hydrologically closed basin where most surface water ultimately flowed into Benton Lake and no outlet was present. Gently dipping sedimentary bedrock underlies the Benton Lake deposits; this bedrock is mostly seleniferous marine shale of the Cretaceous Colorado Group. Most geomorphic surfaces at Benton Lake are Quaternary Lake deposits, with secondary alluvium-colluvium deposits at the mouths of Lake Creek (the primary drainage into Benton Lake) and other small tributaries. Quaternary terraces adjoin Benton Lake and high ridges contain older Cretaceous outcrop deposits. Soils at Benton Lake are mostly clays and silt clays deposited in lacustrine conditions. Topography at Benton Lake NWR reflects dominant geomorphic surfaces including the relatively flat historic lake bed, alluvial fans, and older terraces and ridges.

The Benton Lake Basin is semiarid with 70-80% of annual precipitation and runoff occurring April to September. Historic water levels in Benton Lake were strongly unimodal, with peaks in early summer followed by gradual declines to low stable levels in fall and winter. In addition to strong seasonal patterns of flooding, Benton Lake had evidence of long recurring 15-20 year patterns of peaks and lows in regional precipitation, runoff, and water levels. Natural water inputs to Benton Lake come primarily (65-70%) from the Lake Creek watershed.Deeper ground water beneath Benton Lake is confined to the aquifer within the Colorado Shale formation, which is poor quality. Historically, low annual precipitation was captured quickly and used by native grassland; little water moved deeply into soil and subsoil layers. Consequently, deposition of salts and elements, including selenium, from Cretaceous formations did not historically accumulate to high levels in Benton Lake.

Historic vegetation communities at Benton Lake ranged from dense emergent wetland species in low elevations to upland grassland on terraces and ridges. The gradation of communities included robust emergent, sedge-rush, seasonal herbaceous, wet grassland, and upland grassland habitat types. A rich diversity of animal species historically used the Benton Lake ecosystem; waterbird abundance and productivity was tied to seasonal and long-term patterns of water levels.

The Benton Lake ecosystem was relatively unchanged from historical condition until the late 1880s, when initial settlement of the area occurred. Early attempts to ditch, drain, and farm the Benton Lake bed were unsuccessful and little conversion of native grassland to agricultural crops in the surrounding area did not occur until the 1920s following development of the Sun River Irrigation Project. Much native grassland was converted to dry-land crop/fallow rotation from

1930 to 1950 and this farming practice gradually increased the number and severity of saline seeps in the region, and ultimately the discharge of selenium into Benton Lake.

Benton Lake NWR was established in 1929, but little development or management occurred until the early 1960s, when the area was staffed and a major water pumping and conveyance system was constructed to bring irrigation return flow from Muddy Creek 15 miles to Benton Lake. In addition to the pump station and conveyance system, the historic Benton Lake bed was divided into six pools by dikes, levees, and water-control structures to facilitate more predictable and prolonged flooding regimes in summer for breeding waterfowl. Water management on Benton Lake NWR from the early 1960s through the late 1980s typically sought to regularly pump water from Muddy Creek to Benton Lake to extensively flood most wetland pools for prolonged periods; relative amounts pumped from Muddy Creek compared to natural runoff from Lake Creek varied substantially among years related to annual precipitation and runoff.

More permanent water regimes in Benton Lake gradually changed vegetation communities to more water tolerant types, increased selenium accumulation, promoted expansion of invasive plant species, and increased severity and occurrence of avian botulism. Water management at Benton Lake since the early 1990s has reduced pumping during summer and attempted to create more seasonal water regimes, except in Pools 1 and 2, which continue to be managed for permanent flooding and water storage. A model of selenium cycling within Benton Lake pools indicates continued accumulation in Pools 1 and 2 and near saline seeps in Pool 4c unless water regimes are restored to more seasonal patterns in these areas and seeps are reduced. Vegetation communities at Benton Lake also contain increasing amounts of the aggressive introduced creeping foxtail.

Based on the HGM data obtained and analyzed in this report, future management of Benton Lake NWR should seek to:

1. Maintain the physical integrity of the hydrologically closed Benton Lake Basin and emulate more natural seasonally- and annually-dynamic water regimes within Benton Lake proper.

2. Control and reduce accumulation of salts and contaminants, especially selenium.

3. Restore and maintain the diversity, composition, distribution, and regeneration of historic wetland and upland vegetation communities in relationship to topographic and geomorphic landscape position.

4. Provide functional complexes of resource availability and abundance including seasonal food, cover, reproductive, and refuge resources for key animal species.

Specific recommendations to meet ecosystem restoration goals identified above are provided and include:

- Retain the closed nature of Benton Lake proper and protect watersheds and drainage routes of its tributaries.

- Restore natural topography and reconnect water flow corridors and patterns where possible. This recommendation suggests careful evaluation of the need for existing levees, roads, water-control structures and the pool configuration with removal of those not desired for future management.

- Manage Benton Lake water levels (with or without the current or altered pool configuration) for more natural seasonal and annual water regimes.

- Restore natural hydroperiods to Benton Lake proper and balance seasonal and long-term inputs from Muddy Creek pumping vs. natural runoff in the Lake Creek watershed.

- Encourage and participate in conservation programs in regional watersheds to reduce the extent and severity of saline seeps.

- Evaluate vegetation manipulation techniques for possibilities of reducing accumulation of selenium.

- Restore more natural distribution and composition of native plant communities.

- Control expansion of invasive plant species, especially creeping foxtail.

- Provide a rotational complex of wetland habitats and seasonal resources.

- Protect native terrace and upland grasslands.

- Maintain functional seasonal refuges.

Future management of Benton Lake NWR that incorporates the recommendations of this report can be done in an adaptive management framework where: 1) predictions about community restoration and water quality/quantity are made relative to specific management actions and then; 2) follow-up systematic monitoring and evaluation are implemented to measure ecosystem responses and to suggest future changes or strategies based on the monitoring data. Critical issues that need this monitoring include:

1. Restoring seasonally- and annually-dynamic water regimes.

2. Salt and selenium accumulation levels.

3. Long-term changes in vegetation communities related to changed water management.

4. Endemic and invasive species.

HISTORICAL PHOTOS

FROM BENTON LAKE NATIONAL WILDLIFE REFUGE ARCHIVES

East side of Benton Lake, 1938

Coulee June 9, 1938 NW side of Benton Lake

1938

Notes about these pics:
"On April 14, the coulee in the northwest portion of the Benton Lake Refuge had water in it for a distance of about five miles and a width of about 20 ft. On June 9, this coulee was practically dry, with the exception of small potholes in its deeper portions (*top right here*). On June 30, just after unusually heavy rains the lake bed itself had some water."

HISTORICAL PHOTOS

FROM BENTON LAKE NATIONAL WILDLIFE REFUGE ARCHIVES

Refuge Manager's wife with flower garden, 1954

Cattle guards, barley field, unknown date

Grazing domestic livestock controlling cattail growth, unknown date

Benton Lake Unit II on left, Unit I on right, unknown date

INTRODUCTION

Benton Lake National Wildlife Refuge (NWR), owned and managed by the U.S. Fish and Wildlife Service (USFWS), contains 12,383 acres on the western edge of the Northern Great Plains about 50 miles east of the Rocky Mountains and 12 miles north of Great Falls, Montana in Cascade and Chouteau counties (Fig. 1). Established in 1929 by Executive Order, Benton Lake NWR was created as "a refuge and breeding ground for birds." The name "Benton Lake" refers to the dominant feature of the NWR, which is a ca. 5,600 acre shallow wetland "lake bed" created during the last Pleistocene glacial period. This large wetland lies within the 146 mile^2 Benton Lake Basin, which is hydrologically "closed"; most natural runoff drains to Benton Lake proper and the basin has no outlet. About 6,800 acres of upland on Benton Lake NWR surround Benton Lake. Benton Lake NWR is recognized as a wetland ecosystem of importance by the North American Waterfowl Management Plan and Western Hemisphere Shorebird Reserve Network. Nineteen bird species of concern, classified by the Montana Natural Heritage Program, currently or historically used habitats and resources on the refuge. Despite alterations to this ecosystem, Benton Lake remains one of the finest examples of a large, closed, wetland basin in the Great Plains of the western United States.

Although Benton Lake NWR was established in 1929, the refuge was not staffed until 1961; until that time the refuge was administered by the National Bison Range located in western Montana. Water levels in Benton Lake historically fluctuated seasonally and annually depending on annual patterns of precipitation and runoff. During wet years Benton Lake contained more extensive surface water area and supported large numbers of breeding and migrating waterbirds, especially dabbling ducks. The large abundance of waterfowl present on Benton Lake in wet years was a primary factor leading to the recognition of the ecological importance of the area and ultimate motive for establishment of the NWR. During dry years, less water was present in Benton Lake and fewer birds were present. Because of a desire to support more predictable and frequent flooding of the lake bed during summer water for breeding waterbirds, Benton Lake NWR constructed water source, conveyance, and management systems

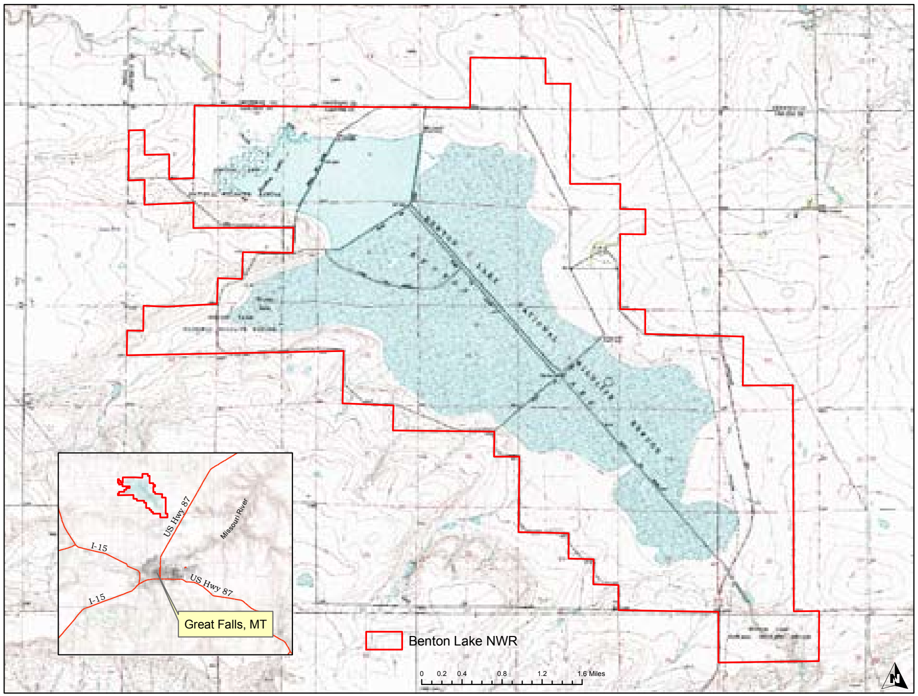

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Figure 1. General location map of Benton Lake National Wildlife Refuge.

beginning in the late 1950s and early 1960s. This water "system" included a pump station and pipeline that moved irrigation return flow from Muddy Creek, about 15 miles to the west, to Benton Lake. Water from Muddy Creek was moved about 5 miles through an underground pipeline over a low drainage divide and then discharged into the Lake Creek natural drainage channel where it flowed about 12 miles to its mouth in Benton Lake.

The historic Benton Lake bed was divided into 6 "pools" or water management "units" by dikes/levees, ditches, and water-control structures from 1960 to 1962. Since the early 1960s, management of Benton Lake NWR has focused on managing water and wetland vegetation within Benton Lake, mostly to enhance waterfowl production and migration habitat. Management of uplands also has occurred to sustain native grassland communities, provide nesting cover for waterfowl, and provide forage/cover for native birds and mammals. Over time the refuge developed a series of roads that provide access to refuge lands and also constructed numerous parking lots, building complexes, walk-ways into wetlands, and excavations in wetland pools to create nesting islands, drainage ditches, and deeper open water areas.

The combination of hydrological and topographic alterations on Benton Lake NWR and land use changes in the watershed areas surrounding the refuge have gradually altered this ecosystem and created many management challenges to sustaining historic Benton Lake plant and animal communities. Ecological issues that have developed over time at Benton Lake NWR include increased concentrations of contaminants, especially selenium; siltation and altered topography of the historic lake bed; altered vegetation communities; increased distribution and abundance of invasive species; periodic botulism outbreaks that cause high mortality of waterbirds in some years; and decreased presence and productivity of waterbirds (e.g., Hultman 1991, Nimick 1997, Thompson and Hansen 2002).

In 2009, the USFWS began efforts to prepare a Comprehensive Conservation Plan (CCP) for Benton Lake NWR. The CCP process seeks to articulate the management direction for the refuge for the next 15 years and it develops goals, objectives, and strategies to define the role of the refuge and its contribution to the overall mission of the National Wildlife Refuge system. At Benton Lake NWR, the CCP process is being facilitated by a contemporary evaluation of ecosystem restoration and management options using Hydrogeomorphological Methodology (HGM). HGM now is commonly used to evaluate ecosystems on National Wildlife Refuges (e.g., Heitmeyer and Fredrickson 2005, Heitmeyer et al. 2006, Heitmeyer and Westphall 2007) by obtaining and analyzing historic and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) plant and animal communities, and 6) physical anthropogenic features of refuges and surrounding landscapes. Specifically, HGM analyses for Benton Lake NWR: 1) uses the above information to develop appropriate, realistic, and sustainable "habitat-based" objectives for the refuge; 2) seeks to emulate natural hydrological and vegetation/animal community patterns and dynamics within the Benton Lake Basin ecosystem; 3) understands, complements, and at least partly mitigates negative impacts and alterations to Benton Lake and surrounding lands; 4) incorporates "state-of-the-art" scientific knowledge of ecological processes and requirements of key fish and wildlife species in the region; and 5) identifies important monitoring needs of abiotic and biotic features.

This report provides HGM analyses for Benton Lake NWR with the following objectives:

1. Identify the pre-European settlement ecosystem condition and ecological processes in the Benton Lake region.

2. Evaluate changes in the Benton Lake ecosystem from the pre-settlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.

3. Identify restoration and management options and ecological attributes needed to successfully restore specific habitats and conditions within the area.

Karen Kyle

THE HISTORIC BENTON LAKE ECOSYSTEM

GEOLOGY, SOILS, TOPOGRAPHY

The geology of the Benton Lake Basin is characterized by gently dipping sedimentary bedrock overlain in many places by unconsolidated glacial and alluvial deposits (Maughan 1961). Bedrock in most of the Benton Lake Basin is seleniferous marine shale of the Cretaceous Colorado Group, often referred to as "Colorado Shale." The Colorado Group, in ascending order, consists of the Lower and Upper Cretaceous Blackleaf Formation and the Upper Cretaceous Marias River Shale. These formations are dark-gray shale with some interbedded siltstone, standstone, and bentonite. The combined thickness of both formations is about 1,500 feet (Condon 2000). A second bedrock unit, the Upper Cretaceous Montana Group, is exposed along the western margin of the Benton Lake Basin and consists of relatively non-seleniferous mudstone, siltstone, and sandstone. Unconsolidated deposits in the basin are mostly Quaternary gravel terraces, 4-50 feet thick, deposited by an ancestral Sun River and glacial material. These deposits underlay the topographically isolated "Greenfields Bench", which is a prairie plateau of Cretaceous age (Vuke et al. 2002). Detailed geologic mapping has been completed for the Benton Lake area (Maughan 1961, Lemke 1977, Maughan and Lemke 1991) and includes the extent of the last Pleistocene continental ice sheet into the region (Alden 1932, Colton et al. 1961).

The last Pleistocene ice sheet dammed the ancestral Missouri River and formed glacial Lake Great Falls, which covered low-lying parts of the Benton Lake region. Glacial lake deposits near Benton Lake are primarily clay and silty clay and are up to 100 feet thick (Lemke 1977). Glacial drift associated with the last ice sheet was deposited northeast of Benton Lake and east of Priest Butte Lakes and formed the "closed" Benton Lake Basin and the Benton Lake bed depression that received most water runoff in the basin. Glacial drift deposits are primarily glacial till consisting of unsorted and unstratified clay, silt, sand, and some coarser material. Locally, glacial drift includes stratified sand and gravel alluvial deposits (Mudge et al 1982, Lemke 1977).

Most geomorphic surfaces on Benton Lake NWR are Quaternary lake "Ql" deposits from glacial Lake Great Falls and the Benton Lake depression (Fig. 2). A second surface of Quaternary alluvium and

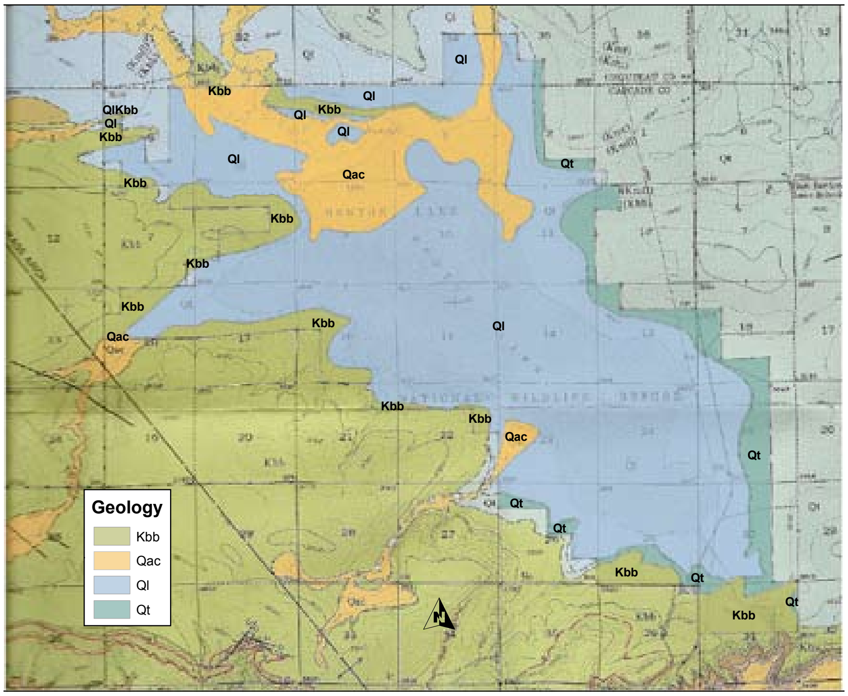

Figure 2. Geomorphology maps of the Benton Lake region (from Maughan 1961)

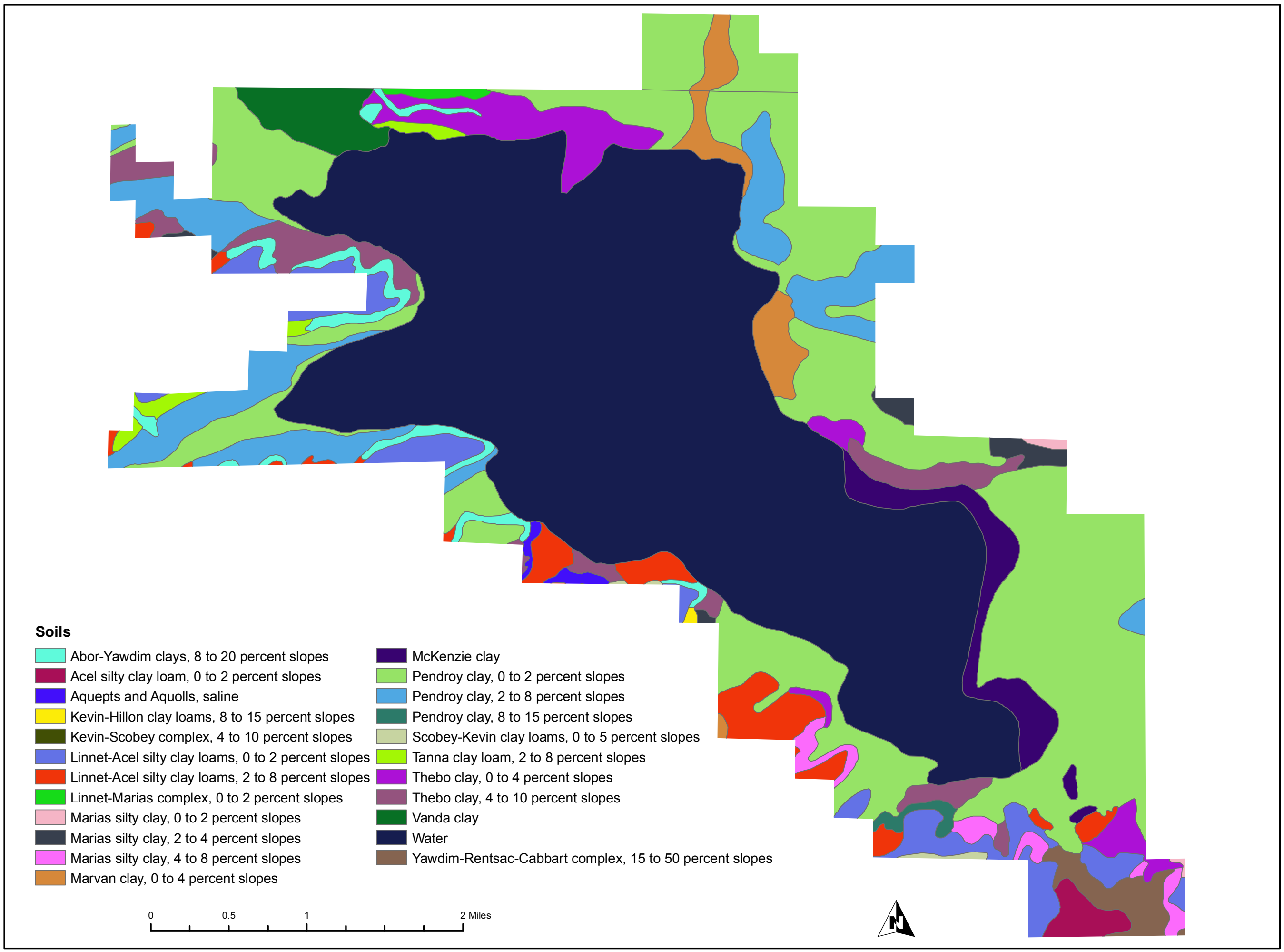

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Figure 3. Soils on Benton Lake National Wildlife Refuge (from U.S. Department of Agriculture, Natural Resources Conservation Service www.websoilsurvey.nrcs.usda.gov).

colluvium "Qac" deposits covered a small area along the Lake Creek drainage on the north, and a small tributary drain on the southwestern, sides of Benton Lake. "Qac" deposits are comprised of local stream and sheetwash alluvium, floodplain and tributary channel alluvium, and undivided colluvium (Vuke et al. 2002). "Qac" deposits were formed by overbank deposition and scouring of sediments along the drainages that entered Benton Lake and resemble small natural levee and alluvial/colluvial fans that are slightly higher elevation than the adjacent "Ql" deposits within the current Benton Lake bed. Some "Qac" deposits date to about 6,800 years before the present (BP) (Bacon 1983, Vuke et al. 2002). Alluvial Quaternary terrace "Qt" deposits occur on the upland edges of the historic Benton Lake bed, and are most extensive on the east side of the lake. Most "Qt" terraces were formed by glacial till Holocene deposits and extend to the Sun River, Muddy Creek, and Teton River regions (Maughan and Lemke 1991). The highest ridges on the west side of Benton Lake NWR are Bootlegger Member (Upper Cretaceous) "Kbb" deposits (named after the Bootlegger Trail north of Great Falls). Upper portions of "Kbb" contain well cemented beds of sandstone and siltstone interbedded with dark-gray silty shale and several yellowish-gray bentonite beds. These upper regions of "Kbb" contain abundant fish scales and fish bones in some locations and indicate historic marine and lacustrine environments. The middle parts of "Kbb" deposits are dark-gray shale with some fine-grained, medium-gray sandstone and bentonite. The basal parts of "Kbb" deposits are mostly light-gray, fine-to medium-grained sandstone separated by dark-gray silty shale. "Kbb" deposits range from 150 to 330 feet thick.

Surface soils at Benton Lake NWR are predominantly clays and silty clays deposited in the lacustrine environments of glacial Lake Great Falls and Benton Lake (Fig. 3). "Ql" lacustrine-type soils consist mostly of plastic clays and exceed 100 feet deep under

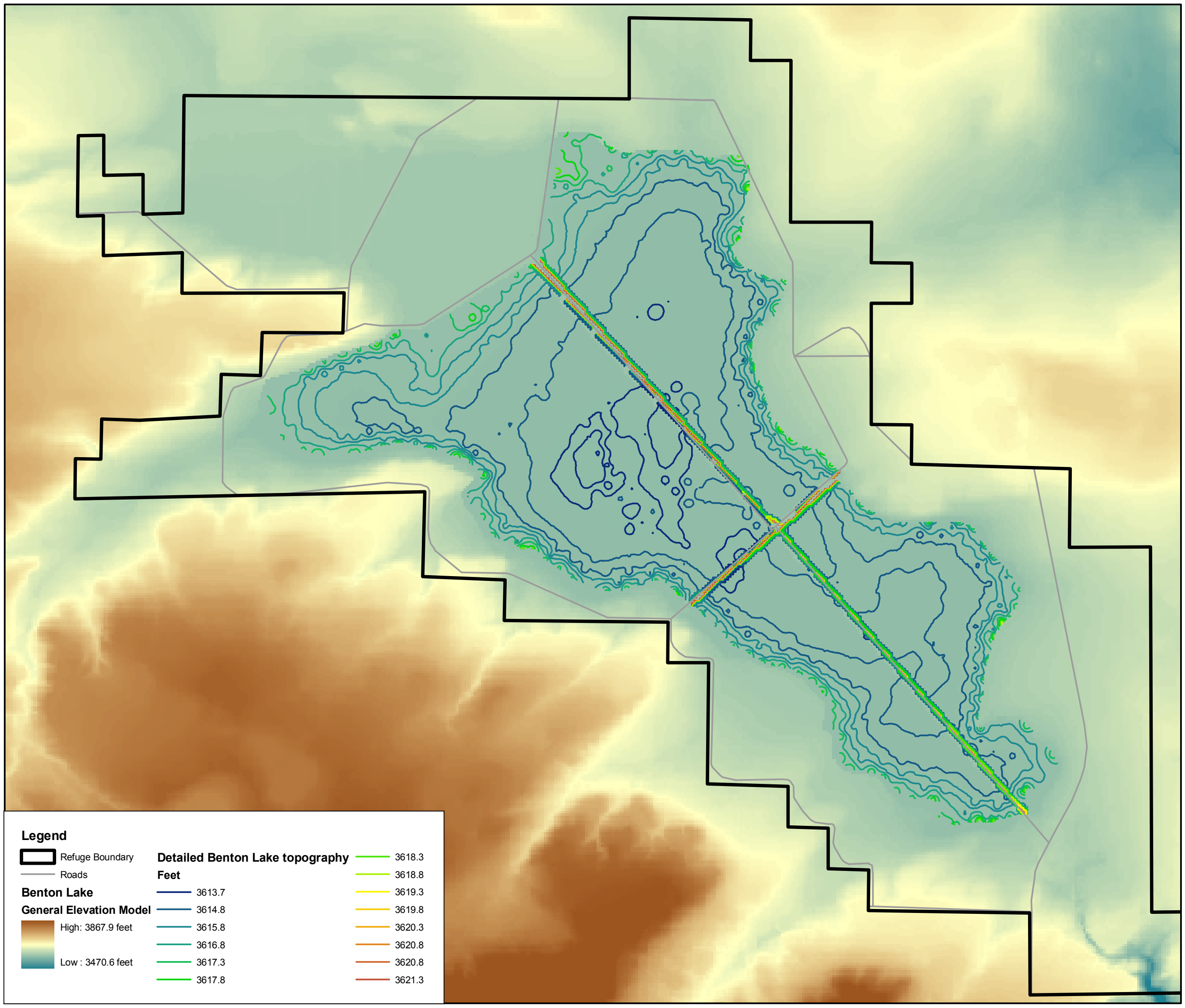


Figure 4. General elevation map of the Benton Lake region.

parts of Benton Lake. "Qac" soils are mostly silt and sand with minor clay and gravel present in soil stratigraphy. Thickness of "Qac" soils ranges from 10 to 40 feet where they then become intermixed with underlying lacustrine-type deposits. "Qt" terrace-type soils are mostly 10-30 feet thick clay loam types overlying reddish-brown, poorly sorted sand and gravel dominantly of subangular to slabby sandstone and subrounded quartzite, shale, granite, and argillite (Maughan and Lemke 1991). "Kbb" surfaces have interesting, stratified soils indicating various depositions from historic marine environments, Lake Great Falls, and underlying Colorado Shale (Condon 2000).

The topography of Benton Lake NWR reflects the dominant geological surfaces and features of the region. Within Benton Lake proper, elevation gradients are relatively subtle ranging from about 3,614 feet above mean sea level (amsl) in the lowest depressions in the middle of the historic lake bed to about 3,622 feet amsl on the edge of the lake that defines its "full-pool" water level (Fig. 4). A detailed elevation map of the south part of Benton Lake prepared in the early 2000s indicates several deeper depressions historically were present in the lake bed, and likely reflected glacial scouring when the basin was created. The "Qac" surfaces along Lake Creek and the small tributary on the southwest side of Benton Lake are 2-8 feet higher than Benton Lake surfaces and form the small alluvial fans in these areas. "Qt" terraces range from about 3,622 to 3,700 feet amsl and the "Kbb" ridges on the edge of the

Benton Lake Basin rise to about 3,850 feet amsl. In general, the gradual sloping of the historic Lake Great Falls region and the contemporary Benton Lake bed produced a low-gradient topographic and hydrological setting within the closed Benton Lake Basin. This low gradient and closed system produced relatively little scouring and depositional surfaces within the basin, with the small exception of the slightly raised alluvial fan/natural levee along Lake Creek where it entered Benton Lake.

CLIMATE AND HYDROLOGY

The climate of the Benton Lake region is generally characterized by pleasant summers with warm, mostly sunny, days and cool nights (National Oceanic and Atmospheric Administration (NOAA) 2009). Winters are cold but warmer than expected for its latitude because of frequent Chinook winds; average wind speed for the year is 14.2 miles/hour (Clark et al. 1979). Sub-zero weather normally occurs several times during a winter, but the duration of cold spells typically lasts only several days to a week after which it can be abruptly terminated by strong southwesterly Chinook winds. The sudden warming associated with these winds can produce temperature rises of nearly 40 degrees in less than a day. Conversely, strong intrusions of bitterly cold arctic air moves south from Canada several times each winter and can drop temperatures 30 to 40 degrees within 24 hours. The dynamic Chinook winds prohibit large accumulation of snow over winter and reduce large spring runoffs, because snow melts in smaller increments throughout winter and is mostly absorbed into the ground. The average annual daily maximum temperature at Great Falls is 45.3 degrees Fahrenheit (Table 1). Average frost-free days that define the growing season at Great Falls is 121 days usually ranging from mid April to mid September (Table 2).

Table 1. Mean annual and monthly temperatures and precipitation at Great Falls, Montana (from Clark et al. 1979).

Month	Temperature				Precipitation
	Average daily maximum[1]	Average daily minimum[1]	2 years in 10 will have at least 4 days with--		
			Maximum temperature equal to or higher than--[2]	Minimum temperature equal to or lower than--[2]	Average[1]
	°F	°F	°F	°F	In
January	29.3	11.6	48	-25	0.9
February	35.9	17.2	57	- 2	0.8
March	40.4	20.6	63	- 3	1.0
April	54.5	32.3	70	+ 8	1.2
May	65.0	41.5	82	+23	2.4
June	72.1	49.5	93	+32	3.1
July	83.7	54.9	94	+42	1.3
August	81.8	53.0	95	+38	1.1
September	70.0	44.6	89	+23	1.2
October	59.4	37.1	75	+14	0.7
November	43.4	25.7	59	-15	0.8
December	34.7	18.2	54	-20	0.7
Year	45.9	33.8			15.2

[1] Period of record 1941-70.

[2] Period of record 1961-70.

The Benton Lake Basin is classified as "semiarid" with 70-80% of total annual precipitation falling during April to September (about 10 inches of rainfall at this time, Table 1). Highest rainfall months are May and June. Precipitation generally falls as snow during winter, late fall, and early spring. Rain intermittently occurs during these periods, but freezing rain is rare. Average annual precipitation at Great Falls is 14.98 inches. During the period of record at Great Falls, yearly precipitation extremes have ranged from 25.24 inches in 1975 to 6.68 inches in 1904. Average snowfall is 63.5 inches. Thunderstorms occur on about 50 days each year, about 90% during May-August. The sun shines about 64% of possible time during the year ranging from 46% sun in November to 80% sun in July. Average relative humidity at 5:00 am ranges from 63% in July and August to 74% in June; relative humidity at 5:00 pm ranges from 62% in January to 29% in August.

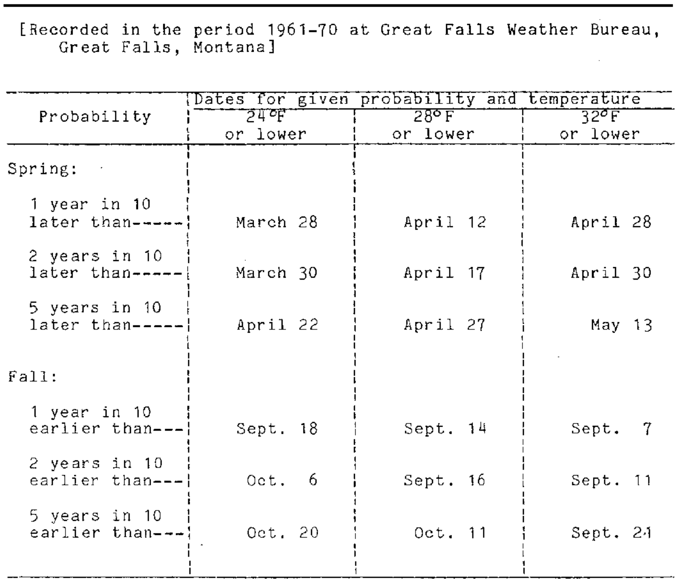
Long-term temperature and precipitation data indicate dynamic patterns of recurring peaks and lows. Regional precipitation decreased and temperatures rose from the late 1910's to the late 1930s (NOAA 2009). A steady rise in precipitation and declining temperatures occurred from the early 1940s to the mid 1950s followed by another decline in precipitation and local runoff in the 1960s. Precipitation rose again during the late 1970s and early 1990s, and remained about average during the 1980s and late 1990s to early 2000s (Fig. 5). Regional precipitation appears to be gradually increasing again in the late 2000s.

Because Benton Lake is a closed basin, natural water inputs to the lake come primarily (average of 65-70% of annual natural input) from the 137 mile^2 Lake Creek watershed (Fig. 6); the remainder is derived from on-site precipitation and runoff from several small local drainages and surrounding uplands. Surface water entering Benton Lake historically flowed across the lake bed in a "sheetflow" manner to gradually inundate lowest depressions first and then spread to higher lake bed surfaces and eventually to alluvial benches and lake-edge terraces as more water entered the basin during wet seasons and years.

Generally, the hydrological regime in Benton Lake mirrors seasonal and long-term regional precipitation patterns (e.g., Nimick 1997). Natural runoff from Lake Creek into Benton Lake is strongly correlated with seasonal and annual precipitation in the region (Fig. 5). Consequently, historic water levels in Benton Lake basin were highly dynamic and had a strong seasonal pattern of increased water inputs and rising water levels in spring and early summer followed by gradual declines during summer and fall. This seasonal flooding pattern was superimposed on a long term pattern of regularly fluctuating peaks and lows in precipitation, runoff, and water levels in the lake at 15-20 years intervals (Fig. 7). Historic records, articles, General Land Office (GLO) survey notes, and aerial photographs indicate Benton Lake had high water levels in the early 1920s, late 1930s, and late 1950s prior to major water delivery and control infrastructure developments on Benton Lake NWR in the late 1950s and early 1960s (e.g., Fig. 8). Since the 1960s, high runoff and flooding conditions at Benton Lake occurred in the mid 1970s and early 1990s (Fig. 5). These wet, highly flooded periods, at Benton Lake were intercepted by dry periods when the lake bed was mostly dry during the late 1920s and early 1930s, late 1940s, early 1960s, mid 1980s, and late 1990s and early 2000s.

Lake Creek, the largest tributary to Benton Lake, is an intermittent, ephemeral, stream with greatest flows during spring and early summer following snowmelt and increased spring rains. Although ground-water discharge maintains a small base flow in Lake Creek and some of its tributaries during spring and fall, and sometimes in wet summers, most ground water discharged to seeps and tributaries does not reach Benton Lake (Nimick 1997). Natural runoff in Lake Creek and other small tributaries to Benton Lake generally is a magnesium-sodium-sulfate type water and is acidic (Nimick 1997). During periods of greater regional precipitation and

Table 2. Mean number of frost-free days annually at Great Falls, Montana (from Clark et al. 1979).



[Recorded in the period 1961-70 at Great Falls Weather Bureau, Great Falls, Montana]

Probability	Dates for given probability and temperature		
	24°F or lower	28°F or lower	32°F or lower
Spring:			
1 year in 10 later than-----	March 28	April 12	April 28
2 years in 10 later than-----	March 30	April 17	April 30
5 years in 10 later than-----	April 22	April 27	May 13
Fall:			
1 year in 10 earlier than---	Sept. 18	Sept. 14	Sept. 7
2 years in 10 earlier than---	Oct. 6	Sept. 16	Sept. 11
5 years in 10 earlier than---	Oct. 20	Oct. 11	Sept. 21

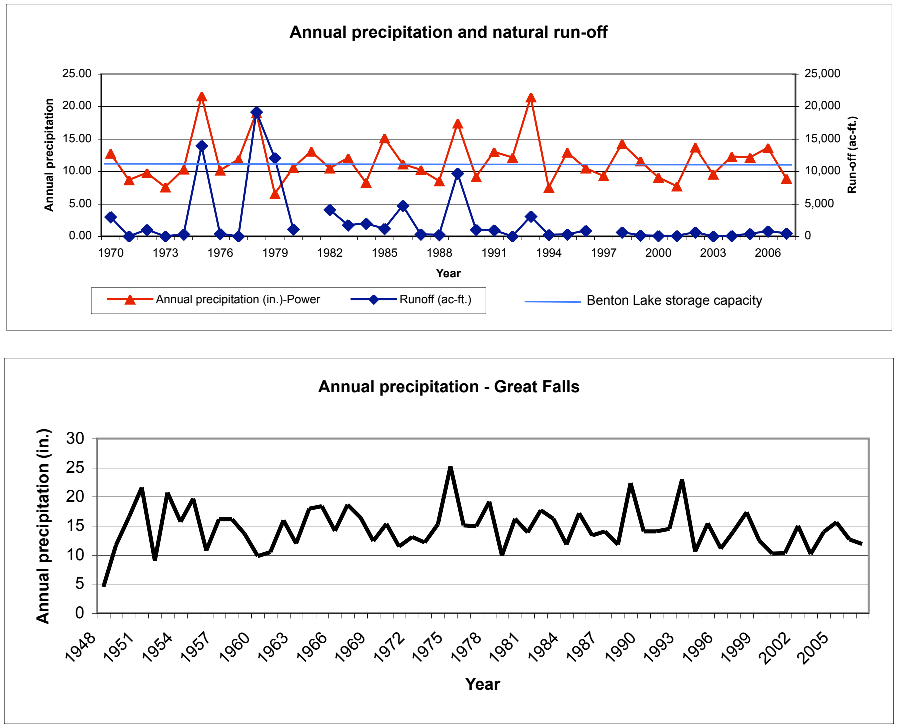


Figure 5. Long term precipitation at Great Falls and Power, Montana and annual runoff from Lake Creek into Benton Lake (from NOAA 2009 and USFWS, Benton Lake National Wildlife Refuge, unpublished files).

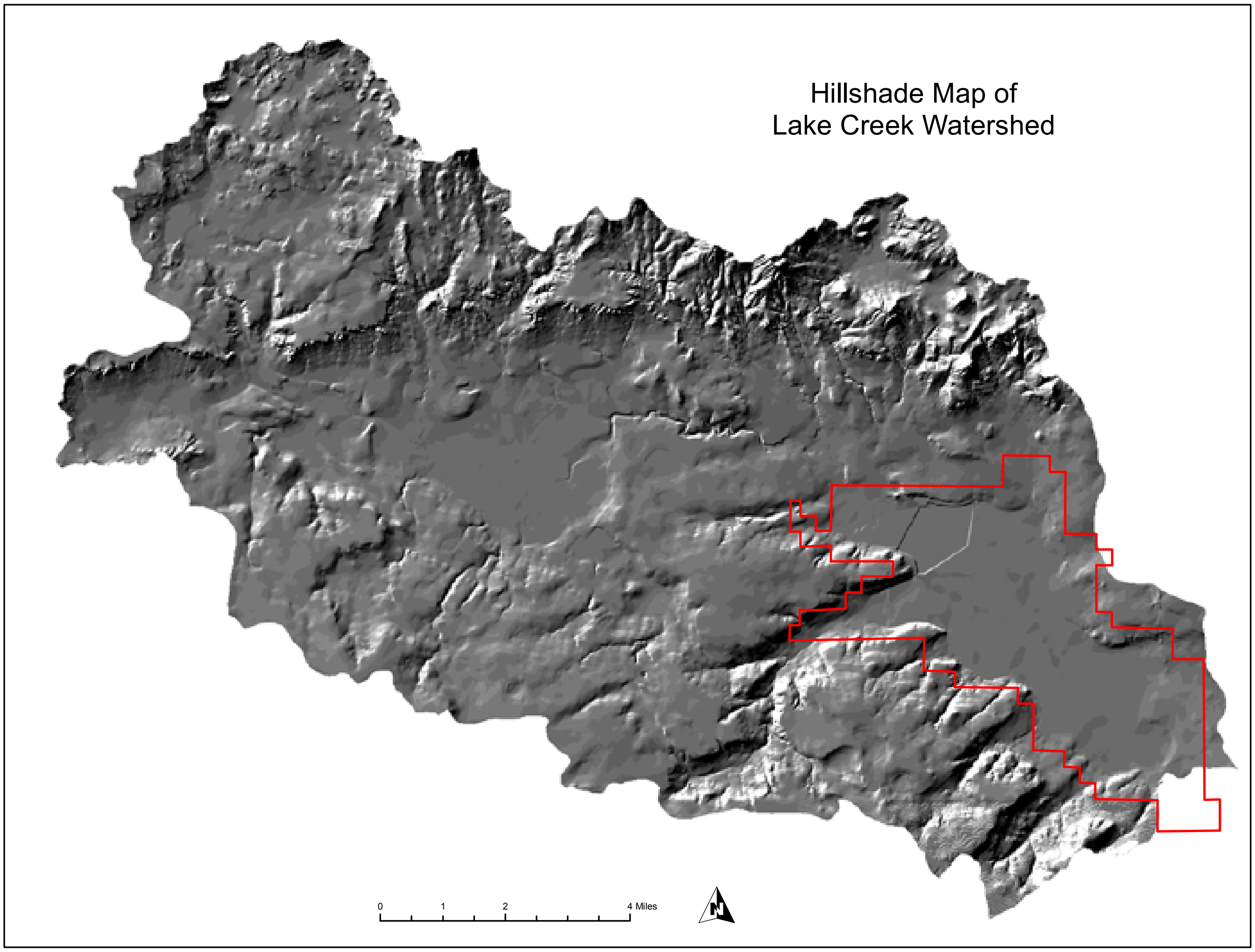


Figure 6. Lake Creek watershed map.

snowmelt runoff, more relatively dilute water flowed in Lake Creek and entered Benton Lake (Fig. 5) and periodically caused very high water levels, e.g. peak levels in 1954 (Fig. 8). Typically, regional precipitation and runoff declined for several years following precipitation peaks, and annual water levels in Benton Lake gradually declined to low levels due to evapotranspiration, which averages about 40-41 inches/year (U.S. Soil Conservation Service 1970). Surface water remaining in Benton Lake during dry seasons and years was confined to the lowest elevation depressions (e.g., GLO 1920).

The ground water aquifer beneath the Benton Lake Basin is confined mainly to the basal Colorado Shale formation (Nimick 1997, Miller et al. 2002). A number of sandstone beds, which are porous and transmit water freely, occur in this formation. Water quantity in this aquifer is poor quality; chloride concentrations are low, dissolved-solid concentrations are moderate, pH is basic (8-9), sulfate and bicarbonate are predominant anions, redox conditions are reducing, and selenium levels are low (Nimick 1997). The poor quality of this deep aquifer discouraged well drilling for water sources in the region and a basin-wide potentimetric-surface map is not available. Shallow ground water (< 100 feet deep) in the Benton Lake region has different chemical constituents than the deep Colorado Shale aquifer; shallow water typically is acidic with higher levels of calcium, sulfate, chloride and magnesium. The thick lacustrine-type clay surfaces in Benton Lake prohibit water movement, or recharge, from the lake into ground water (Nimick et al. 1996, Nimick 1997). Other ground water in the Benton Lake Basin appears to move slowly to the east and discharges to some shallow wetland depressions between Benton Lake and the Missouri River (Nimick 1997).

Historically, the relatively low annual amount of surface precipitation falling on uplands surrounding Benton Lake was typically was captured quickly and used by native grassland; little water moved deeply into soil and subsoil layers. Where water did percolate downward, it subsequently moved slowly into aquifers and occasionally exited slopes as springs or saline seeps. The historically sparse saline seeps in the Benton Lake Basin undoubtedly discharged dissolved solids and elements like selenium into basin streams and drainages into Benton Lake at certain times. Deposition of salts and elements in Benton Lake did not historically accumulate to high levels, however, because of elemental volatilization in water, sediment, and wetland plants during dry periods of the long-term hydrological cycle (Zhang and Moore 1997a). Higher temperatures, higher airflow, drier sediments, and decomposition of wetland plants increase removal rates of selenium. Additionally, selenium volatilization is more efficient in seasonally flooded wetland areas than in permanently flooded wetlands. Eventually, salts and elements in annually dynamic western wetlands, with functional seasonal and long-term hydrology, such as in the historic Benton Lake, reach a dynamic equilibrium where the amount of salts and elements removed by wind erosion and volatilization equaled the amount of input and solute accumulation or movement into deeper lakebed sediments from diffusion and advection (Zhang and Moore 1997b).

VEGETATION COMMUNITIES

Historic vegetation communities on Benton Lake NWR ranged from dense emergent wetland vegetation in the lowest elevation depressions of Benton Lake to upland grassland on higher elevation terraces and benches adjacent to the lake bed (Figs. 9, 10; Appendix A). This gradation of plant communities is typical of wetland basins in the Northern Great Plains of Montana (Hansen et al. 1995). Plant species distribution reflected tolerance to timing, depth, and duration of annual flooding, salinity, and underlying soils and geomorphic surfaces (Table 3). The precise distribution of historic wetland vegetation species groups in Benton Lake proper undoubtedly varied over time as surface water coverage and depth changed in the long-term wet to dry cycles (e.g., Van der Valk and Davis 1978, Van der Valk 1989). The relative juxtaposition of historic plant communities occurred along a wetness continuum where specific groups expanded or contracted and moved either up or down elevation gradients as water levels rose and fell in Benton Lake over time (Table 4). Further, some communities with specific distribution associations, such as saltgrass that was associated with higher alkaline or saline conditions, also probably changed locations somewhat over time depending on intensity and location of saline seeps as saline conditions in the lake became more or less concentrated/diluted during more extreme flooding vs. drawdown phases of the long term hydrological cycle.

Table 3. Hydrogeomorphic (HGM) matrix of historic distribution of vegetation communities/habitat types on Benton Lake National Wildlife Refuge. Relationships were determined from land cover maps prepared by the GLO (1920), geomorphology maps (Maughan 1961), soils maps prepared by NRCS, hydrological data (NOAA and USFWS, Benton Lake National Wildlife Refuge, unpublished files), and various naturalist/botanical/settler accounts and publications from the late 1800s and early 1900s.

Habitat Type	Geomorphic surface[a]	Soil type	Flood frequency[b]	Elevation[c]
Robust emergent	Ql	clay	A-PM	< 3614.5
Sedge/rush 3615.7	Ql	clay	A–SP	3614.6 –
Sedge/rush alkaline 3615.7	Qac	clay	A–SP	3614.6 –
Seasonal Herbaceous 3616.3	Ql	silt-clays	A–SE	3615.8 –
Cordgrass/ saltgrass 3616.3	Qac	silt-clays	A–SE	3615.8 –
Wet grassland 3622	Ql	silty/clay	I–SE	3616.4 –
Wet grassland alkaline 3622	Qac	silty/clay	I–SE	3616.4 –
Upland Grassland	Qt and Kbb	silty clay	R	3622

[a] Ql = Quaternary lake, Qac = Quaternary alluvium/colluviums, Qt = Quaternary terrace, Kbb = Cretaceous Bootlegger.

[b] A–PM = annually flooded permanent, A-SP = annually flooded semipermanent, A-SE = annually flooded seasonal, I-SE = irregularly flooded among years seasonal, R = rarely if ever flooded.

[c] Feet above mean sea level.

Table 4. Temporal occurrence of representatives from six plant communities on alluvial fans and depressional wetlands in a closed basin during wet and dry seasons.

	Alluvial Fan		Low Depression		High Depression	
	Wet Year	Dry Year	Wet Year	Dry Year	Wet Year	Dry Year
Robust emergents	0	0	X	X	X	0
Sedge/rush	X	X	0	X	X	X
Seasonal herbaceous	X	X	0	X	X	0
Wet grassland	X	0	0	0	X	0
Upland grassland	0	X	0	0	0	X

Recognizing the annual variation in flooding regimes and latent chronological and distribution response dynamics of wetland plant species to changing moisture conditions, we developed an HGM matrix of potential vegetation communities related to geomorphologic, soil, elevation, and hydrology conditions historically present at Benton Lake (Table 3). The distribution of these HGM-predicted vegetation communities assumes average long-term flooding and drying periods of 15-20 years with peak highs and lows lasting about 5-6 years. This duration of peaks and lows is based primarily on historic aerial photographs of Benton Lake, especially the sequential basin photographs from 1950, 1951, 1954, 1956, and 1957. This HGM matrix was extrapolated to a historic (i.e., pre-levee and water-control structure construction) spatial resolution using the geographical information data sets on geomorphology, soils, and elevation (Fig. 11).

Using this HGM matrix (Table 3) and potential historic vegetation map (Fig. 11), about 73 acres of the lowest elevations in Benton Lake (< 3,614.2 feet amsl) contained some surface water throughout most years and supported "open water" aquatic plant communities surrounded by concentric bands of robust emergent vegetation including cattail (Typha latifolia and Typha angustifolia) and hardstem bulrush (Scirpus acutus). Soils in these depressions were heavy clays and within the "Ql" geomorphic surface formed by historic lacustrine environments. Water in these depressions was fresh, with little salt concentration. Historic aerial photographs and survey/naturalist accounts from the Benton Lake region indicate that dense emergent vegetation was present in the deeper depressions at Benton Lake, at least during wet years of the long term flooding cycle, but it is unclear which emergent species were present. We suspect most emergent vegetation was hardstem bulrush, but some cattail probably was present also, based on similar wetland conditions in western Montana (Hansen et al. 1995) and the extensive presence of cattail within Benton Lake at present. The width of this emergent vegetation band varied depending on extent and duration of flooding and chronological position of the long-term hydrological cycle. Submergent aquatic plants such as pondweeds (Potamogeton spp.), naiads (Najas sp.), coontail (Ceratophyllum sp.), wigeon grass (Ruppia sp.), and milfoil (Myriophyllum spp.) were present in the deepest open areas and rich algal blooms occurred in these areas.

Semipermanently flooded sites that were slightly higher elevation (3,614.3 to 3,615.2 feet amsl) adjacent to cattail and bulrush zones contained slightly less permanent water regimes and supported diverse sedge and rush species such as Carex, Sagittaria, and Juncus (Table 3, Fig. 11). These "sedge/rush" communities covered about 1,728 acres and supported diverse herbaceous wetland plants including alkali bulrush (Scirpus maritimus), three-square rush (Scirpus pungens), Nutall's alkaligrass (Puccinellia nuttaliana), beaked sedge (Carex rostrata), Nebraska sedge (Carex nebrascensis), and water smartweed (Polygonum coccineum). Sedge/rush communities were almost entirely on "Ql" surfaces and had clay soils, similar to robust emergent communities. The small area (53 acres) of sedges/rush vegetation on "Qac" may have contained slightly more alkaline species, but this is unclear. The sedge/rush community apparently covered more area within the Benton Lake bed than other communities and historic accounts of the lake (e.g., GLO 1920) comment on the wide bands and extensive coverage of sedges and rushes. This sedge/rush community may have expanded during wet periods to even higher

Figure 7. Model of long-term dynamics of water levels in Benton Lake (extrapolated from historic aerial photographs; USFWS Benton Lake National Wildlife Refuge, unpublished files; NOAA 2008, naturalist observations, and published articles).

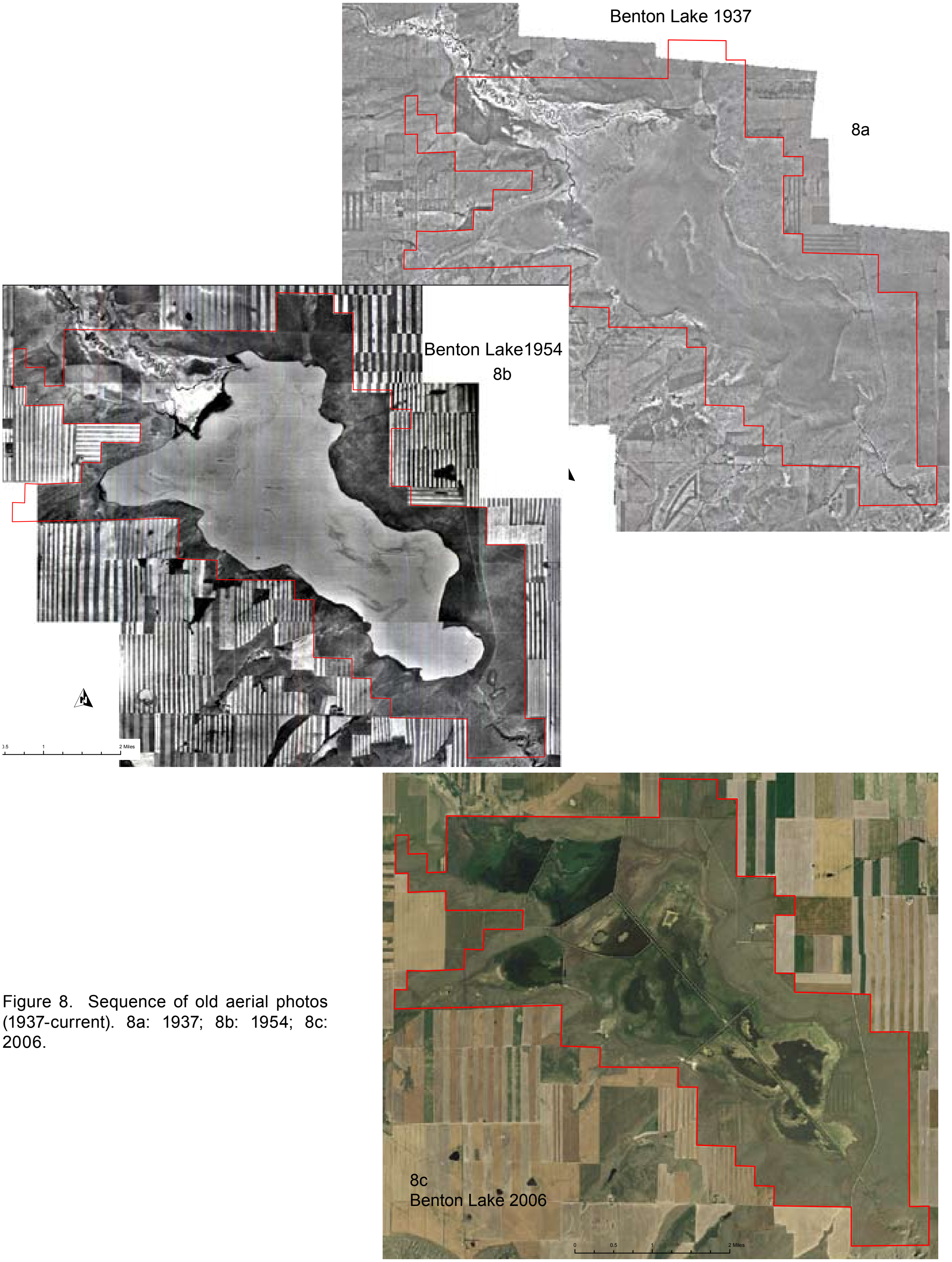


Figure 8. Sequence of old aerial photos (1937-current). 8a: 1937; 8b: 1954; 8c: 2006.

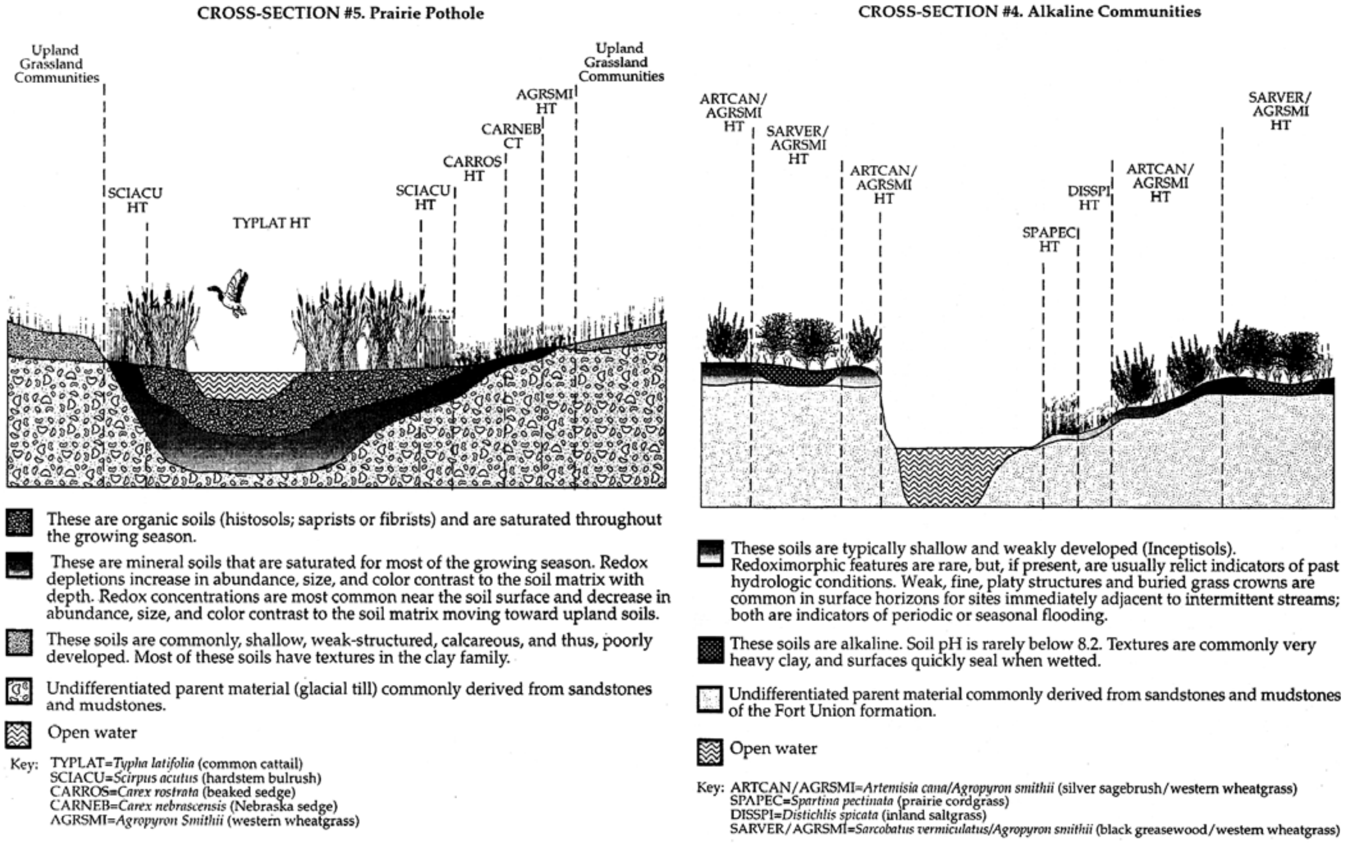


Figure 9. Cross-section of vegetation communities typically found in Northern Prairie and alkaline flat wetlands in western Montana (from Hansen et al. 1995).

elevation edges of Benton Lake and then contracted to lower elevations during extended dry periods. The periodic flooding and drying of these vegetation zones likely caused moderate alkaline soil conditions.

Seasonally flooded areas adjacent to sedge/rush communities (3,615.3 to 3,615.7 feet amsl) contained diverse annual and perennial herbaceous plants and wet prairie/meadow grasses such as spikerush (Eleocharis spp.), lambsquarter (Chenopodium album), annual smartweeds (Polygonum spp.), prairie cordgrass (Spartina pectinata), and saltgrass (Distichlis spicata). Most seasonally flooded communities were within “Ql” surfaces (1,040 acres), but 143 acres of “Qac” also supported more distinctive species groups (Fig. 11). For example, prairie cordgrass apparently occurred in temporary and overflow areas along streams and the edges of marsh sites that had silty clay soils, less alkaline conditions, and where seasonal (usually spring) sheetflow of surface water occurred. Eleocharis usually was in relatively narrow bands along yearly flooded stream and tributary sites and the margins of lake communities. In contrast, saltgrass was most common in more saline or alkali sites including areas where seeps flowed into Benton Lake and in some overflow areas adjacent to Lake Creek.

The highest elevation edges of Benton Lake (3,615.8 to 3,620 feet amsl) typically had short duration seasonal flooding regimes and represented the transition zone from wetland to upland grassland plant communities (Table 3, Fig. 11). These sites included both “Ql” (3,167 acres) and “Qac” (1,216 acres) geomorphic surfaces and usually had more silty clay soils compared to dense heavy clays within depressions of Benton Lake. Foxtail barley (Hordeum jubatum) was present on the higher annually drawn down margins of the lake basin and in some ephemeral depressions. Foxtail barley gradually graded to western wheatgrass (Agropyron smithii) and silver sagebrush (Artemisia cana) on “Qt” alluvial terraces adjacent to the lake. Eventually, these wetland-edge grass communities graded into about 4,802 acres of upland grassland (elevations > 3,620 feet amsl) present on “Qt” and “Kbb” surfaces that supported many native grass species and numerous shrubs and forbs typical of this part of Montana including bluebunch wheat-

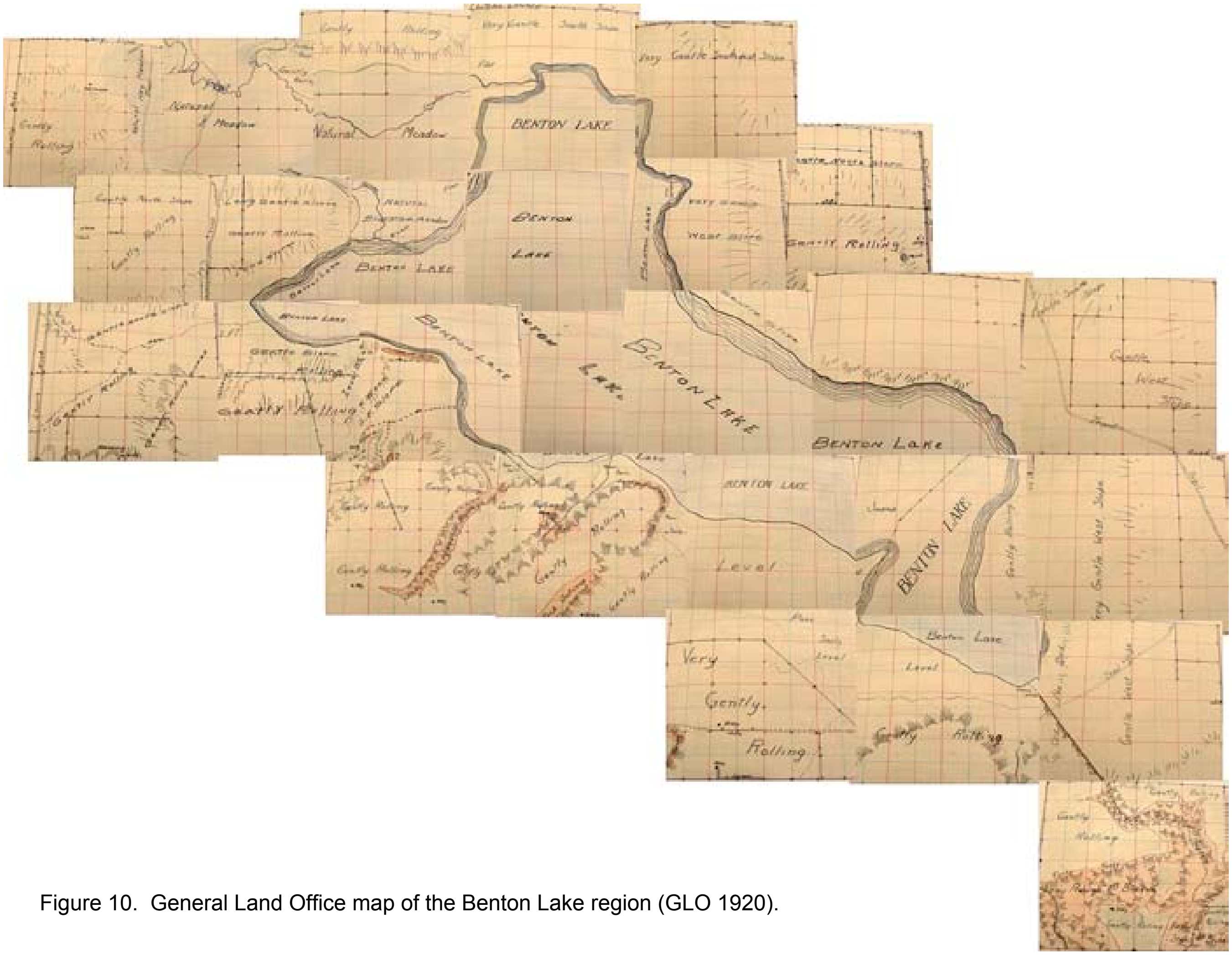


Figure 10. General Land Office map of the Benton Lake region (GLO 1920).

grass (Agropyron spicatum), green needlegrass (Stipa viridula), and prairie junegrass (Koeleria macrantha).

Recently developed models of water coverage in Benton Lake, assuming complete restoration of the hydrology and topography of the lake bed by removal of all levees, water-control structures, and ditches and no pumping of water from Muddy Creek, demonstrate the long-term dynamics of water area and potential effects on vegetation distribution and coverage in the basin (Fig. 12, Nimick and Fields, unpublished data). This "cycle" of increasing water area throughout the lake bed during wet years and gradual drying to very limited water area during dry years is similar to long-term dynamics in other larger Northern Prairie wetland basins and creates dynamic distribution of vegetation communities and animal responses (Weller and Spatcher 1965, Weller and Fredrickson 1974, Van der Valk and Davis 1978, Kantrud et al. 1989). These dynamics suggest historic relative changes in communities and resources at Benton Lake over time in a recurring long-term pattern (Fig. 13, 14).

KEY ANIMAL COMMUNITIES

A rich diversity of animal species historically used the Benton Lake ecosystem (Appendix B). The relative abundance of species and specific food and cover resources used by animals varied with the long term dynamics of flooding and drying in the system. Over 100 bird species from 12 taxonomic orders have been documented at Benton Lake during various seasons. More birds were present during spring and fall migration than in other seasons; abundance in winter was low because of extensive ice, snow, and cold temperatures.

Many waterbirds historically bred in the Benton Lake area, but species richness, abundance, and production apparently varied related to extent and duration of flooding in the basin. The most common

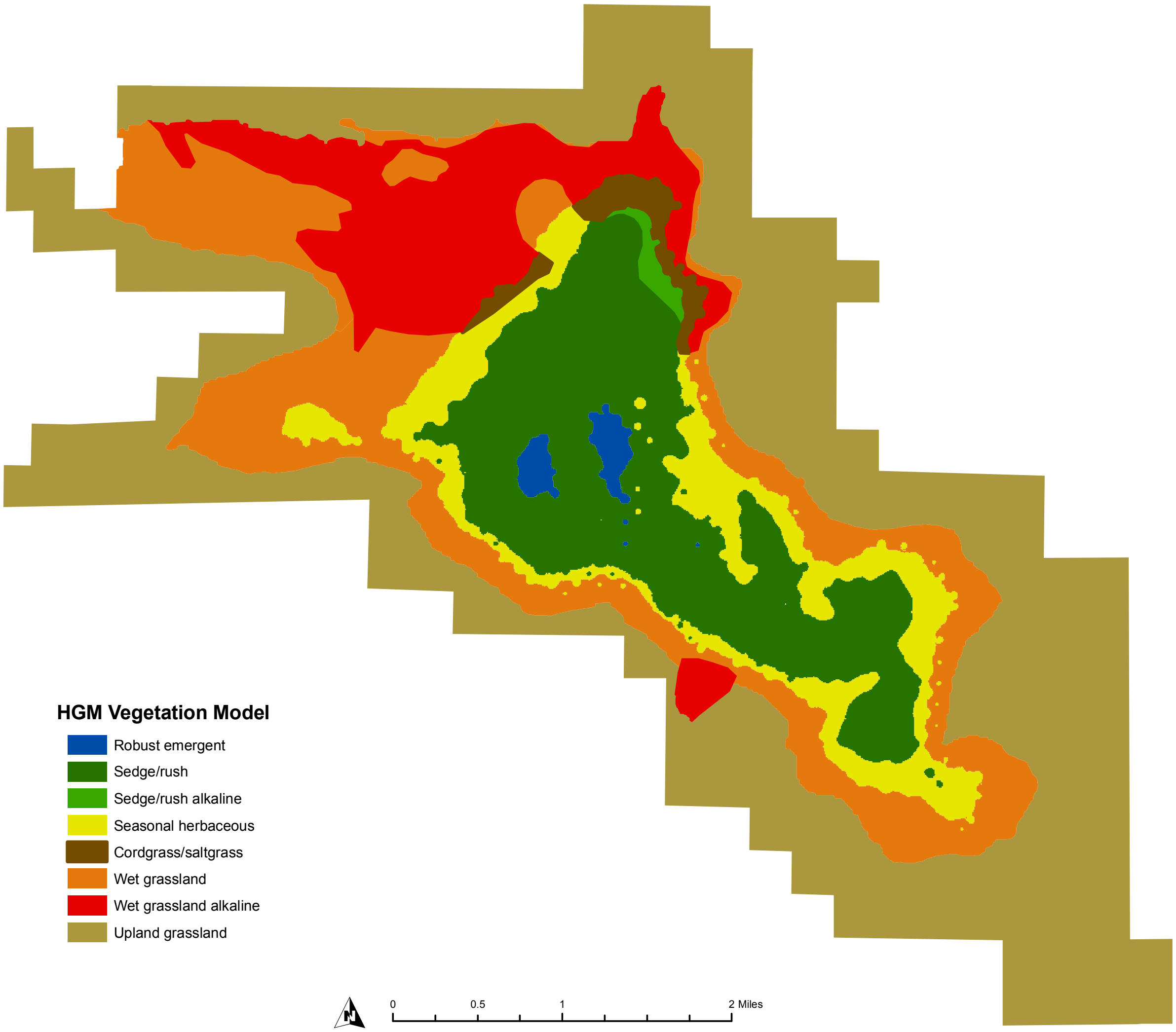
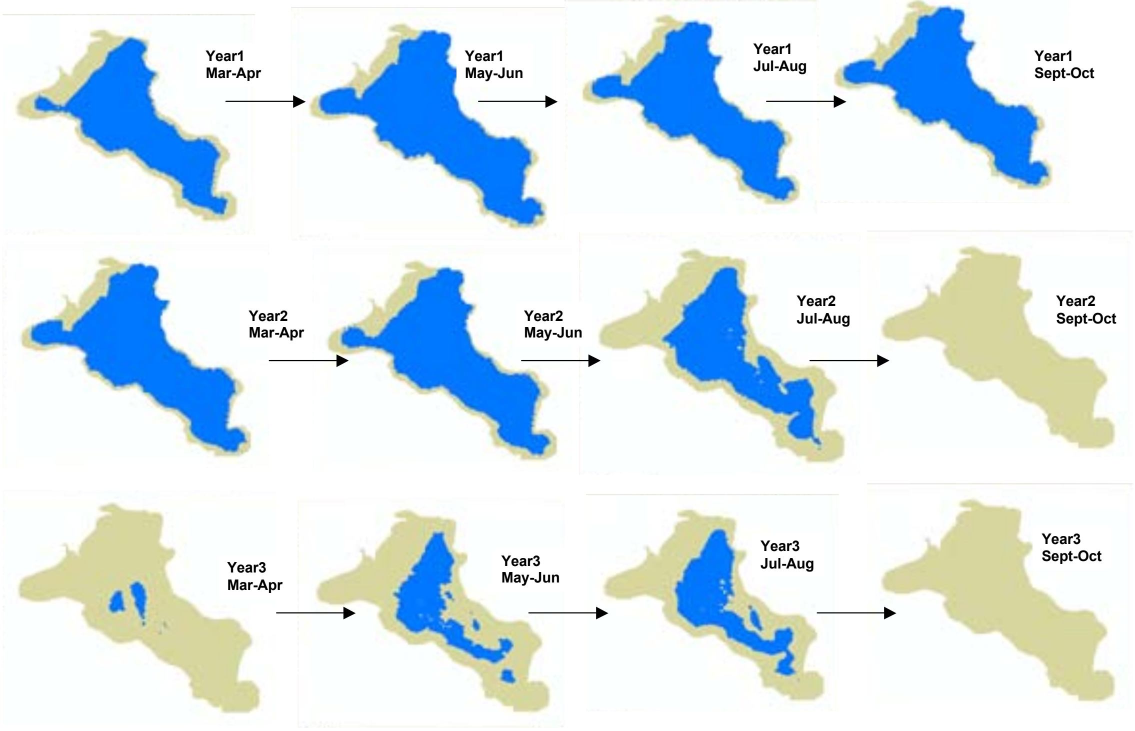
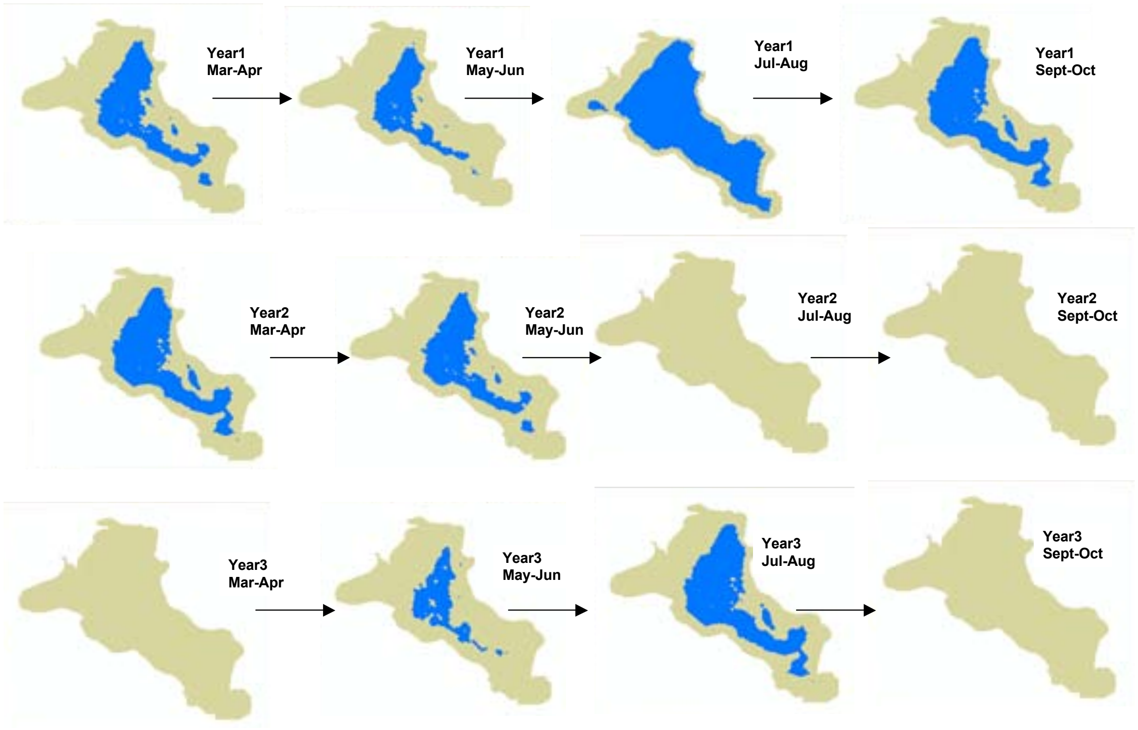


Figure 11. Map of potential historic vegetation communities on Benton Lake National Wildlife Refuge (determined from various HGM data sets listed in Table 3 including geomorphology, soils, topography, hydrological, and botanical accounts).

breeding species included eared grebe (Podiceps nigricollis), mallard (Anas platyrhynchos), northern pintail (Anas acuta), gadwall (Anas strepera), blue-winged teal (Anas discors), cinnamon teal (Anas cyanoptera), American wigeon ((Anas Americana), northern shoveler (Anas clypeata), redhead (Aythya americana), lesser scaup (Aythya affinis), ruddy duck (Oxyura jamaicensis), Canada geese (Branta Canadensis) American coot (Fulica americana), American avocet (Recurvirosta americana), Wilson's phalaropes (Phalaropus tricolor), marbled godwits (Limosa fedoa), willets (Catoptrophorus semipalmatus), Franklin's gull (Larus pipixcans), white-faced ibis (Plegadis chihi), black tern (Chlidonias niger), common tern (Sterna hirundo), Forster's tern (Sterna forsteri), and black-necked stilt (Himantopus mexicanus). During wetter periods of the long term precipitation and flooding cycle many waterfowl, shorebirds, wading birds, gulls and terns, and other wetland-dependent species were present and production was high. Breeding waterbird productivity in the Benton Lake ecosystem likely followed long term dynamics of production in other northern prairie systems as vegetation, invertebrate, and nutrient cycling changes when wetlands dry, reflood, reach peak flooding extent, and then begin drying again (e.g., Murkin et al. 2000). Aquatic invertebrates reach high abundance and biomass during wet periods of long-term water cycles in High Plains wetlands and include a rich diversity of Crustacea such as Daphnia sp., Gammarus sp., and Hyalella azteca) and insects such as Corixid beetles, damselflys and dragonflys, Notonectid backswimmers, and Chironomids. During dry periods of the long term hydrological cycle, fewer waterbirds bred at Benton Lake, and the smaller area, more concentrated, and ephemeral nature of



Complete restoration (no pumping) -- Wet Cycle (1989-1991)



Complete restoration (no pumping) – Dry Cycle (2006-2008)

Figure 12. Predicted extent of flooding (blue) and drying (tan) within the Benton Lake basin without artificial pumping or infrastructure. Models were run for a series of 3 wet years and 3 dry years using actual precipitation and run-off data.

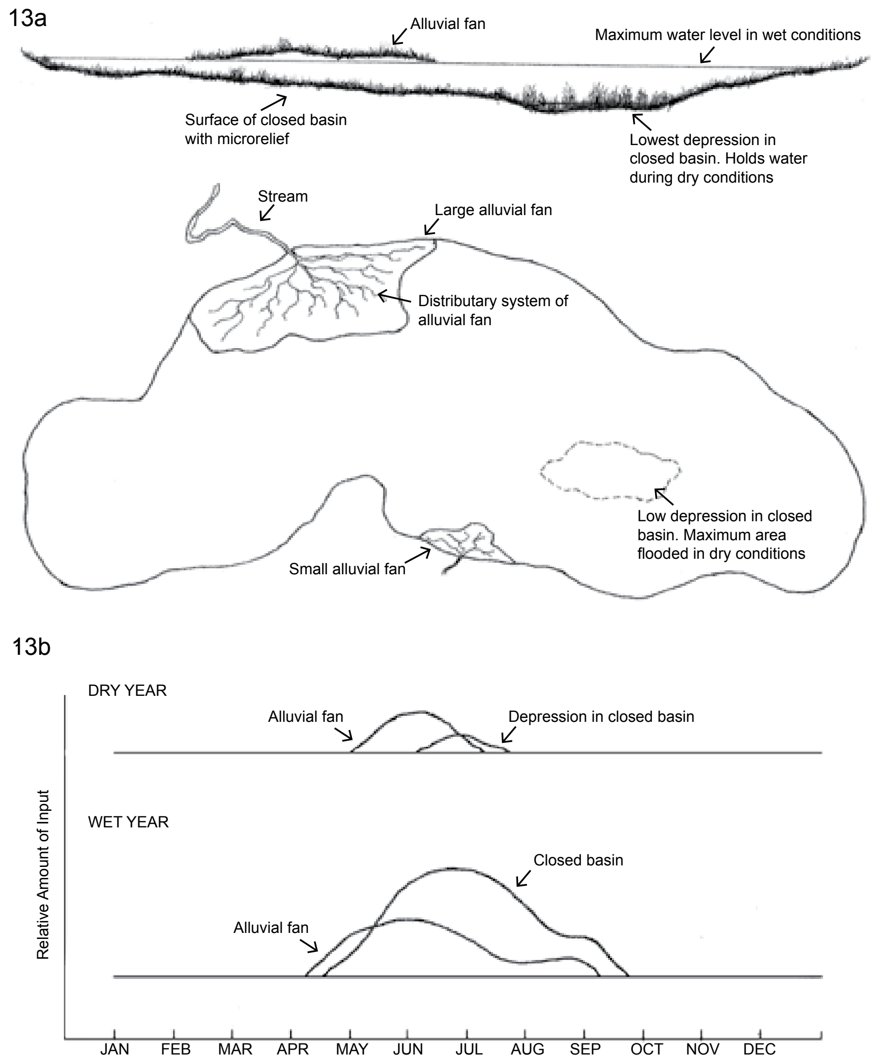


Figure 13. (a) A conceptual schematic of a closed basin with hydrologic inputs entering across a large and a small alluvial fan that receive inputs from small streams with variable annual flows. A deeper depression has the only robust emergent vegetation in the basin. (b) The hydrograph for a closed basin is highly variable within and among years with alluvial fans receiving the most consistent inputs.

summer water probably reduced nesting attempts and success.

Waterbird use of Benton Lake historically was high during fall and spring migration periods both in wet and dry periods. During drier periods, extensive mudflat areas likely were present as surface water evaporated and receded to deeper depressions. These mudflats likely attracted large numbers of shorebirds that utilized rich benthic and terrestrial invertebrate resources and drying wetlands concentrated aquatic prey that was utilized by wading birds, some terrestrial birds, and mammals that ranged into the basin. As water in Benton Lake rose during wetter periods, more of the basin was flooded in both spring and fall (e.g., Fig. 12) and provided critical migration stopover areas for waterfowl, shorebirds, wading birds, and other species such as birds of prey, songbirds, rails, and blackbirds. Bald eagle (Haliaeetus leucocephalus) and peregrine falcon (Falco peregrines), now raptor species of concern, were attracted to the region when large numbers of waterfowl and waterbirds were present.

Mammal species diversity and abundance in the Benton Lake ecosystem was low, except for many small rodents such as mice and voles. The relative abundance and productivity of wetland-dependent species like muskrat, mink, etc. probably tracked long term hydrological and vegetation dynamics. Additionally, many mammal species that mostly used the uplands surrounding Benton Lake, such as coyote (Canis lutrans), white-tailed deer (Odocoileus virginianus), mule deer (Odocoileus hemionus), pronghorn antelope (Antilocapra americana), and elk (Cervus canadensis) moved into the lake basin during dry seasons and years to forage and breed.

Several amphibian and reptile species also used Benton Lake and surrounding uplands, historically. Similar to birds and mammals, the presence and abundance of some species like tiger salamanders (Ambystoma tirgrinum) varied among years as flooding and drying changed resource availability and species susceptibility to being prey for other species groups. Only a few small stream fishes imported from Lake Creek, occurred in Benton Lake, and their presence likely was limited and ephemeral during extremely wet years.

The Benton Lake ecosystem played an important role in providing key resources that helped sustain populations of the above species throughout the Northern Great Plains and Intermountain regions of North America. These species included those that had continental, regional, and local mobility (Laubhan and Fredrickson 1997). Birds were the predominant

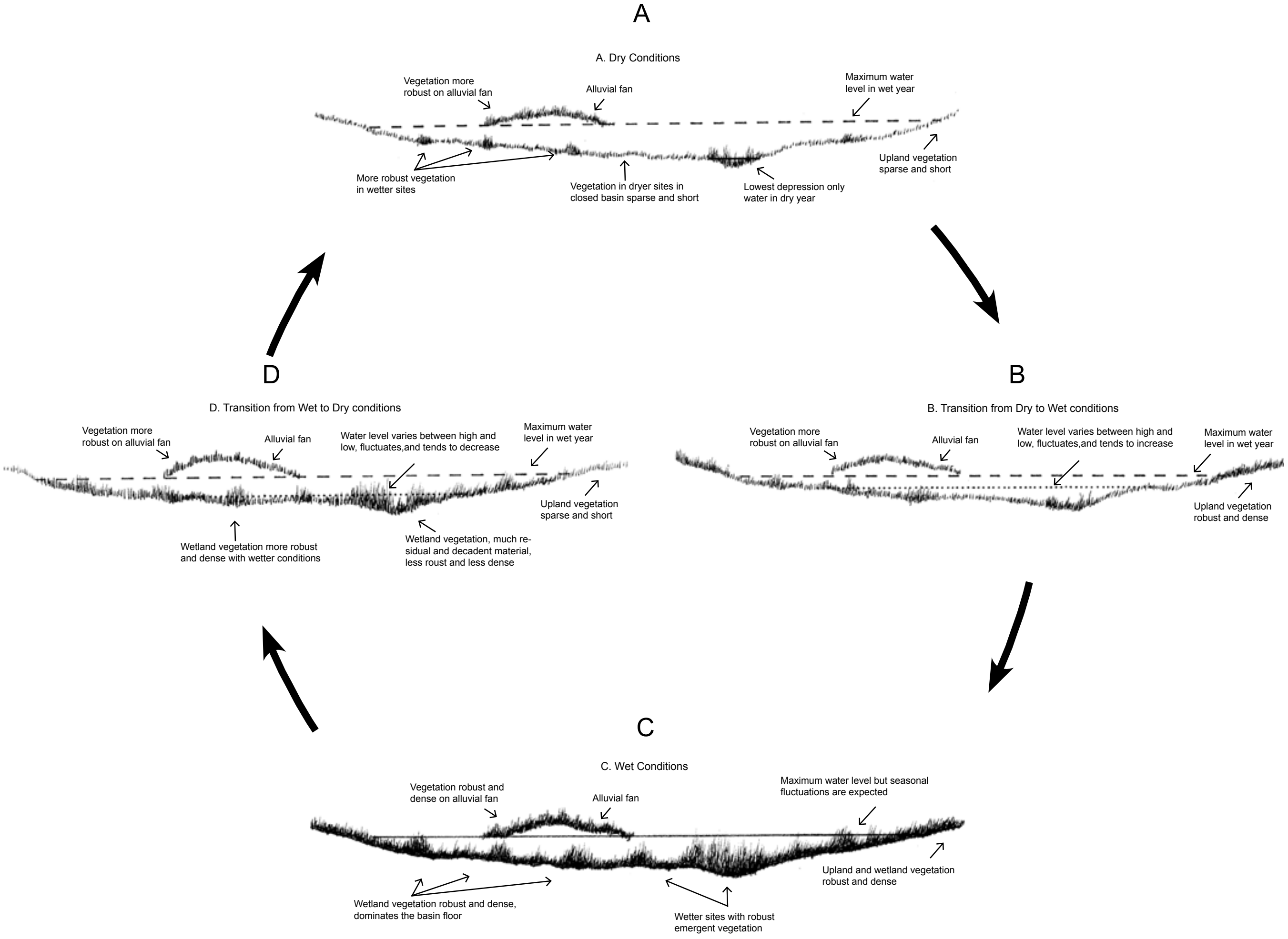


Figure 14. A conceptual model of the variability within a closed basin associated with water levels, wetland vegetation and wetland dependent animals that characterize wetland dynamics in an arid region during the wet/dry cycle. (A) Dry Conditions: Dry conditions are recurring and often last for 3 or more years in a 15-20 year cycle. The large alluvial fan receives limited water annually and is the wettest site in the basin during this phase. The area of wetland vegetation and the vigor of these wetland plants are reduced whereas the extent of terrestrial plants expands. Wetland dependent species richness is low but limited breeding of wetland associated species adapted to conditions on alluvial fans may occur. (B) Transition from Dry to Wet Conditions: Once drought conditions are broken, the basin may flood rapidly when sufficient precipitation occurs, whether fall or spring. The newly flooded conditions may attract thousands of migrant birds immediately and some may stay and nest. Invertebrates respond immediately and occur in great abundance. The upland vegetation responses rapidly and tends to be robust and dense whereas wetland vegetation within the basin may take a season or more to develop the composition and structure characteristic of a wetland with a longer hydroperiod. (C) Wet Conditions: If adequate precipitation continues for more than a season, the area of wetland vegetation expands rapidly and creates a diversity of conditions suitable for nesting as well as for use by migrant species. These wet periods occur for 3 or more years in the 15-20 year cycle. Wetland foods are abundant. Reproductive response and success of wetland-dependent species tends to be high. (D) Transition from Wet to Dry Conditions: As precipitation declines inputs into the basin are insufficient, water levels decline from transpiration, and vegetation shifts from wetland to a more terrestrial phase. Wetland species richness declines and reproductive response and success decline.

vertebrates with continental mobility and Benton Lake provided varying resources during wet and dry periods that contributed to breeding and migration periods of the annual cycle. Because of its size, many bird populations undoubtedly depended on Benton Lake for specific resources during at least some periods of their life spans. The most common large waterbirds in the Great Plains (e.g., wading birds, waterfowl, etc.) have average life spans (excluding human-caused mortality) of >10 years (Palmer 1978, Bellrose 1980). For these species that occasionally bred at Benton Lake (during wet years), the long-term flooding cycles of peak water and habitat about every 10-15 years offered at least one option for potentially abundant nesting habitat and breeding resources during their life span. For other shorter lived species, the intermittent wet or dry state more regularly provided late spring and early summer habitats and resources for migration and breeding, and occasional flooding and regular mudflat conditions for fall migration. For all species with continental mobility, Benton Lake undoubtedly was a critical, albeit annually dynamic, habitat for western populations of many birds, especially waterbirds.

Mammals were the most common vertebrates that exhibited regional mobility in the Benton Lake Basin. Although most mammals in the Northern Great Plains have widespread distributions, individual animals typically are restricted to much smaller areas. Consequently, portions or even subpopulations of some mammal species in the Western Great Plains apparently likely were dependent on seasonal resources provided in the Benton Lake ecosystem. Mammals that regularly use or depend on wetland resources required a variety of wetland basins and types within their home range. However, the reduced mobility of this group dictates that the distribution of wetland types must be closer to each other if recolonization is to occur after extended drought or floods. Otter, beaver, mink, and fish are examples of regionally mobile species dependent on aquatic habitats – and, none of these species apparently were historically common at Benton Lake. In contrast, more common mammals at Benton Lake were species that ranged into the lake bed during either dry or wet periods, such as ungulates, but generally were supported more by upland habitats and resources.

Species with limited mobility tend to be small and include amphibians, reptiles, and small mammals. Nearly 40 species of herpetofauna in the Northern Great Plains are primarily aquatic or require surface water during some stage of their life cycle (Corn and Peterson 1996). Many species are capable of exploiting seasonally, or periodically, flooded wetlands such as Benton Lake because of behavioral adaptations that enable survival during drought. For example, leopard frogs (Rana blairi) can survive dry periods by migrating short distances or remaining in depressions (Grzimek 1974). Undoubtedly, Benton Lake was critical to sustaining populations of many limited mobility species in the region.

Frank Nelson

CHANGES TO THE BENTON LAKE ECOSYSTEM

SETTLEMENT AND REGIONAL LANDSCAPE CHANGES

The historic landscape in the Benton Lake Basin contained vast expanses of grasslands, undulating topography, a few intermittent streams and wooded "riparian" corridors, and scattered wetland basins, with Benton Lake being the largest. This area was inhabited by Native Americans for at least 10,000 years prior to European assimilation. The Blackfeet, Cheyenne, and Crow tribes lived in the plains region, but had mobile lifestyles and they apparently had relatively little influence on the plains landscape, with the exception of occasionally setting fires. A few French trappers apparently visited areas along the nearby Missouri River in the mid to late 1700s, but the area was not explored until 1805 when members of the Lewis and Clark expedition viewed the Great Falls of the Missouri River and Black Eagle Falls. These Lewis and Clark explorers spent about three weeks in the area and recorded in their journals descriptions of the falls and surrounding area, which would eventually fuel interest in settlement. Expedition members returned to the area in 1806 and reported large numbers of bison, elk, deer, and antelope in the area along with grizzly bear and mountain lions. After 1807, trappers and fur traders became active in the region; the American Fur Company built Fort Benton on the Missouri River in 1847.

The United States received most of what is now Montana as part of the Louisiana Purchase in the early 1800s; the northwest part of the state was gained by treaty with Great Britain in 1846. In 1862, prospectors found gold in southwest Montana and many settlers moved to the state thereafter. The area around Benton Lake was not a source of gold, however, and only occasional trappers, hunters, and gold seekers occupied the area. Threats of Indian aggression also deterred European settlement in the region until the 1870s. Consequently, the physical and ecological nature of the Benton Lake Basin remained essentially unchanged from its historic condition until about 1880, when settlers increasingly moved to the Missouri River Valley. Between 1880 and 1890 the population of Montana grew from about 39,000 to nearly 143,000. In 1884, Paris Gibson founded the city of Great Falls at the confluence of the Sun and Missouri Rivers and the city was incorporated in 1888 (Yuill and Yuill 1984). The Mullan Road, a common western pathway built in the early 1860s for pioneers and settlers traveling from Fort Benton by way of Coeur d' Alene to the Pacific northwest wound around the north end of Benton Lake, which was dry in most years (Cascade County Historical Society 1999). Interestingly, another early road near Benton Lake, running north of Great Falls from the current Highway 87 to Canada, was heavily used to carry bootlegged liquor to Great Falls and other towns further south during the Prohibition Era of the early 1900s. Named "Bootlegger Trail", it crossed the old Mullan Road and homesteaders along the trail near Benton Lake augmented their income by allowing bootleggers to use their barns to layover during the daytime.

In 1885, the U.S. Government excluded Benton Lake and the area immediately around it from homesteading so that it could be used as a reservoir for irrigating lands to the east. This plan proved impractical because of the dynamic natural water regimes in the lake. Subsequently, most lands in the area around the lake were deeded from the U.S. Government to settlers from 1900 to 1920. The GLO survey of the Benton Lake region was conducted from 1918 to 1920 and established formal range and township survey designations for land ownership (GLO 1920). Early settlers mostly grazed cattle in the area and used Benton Lake as a water source for livestock (Gieseker et al. 1929). Small areas of grassland on uplands

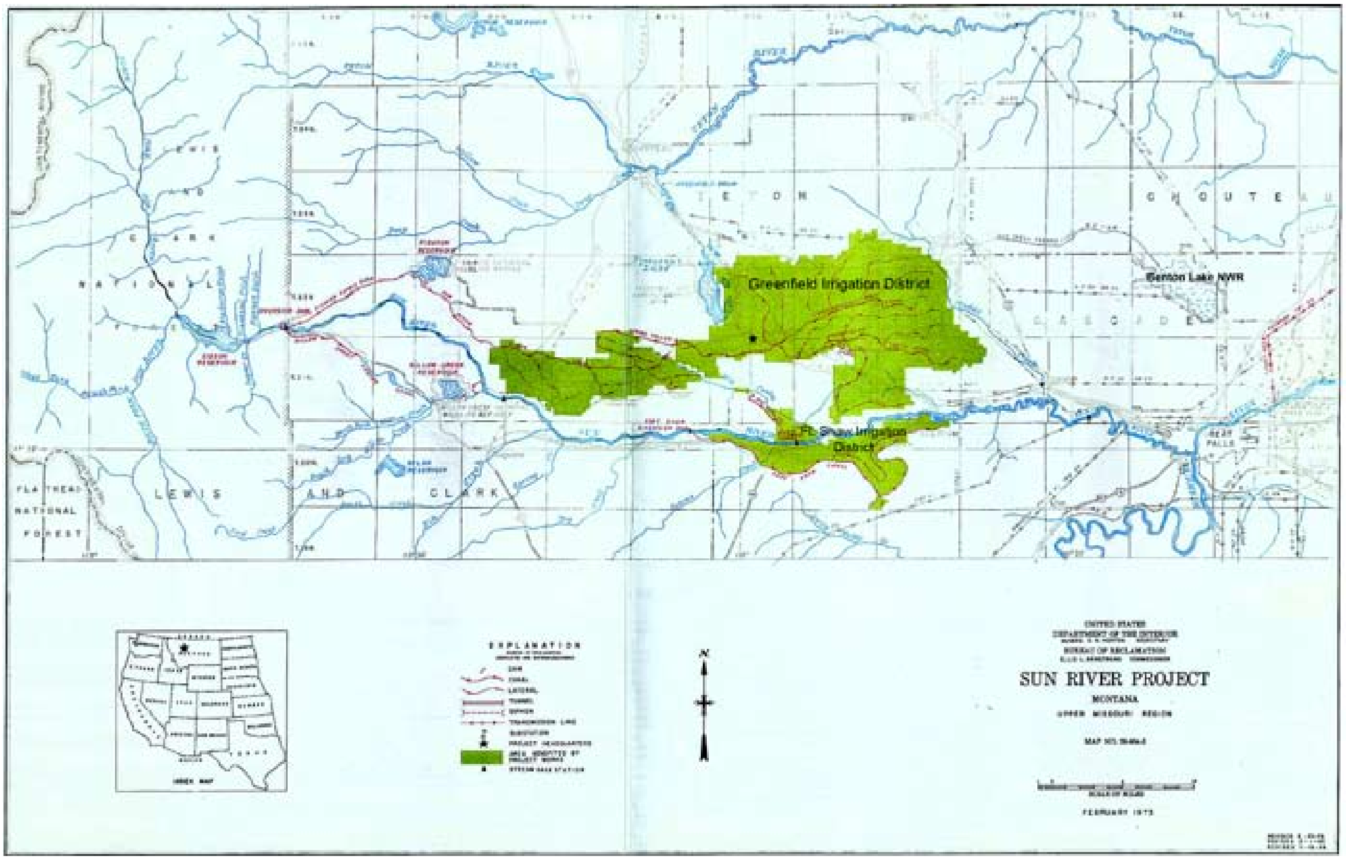


Figure 15. Map of the Sun River Irrigation Project.

and terraces adjacent to Benton Lake were plowed in an attempt to grow small grains, especially wheat and barley. In the early 1920s, several Montana business men planned to "reclaim" Benton Lake for use as cropland and a 1.5 mile ditch long was dug in the south end of the lake bed. This drainage proved unsuccessful because of the closed nature of the basin and the project was abandoned. Likely, the heavy wet clay soils, dense stands of sedges and rushes, and wet periods during spring and early summer deterred this drainage project. Use of the Benton Lake bed by early settlers probably was restricted to free-range grazing by livestock during seasons and years when the lake bed was mostly dry. Most early records indicate that Benton Lake proper was mostly dry except for the deepest interior depressions and that it was rarely completely flooded (GLO 1920; Great Falls Tribune 1929a,b,c; Cascade County Historical Society 1999)

Beginning in the early 1900s, efforts to increase opportunity for small grain farming in the region began with the initiation of the Sun River Reclamation Project, later known as the Sun River Irrigation Project. This Sun River project was authorized by the Secretary of the Interior in 1906 and contains over 100,000 acres of potentially irrigated land along the Sun River and its tributaries west of Benton Lake (Knapton et al. 1988, Fig. 15). The Sun River project contains two major divisions, the Fort Shaw Irrigation Division that borders the Sun River contains about 10,000 acres and the Greenfields Irrigation Division, contains about 83,000 acres. While not in either Irrigation Division, Benton Lake and some area around it was owned by the Sun River Reclamation Project.

Construction of the Fort Shaw Division began in 1907; the first water was delivered to Division farmlands in 1909 (Knapton et al. 1988). Construction of facilities within the Greenfields Irrigation Division began in 1913 and the first water was delivered to area grain farmers in 1920. The main storage structure, Gibson Reservoir was constructed on the Upper Sun River during 1922-29. Gibson Reservoir has an active storage capacity of about 105,000 acre-feet. Water from Gibson Reservoir is diverted about 3 miles down the Sun River and flows by canal for about 10 miles to Pishkun Reservoir, which is an off-stream storage reservoir with a capacity of about 46,300 acre-feet. From Pishkun Reservoir, water flows through a canal for 18 miles before entering the major distribution facility, Greenfields Main Canal. This Main Canal has an initial capacity of 1,200

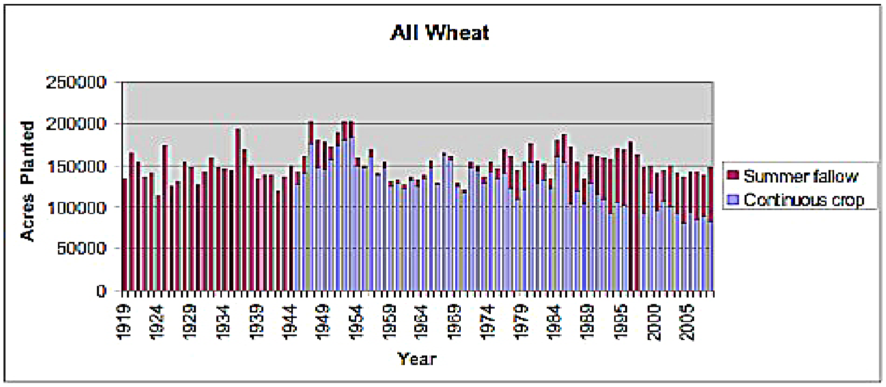


Figure 16. Total acres planted to wheat in Cascade County and portion of those acres following a summer fallow. Fallow data was not reported prior to 1945 and in 1996-1997. Almost all acres of wheat planted in Cascade County are non-irrigated (NASS 2009)

cubic feet/second (cfs) and extends over 25 miles northeast across the topographically isolated "Greenfields Bench" ending in a wasteway canal that flows into Muddy Creek. Approximately 300 miles of canals and lateral distribution ditches distribute water across the Greenfields Bench.

The development of the Greenfields Irrigation Division dramatically changed the landscape west of Benton Lake and also influenced land use near the lake bed. During this time, native grassland was converted to irrigated cropland, mostly wheat and barley, and pasture/hayland. The advent of increased small grain production in the region and accompanying storage, transportation, and milling facilities encouraged grain production outside of the irrigation division also. As early as 1919, 135,000 acres were already in wheat production in Cascade County and by the early 1950s, wheat production peaked at just over 200,000 acres (Fig. 16) Much of the native grassland immediately west of Benton Lake was converted from native grassland to "dryland" cropland. By the late 1950s, over 90% of the ca. 36 mile^2 immediate watershed of Benton Lake was cropland. The predominant crops grown in this area until the 1980s were wheat, barley, oats, and flax using crop-fallow rotations (Fig. 17) where alternating linear fields were either cropped or kept fallow (free of vegetation using tillage or chemical treatments) for 1-2 years. Since the mid-1980s, over 60% of the cropland in the Greenfields Division has been contracted for growing malting barley, which has improved the financial sustainability of cropping lands in the area and has provided over $20 million annual return.

The alternate crop-fallow rotation in the region gradually increased the number and severity of saline seeps within the Benton Lake Basin (Miller and Bergantino 1983). The crop-fallow system causes increased areal recharge to shallow ground water through elimination of surface vegetation in the fallow strips and the associated water consumption in the former vegetative root zone. Salts that had accumulated in the vadose zone under pre-farming conditions (such as native grassland) become dissolved by the increased infiltration of precipitation and are transported to shallow ground

Figure 17. Crop-fallow agricultural fields in Benton Lake region.

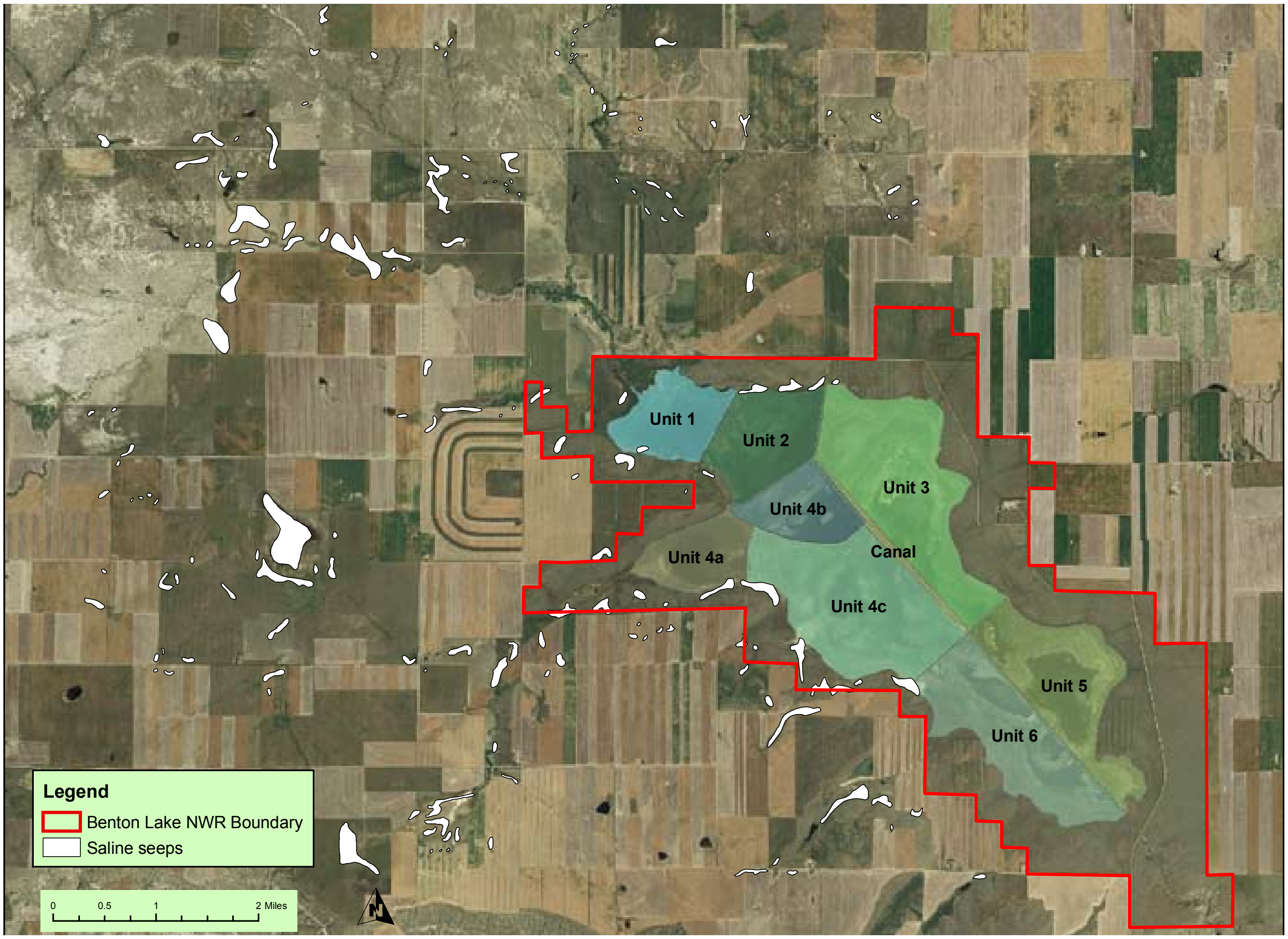


Figure 18. Saline seeps in the Benton Lake region.

water. Ground water flows toward nearby hill slopes along the Greenfields Bench or low-lying areas and depressions such as Benton Lake. This groundwater flow then is discharged via seeps and subsequently evaporates, forming areas of salt precipitates and increased salinity of surface water (Halvorson and Black 1974, Doering and Sandoval 1976, Miller et al. 1981, Brown et al. 1982, Nimick 1997). Predominant dissolved materials in water discharged from the seeps are sodium, magnesium sulfate, and nitrate. Trace metallic elements, often found in high concentrations, are aluminum, iron, manganese, strontium, lead, copper, zince, nickel, selenium, chromium, molybdenum, and vanadium (Palawski and Martin 1991, Palawski et al. 1991).

Saline seep formation within the Benton Lake Basin has likely fluctuated with total acres in summer fallow and local precipitation. From 1919 to 2008, total acres in Cascade County planted to wheat have fluctuated from 114,000 to 203,000 with an average of 153,000 acres (National Agricultural Statistics Service 2009). Interestingly, the long-term trend for planted wheat acres in the area appears to closely follow the long-term precipitation trends (e.g., Figs 7, 16). Due to the thin layer of glacial till in the Benton Lake Basin, seeps can form within 1-2 years in periods of near average precipitation (S. Brown, personal communication). Consequently, during periods of increased wheat production and higher precipitation, total acres of saline seeps would have increased in the basin, and periods of drought and lower wheat production would have caused drying and shrinking of seeps. Saline seeps increased at a rate of about 8-10%/year in parts of Cascade County and surrounding plains areas in the 1970s and 1980s, which corresponds to a period of increased wheat production and increased precipitation.

By the early 2000s, more than 250 saline seeps had been mapped in the Benton Lake Basin (Fig. 18, Nimick 1997). Most of the seeps are located in the south and west parts of the basin in areas underlain by sedimentary rocks of the Colorado Group. These seeps were identified as areas where surface salts have accumulated and native plant communities have been replaced with salt-tolerant species and the ground generally is saturated most of the year. Most seeps immediately adjacent to Benton Lake do not have measurable discharge except for short periods following snowmelt or when heavy precipitation has recharged local ground water. In contrast, saline seeps associated with crop-fallow agriculture have substantial discharge into the Lake Creek drainage system and have mobilized salts and potential contaminants such as selenium, which ultimately flows into Benton Lake NWR (Nimick 1997).

The percentage of the annual wheat crop planted following summer fallow has increased since the early 1990s, which could potentially increase saline seep formation (Fig. 16). Conversely, approximately 70,000 acres of cropland have been enrolled in the Conservation Reserve Program (CRP) since 1990. Retired cropland combined with below normal precipitation in the mid-1990s to mid-2000s, suggest that current saline seeps on the landscape may be less than during previous decades. However, a return to higher precipitation and possible reductions in CRP acreage in the future could quickly lead to an increase in seep formation and severity.

LAND AND WATER USE CHANGES ON BENTON LAKE NWR

Acquisition and Development of Benton Lake NWR

Benton Lake NWR was established by Executive Order of President Herbert Hoover in 1929. The original area of the refuge was 12,234 acres, about 3,000 of which was water area in 1928 (Great Falls Tribune 1929b). Originally owned and managed as part of the Sun River Reclamation Project, and managed by the Bureau of Reclamation of the Department of the Interior, Benton Lake subsequently became part of the USFWS national wildlife refuge system and was administered by the National Bison Range located in western Montana. Impetus for establishing the refuge came mostly from local sportsmen, especially waterfowl hunters, in the mid 1920s when about 8,000 acres of U.S. Government controlled land in the vicinity of Benton Lake was proposed to be opened for settlement. Sportsmen supported the establishment of Benton Lake NWR even though this designation would potentially close the lake for waterfowl hunting, because they understood that a refuge would secure habitat and resources that attracted migratory waterfowl to the area and would control excessive disturbance and shooting that usually caused birds to leave the area in fall (Great Falls Tribune 1929a).

Soon after establishment of Benton Lake NWR, sportsmen and elected officials began expressing concern that water levels in Benton Lake were low in most years, which caused lower waterfowl production, fall migration numbers, and hunting opportunity. For example, in 1928 about 3,000 acres of water area were present in Benton Lake during fall, but in 1929 the area had “only a limited amount of water” (Great Falls Tribune 1929c). Among the proposals to assure a water supply for the lake was to take advantage of water not used in the recently developed Fairfield and Power Irrigation districts (part of the Greenfields Irrigation Division). Engineers believed that waste irrigation water could be diverted to Benton Lake by grading a ditch near the town of Power to natural drainage beds that emptied into Benton Lake (Lake Creek). This early proposal was not pursued until 1957 when members of the Cascade County Wildlife Association secured funding to construct major pumping and water delivery structures from Muddy Creek to the refuge.

A pump station, pipeline, and water-control structures were constructed 1958-62 (Fig. 19) to bring irrigation return flow water from Muddy Creek, about 15 miles to the west, to Benton Lake NWR. In 1961, full time USFWS staff were assigned to, and housed on, Benton Lake NWR. The first water pumped to Benton Lake from Muddy Creek occurred in 1962. Water from the Muddy Creek pump station is moved about 5 miles through an underground pipeline over a low drainage divide and then is discharged into the natural Lake Creek channel where it flows for about 12 miles to its mouth in Benton Lake. Pumping from Muddy Creek has corresponded to times of irrigation return flow in the Greenfields Irrigation system and is generally from May until mid-October. Benton Lake NWR has rights for up to 14,600 acre-feet of water from Muddy Creek each year depending on adequate flows in the creek (Palawski and Martin 1991). Water from Muddy Creek is free, but the NWR must pay electrical costs for the three pumps (two 350 horsepower and one 250 horsepower).

The historic Benton Lake bed was divided into 6 wetland management pools (Pool 4 was later subdivided into three subunits with interior cross levees) by dikes/levees, ditches, and water-control structures

Figure 19. Construction of levees and water-control structures on Benton Lake National Wildlife Refuge in 1960.

to facilitate management of water and vegetation for waterfowl production from 1960 to 1962 (USFWS 1961-99, Figs. 19, 20). Management of these wetland pools including pumping water from Muddy Creek and moving water among the management compartments was initiated in 1962 (Fig. 21). Movement of water between, and within, pools and subunits is managed by a series of ditches and nine water-control structures. Most water enters Benton Lake from Lake Creek (either natural runoff or water pumped from Muddy Creek) and flows into Pool 1 and then is conveyed to Pool 2 and then to the remaining 4 pools by gravity flow through canals and ditches. The primary conveyance ditch extends south from Pool 2 and divides Pools 3 and 4 and Pools 5 and 6. Water storage capacity varies among pools; total capacity is 11,036 acre-feet (Fig. 22).

In addition to construction of levees, ditches, water-control structures, and pumps many other topographic alterations have occurred on Benton Lake NWR since the early 1960s. These alterations include roads, parking lots and building complexes, excavations and mounds within wetland pools for nesting islands, sedimentation and filling of some wetland depressions, rerouting natural water movement patterns from tributaries into the lake bed, construction of drainage ditches within pools, and deposition of hard material (e.g. rip rap rock, concrete, gravel) into wetlands (USFWS 1961-99). Most of the nesting islands were built in the early 1980s; the islands in Pool 4b were removed in 1995-96. In the late 1980s and early 1990s, several drainage ditches were dug in Pools 3 and 4c from the lowest elevations in the pools to external borrow ditches to facilitate draw downs in summer. Collectively, the many topographic changes at Benton Lake NWR have disrupted natural water flow patterns into and through Benton Lake, affected wind-

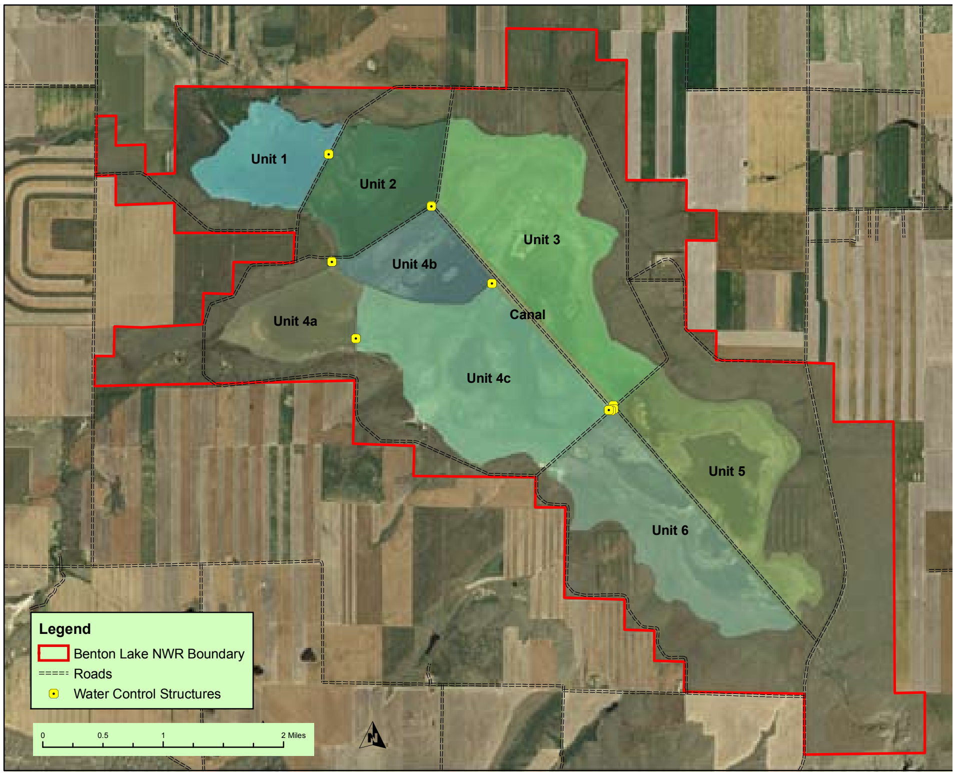


Figure 20. Water management pools on Benton on Benton Lake National Wildlife Refuge.

and water-related soil erosion and deposition patterns, and changed public access and disturbance of many areas on the refuge.

Figure 21. An example of water management in Benton Lake pools in 1964.

Several additional physical/hydrological projects have been considered at Benton Lake NWR over the past 50 years, but have never been constructed. These potential projects included a water storage and flood control reservoir upstream of the refuge on Lake Creek, creating a drainage outlet on the south side of the Benton Lake, siphons to divert water flows into and around management pools, and hydrological connectivity between Benton Lake and the nearby Black Horse Lake, which is small closed basin. The motivation for the Lake Creek reservoir came after high water and basin flooding in 1975 and 1978. This flooding was exceptional, however, and managers recognized that flood control for Benton Lake was unnecessary. The drainage outlet ideas were discussed after documentation of potential selenium and salt accumulation in Benton Lake. While the concept of "flushing" water through the Benton Lake bed theoretically could have reduced accumulation of these elements, it also would have further disrupted the basic historical hydrology of this "closed" basin and potentially caused accumulation/deposition problems in an artificial outlet and receiving area and drainage routes below the refuge, ultimately including the Missouri River. Considerations of siphons were motivated by thoughts of bringing additional water to Benton Lake and providing more independence and flexibility in water management among pools. High construction cost and uncertainty about water availability, timing, and accepting water under contractual agreements have discouraged these proposals to date.

Water Management in Benton Lake

Water management in Benton Lake NWR, since the Muddy Creek pumping system was developed, has typically sought to more predictably, and consistently, flood some wetland pools each year to provide breeding and migration habitat for waterbirds (USFWS 1961-99). This water management has varied among years and has significantly altered natural hydrological regimes, both seasonally and long-term in Benton Lake proper. Historically, Benton Lake had a strong seasonal pattern of increased water inputs during spring and early summer followed by drying during summer and fall to low water levels in winter. Further, the Benton Lake Basin had long-term dynamics of high vs. low water levels at about 15-20 year patterns. Over the past 50 years, water management at Benton Lake has reduced annual variability in water levels including major disruptions in long-term hydrological patterns. Since 1962, water from Muddy Creek typically has been pumped into Benton Lake from mid-April to mid-June to raise water levels in NWR pools for waterbird reproduction (Nimick 1997, USFWS 1961-99). From 1962 through the late 1980s, some water was pumped to the refuge

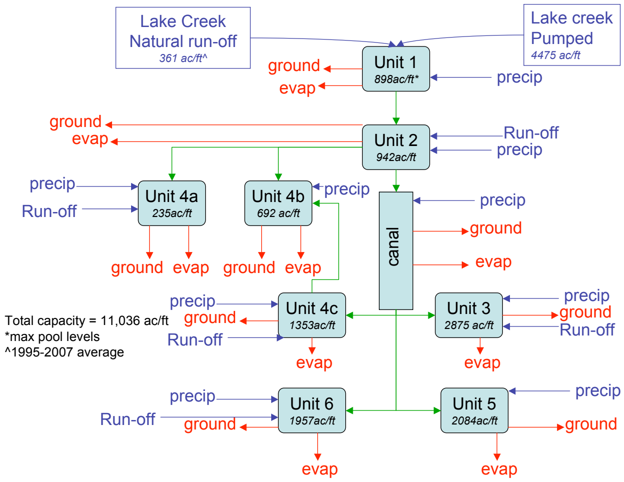


Figure 22. Flow chart of water source, storage, and movement in Benton Lake pools (data from 1970-97 records, USFWS, Benton Lake National Wildlife Refuge, unpublished files).

during summer in most years to maintain water levels in the management pools (Table 5, USFWS 1961-99), however in the last 20+ years the pumps generally have not been operated during summer and water levels in pools have receded from evapotranspiration. This gradual change in water management represented an evolution in learning that deep, season-long flooding was not ideal, especially in the lower pools (3-6) and that shallower, seasonal flooding encouraged more desirable herbaceous wetland vegetation and helped reduce incidence and severity of botulism (USFWS 1961-99). Since the 1960s, water usually has been pumped into Benton Lake again in late-August through October to provide water for fall migrant waterfowl and to store water in pools for the next spring.

Table 5. Annual volumes of natural runoff and pumped water entering Benton Lake; annual precipitation at Benton Lake and Power, Montana; and amount and source of selenium entering Benton Lake, 1970-2008 (from USFWS, Benton Lake National Wildlife Refuge, unpublished files).

Calendar year	Pumped water	Natural runoff	Annual precip-Power	Annual precip-Benton Lake	Pumped Se Load (lb)	Natural Se Load (lb)	Total Se load
1970	3,670	3,000	12.78		49.9	122.3	172.2
1971	6,371	0	8.69		86.6	0.0	86.6
1972	9,079	990	9.75		123.4	40.4	163.8
1973	6,643	0	7.59		90.3	0.0	90.3
1974	5,897	334	10.30		80.1	13.6	93.8
1975	0	13,933	21.60	19.46	0.0	568.1	568.1
1976	2,978	400	10.19	11.58	40.5	16.3	56.8
1977	4,167	0	11.81	13.02	56.6	0.0	56.6
1978	0	19,200	18.99	21.71	0.0	782.9	782.9
1979	68	12,100	6.51	9.03	0.9	493.4	494.3
1980	2,000	1,100	10.60	16.66	27.2	44.9	72.0
1981	3,650	500	13.13	13.83	49.6	20.4	70.0
1982	3,037	4,132	10.47	16.11	41.3	168.5	209.8
1983	2,822	1,763	12.04	15.22	38.4	71.9	110.2
1984	4,790	1,947	8.25	10.11	65.1	79.4	144.5
1985	6,380	1,157	15.11	16.90	86.7	47.2	133.9
1986	3,376	4,759	11.10	11.59	45.9	194.0	239.9
1987	7,987	350	10.25	11.52	108.6	14.3	122.8
1988	7,517	208	8.49	8.36	102.2	8.5	110.6
1989	212	9,710	17.42	21.16	2.9	395.9	398.8
1990	4,797	1,056	9.12	11.30	65.2	43.1	108.3
1991	8,028	943	13.00	12.93	109.1	38.5	147.6
1992	7,276	21	12.14	10.43	98.9	0.9	99.7
1993	1,932	3,049	21.49	17.81	26.3	124.3	150.6
1994	5,800	227	7.52	9.00	78.8	9.3	88.1
1995	5,555	344	12.97		75.5	14.0	89.5
1996	3,969	846	10.52		53.9	34.5	88.4
1997			9.28				
1998	5,693	622	14.29		77.4	25.4	102.7
1999	5,033	122	11.58		68.4	5.0	73.4
2000	5,385	54	9.06		73.2	2.2	75.4
2001	5,082	51	7.74		69.1	2.1	71.2
2002	3,975	610	13.71		54.0	24.9	78.9
2003	3,868	4	9.54		52.6	0.2	52.7
2004	3,985	73	12.32		54.2	3.0	57.1
2005	2,730	422	12.18		37.1	17.2	54.3
2006	3,951	827	13.62		53.7	33.7	87.4
2007	3,542	486	8.95		48.1	19.8	68.0
2008	4,204	673			57.1	27.4	84.6
1970-2008							
mean	4,354	2,264	11.69		59	92	151
median	3,985	610	10.85		54	25	94
1970-1994							
mean	4,339	3,235	11.93		59	132	191
median	4,167	1,056	10.60		57	43	123
1991-1995							
mean	5,718	917	13.42		78	37	115
median	5,800	344	12.97		79	14	100
1996-2006							
mean	4,292	374	11.07		58	15	74

Pools 1 and 2 on Benton Lake NWR traditionally have been managed for more permanent water regimes and water storage. Water from Lake Creek enters these pools first and seasonal (both summer and over winter) storage of water, with current water-control infrastructure, has been perceived as most efficient in these pools. Water levels in the deepest parts of these pools are > 3 feet deep in some areas. Depending on annual water availability and management objectives, some or all of Pools 3-6 have been flooded seasonally or for longer periods. From 1962 to the mid-1980s water was typically moved into these pools in spring and held at higher, more completely flooded, levels through summer to provide nesting and brood rearing habitat for waterfowl and other waterbirds. For example, Pool 3 was managed for year-round inundation from 1964 to 1975 (USFWS 1961-99). In the last 15+ years, water moved into these pools in spring has not been supplemented with summer pumping and water levels have gradually receded until fall when pumping usually began to provide fall migration habitat.

The amount of natural runoff into Benton Lake from the Lake Creek watershed vs. water pumped from Muddy Creek has varied substantially since the pump station was developed. For example, natural runoff has varied from 0 (1971, 1973, 1977) to 19,200 (1978) acre-feet (Fig. 5) and pumped water has ranged from 0 during the very wet years of 1975 and 1978 to 8,028 acre feet in 1991 (Table 5). Mean annual natural runoff into Benton Lake was 3,349 acre-feet during 1970-94, while pumped water averaged 4,339 acre-feet over this same time period. Since 1995, only 361 acre-feet of natural runoff from the Lake Creek watershed has entered Benton Lake on average annually while an average of 4,475 acre-feet of water has been pumped from Muddy Creek (Fig. 22). Given the highly variable nature of flooding into Benton Lake, it is useful to consider the median values for the period of record. Over the last 38 years, the median value for natural run-off into Benton Lake was 610 acre-feet, which indicates that for half of these years, Benton Lake would have been 5% or less full without pumping. The median value for pumping during this time was 3,985 acre-feet or six times the natural runoff levels.

Natural runoff in the intermittent Lake Creek typically occurs from March through June and averages about 0.1 cubic feet/second (cfs) except during periods of snowmelt and heavy precipitation. The largest daily mean discharge at the Lake Creek gauge during 1990-95 was about 300 cfs during snowmelt runoff on 6 March, 1993. During July and August, Lake Creek normally is dry except when summer thunderstorms cause brief periods of flow. Without pumped water, Lake Creek would also be dry in September and October, however low flows now are maintained in most years in fall for 1-2 months after late summer pumping is stopped, probably because of bank-storage discharge (Nimick 1997). In contrast to natural runoff and in-stream flows in Lake Creek, streamflow during periods of pumping generally ranges from 30-42 cfs when the three Muddy Creek pumps are operated simultaneously. Occasionally, and for short periods, only one or two pumps have been operated and pumped streamflow obviously is less. The full capacity of the three pumps is utilized only when streamflow in Muddy Creek is augmented sufficiently by irrigation drainage within the Greenfields Irrigation Division.

Water Quality, Contaminants, and Botulism

The long-term land use changes in the Benton Lake Basin, primarily conversion of native grassland to cropland, and alterations to natural hydrology (water source, timing, and duration of flooding) have changed the water quality within Benton Lake. Specifically, certain contaminant constituent concentrations in water sediment, and biota at Benton Lake have become moderately to considerably higher than established standards, with selenium having the greatest potential for toxicity to aquatic organisms and waterfowl (Lemly and Smith 1987, Lambing et al. 1994, Nimick et al. 1996). The primary source of dissolved solids and selenium that enters Benton Lake is agricultural irrigation drainage water pumped to the refuge from Muddy Creek and surface and ground water drainage from numerous saline seeps through natural runoff from the Lake Creek Basin. The relative proportion of pumped vs. natural runoff water that enters Benton Lake varies annually depending on annual precipitation (Fig. 5, Table 5). Likewise, the inputs of selenium and dissolved solids to Benton Lake also are highly variable among years depending on relative amounts of water flowing to the lake from natural runoff in the Lake Creek watershed vs. water pumped from Muddy Creek (Fig. 5). The mean annual selenium load delivered to Benton Lake was 151 lbs/year from 1970 to 2008 (Table 5). Over the past 38 years pumped water has averaged 65.8% of water but only 39.1% of selenium inputs to Benton Lake, while natural runoff has averaged 34.2% of water but 60.9% of selenium inputs (Table 5).

Although selenium is transported to the refuge in the surface and ground water that flows to Benton Lake, almost all of the selenium that enters the lake accumulates in wetland sediment. Selenium is not evenly distributed among or within pools but rather accumulates more rapidly near the locations of primary selenium inputs and more permanently flooded pools (Zhang and Moore 1997a). In general, selenium concentrations in sediments are highest where Lake Creek enters Pool 1 and in Pool 4c near a large seep (Knapton et al. 1988, Nimick et al. 1996, Zhang and Moore 1997a,b).

A model of selenium cycling (Zhang and Moore 1997a) was developed to predict when selenium concentrations in Benton Lake sediments would become hazardous. The hazard threshold was set at 4 micrograms/g based on data from Kesterson NWR in the San Joaquin Valley of California (Skorupa and Ohlendorf 1991) where selenium concentrations caused widespread bird deformities, and ultimately closure of the refuge. Assuming the input and output of selenium to Benton Lake remained constant, the model predicted that Pools 1 and 2 would exceed this threshold by 2004 and 2012, respectively. Both of these pools receive Lake Creek water first as it enters the lake bed and have been managed for more permanent water regimes and water storage for over 30 years; they are seldom drawn down or allowed to dry. The remaining pools in Benton Lake now are dry for at least 1-2 months annually, which increases the rate of selenium removal through volatilization into the air and the model predicted these wetland pools

Table 6. Lemly Hazard Assessment Results for four sites at Benton Lake NWR. Contamination hazard levels are assigned to each of four trophic levels sampled at each site between May 15 and July 15, 2006. The overall hazard level is determined by combining the individual hazard assessments according to Lemly (1995).

	Water		Sediment		Invertebrates		Bird	Egg		Overall
	(μg/L)	Hazard	(μg/g dw)	Hazard	(μg/g dw)	Hazard	Species	(μg/g dw)	Hazard	Hazard
Unit I	2.20	low	2.73	low	7.65	high	Eared grebe	8.71	low	moderate
Unit IVc seep	33.80	high	20.30	high	4.01	moderate	Gadwall	1.86	none	high
Unit III	0.56	none	0.32	none	2.14	minimal	Cinnamon teal	3.19	minimal	minimal
Unit V	2.20	low	1.09	minimal	1.75	none	American avocet	5.32	low	low

would not exceed threshold levels. Further, the model showed that a 50% reduction in selenium input could reduce selenium accumulation by 50% and extend the viable "life" of Pools 1 and 2. Recent sampling in 2006 found that the mean selenium concentration in the Pool 1 sediment was significantly higher in 2006 (2.73 micrograms/g) than in 1994 (2.30 micrograms/g) although one sample did have a concentration of 4 micrograms/g. In contrast, the mean concentration of sediment in Pool 4c near the saline seep had 20.3 micrograms/g selenium concentration (Table 6). Selenium in eared grebe eggs collected from Pool 1 had a mean selenium concentration of 8.32 micrograms/g in 2006 and gadwall eggs from Pool 5 had selenium concentrations of 4.42 micrograms/g.

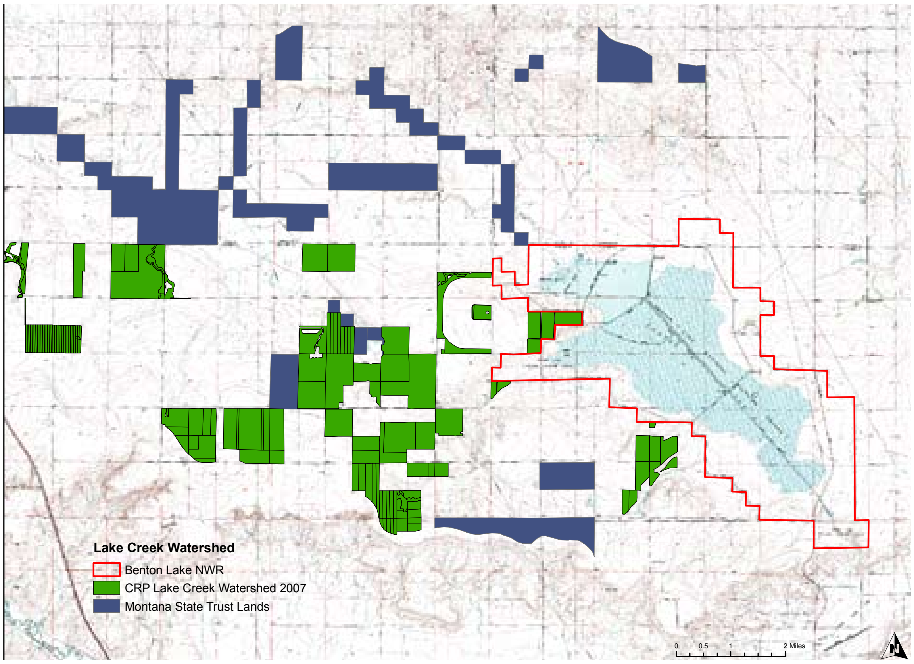


Figure 23. Map of Conservation Reserve Program (CRP) lands in the Benton Lake region (from U.S. Department of Agriculture, Natural Resources Conservation Service).

While selenium concentrations in most Benton Lake pools have not accumulated to exceed toxicity thresholds in recent years, Pool 1 and 2 remain susceptible to dangerous level accumulation because they are at the primary source of selenium entry to Benton Lake (i.e., the Lake Creek mouth) and have been managed for more permanent water regimes. Revisions to the Zhang and Moore (1997a) selenium and water mass-balance model currently are ongoing and suggest possibilities of toxic accumulations in some pools, especially 1 and 2, if higher water and selenium inputs occur in the future (V. Fields, personal communication). Reduced selenium input and/or accumulation in Benton Lake in recent years probably have occurred because of drier conditions and reduced volume of natural runoff water entering the lake, and possibly to a small part because of increased CRP acreage in the watershed surrounding Benton Lake where crop-fallow rotation has been replaced by continuous cover, mostly tame grasses (Fig. 23).

Long-term water management on Benton Lake certainly has contributed to selenium accumulation concerns. Selenium volatilization is most efficient in seasonally flooded wetlands and is lowest in more permanently flooded sites (Zhang and Moore 1997a). This increased volatilization occurs because of higher temperature, air flow, and decomposition of plants during dry periods, both seasonally and long term. Historically, the Benton Lake ecosystem did not have large amounts of selenium inputs and seasonal and long-term dynamic water regimes that included extended drying periods during summer and consecutive dry years caused selenium (and other dissolved solids like salts) to reach a dynamic equilibrium where the amount of salt and selenium removal from the wetland through volatilization equaled the amount of accumulation (Zhang and Moore 1997b). Since the early 1960s, however, the introduction of increased, and annually consistent, water to the lake bed has created more permanent water regimes, at least in some pools (e.g., Pools 1 and 2 over a long period and other pools managed for summer water until the mid to late 1980s) and not included extended seasonal drying through fall or over long-term dynamic dry periods lasting several years.

While monitoring selenium accumulation levels has been a priority at Benton Lake, other water chemistry and disease variables also have been studied (Knapton et al. 1988, Nimick 1997). Water quality, especially in Lake Creek, is variable among years depending on the source of streamflow that enters Benton Lake. During wetter periods, such as increased snowmelt or local precipitation, specific-conductance is relatively low because of dilution of the poor ground water contribution. However, during dry periods, saline seeps contribute a higher proportion of chemical constituency and specific-conductance values are high (Nimick 1997). Specific conductance values in Pools 1 and 2 are lower and less variable than in Pools 3-6 because of their flow-through operation and the effects of inflows from Lake Creek. In contrast, evapoconcentration causes more variable specific conductance values in Pools 3-6, which are the terminal basins in Benton Lake and over the past 15+ years are flooded only seasonally. The water type in Benton Lake is generally magnesium-sodium-sulfate, but when large amounts of water are pumped from Muddy Creek, bicarbonate becomes the dominant ion with sulfate. Since 1974, accumulation of dissolved solids in Benton Lake appears negligible (Nimick 1997, Zhang and Moore 1997a).

Avian botulism outbreaks, caused by the ingestion of a toxin produced by the bacterium Clostridium botulinum, have occurred at Benton Lake at least since the mid 1960s (USFWS 1961-99). Occurrence of botulism at Benton Lake prior to the 1960s is unknown (no records or monitoring data are available), but documentation of historic outbreaks in other large wetland basins in the western U.S. suggest it probably occurred at least in some years (e.g., Wetmore 1915, Giltner and Couch 1930, Kalmbach 1930, Wobeser 1981). Peak waterbird mortality caused by botulism at Benton Lake occurred in 1970-72 when over 18,000 birds (17,127 ducks) died in 1970 and over 10,000 birds died in 1971 and 1972 (USFWS 1970-99, Table 7). 1971 and 1972 were very dry years and water levels in pools that had been managed for higher summer water levels to support duck broods (i.e., Pools 3, 4c, and 5) receded quickly. In contrast, 1970 had average precipitation and less rapid drying of wetland pools. Waterbird mortality from botulism at Benton Lake declined during the remainder of the 1970s when water levels were high in the lake caused by increased precipitation and runoff from Lake Creek. Since the 1980s, botulism mortality at Benton Lake has been relatively low (i.e., < 500) in most years except 1989 and 1991, when 2,025 and 3,743 ducks died, respectively. Generally botulism outbreaks at Benton Lake have been greatest in Pools 3, 4c, and 5 when they had greater amounts of flooding and rapid drawdown in late summer. Water management in Benton Lake in recent years has reduced summer flooding, which seems to decrease the recurrence of botulism. Previously, pools were held higher in summer and extensive mudflat edges became exposed during rapid draw-downs in hot summer months during the 1970s and 80s.

Vegetation Communities

The historic gradation of vegetation zones within Benton Lake from robust emergent in deeper depres-

Table 7. Annual mortality of ducks caused by botulism at Benton Lake National Wildlife Refuge (USFWS 1970-90 and USFWS, unpublished records).

Year	Number of ducks
1970	17,127
1971	10,778
1972	10,081
1973	1,602
1974	884
1978	812
1979	1,148
1987	83
1988	597
1989	2,025
1990	509
1997	88

sions to grasslands on uplands has been altered over time. Most historic vegetation communities are still present on Benton Lake NWR, but their distribution and extent are changed. Developments for water management and subsequent altered hydrology and water chemistry in Benton Lake pools are responsible for most changes. Generally, communities have shifted to more extensive distribution of wetter and more alkaline-tolerant species. Increasing amounts of exotic and invasive species also now occur on the refuge.

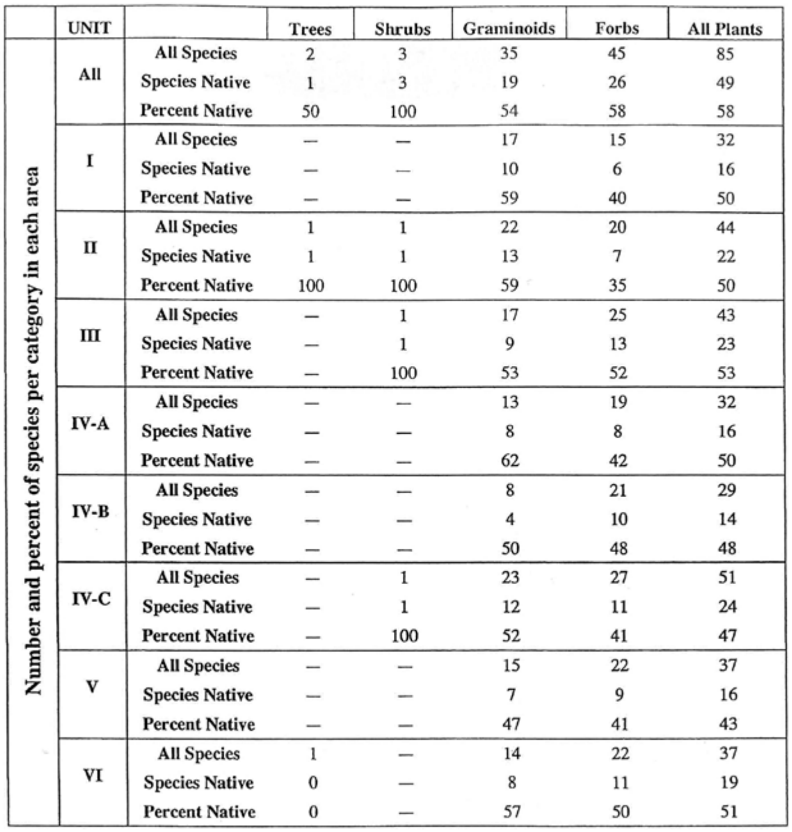
A survey of vegetation in Benton Lake pools was conducted in 2001 and documented composition and distribution of plant communities (Thompson and Hansen 2002). At that time 91 plant species were documented in wetland pools and the dominant vegetation communities (habitat types) were alkali bulrush (31.2% of total area within wetland pools), western wheatgrass (18.1%), foxtail barley (17.4%), open water (9.6%), varied moist-soil annuals (8.8%), and cattail/hardstem bulrush (6.6%) (Table 8, Fig. 24). The invasive creeping foxtail (Alopecurus arundinaceus) covered only 2.8% of the pools in 2001. The precise taxonomy of this creeping foxtail at Benton Lake is unknown, but may be the "Garrison" cultivar named and released by the Natural Resources Conservation Service (NRCS) Plant Materials Center in Bismarck, North Dakota in 1963 (NRCS 2007). The

Table 8. Vegetation community types recorded on Benton Lake National Wildlife Refuge in 2001 (from Thompson and Hansen 2002).

	Percent of Area Per Type in Each Unit								
Habitat or Community Type Name	**I**	**II**	**III**	**IV-A**	**IV-B**	**IV-C**	**V**	**VI**	**ALL**
Agropyron smithii (Western Wheatgrass) HT	23.26	23.76	14.51	20.56	18.49	26.40	2.73	18.52	***18.05***
Agrostis stolonifera (Redtop) CT	0	0	0	0	0	0.10	0	0	***0.02***
Bromus inermis (Smooth Brome) CT	0	0.41	0	0	0		0	0	***0.04***
GRAVEL ROADWAY: Land occupied by loose gravel-surfaced public roadways, not including vegetated rights-of-way	0.58	1.01	1.08	0.68	1.70	0.83	0.94	0.40	***0.88***
Hordeum jubatum (Foxtail Barley) CT	7.19	0.21	31.03	2.10	24.46	28.61	9.73	8.61	***17.36***
OPEN WATER: Area covered by unvegetated open water	33.48	33.15	2.33	11.52	0	1.72	1.21	15.70	***9.65***
Poa pratensis (Kentucky Bluegrass)	4.35	2.38	0	0	0	0.94	0	0	***0.78***
Salicornia rubra (Red Glasswort) CT	0	0.16	0	0.02	0	0.11	0	0.20	***0.07***
Salix exigua (Sandbar Willow) CT	0	0.04	0	0	0	0	0	0	***<0.01***
Scirpus acutus (Hardstem Bulrush) HT	0.06	0.32	0.39	0	0	0.05	<0.01	0.54	***0.20***
Scirpus maritimus (Alkali Bulrush) HT	1.79		29.29	57.41	8.48	28.75	54.56	53.84	***31.20***
Scirpus pungens (Sharp Bulrush) HT	0	0	0	0.06	0	0.78	0	0.10	***0.18***
Spartina pectinata (Prairie Cordgrass) HT	0	0.02	0	0	0	0	0	0	***<0.01***
Typha latifolia (Common Cattail) HT	18.73	15.42	10.24	0	0.75	5.59	0	0.07	***6.57***
UNCLASSIFIED WETLAND TYPE Dominated by *Alopecurus arundinaceus* (creeping foxtail)	8.19	19.83	0	0.41	0	0.88	0	0	***2.85***
UNCLASSIFIED WETLAND TYPE Dominated by Annual Species	0.68	0.20	8.58	4.63	39.70	0.12	29.06	0	***8.84***
UNCLASSIFIED WETLAND TYPE: Dominated by Saline Tolerant and Other Species	0	0.49	0.73	0.42	1.40	2.85	0	0	***0.91***
UPLAND TYPE: Vegetated land showing no wetland indicators and that can not be keyed to a riparian/wetland habitat type or community type	0	0.28	0.26	0.03	4.67	0.56	0.41	0.09	***0.57***

original collection of "Garrison" was made in 1950 where plants were growing on the margins of prairie pothole wetland basins; it is especially adapted to cold temperature regions adjacent to wet areas such as the Benton Lake bed. Native species composed 50%, 100%, 54%, 58%, and 58% of tree, shrub, grass, forb, and total plants in wetland pools in 2001 (Table 9).

Table 9. Distribution of native vs. introduced or exotic plant species on Benton Lake National Wildlife Refuge in 2001 (from Thompson and Hansen 2002).



	UNIT		Trees	Shrubs	Graminoids	Forbs	All Plants
Number and percent of species per category in each area	All	All Species	2	3	35	45	85
		Species Native	1	3	19	26	49
		Percent Native	50	100	54	58	58
	I	All Species	—	—	17	15	32
		Species Native	—	—	10	6	16
		Percent Native	—	—	59	40	50
	II	All Species	1	1	22	20	44
		Species Native	1	1	13	7	22
		Percent Native	100	100	59	35	50
	III	All Species	—	1	17	25	43
		Species Native	—	1	9	13	23
		Percent Native	—	100	53	52	53
	IV-A	All Species	—	—	13	19	32
		Species Native	—	—	8	8	16
		Percent Native	—	—	62	42	50
	IV-B	All Species	—	—	8	21	29
		Species Native	—	—	4	10	14
		Percent Native	—	—	50	48	48
	IV-C	All Species	—	1	23	27	51
		Species Native	—	1	12	11	24
		Percent Native	—	100	52	41	47
	V	All Species	—	—	15	22	37
		Species Native	—	—	7	9	16
		Percent Native	—	—	47	41	43
	VI	All Species	1	—	14	22	37
		Species Native	0	—	8	11	19
		Percent Native	0	—	57	50	51

Observations by Benton Lake staff since 2001 and site visits conducted in this study in 2008 also provided information on vegetation community changes. These observations did not attempt to quantify changes since the 2001 survey, but provide qualitative information on continued changes over time. Pools 1 and 2, which have been managed for more permanent water regimes, now contain large amounts of open water with extensive stands of cattail adjacent to deeper open water areas. Open water areas contain abundant aquatic submergent vegetation, especially milfoil and pondweed. Creeping foxtail has spread into areas formerly dominated by foxtail barley at higher elevation edges of Pools 1 and 2. Creeping foxtail is an introduced rhizomatous perennial species that has regenerative advantage on sites with conditions transitional between the more permanently flooded fresh water cattail and hardstem bulrush and more seasonal and alkaline communities such as alkali bulrush. Its distribution has expanded through Benton Lake in recent years and generally occurs in bands or zones lying immediately above the zone occupied by cattail. Foxtail barley now occupies a relatively small amount of area of each pool. Western wheatgrass still occupies large areas on the highest upland edge of Pools 1 and 2 but invasive Kentucky bluegrass (Poa pratensis), crested wheatgrass (Agropyron cristata) and smooth brome (Bromus inermis) are expanding area. Some reed canary grass (Phalaris arundinacea) also now is present in both pools.

Pool 3 contains extensive, but declining areas of alkali bulrush in lower elevations and foxtail barley in higher sites. Creeping foxtail is gradually expanding coverage in the pool, but remains a minor component so far. In contrast, Canada thistle (Cirsium arvense) and field milk-thistle (Sonchus arvensis) now occupy large areas of higher, drier edges of the pool. Former island areas also have small coverage by woods rose (Rosa woodsii). Pool 3 now is managed for short duration seasonal flooding, but for over 15 years (1964-78) it was managed for year-long inundation (USFWS 1961-99).

Vegetation in Pool 4 varies among the three subunits and reflects permanency of water regimes and past excavations and construction of levees, nesting islands, and internal drainage ditches. Pool 4a has more natural vegetation communities than other subunits and is dominated by alkali bulrush. Subunit 4a has been allowed to flood and dry on more natural patterns, with deeper interior areas holding water for longer periods and supporting more alkali bulrush communities, compared to Pools 4b and 4c. Foxtail barley and western wheatgrass remain dominant species on the edges of Pool 4a, but Kentucky bluegrass and creeping foxtail are beginning to invade some areas. Vegetation in Pool 4b is highly altered from historic condition. The historic geomorphology of the Pool 4b area was a higher alluvial depositional surface that historically flooded only for short periods during high flow events of Lake Creek, mainly in spring, and it appears to have been dominated by prairie cordgrass, foxtail barley, wheatgrass, and possibly some saltgrass. Construction of the

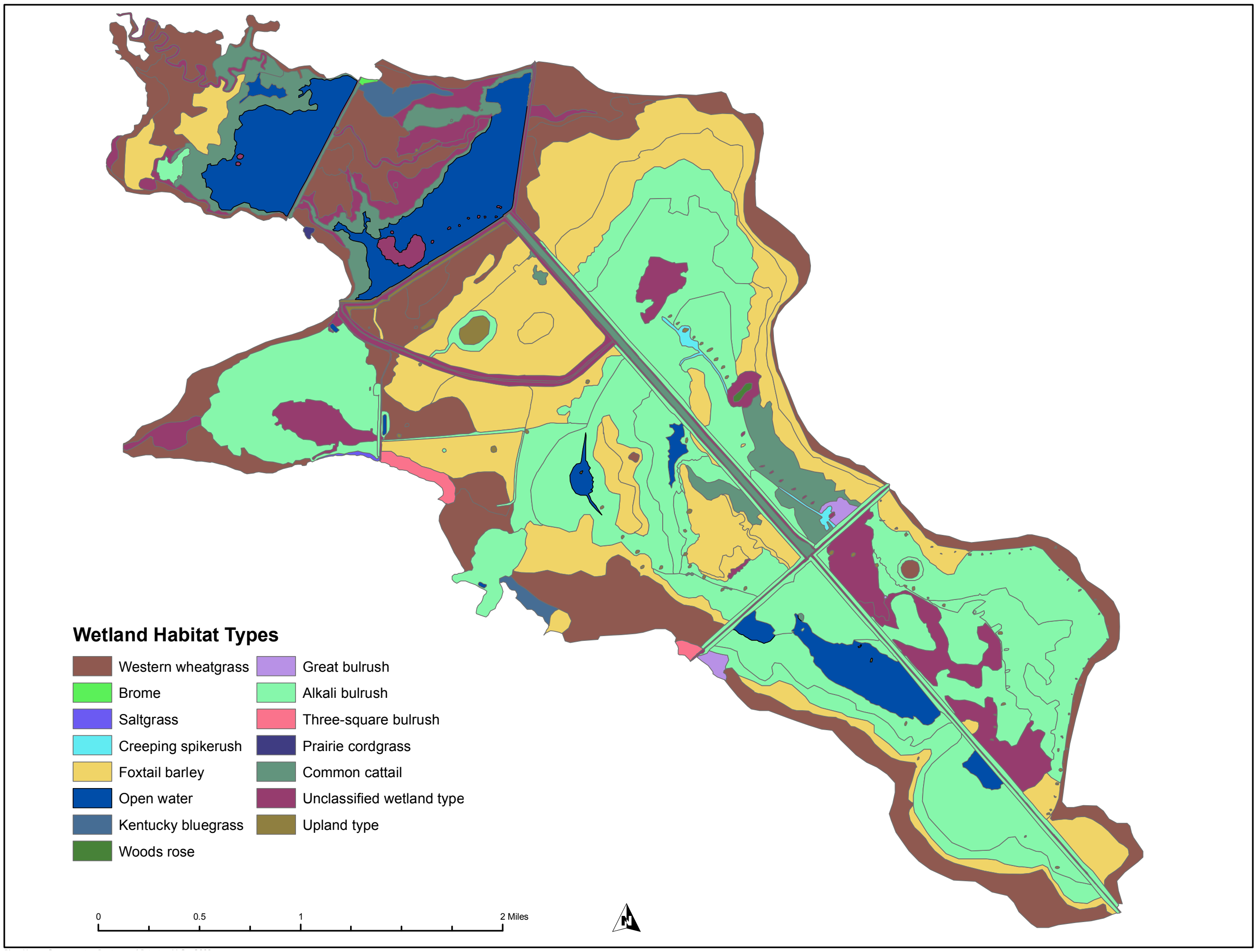


Figure 24. Distribution of major vegetation communities on Benton Lake National Wildlife Refuge, 2002 (adapted from Thompson and Hansen 2002).

internal levee to subdivide Pool 4 and construction of nesting islands and excavations shifted this site to wetter regimes in the 1960s to 1980s. In more recent years Pool 4b has been managed for shorter duration flooding. Common species in Pool 4b are foxtail barley, common orache (Atriplex patula), lambsquarter (Chenopodium album), prickly lettuce (Lactuca serriola), western wheatgrass, and the invasive crested wheatgrass. Little creeping foxtail is present in the subunit, but it may be expanding in coverage. Pool 4c is the largest subunit of Pool 4 and is becoming highly invaded by creeping foxtail. In 2001, the subunit retained a large amount of foxtail barley, western wheatgrass and alkali bulrush (Thompson and Hansen 2002), but each of these species is declining at present. Expansion of creeping foxtail may be increasing because the site appears to have prolonged soil saturation, but not extensive surface flooding. Soil saturation may be discouraging less water tolerant native grasses and moist-soil-type species. It is uncertain if this saturation is being caused by leakage from the main water distribution canal or seasonal diversion of surface water into the pool.

Pools 5 and 6 historically had several deeper depressions and these deeper sites remain dominated by alkali bulrush with some scattered cattail present. Edges of these pools are now covered mainly by foxtail barley, lambsquarter, strawberry blight (Chenopodium capitatum), rillscale (Atriplex dioica), and western wheatgrass. Exotic and invasive species are encroaching on the edges of these pools, but not as rapidly as other pools.

Fish and Wildlife Populations

Little quantitative data are available to determine changes in presence, abundance, and productivity of animal populations at Benton Lake

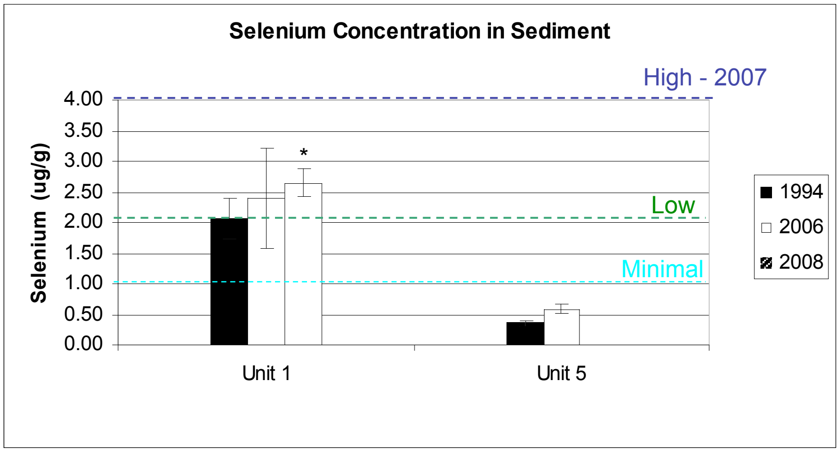
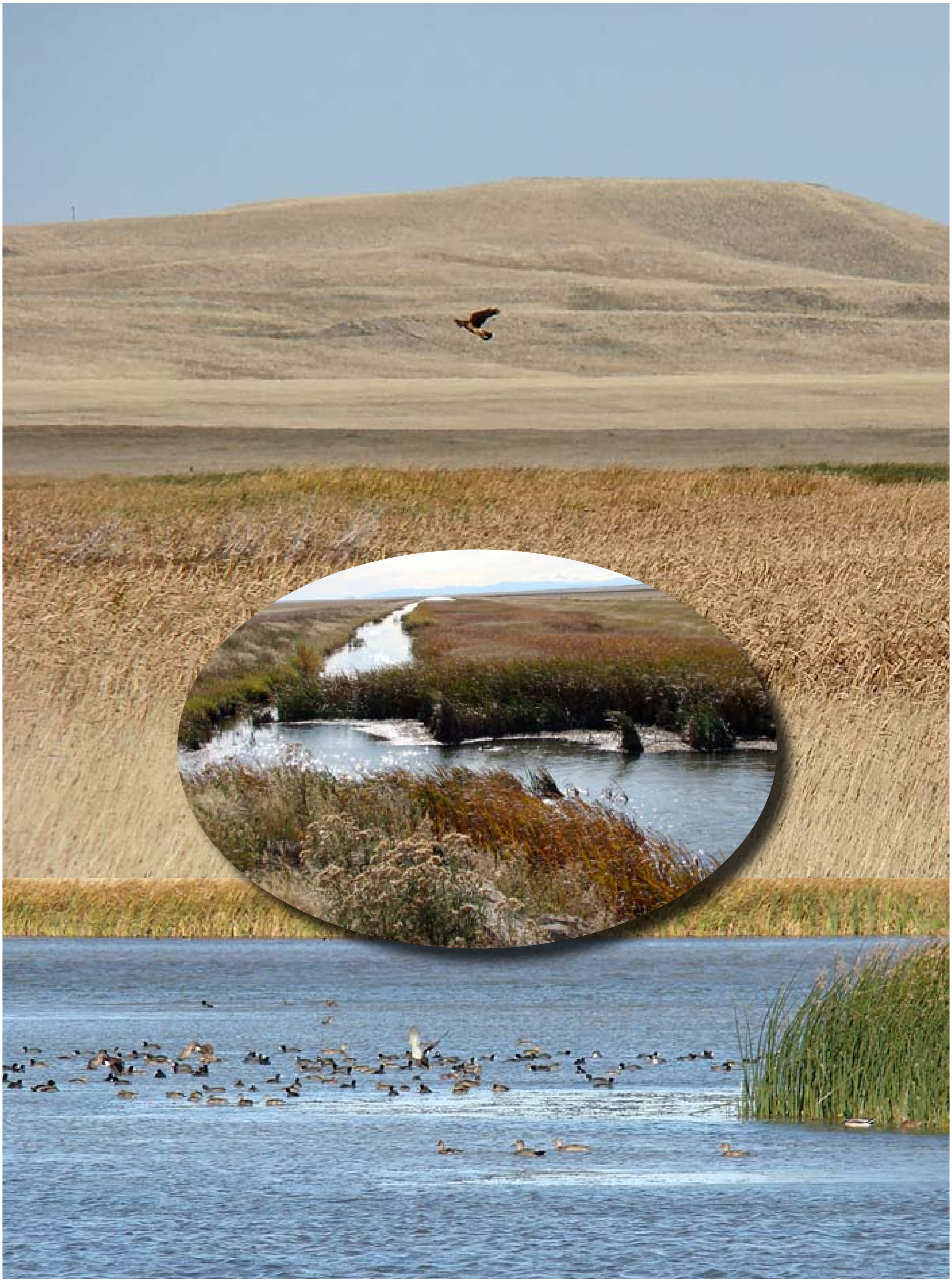


Figure 25. Selenium concentration in sediment in Units 1 and 5 on Benton Lake National Wildlife Refuge 1994, 2006, and 2008.

NWR over time. Certain data indicate increasing numbers and production of waterbirds, especially dabbling ducks on the refuge in the late 1960s to late 1970s when pools were managed for more prolonged water regimes (USFWS 1961-99). During this period annual duck production was high (several thousand ducklings) and included primarily northern shoveler, blue-winged teal, gadwall, cinnamon teal, northern pintail, and mallard. An increasing number of Canada geese also began using Benton Lake at this time and produced several hundred goslings in some years. Other common nesting waterbirds included American avocet, marbled godwit, willet, Wilson's phalaropes, American coot, and eared grebe. Franklin's gull nested in several large colonies containing upward of 15,000 nests. Number of breeding waterbirds has declined on Benton Lake in the last two decades as water management has reduced the amount of permanent and prolonged flooding of pools in summer (USFWS 1961-99). This reduction in breeding bird presence probably occurred historically as Benton Lake went through long-term cycles of flooding and drying among years.

Large numbers of migrant waterbirds still use Benton Lake during spring and fall migration. Up to 20,000 ducks, 400 tundra swans (Cygnus columbianus), and 2,000 Canada geese regularly use the lake and region each fall; numbers in spring are lower, but birds are more dispersed throughout the Benton Lake Basin. Similarly, large numbers of shorebirds, wading birds, and gulls/terns use Benton Lake in fall and spring. Some survey data suggest gradually declining numbers of all waterbirds using Benton Lake in the past two decades (USFWS 1961-99).

In the 1980s, concerns about selenium contamination in the Sun River Irrigation District, including Benton Lake, precipitated several studies of selenium accumulation in biota. These studies specifically investigated selenium concentration in aquatic plants, invertebrates, fish, and waterbirds to document accumulation levels and incidences of mortality, physical abnormalities, and reproductive failures (Knapton et al. 1988, Palawski et al. 1991, Lambing et al. 1994, Nimick et al. 1996, Henny et al. 2000). Impacts of selenium concentration commonly are manifested in the reproduction of waterbirds (Lemly and Smith 1987, Ohlendorf and Skorupa 1989, Skorupa and Ohlendorf 1991) but to date studies have not detected overt evidence of reproductive toxicity at Benton Lake. However, selenium in aquatic invertebrates, forage fish, waterbird eggs, and waterbird livers had selenium concentrations that were elevated relative to other regional areas and related to environmental reference concentration for biological risk (Nimick et al. 1996). Bioassays of aquatic organisms using surface water samples from several locations resulted in toxic responses in fathead minnows and two species of invertebrates. All studies to date have consistently found the highest levels of selenium accumulation in biota at Benton Lake in Pool 1. While selenium has accumulated in Benton Lake biota, currently residues in biological tissues are mostly below biological risk levels and appear to be stable or slightly increasing in this system in recent years (Fig. 25). Much of the selenium discharged to wetlands is accumulating in bottom sediment, predominantly in near-shore areas and potential impacts to biota appear greatest near the mouths of inflows near several seeps around the lake (e.g., the larger saline seep on the west side of Pool 4c) and the mouth of Lake Creek where it enters Pools 1 and 2.



Karen Kyle

ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS

A SUMMARY OF CONDITIONS

Information obtained and analyzed during this study were sufficient to conduct a HGM-based evaluation of historic and current ecological conditions on Benton Lake NWR and the surrounding region. The dominant feature of Benton Lake NWR is the historic Benton Lake bed formed during Pleistocene glacial and post-glacial events. The historic extent of the Benton Lake bed (Fig. 10) is intact, however, the physical integrity of the historic Benton Lake bed is highly altered from infrastructure developments for water management to enhance waterfowl production. These infrastructure developments and water management in Benton Lake since the early 1960s have dramatically changed historic seasonal and long-term water regimes and the associated distribution and extent of native plant communities. These changes in the primary ecological driver of the Benton Lake ecosystem (i.e. seasonally and annually dynamic water regimes within a closed basin) and structural elements of it (topography and plants) have impacted resources used by many animal species. Further, conversion of native grassland to agricultural crop-fallow rotation in much of the immediate watershed of the Benton Lake Basin has degraded quality of regional surface and groundwater and increased the number and severity of saline seeps that periodically flow into Benton Lake. Changes in local ground and surface water quality and runoff to Benton Lake are exacerbated by pumping irrigation return water (large amounts in some dry years) from Muddy Creek, into the Lake Creek channel and ultimately into Benton Lake. These regional land use changes and pumping schedules have caused increased salt and selenium deposition in some parts of Benton Lake.

The information obtained and analyzed in the first two sections of this report are critical precursors to the next step of this HGM evaluation for Benton Lake NWR, which is to "Identify Potential Approaches to Successfully Manage and Restore Specific Habitats and Conditions." The obvious challenge for this evaluation is to understand what management actions will be possible and most efficient/effective in restoring basic ecological attributes and processes to this unique ecosystem in a sustainable manner.

The key summary data and observations obtained in this study are:

1. The Benton Lake Basin, including the Benton Lake bed depression, were formed during the last Pleistocene glacial period when ice sheets dammed the ancestral Missouri River and formed glacial Lake Great Falls, which covered low-lying parts of this region.

2. Glacial drift associated with this last ice sheet was deposited northeast of Benton Lake and east of Priest Butte Lakes and created a hydrologically "closed" Benton Lake Basin where most surface waters ultimately flowed into Benton Lake proper and no outlet was present.

3. Gently dipping sedimentary bedrock underlies the unconsolidated glacial, alluvial, and lacustrine-type deposits at Benton Lake; the bedrock is mostly seleniferous marine shale of the Cretaceous Colorado Group.

4. Most geomorphologic surfaces at Benton Lake are Quaternary Lake (Ql) deposits. Secondary geomorphic surfaces are Quaternary alluvium-colluvium (Qac) deposits at the mouths of Lake Creek and other small tributaries where they entered Benton Lake; Quaternary terrace (Qt) deposits adjacent to the Benton Lake bed;

and Upper Cretaceous Bootlegger Member (Kbb) deposits on high ridges adjacent to “Qt” surfaces.

5. Surface soils at Benton Lake are predominantly clays and silty clays deposited in the lacustrine environments of glacial Lake Great Falls and later Benton Lake proper.

6. Topography at Benton Lake NWR reflects dominant geomorphologic surfaces (i.e., relatively flat lake bed, alluvial-colluvial fans, terraces, and old Cretaceous ridges). Within Benton Lake proper, elevations range from about 3,614 feet amsl in the lowest depressions to about 3,620 on terraces.

7. The climate of the Benton Lake region is generally characterized by pleasant summers with warm, mostly sunny, days and cool nights characteristic of Northern Great Plains regions where frequent Chinook winds occur. The growing season averages 121 days from mid-April through mid-September.

8. The Benton Lake Basin is semiarid with 70-80% of total annual precipitation (mean of 14.98 inches) occurring April to September. Consequently, rains and snowmelt during spring and summer contribute runoff water to Benton Lake and create a strongly unimodal seasonal peak of water levels in early summer followed by gradual declines, mostly caused by 40-41 inch/year evapotranspiration, to low stable (or dry in some years) water levels in fall and winter.

9. In addition to strong seasonal patterns of flooding, Benton Lake has evidence of long-term 15-20 year recurring patterns of peak lows and highs in regional precipitation, runoff, and therefore water levels are evident at Benton Lake. High water levels (followed by declines to lows) caused by natural runoff have occurred at Benton Lake in the late 1920s, early 1940s, late 1950s, mid 1970, and early 1990s.

10. Natural water inputs to Benton Lake come primarily (65-70%) from the 137 mile^2 Lake Creek watershed; the remainder is derived from on-site precipitation and runoff from small local drainages.

11. Deeper ground water beneath the Benton Lake Basin is confined primarily to the aquifer within the Colorado Shale formation and this groundwater is poor quality with low chloride concentration, moderate dissolved-solids, basic, and reduction conditions.

12. Shallow ground water in the Benton Lake Basin, in contrast, is acidic with high levels of calcium, sulfate, chloride, and magnesium.

13. Historically, the relatively low amount of annual precipitation in the basin was captured quickly and used by native grassland; little water moved deeply into soil or subsoil layers. Where water did percolate downward, it subsequently moved slowly and occasionally exited slopes as springs and saline seeps.

14. Deposition of salts and elements such as selenium did not historically accumulate to high levels in Benton Lake because of lower natural inputs from water, low ground water discharge, wind erosion, and elemental volatilization in water, sediment, and wetland plants during dry periods of the long-term hydrological cycle.

15. Historic vegetation communities at Benton Lake ranged from dense emergent wetland species in low elevations with more permanent water regimes to upland grassland on terraces and ridges. This gradation of communities included: 1) robust emergent, 2) sedge-rush, 3) seasonal herbaceous, 4) wet grassland, and 5) upland grassland habitat types.

16. The distribution of vegetation communities at Benton Lake were related to both geomorphology and elevation/flood frequency both seasonally and long-term; precise community distribution likely varied to some degree during wet vs. dry long-term water and flooding regimes. Sedge-rush communities apparently composed more area of historic Benton Lake than other vegetation associations.

17. A rich diversity of animal species historically used the Benton Lake ecosystem, especially birds. Waterbird use and production of Benton Lake proper varied among years depending on extent and duration of annual flooding.

18. Native people occupied the Benton Lake region since about 10,000 years BP but apparently had little influence on local ecosystems because of their mobile lifestyles, except to occasionally set fires in upland grasslands.

19. European settlers were not common in the area until the mid 1800s and the Benton Lake Basin remained relatively unchanged from historic condition until about 1880.

20. Lands within the Benton Lake Basin were acquired as part of the Louisiana Purchase and were kept in U.S. Government ownership until the early 1900s. Lands in and immediately adjacent to Benton Lake were owned and managed by the Bureau of Reclamation as part of the Sun River Reclamation (late Irrigation) Project with the intent of using it as a water storage reservoir. Dynamic water levels and climate in the region prohibited this use.

21. One early attempt was made to ditch and drain Benton Lake, but the "closed" basin topography and hydrology caused this effort to fail.

22. Conversion of native grassland to agricultural crops in the region began in earnest in the 1920, following development of the Greenfields Irrigation Division of the Sun River Project and accompanying markets and transportation mechanisms for locally-grown grain, mostly wheat. Much of the native grassland adjacent to Benton Lake was converted to "dry-land" crop-fallow rotation from 1930 to 1950.

23. The alternate crop-fallow rotation in the region has gradually increased the number and severity of saline seeps within the Benton Lake Basin; over 250 saline seeps now are mapped. Ground water flows in crop-fallow areas move to nearby hill slopes where it discharges and evaporates, forming areas of salt precipitates, increasing water salinity, and depositing dissolved metallic elements including potential contaminants such as selenium.

24. Benton Lake NWR was established by Executive Order in 1929 but little development or management occurred until the late 1950s and early 1960s; until that time it was administered by the National Bison Range in western Montana.

25. A pump station located on Muddy Creek, about 15 miles east of Benton Lake NWR, and a pipeline were constructed 1958-1962 to bring irrigation return flow water to the refuge to provide an annual available source of water to flood Benton Lake. Water from the Muddy Creek pump station is moved 5 miles through underground pipe and then is discharged into the Lake Creek channel where it flows about 12 miles to its mouth at Benton Lake.

26. In addition to the pump station and pipeline, the historic Benton Lake bed was subdivided during 1960-62 into 6 pools by dikes, levees, ditches, and water-control structures to facilitate management of water and vegetation for waterfowl production. Later, Pool 4 was subdivided into 3 pools (4a-4c). Pumped and natural runoff water in Lake Creek flows into Pools 1 and 2,, which were constructed at the mouth of Lake Creek, and then by gravity flow into other pools. Other physical developments on the refuge have altered natural topography, water flow patterns, and local hydrology.

27. Water management within Benton Lake from the early 1960s through the late 1980s typically sought to regularly pump water to the lake from Muddy Creek and to extensively flood most wetland pools for prolonged periods each year to provide waterbird breeding habitat, brood-rearing areas, and waterfowl fall migration and hunting areas. This management ultimately changed historic hydrological patterns to more prolonged, less dynamic, and more consistent regimes. The relative amounts of water pumped to Benton Lake from Muddy Creek compared to natural runoff from Lake Creek varied substantially over years.

28. More permanent water regimes in Benton Lake gradually changed vegetation communities to more water tolerant types, increased salinity and selenium accumulation, promoted expansion of invasive plant species, and increased severity and occurrence of avian botulism outbreaks that killed thousands of waterbirds in some years.

29. Water management at Benton Lake since the early 1990s has reduced pumping during summer and now employs more seasonal water regimes, except in Pools 1 and 2, which continue

to be managed for permanent flooding to store water and provide summer waterbird habitat. Most pools received pumped or natural runoff water in spring, are allowed to dry to varying degrees during summer, and then receive more pumped water in early fall to provide habitat for waterfowl hunting and to store water for the following year.

30. The primary source of dissolved solids and selenium that enters Benton Lake is agricultural irrigation drainage water pumped from Muddy Creek and surface and subsurface ground water flow from numerous saline seeps in the Lake Creek watershed. The mean annual selenium load delivered to Benton Lake was 151 lbs/year from 1970 to 2008, with natural runoff contributing an average of 60.9% of the selenium.

31. A model of selenium cycling within Benton Lake pools was developed (Zhang and Moore 1997a), and is currently being refined, to predict when selenium concentrations in Benton Lake sediments would become hazardous. The 1997 model predicted that more permanent water regimes in Pools 1 and 2 and an area near saline seeps in Pool 4c would exceed toxicity thresholds by 2008 and 2014, respectively. Recent sampling indicates these toxicity threshold levels have not been exceeded, but potential accumulation rates are of concern.

32. Vegetation communities at Benton Lake NWR now contain highly altered communities and expansion of the aggressive introduced creeping foxtail.

33. Documentation of long-term changes in animal populations at Benton Lake NWR is constrained by lack of, or short tenure, surveys and monitoring. Certain evidence suggests reduced occurrence and productivity of waterbirds, with some potential contamination to toxic levels of selenium.

GENERAL RECOMMENDATIONS FOR RESTORATION AND MANAGEMENT OBJECTIVES

This study is an attempt to evaluate restoration and management options that will protect, restore, and sustain natural ecosystem processes, functions, and values at Benton Lake NWR rather than to manage for specific plant/animal guilds or species. Benton Lake NWR provides key resources to meet annual cycle requirements of certain trust, priority, and concern species, and these needs will continue to be addressed, but within the context of more holistic regional landscape- and system-based management objectives. The National Wildlife Refuge System Improvement Act of 1997 seeks to ensure that the biological integrity, diversity, and environmental health of the (eco)system (in which a refuge sets) are maintained (USFWS 1999,Meretsky et al. 2006). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation, 2) assessment of each refuge's importance across landscape scales, and 3) recognition that restoration of historical processes is critical to achieve goals (Mertetsky et al. 2006). Most of the CCP's completed for NWR's to date have highlighted ecological restoration as a primary goal, and choose historic conditions (those prior to substantial human-related changes to the landscape) as the benchmark condition (Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historic conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s)." (USFWS 2001)

Given the above USFWS policies and mandates for management of NWR's, the basis for developing recommendations for Benton Lake NWR, and use in developing the CCP for the refuge, is the HGM-approach used in this study. The HGM approach objectively seeks to understand how this ecosystem was created, the fundamental processes that historically "drove" and "sustained" the structure and functions of the system and its communities, and what changes have occurred that have caused degradations and that might be reversed and restored to historic and functional conditions within a "new desired" environment. This HGM approach also sets the NWR within the context of appropriate regional and continental landscapes it sets, and identifies its "role" in meeting larger conservation goals and needs at all geographical scales. In many cases, restoration of functional ecosystems on NWR lands helps that refuge serve as a "core" of critical, sometimes limiting, resources than can complement and encourage restoration and management on adjacent and regional private and public lands.

Based on the HGM context of information obtained and analyzed in this study, we believe that future management of Benton Lake NWR should seek to:

1. Maintain the physical integrity of the hydrologically closed Benton Lake Basin and emulate a more "natural" seasonally- and annually-dynamic water regime within Benton Lake proper.

2. Control and reduce accumulation of salts and contaminants such as selenium within the Benton Lake system.
3. Restore and maintain the diversity, composition, distribution, and regeneration of wetland and upland vegetation communities on Benton Lake NWR in relationship to topographic and geomorphic landscape position.

4. Provide functional complexes of resource availability and abundance including seasonal food, cover, reproductive, and refuge resources for endemic animal species.

The following general recommendations are suggested to meet these goals for Benton Lake NWR:

1. *Maintain the physical integrity of the hydrologically closed Benton Lake Basin and emulate a more "natural" seasonally- and annually-dynamic water regime within Benton Lake proper.*

The Benton Lake ecosystem developed under, and was adapted to, strong seasonally- and annually-dynamic flooding regimes caused by variable regional precipitation and runoff within the hydrologically closed Benton Lake Basin. Benton Lake proper received most of the runoff within this basin, primarily through the Lake Creek watershed, and was the terminal repository of water and dissolved or suspended constituents including sediments, salts, and elements. In general, this ecosystem was characterized by spring flooding from regional rain runoff and snowmelt followed by gradual drying to low water conditions in fall and winter. The degree of spring flooding and subsequent summer drying varied among years, with regular peaks and lows of wet and dry periods occurring on about 15-20 year patterns. Historic and current hydrological information suggests wet, highly flooded, periods typically lasted 2-3 years; followed by gradual drying to extreme dry periods of 3-5 years, and then gradual return to wet conditions. This undulating pattern of flooding and drying greatly influenced plant communities and evolution of endemic animal populations in this Great Plains ecosystem.

This physical integrity of the Benton Lake bed was sustained because:

a. No outlet to the lake bed was present and the primary tributaries to the lake were not diverted or altered.

b. Native grassland in the watershed filtered and reduced erosion and sediment entry to tributaries, thereby reducing sedimentation of the lake bed.

c. Drying of most, and occasionally all, of the lake bed during dry long-term climatic periods prohibited accumulation of organic material and contaminants through accelerated decomposition of vegetative material, wind erosion of accumulated salts, and volatilization of trace elements including selenium.
d. Seasonal flooding and drying also reduced organic and contaminant accumulation through annual decomposition and wind erosion/volatilization

Vegetation and animal communities, nutrient cycling, and energy flow within Benton Lake were sustained because:

a. Seasonal flooding dynamics provided heterogeneous wet and dry surfaces for germination of diverse wetland plant communities and production of seasonal resources used by many animals. Most animal groups used Benton Lake only seasonally and their entry to, and exit from, the lake system helped form complex food and energy webs.

b. Long-term flooding and drying cycles within a closed basin conserved and recycled nutrients and energy through periodic "pulses" of energy flow into the system and decomposition/recycling of nutrients and elements.

c. Grasslands on uplands and terraces adjacent to the lake and within the Benton Lake watershed prevented excessive groundwater infiltration and subsequent solution and transport of salts and trace elements, such as selenium that originates from the underlying Colorado Shale deposits of the region, into seeps that then flowed into tributaries or slope edges of Benton Lake.

Maintaining and restoring the physical and biotic attributes that created the above dynamic hydrological regime within Benton Lake should be a priority to allow natural ecological processes to sustain this ecosystem. Few, if any alterations to the physical and hydrological attributes of the Benton Lake ecosystem occurred until the early 1900s, and unfortunately, most site-specific alterations have occurred since the early 1960s when the refuge began intensive development and management. Certain of these alterations may be difficult to reverse, while others are directly under the control of the NWR.

2. *Control and reduce accumulation of salts and contaminants such as selenium within the Benton Lake system.*

Terminal wetland basins in semiarid environments of the Northern Great Plains, such as Benton Lake, typically are alkaline, but have equilibrium-dynamic of elements and salts that prevent the system from becoming highly saline and with depauperate vegetation communities. Wetland ecosystems that retain the physical, hydrological, and biotic components that provide system integrity (such as listed under #1 above) are capable of supporting more diverse, and productive plant and animal communities. When these Northern Great Plains wetlands become degraded from naturally-occurring historic conditions, either from regional or site-specific alterations, then the balances of salt and elemental inputs vs. outputs becomes altered and accumulation and contamination often occurs.

Since the early 1900s, conversion of native grassland to crop-fallow rotations in the Benton Lake watershed have gradually changed chemical balances within soils and water in the region. The most critical changes have been the increased development of saline seeps in the watershed that developed when ground water infiltration increased greatly in fallow fields and subsequently caused salts and metallic elements, especially selenium, to become dissolved and be transported to seeps. Water discharged from the seeps formed precipitates that accumulated either locally near the seep site or were transported ultimately to Benton Lake through multiple small drainages and Lake Creek. Increased transport and accumulation of salts and elements in Benton Lake was exacerbated when irrigation return water from Muddy Creek also was pumped to the lake after 1962. Development and management of wetland pools within Benton Lake proper in the early 1960s promoted extended seasonal inundation of many parts of the historic lake bed and effectively removed long-term dynamics of periodic very dry vs. very wet periods. This “dampening” of both seasonal and long term hydrological cycles, with more consistent and prolonged flooded, also caused accumulation of salts and elements within the closed system of Benton Lake, because the dry periods when wind erosion and volatilization occurred were reduced or eliminated. Fortunately, most pools on Benton Lake have been managed for more natural water regimes in the last decade or so, however, Pools 1 and 2 continue to be managed for more permanent water regimes and water storage. Modeling of selenium accumulation at Benton Lake has forecast additional accumulation (potentially to toxic levels for many biota) if this more permanent water management continues in Pools 1 and 2 and actions to reduce the extent and severity of saline seeps, at least immediately adjacent to Benton Lake, are not pursued.

Obviously, the threats of potential continued, or accelerated, accumulation of salts and selenium in Benton Lake are serious and must be addressed. Lessons from sites of salt and selenium accumulation on other NWRs (e.g., Skorupa and Ohlendorf 1991, Seiler et al. 2003) mandate actions to assure that salts and selenium do not accumulate and cross sometimes irreversible toxicity thresholds for water quality, sediment, and vegetation. These actions will require land use and water management changes both on and off Benton Lake NWR.

3. *Restore and maintain the diversity, composition, distribution, and regeneration of wetland and upland vegetation communities on Benton Lake NWR in relationship to topographic and geomorphic landscape position.*

A rich diversity of vegetation communities historically was present on Benton Lake NWR and they were distributed along geomorphic surface, topography, and flood frequency gradients (Fig. 12). In this closed basin, the dominant factor determining distribution of plant species was topography as it was related to the seasonal flooding regime caused by interannual and intraannual dynamics of water flow into the lake bed and its subsequent surface water retention and recession in this semiarid environment with high annual evapotranspiration rates. Most historic vegetation communities at Benton Lake still are present, however, the extent, distribution, and composition of these communities has changed. Also, native communities are increasingly being replaced by invasive or exotic species. Many factors have changed these communities; the most important influences have been physical and hydrological changes to the lake bed and altered water chemistry, especially salt balances. Certain of these changes may be reversible, while others may not be possible or desirable depending on regional land use and on-site NWR management objectives.

Generally, ecosystem restoration and wetland management strategies should seek to restore elements of the diversity and natural distribution patterns of habitats in a region/site where they have been altered. This is a goal of Benton Lake NWR. Such restoration is important to sustain native plant and animal communities and provide critical ecosystem functions and values such as nutrient flow, carbon sequestration, water storage and filtration/volatilization, sediment reduction, groundwater recharge, etc. The challenge for system managers will be to understand what habitat/community types can be restored given the long-term physical and hydrological changes to this system. Additionally, management must consider: 1) whether patch sizes of restored habitats are large enough to be sustainable; 2) whether configuration of habitats will create and enhance basic desirable landscape attributes such as providing travel and energy corridors, refuge, and seasonal foods; 3) the balance between tolerating short- and long-term natural flooding and dry periods/years vs. desires to provide predictable resources for select animal species or groups (e.g., breeding waterbirds); 4) what management actions will be required to control invasive species and how this control may impact restoration of native communities; and 5) what intensity and cost of management (water, manipulation, etc.) will be required to maintain habitats. The primary ecological factor that will control the success of restoring sustainable native habitats at Benton Lake is future water management and the capabilities to manage primarily for seasonal hydroperiods and occasional extended dry conditions in pools.

4. *Provide functional complexes of resource availability and abundance including seasonal food, cover, reproductive, and refuge resources for endemic animal species.*

Annual primary and secondary productivity and total community biomass historically were high in the Benton Lake wetland ecosystem primarily because of the diverse vegetation communities that were supported by rich alluvial/lacustrine-type soils and dynamic seasonal pulses of water, nutrients, and energy flow. Upland grasslands adjacent to Benton Lake were critical for the wetland system to function properly because they buffered erosion and movement of sediments, salts, and trace elements into the lake, created continuums of communities and nutrient flow, and provided corridors for animal movement into and out of the basin. Each community type on Benton Lake NWR provided different, yet complementary seasonal resources that ultimately supported large populations of many animals, especially migrant waterbirds. The long-term interannual dynamics of water in Benton Lake proper caused irregular use and abundance of many species with alternating “booms” and “busts” in use and productivity during respective wet and dry periods. Basic adaptations of animals in this highly dynamic system included relative long life span, high mobility or seasonal torpor, seasonal omnivory, and diverse diets within a trophic level (Van der Valk 1989). Historically, many small and large wetland basins were present throughout the western Great Plains and foothills/valleys of adjacent mountain ranges, therefore animals, especially birds, had many options for obtaining resources and reproducing within and among years. For example, several small wetland basins in addition to Benton Lake proper were present within or near the Benton Lake Basin including Freezeout Lake, Black Horse Lake, etc. Unfortunately, many regional wetland basins in the Western Great Plains have been destroyed or are no longer functional to provide key resources to certain animals (e.g. Knopf and Samson 1997). This reduction in regional habitat base places greater importance on resources in remaining habitats such as on Benton Lake. A primary management challenge for Benton Lake NWR is to consistently provide key resources without significantly altering, or potentially destroying, the capability of that system to be sustainable.

Restoration and management of Benton Lake NWR ultimately must understand what, and where, native resources historically were present and how the new desired state of habitats can restore or replace them. Collectively, retaining the physical and hydrological integrity of the Benton Lake bed, emulating natural hydroperiods, improving water quality issues, and restoring natural vegetation communities are critical to maintaining long-term sustainable resources, in a pulse-type provision, in this closed basin system. Benton Lake NWR cannot provide highly abundant and diverse resources every year for many consecutive years without compromising basic and inherent capabilities of the system to recycle nutrients and energy, remove salts and contaminants, regenerate native plant communities, and maximize productivity. Understanding and accepting the need for water dynamics in this system is key and will require more regionally- and continentally-comprehensive strategies and planning to protect, restore, and provide essential habitat and resources for animal species using the Western Great Plains.

SPECIFIC RECOMMENDATONS TO MEET ECOSYSTEM RESTORATION GOALS

Protect the Physical Integrity of the Benton Lake Basin and Emulate Natural Hydrological Regimes

1. *Retain the closed nature of Benton Lake proper and protect watersheds and drainage routes of its tributaries.*

The Benton Lake Basin is a hydrologically closed system with Benton Lake proper being the terminal basin for most water runoff in the region. Physical and biotic features of this system reflect historic creation of the basin and the energy/nutrient dynamics of this system. The fundamental sustainability of this system depends on maintaining the balance of natural water, energy, and nutrient inputs vs. exports from evapotranspiration, wind erosion, and animal movements. Attempts to alter the closed nature of the basin, especially Benton Lake proper, run the risk of altering natural constituent balances, basic ecological processes, and endemic plant and animal communities. At various times in the last 100 years, attempts have been made (or at least were suggested) to physically alter this closed system, especially Benton Lake proper, by creating artificial drainage from the lake, inputting more water to the basin and Benton Lake from other basins, and conversely diverting Benton lake water to other wetlands and basins. Pumping water to Benton Lake from Muddy Creek is the primary outside influence to date.

The following actions seem important to maintain the physical integrity of Benton Lake:

- Retain Benton Lake proper as a closed basin with no additional water delivered to it from non-basin sources and no creation of drainage from the basin.

- Maintain the physical and chemical structure and attributes of tributaries to Benton Lake, especially the Lake Creek watershed.

- Do not divert Benton Lake water to other basins or other wetland depressions within the Benton Lake Basin.

2. *Restore natural topography and reconnect natural water flow corridors and patterns where possible.*

Restoration of natural topography, especially reconnecting water flow pathways and types within Benton Lake NWR is important to allow water, nutrients, and animals to move through the system in more natural patterns. Historically, water entered Benton Lake mainly from Lake Creek and then moved across the lake bed in a sheetflow manner, first into deeper depressions and then expanding sequentially onto higher elevations as waters rose from additional inputs. The development of management pools within Benton Lake has greatly disrupted this flow. Ideally, natural water flow patterns, including source, timing, and distribution could be restored at Benton Lake. This is especially desirable at the mouth of Lake Creek.

Important specific restoration items include:

- Restore more natural topography within the Benton Lake bed, including removing artificial islands, filling internal-pool ditches, and restoring natural depressions and drainages.

- Evaluate all levees, roads, and water-control structures to determine if they are necessary, or are detrimental, to desired water management. Priority should be given to removing levees and water-control structures in Pools 1 and 2 where Lake Creek water enters Benton Lake. Remove unnecessary levees and roads and construct spillway breaches in some pools, if the current pool configuration is retained, to allow water to move among units during high water periods. The freeboard between full pool and top levee elevations should not be greater than one foot for interior pools.

- Do not construct additional levees, roads, or ditches within Benton Lake proper.

- Evaluate and restore the historic Lake Creek channel(s) at its mouth in Pools 1 and 2 and restore at least some capability for sheetwater overflow onto the adjacent "Qac" geomorphic surface.

3. *If the "Pool" configuration of Benton Lake is retained, improve water-delivery and control infrastructure and manage wetland pools for more natural seasonal and annual water regimes.*

The most important factor that will enable restoration of the Benton Lake ecosystem will be to change water management to more closely emulate natural hydrological regimes. This means that retained wetland pools within the historic Benton Lake bed should have seasonally- and annually-dynamic water levels. Retained pools should be managed as seasonally flooded wetlands where water inputs occur in spring and then surface waters are subsequently allowed to recede from evapotranspiration or perhaps movement into other pools during summer and fall to low sustained levels over winter. Higher elevations in all existing pools were not historically flooded except during very wet years and even in these years the higher elevations apparently were flooded only for short periods in spring and summer. Pools also should be managed for periodic times of more extensive flooding and also more extended drying. The current water-control infrastructure at Benton Lake is capable of gravity flowing water from Pools 1 and 2 into lower pools and some additional inter-pool transfer. However, levees have disrupted the capability of water moving first into low depressions and then expanding to higher elevations. Further, some ditches and levees appear to have seepage, which may be making some parts of some pools (e.g., the southeast part of 4c) saturated for extended periods.

The following water management and water-control infrastructure items should be considered:

- Manage pools for interannually-variable seasonal water regimes.

- Allow lower elevation pools and depressions to become more extensively flooded in some years.

- Allow all pools to have extended (2-4 years) drying periods during each ca. 15 year cycle.

- Rotate flooding and drying regimes among pools so that some pools are either dry or more flooded in most years – this will allow the basin to have complexes of habitats and resources available to priority species in most seasons and years.

- Reduce annual water pumping from Muddy Creek to Benton Lake. In wet years when more runoff from Lake Creek occurs, pumping from Muddy Creek could be greatly curtailed or eliminated.

- Evaluate all infrastructure to determine efficiency in water movement into and among pools and to reduce seepage.

Control and Reduce Accumulation of Salts and Contaminants

1. *Restore natural hydroperiods to Benton Lake proper and balance seasonal and long-term inputs from Muddy Creek pumping vs. natural runoff in the Lake Creek watershed.*

Accumulation of salts and selenium within water, sediments, and biota of Benton Lake has occurred over time, in part because the natural hydroperiods of the system have been changed to more permanent, and annually consistent, flooding regimes. Management should seek to restore the natural dynamic equilibrium where the amount of selenium and salt removal from the basin through volatilization and wind erosion equals the amount of salt and selenium accumulation in the system. Volatilization and wind erosion are controlled by various environmental factors with high summer temperatures, higher air flow, evapotranspiration, natural flooding-drying cycles, exposure of mudflats and wetland soil surfaces, and decomposition of plants increasing the removal rates. Consequently, a key to restoring this equilibrium and reducing accumulation will be restoring more natural hydroperiods, both seasonally and annually.

Strategies and options to achieve this were provided in the previous "Emulating natural water regimes" section and include:

- If the pool configuration is retained, manage pools in an annually rotated manner to provide extended drying periods for all pools in more natural long-term patterns.
- Manage all higher elevations including "Qac" and "Qt" geomorphic surfaces for seasonally flooded regimes.
- Reduce non-basin water inputs to Benton Lake with most delivery occurring for select pools in dry years.
- Develop water-control infrastructure to allow more independence in pool water management.

2. *Encourage and participate in conservation programs in regional watersheds to reduce the extent and severity of saline seeps.*

The primary source of increased salts and elements, especially selenium, into Benton Lake is the numerous saline seeps within the watershed of the lake. Development and expansion of these seeps has been caused by extensive crop-fallow rotation farming in the region. Efforts to reduce seeps include landscape programs to revegetate fallow areas and/or reduce their extent and frequency of use. Efforts to change some land use in the region should be supported by the USFWS and Benton Lake NWR should encourage and participate in these programs as possible. Specific landscape programs might include:

- Expansion and maintenance of CRP programs within the Benton Lake watershed with native grassland used as the cover crop.
- Possible rest-rotational subsidies to discourage fallowing and with longer-term cycles of production.
- Conversion of some marginal small-grain cropland or highly erodible sites to native grassland or pasture/hay land (e.g., Brown 1972).

3. *Evaluate vegetation manipulation techniques for possibilities of reducing accumulation of selenium.*

Certain evidence (Zhang and Moore 1997a,b) suggests that significant amounts of selenium can be removed from the Benton Lake system when wetland plants burn and volatilization increases. Accelerated decomposition of wetland plants occurs during dry periods and naturally occurring fires in the Benton Lake Basin may also have occurred more frequently during those years. Fire is an important ecological process in western Great Plains grasslands and wetland basins and helps recycle nutrients and energy, facilitates regeneration of diverse native communities, and maintains structure of these ecosystems. Fires in upland grasslands moved into lower elevation wet area of basins and riparian areas during dry periods and provided similar benefits to these sites. Manipulation of wetland plants during dry periods should be evaluated within Benton Lake Pools, including:

- Occasional fires within select pools during dry periods, especially those pools that have become more monotypic, had expansion of invasive, and greater coverage by robust emergent species.
- Mechanical manipulation of dense monotypic or invasive stands of vegetation during dry years, including tillage and mowing.

Restore Natural Vegetation Communities

1. *Restore more natural distribution and composition of communities.*

Several distinct plant communities occurred within and adjacent to Benton Lake proper. These communities were arrayed primarily along elevation/flooding frequency gradients modified by underlying geomorphologic surfaces and soils. Small areas of robust emergent occurred in the very lowest elevation depressions within the lake bed where surface water was more frequent and prolonged. The most extensive plant communities within Benton Lake were sedge/rush type that covered most of the lower elevations of the lake bed and wet grasslands on the edges of the lake bed. Relatively narrow bands of annual herbaceous plants, often called moist-soil plants, occurred in seasonally flooded areas in between the sedge/rush and wetland grassland communities. Upland grasslands occupied extensive terraces and hills adjacent to the lake bed. Most of these communities still are present in Benton Lake, however their distribution and extent is highly altered. For example, more permanent and annually consistent water regimes have favored expansion of robust emergent and reduced wetland grassland zones.

Restoring more natural distribution and extent of communities will require changes in water management recommended above and would help achieve:

- Reduced area of robust emergent communities to the lowest elevations where water regimes will be more prolonged.
- Increased area of sedge/rushes, especially alkali bulrush and Carex species.
- Relatively narrow bands of annual herbaceous species in seasonally drawdown zones.
- Expansion of native wet grassland on the edges of the historic lake bed.
- Reduction of saltgrass to more saline sites.
- Expansion of prairie cordgrass on “Qac” geomorphic surfaces.

2. *Control expansion of invasive species, especially creeping foxtail.*

Creeping foxtail appears to be rapidly expanding in many wetland pools and may be replacing native species, such as alkali bulrush. Creeping foxtail produces aggressive underground rhizomes, does not go dormant during summer, tolerates a wide range of poorly drained soils, and is well adapted to high moisture conditions (NRCS 2007). It is often found in the hydrological zone adjacent to robust emergent species like cattail and hardstem bulrush and can withstand periodic flooding for up to 2 months. Wetter flooding regimes in the Benton Lake bed probably have contributed to expansion of this species and currently it is thriving where soil saturation, but not surface flooding, is prevalent during summer and fall. Little is known about controlling this species, as it mainly has been promoted as a preferred forage crop for livestock in the Northern Great Plains. Garrison creeping foxtail is often compared to reed canary grass (Phalaris arundinacea), and unfortunately it has similar characteristics of being high aggressive, spreading rapidly and outcompeting native associates, and being difficult to control. The following management may help reduce the presence and expansion of creeping foxtail and other invasive species:

- Return Benton Lake to more natural water regimes, especially extended drying periods both seasonally and annually.
- Disturbance, either mechanical or with fire, during dry periods.
- Chemical applications.

Providing Key Resources

1. *Provide a rotational complex of wetland habitats and seasonal resources.*

The Benton Lake ecosystem historically attracted, and supported, a rich diversity and abundance of animals, especially during wet periods of the long-term hydrological cycle. Most animal species exploited seasonally available resources, and were present during seasons and years when key resources were available to meet specific life-cycle requirements. During wet periods, soon after the lake was flooded, breeding and migration waterbird numbers in particular were spectacular and attracted the attention of hunters and naturalists. Historic management of Benton Lake NWR, and many other Northern Great Plains wetlands owned and managed by state and federal agencies, has sought to create habitat conditions that occurred during wetter periods to maximize production of food/cover resources that increased waterbird production. Unfortunately, water management on many areas, including Benton Lake, has attempted to replicate wetter conditions and communities annually, or least in most years, and consequently has disrupted natural hydrological patterns and basic ecological processes that sustained these systems. Specifically, water management at Benton Lake until the 1990s sought to deeply flood many pools throughout spring, summer, and fall. This alteration to natural hydrological regimes coupled with regional land use changes gradually converted the lake bed to more robust emergent plant communities, increased accumulation of salts and selenium, increased presence of invasive species, reduced abundance and availability of key resources, and ultimately reduced diversity and presence of native plant and animal communities.

Historically, animals, especially waterbirds, using wetlands within the Northern Great Plains had access to many wetlands and habitat types throughout the region. This abundance and wide distribution of wetlands enabled species to withstand dry periods in specific areas because alternate resources usually were present somewhere else. Unfortunately, many wetlands in the region now are destroyed and remaining ones, like Benton Lake, become more critical to support populations, especially those with reduced numbers or specific life-cycle requirements and adaptations. The temptation, therefore, is to try and manage Benton Lake for all species/habitats and to maximize flooded area each year. This temptation has been manifested at Benton Lake by past water management practices. It is important for Benton Lake NWR to continue to provide key resources for endemic animal species and populations, however, management must seek some balance between trying to provide many resources every year vs. sustaining the basic ecological processes, integrity, and productivity of the system. Given this goal, some compromise in management strategy may be possible if:

- Wetland pools can be managed for interannually dynamic water regimes that more closely emulate seasonal and long-term dynamics. Pools should go through rotations of wet vs. dry periods among sequential years and all pools and higher elevation area must have extended dry periods within ca. 15 year periods.

- If a pool has been managed for more prolonged flooding within a year, it must be closely monitored to assure that incidence and severity of disease (e.g., botulism) outbreaks and accumulation of salt/selenium levels do not occur.

2. *Protect native terrace and upland grasslands.*

Grassland communities on the edges of, and adjacent to, Benton Lake were critical to maintaining ecological processes within the lake and its functions and values. These communities buffered water, sediment, and salt/selenium entry to the lake; provided corridors of movement for many species in and out of the lake bed; and provided complementary resources and habitats, such as nesting or winter refuge sites, for species. Consequently, these grassland communities should be sustained by:

- Maintaining an adequate boundary of grassland around the entire Benton Lake bed and its tributaries.

- Convert any cropland immediately adjacent to the lake to grassland. This may require programs to encourage this conversion on private lands or additional acquisition to secure adequate grassland buffers.

- Manage terrace and upland grassland to sustain native species composition and structure.

3. *Maintain functional seasonal refuges.*

A key function of NWRs, including Benton Lake NWR, is the provision of refuge/sanctuary areas that have reduced disturbance and security for animals during specific life-cycle events, such as nesting, over-wintering, and migration. With reduced wetland habitat available in the western Great Plains, options for animals to find refuge are reduced, and areas like Benton Lake become even more important to sustain populations. Management practices that can improve refuge capabilities include:

- Controlling public access to specific areas that are important nesting, foraging, hibernacula, or brood rearing habitats during the seasons of importance.

- Managing hunting programs, especially waterfowl hunting, to reduce disturbance temporally and spatially. This includes setting aside some areas as inviolate sanctuaries during hunting seasons.

- Providing waterfowl/waterbird refuges in both seasonally-flooded and more prolonged-flooded areas each year if possible; some wetland pools should be permanently set aside as sanctuary to encourage and sustain traditions of use to the region. In some dry years, little flooded area may be present and waterfowl hunting may not be possible on the refuge.

MONITORING AND EVALUATION

Many monitoring and evaluation programs and studies have been conducted at Benton Lake NWR in the past two decades and data from these efforts have been important to document changes to the ecosystem and to help design future restoration programs including those identified in this report. Regular monitoring and studies directed toward specific information needs should be continued and expanded at Benton Lake NWR to help determine success or failure of management/restoration actions, provide information on uncertainties about the ecosystem, and ensure institutional memory of management programs.

Ultimately, the success in restoring and sustaining communities and ecological functions at Benton Lake NWR will depend on how well changes in water management can emulate natural water regimes that supported specific habitat types and how changes in water management and regional land use can control accumulation of salts and selenium in the system. Recommendations in this report address these critical issues and propose restoration of fundamental ecological processes that drive ecosystem function. Suggestions are made about the intensity of management that will be needed to achieve these goals. Nonetheless, some uncertainty exists about the short- and long-term ecosystem effects of these changes in water, vegetation, and contaminant management. Future management of Benton Lake NWR that incorporates the recommendations of this report can be done in an adaptive management framework where: 1) predictions about community restoration and water quality/quantity are made (e.g., annual accumulation rates of selenium in Pool 1 sediments) relative to specific management actions (e.g., changing Pool 1 water regimes to more seasonally-flooded patterns with extended drying in long-term patterns) and then 2) follow-up systematic monitoring and evaluation are implemented to measure ecosystem responses to various management actions and to suggest future changes or strategies based on the monitoring data. Critical issues that need this monitoring are described below.

RESTORING SEASONALLY- AND ANNUALLY-DYNAMIC WATER REGIMES

This report recommends many changes to water management in Benton Lake pools. Most changes involve restoring at least some natural water flow patterns and seasonally- and annually-dynamic flooding and drying regimes. The following data and monitoring programs are needed:

- Continue to document annual water budgets for all management pools including source (pumped vs. natural runoff), delivery mechanisms and routes, and extent and duration of flooding.

- Monitor and model surface water movement across elevations, among pools, through natural flow channels, and measures of time required to flood and drain various pools with current and proposed infrastructure developments and water management schedules.

- Determine the adequacy of all water-control structures.

SALT AND SELENIUM ACCUMULATION LEVELS

Since the mid 1980s, many studies have been conducted to document changes in water quality and quantity by source; accumulation of selenium and other trace elements in sediments and biota; and biogeochemical cycling mechanisms in Benton Lake. Certain studies also attempted to model and forecast future changes of selenium, in particular, given various scenarios of water inputs, water management, and climate. Collectively, these studies have been invaluable in establishing a baseline of information to document changes and guide recommendations for future management, including many of the recommendation in this report. Basic monitoring of these factors should continue and include:

- Periodic evaluation of water quality in Muddy Creek, Lake Creek, saline seep discharge, and Benton Lake wetland pools.

- Periodic evaluation of selenium levels in sediments, plants, and animals (including eggs and juveniles) within Benton Lake pools.

- Update water and selenium models for Benton Lake as more information becomes available and as new water management regimes are incorporated.

- Evaluate the effectiveness of using select disturbance techniques, including fire and tillage, in increasing selenium volatilization.

LONG TERM CHANGES IN VEGETATION COMMUNITIES RELATED TO WATER MANAGEMENT

One ultimate goal at Benton Lake NWR is to restore native plant communities in composition and distribution similar to historic conditions where possible. Certain developments, such as ditches, levees, and water-control structures within the Benton Lake bed will obviously constrain restoration of native vegetation communities in exactly the same distribution and extent as in pre-development periods. Nonetheless, general changes in community/habitat type distribution should occur if the recommended changes in water management, topographic restoration, and annual disturbances are followed.

Specific monitoring needs are:

- Periodic monitoring of distribution and composition of major plant communities in all wetland pools, terraces, and uplands using aerial photography, satellite imagery, and ground reconnaissance.

- Evaluation of key individual plant species survival, growth and reproduction including cattail, alkali bulrush, foxtail barley, and sedges.

ENDEMIC AND INVASIVE SPECIES

Complete inventories are needed for all plant and animal species and populations at Benton Lake. These inventories will help establish baseline conditions of population/species occurrence and production and allow managers to determine changes in distribution, survival, and management actions over time. Surveys of some species and periods, e.g., waterfowl numbers during fall migration, have been relatively consistent over time, however, little is known about population dynamics of other species including most amphibians and reptiles, mammals, and non-waterbirds. In all cases, monitoring abundance and distribution of both plants and animals should be coupled with information of annual water regimes and management schedules, water quality, disturbance, public use, and long-term habitat/community changes. New geographical information technologies now enable the integration of digital information into GIS frameworks that can be the basis for documenting and tracking changes in species and communities.

Specific monitoring is needed to:

- Determine changes in distribution and abundance of aggressive invasive plants, especially creeping foxtail, related to changes in water management and control techniques.
- Determine relative abundance and distribution of key amphibian, reptile, and mammal species.
- Continue long-term surveys of waterbirds during breeding and migration periods and relate local and regional distribution to changes in water management, habitat types and distribution, disturbance and refuge, and public access.

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APPENDICES

Appendix A. List of plant species for Benton Lake National Wildlife Refuge, Great Falls, Montana.

Category	Common Name	Scientific Name	Family	Native	Exotic
Robust Emergents					
	Beaked sedge	*Carex rostrata*	Cyperaceae	x	
	Common cattail	*Typha latifolia*	Typhaceae	x	
	Lesser cattail	*Typha angustifolia*	Typhaceae	x	
	Hardstem bulrush	*Scirpus acutus*	Cyperaceae	x	
Sedge/Rush					
	Alkali bulrush	*Scirpus maritimus*	Cyperaceae	x	
	Common spikerush	*Eleocharis palustris*	Cyperaceae	x	
	Needle leaf rush	*Carex eleocharis*	Cyperaceae	x	
	Sharp bulrush	*Scirpus pungens*	Cyperaceae	x	
	Water knotweed	*Polygonum amphibium*	Polygonaceae	x	
	Wooly sedge	*Carex lanuginosa*	Cyperaceae	x	
Seasonal Herbaceous					
	American sloughgrass	*Beckmannia syzigachne*	Poaceae	x	
	Common orache	*Atriplex patula*	Chenopodiaceae	x	
	Creeping foxtail	*Alopecurus arundinaceus*	Poaceae	x	
	Curley dock	*Rumex crispus*	Polygonaceae	x	
	Foxtail barley	*Hordeum jabatum*	Poaceae	x	
	Golden dock	*Rumex maritimus*	Polygonaceae	x	
	Inland saltgrass	*Distichlis spicata*	Poaceae	x	
	Meadow foxtail	*Alopecurus pratensis*	Poaceae		x
	Narrowleaf Cottonwood	*Populus angustifolia*	Salicaceae	x	
	Prairie cordgrass	*Spartina pectinata*	Poaceae	x	
	Red glasswort	*Salicornia rubra*	Chenopodiaceae	x	
	Reed canarygrass	*Phalaris arundinacea*	Poaceae		x
	Sandbar willow	*Salix exigua*	Salicaceae	x	
	Tufted hairgrass	*Deschampsia cespitosa*	Poaceae	x	
	Willow dock	*Rumex salicifolius*	Polygonaceae		x
Wet Grassland					
	Canada thistle	*Cirisium arvense*	Asteraceae		x
	Fivehook bassia	*Bassia hyssopifolia*	Chenopodiaceae		x
	Lambsquarter	*Chenopodium album*	Chenopodiaceae		x
	Marsh aster	*Aster hesperius*	Asteraceae	x	
	Poison hemlock	*Conium maculatum*	Apiaceae		x
	Poverty weed	*Iva axillaris*	Asteraceae	x	

Appendix A. (cont'd)

Category	Common Name	Scientific Name	Family	Native	Exotic
	Rabbitfoot polypogon	*Polypogon monspeliensis*	Poaceae		x
	Summer cypress	*Kochia scoparia*	Chenopodiaceae		x
	Western wheatgrass	*Agropyron smithii*	Poaceae	x	
Upland Grassland					
	Alfalfa	*Medicago* sativa	Fabaceae		x
	American vetch	*Vicia americana*	Fabaceae	x	
	Bahia	*Picradeniopsis oppositifolia*	Asteraceae	x	
	Bearded wheatgrass	*Agropyron caninum*	Poaceae		x
	Biscuit Root	*Lomatium macrocarpum*	Apiaceae	x	
	Bluebunch wheatgrass	*Agropyron spicatum*	Poaceae	x	
	Blue grama	*Bouteleloua gracilis*	Poaceae	x	
	Blue spruce	*Picea pungens*	Pinaceae		x
	Broom snakeweed	*Guiterrezia sarothrae*	Asteraceae	x	
	Caragana	*Caragana arborescens*	Fabaceae		x
	Cheatgrass	*Bromus tectorum*	Poaceae		x
	Clover	*Trifolium* spp.	Fabaceae		x
	Clubmoss	*Salaginella densa*	Lycopodiaceae	x	
	Common plantain	*Plantago major*	Poaceae		x
	Common sunflower	*Helianthus annuus*	Asteraceae		x
	Common willow-herb	*Epilobium cilliatum*	Onagraceae		x
	Crested wheat grass	*Agropyron cristatum*	Poaceae		x
	Curlycup gumweed	*Grindelia squarrosa*	Asteraceae	x	
	Daisy fleabane	*Erigeron* spp.	Asteraceae	x	
	Dandelion	*Taraxacum officinale*	Asteraceae		x
	Elm	*Ulmus* spp.	Salicaceae	x	
	Field Chickweed	*Cerastium arvense*	Capparaceae	x	
	Field penny cress	*Thiaspi arvense*	Brassicaceae		x
	Field milk-thistle	*Sonchus arvensis*	Asteraceae		x
	Fixweed tansymustard	*Descuraiania sophia*	Brassicaceae		x
	Fringed sagewort	*Artemsia frigid*	Asteraceae	x	
	Goatsbeard	*Traopogon dubius*	Asteraceae		x
	Golden pea	*Thermopsis rhombifolia*	Fabaceae	x	
	Green needlegrass	*Stipa viridula*	Poaceae	x	
	Ground plum milk vetch	*Astragalus crassicarpus*	Fabaceae	x	
	Hairy goldaster	*Chrysopsis villosa*	Asteraceae	x	
	Health aster	*Aster ericoides*	Asteraceae	x	
	Honeysuckle	*Lonicera maackii*	Caprifoliaceae		x
	Hood's phlox	*Phlox hoodii*	Polenoniaceae	x	
	Intermediate wheatgrass	*Elytrigia intermedia*	Poaceae	x	
	Japanese brome	*Bromus japonicas*	Poaceae		x
	Kentucky bluegrass	*Poa pratensis*	Poaceae		x
	Lilac	*Syrinigia vulgaris* L.	Oleaceae		x
	Loeselii tumblemustard	*Sisymbrium loeselii*	Brassicaceae		x
	Milk vetch	*Astragalus* spp.	Fabaceae		x
	Musk thistle	*Carduus natans*	Asteraceae		x
	Nuttal's alkaligrass	*Puccinellia nuttaliana*	Poaceae	x	
	Nuttal's sagebrush	*Atriplex nutallii*	Chenopodiaceae	x	
	Needle and thread	*Stipa comata*	Poaceae	x	
	Plains coreopsis	*Coreopsis tinctoria*	Asteraceae		x
	Poverty weed	*Iva axillaris*	Asteraceae	x	
	Prairie june grass	*Koeleria macrantha*	Poaceae	x	

Appendix A. (cont'd)

Category	Common Name	Scientific Name	Family	Native	Exotic
	Prickly lettuce	*Lactuca serriola*	Asteraceae	x	
	Prickly pear cactus	*Opuntia polyacantha*	Cataceae	x	
	Prickly sowthistle	*Sonchus asper*	Asteraceae		x
	Pussy toes	*Antennaria neglecta*	Asteraceae	x	
	Quackgrass	*Agropyron repens*	Poaceae		x
	Rabbit brush	*Chrysothamnus nauseosus*	Asteraceae	x	
	Rayless alkali aster	*Aster brachyactis*	Asteraceae	x	
	Red top	*Agrostis stolonifera*	Poaceae		x
	Rillscale	*Atriplex dioica*	Chenopodiaceae	x	
	Russian olive	*Elaeagnus angustifolia*	Elaeagnaceae		x
	Russian wildrye	*Psathrostachys juncea*	Poaceae		x
	Salsify	*Tragopogon dubis*	Asteraceae		x
	Sandbergs bluegrass	*Poa secunda*	Poaceae	x	
	Sandcherry	*Prunus besseyi*	Rosaceae	x	
	Scarlet globemallow	*Sphaeraicea coccinea*	Malvaceae	x	
	Smooth brome	*Bromus inermis*	Poaceae		x
	Slender wheatgrass	*Elymus trachycaulus*	Poaceae	x	
	Strawberry blite	*Chenopodium capitatum*	Chenopodiaceae	x	
	Tall fescue	*Festuca arundinaceae*	Poaceae		x
	Tickle-grass	*Agrostis scabra*	Poaceae	x	
	Tufted hairgrass	*Descampsia cerpitosa*	Poaceae	x	
	Tumble mustard	*Sisymbrium altissimum* L.	Brassicaceae		x
	Twin Arnica	*Amica sororia*	Asteraceae	x	
	Western yarrow	*Achillea millefolium*	Asteraceae	x	
	White-prairie aster	*Aster falcatus*	Asteraceae	x	
	Wild onion	*Allium textile*	Lilaceae	x	
	Yellow alyssum	*Alyssum simplex*	Brassicaceae		x
	Yellow sweet clover	*Meliotus officinalis*	Fabaceae		x

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Appendix B. Key fish, amphibian, reptile, mammal, and bird species present on wetlands at Benton Lake National Wildlife Refuge, Montana. Data for fish (refuge records, Holton and Johnson 2003), amphibians and reptiles (refuge records, Werner et al. 2004, Kinter and Fields 2006), birds (refuge records, Gilbert 1994, Anonymous 1997, Martin and Dawes 2002, Fields et al. 2007), and mammals (refuge records, Foresman 2001) are presented. * Indicates the species likely is present on the refuge but has not been verified at the time of this report; NB indicates non-breeding; WD indicates species are associated with shelterbelts especially for nesting but use other habitats for foraging as indicated in the table.

Common Name	Scientific Name	Habitats				
		Robust Emergent	Sedge/ Rush	Seasonal Herbaceous	Wet Grassland	Upland Grassland
FISH						
Fathead Minnow	Pimephales promelas	x	x			
AMPHIBIANS						
Tiger salamander	Abystoma tigrinum	x	x	x		
Plains Spadefoot*	Spea bombifrons			x	x	
Woodhouse's Toad*	Bufo woodhousii		x	x	x	
Western Toad	Bufo boreas		x	x	x	
Great Plains Toad*	Bufo cognatus		x	x	x	
Boreal Chorus Frog	Pseudacris maculate		x	x	x	
Northern Leopard Frog	Rana pipiens	x	x	x	x	
REPTILES						
Painted Turtle	Chrysemys picta	x	x			
Great Short-nosed Lizard	Phrynosoma hernandesi					x
Eastern Racer	Coluber constrictor			x	x	x
Common Garter Snake	Thamnophis sirtalis			x	x	x
Plains Garter Snake	Thamnophis radix				x	x
Terrestrial Garter Snake	Thamnophis elegans				x	x
Western Hog-nosed Snake*	Heterodon nasicus				x	x
Milk Snake*	Lampropeltis triangulum				x	x
Gopher Snake	Pituophis catneifer			x	x	x
Western Rattlesnake	Crotalus viridis				x	x
BIRDS						
Podicipediformes						
Eared Grebe	Podiceps nigricollis	x				
Pied-billed Grebe	Podilymbus podiceps	x	x			
Western Grebe	Aechmophorus occidentalis	x				
Clark's Grebe	Aechmophorus clarkia	x				
Pelicaniformes						
American White Pelican (NB)	Pelecanus erythrorhynchos	x				
Double-crested Cormorant(NB)	Phalacrocorax auritus	x				
Ciconiiformes						
American Bittern	Botaurua lentiginosus	x	x	x	x	
Great Blue Heron (NB)	Ardea Herodias	x	x	x		
Black-crowned Night Heron	Nycticorax nycticorax	x	x			
White-faced Ibis	Plegadis chihi	x	x	x		
Anseriformes						
Tundra swan (NB)	Cygnus columbianus	x	x			
Trumpeter Swan (NB)	Cygnus buccinators	x	x			
Canada Goose	Branta canadensis	x	x	x		
Ross's Goose (NB)	Chen rossii	x	x	x		
Lesser Snow Goose (NB)	Chen caerulescens	x	x	x		
Mallard	Anas platyrhynchos	x	x	x	x	x

Appendix B. (cont'd)

Common Name	Scientific Name	Habitats				
		Robust Emergent	Sedge/ Rush	Seasonal Herbaceous	Wet Grassland	Upland Grassland
Gadwall	Anas strepera	x	x	x	x	x
Northern Pintail	Anas acuta	x	x	x	x	x
American Wigeon	Anas americana	x	x	x	x	x
Northern Shoveler	Anas clypeata	x	x	x	x	
Cinnamon Teal	Anas cyanoptera	x	x	x	x	x
Blue-winged Teal	Anas discors	x	x	x	x	x
Green-winged Teal	Anas crecca	x	x	x	x	x
Canvasback	Aythya valisineria	x	x			
Redhead	Aythys americana	x	x			
Ring-necked Duck	Aythya collaris	x	x			
Lesser Scaup	Aythya affinia	x	x			
Common Goldeneye (NB)	Bucephala clangula	x				
Bufflehead (NB)	Bucephala albeola	x	x			
Ruddy Duck	Oxyura jamaicensis	x	x			
Falconiformes						
Northern Harrier	Circus cyaneus	x	x	x	x	
Swainson's Hawk	Buteo swainsoni			x	x	WD
Red-tailed Hawk	Buteo jamaicensis		x	x	x	x
Ferriginous Hawk	Buteo regalis			x	x	x
Rough-legged Hawk (NB)	Buteo lagopus		x	x	x	x
Golden Eagle	Aquila chrysaetos		x	x	x	x
Bald Eagle	Haliaeetus leucocephalus	x	x	x	x	
Merlin	Falco columbarius			x	x	x
American Kestrel	Falco sparverius			x	x	x
Prairie Falcon	Falco mexicanus				x	x
Peregrine Falcon (NB)	Falco peregrines	x	x	x	x	x
Galliformes						
Gray Partridge	Perdix perdix					x
Ring-necked Pheasant	Phasianus colchicus	x	x	x	x	x
Sharp-tailed Grouse	Tympanuchus phasianellus				x	x
Gruiformes						
American Coot	Fulica americana	x	x			
Virginia Rail	Rallus limicola	x	x	x		
Sora	Porzana carolina	x	x	x	x	
Sandhill Crane (NB)	Grus canadensis	x	x	x	x	
Charadriiformes						
Killdeer	Charadrius vociferous		x	x	x	x
American Avocet	Recurvirostra americana		x	x		
Black-necked Stilt	Himantopus mexicanus		x	x		
Lesser Yellowlegs (NB)	Tringa flavipes		x	x		
Willet	Catoptrophorus semipalmatus			x	x	
Spotted Sandpiper	Actitis macularia	x	x	x		
Upland Sandpiper	Bartramia longicauda			x	x	x
Long-billed Curlew	Numenius americanus		x	x	x	x
Marbled Godwit	Limosa fedoa		x	x	x	x
Baird's Sandpiper	Calidris bairdii		x	x		
Least Sandpiper	Calidris minutilla		x	x		
Long-billed Dowitcher (NB)	Limnodromus scolopaceus	x	x	x		
Short-billed Dowitcher (NB)	Limnodromus griseus	x	x	x		
Wilson's Snipe	Gallinago delicata	x	x	x	x	
Wilson's Phalarope	Phalaropus tricolor	x	x			
Franklin's Gull	Larus pipixcan	x	x	x	x	

Appendix B. (cont'd)

Common Name	Scientific Name	Habitats				
		Robust Emergent	Sedge/ Rush	Seasonal Herbaceous	Wet Grassland	Upland Grassland
Ring-billed Gull	Larus delawarensis	x	x			
California Gull	Larus californicus	x	x			
Common Tern	Sterna hirundo	x	x			
Forester's Tern	Sterna forsteri	x	x			
Black Tern	Chlidonias niger	x	x			
Columbiformes						
Mourning Dove	Zenaida macroura					WD
Strigiformes						
Short-eared Owl	Asio flammeus			x	x	x
Great-horned Owl	Bubo virginianus	x	x	x	x	x
Snowy Owl (NB)	Nyctea scandiaca	x	x	x	x	x
Burrowing Owl	Athene cunicularia				x	x
Caprimulgiformes						
Common Nighthawk	Chordeiles minor			x	x	x
Piciformes						
Northern Flicker	Colaptes auratus					WD
Passeriformes						
Say's Phoebe	Sayornis saya					Buildings
Eastern Kingbird	Tyrannus tyrannus		x	x	x	WD
Western Kingbird	Tyrannus verticalis		x	x	x	WD
Northern Shrike (NB)	Lanius excubitor		x		x	x
Loggerhead Shrike	Lanius ludovicianus			x	x	WD
Black-billed Magpie	Pica hudsonia		x	x	x	
American Crow	Corvus brachyrhynchos		x	x	x	x
Horned Lark	Eremophila alpestris					x
Tree swallow	Tachycineta bicolor	x	x	x	x	Nest Boxes
Cliff Swallow	Petrochelidon pyrrhonota	x	x	x	x	
Barn Swallow	Hirundo rustica	x	x	x	x	
Black-capped Chickadee(NB)	Poecile atricapilla					WD
Marsh Wren	Cistothorus palustris	x	x	x		
Rock Wren	Salpinctes obsoletus	Rip-rap				
Ruby-crowned Kinglet (NB)	Regulus calendula					WD
American Robin	Turdus migratorius				x	WD
Gray Catbird	Dumetella carolinensis					WD
Sprague's Pipit	Anthus spragueli				x	x
American Pipit (NB)	Anthus rubescens				x	x
Bohemian Waxwing (NB)	Bombycilla garrulus					WD
Cedar Waxwing (NB)	Bombycilla cedrorum					WD
Yellow Warbler	Dendroica petechia	x	x	x		
Yellow-rumped Warbler	Dendroica coronate		x	x		
Common Yellowthroat	Geothlypis trichas	x	x	x		
Lazuli Bunting	Passerina amoena					
Clay-colored sparrow	Spizella pallid				x	x
Baird's Sparrow	Ammodramus bairdii				x	x
Grasshopper Sparrow	Ammodramus savannarum				x	x
Savannah Sparrow	Passserculus sandwichensis				x	x
Vesper Sparrow	Poocetes gramineus				x	x
Lark Bunting	Calamospiza melanocorys				x	x
Lark Sparrow	Chondestes grammacus				x	x
Song Sparrow (NB)	Melospize melodia				x	x
Dark-eyed Junco (NB)	Junco hyemalis				x	x

Appendix B. (cont'd)

Common Name	Scientific Name	Habitats				
		Robust Emergent	Sedge/ Rush	Seasonal Herbaceous	Wet Grassland	Upland Grassland
McCown's Longspur	Calcarius mccownii				x	x
Chestnut-Collared Longspur	Calcarius ornatus				x	x
Western Meadowlark	Sturnella neglecta				x	x
Brown-headed Cowbird	Molothrus ater					WD
Yellow-headed Blackbird	Xanthocephalus xanthocephalus	x	x			
Red-winged Blackbird	Agelaius phoeniceus	x	x	x	x	
Brewer's Blackbird	Euphagus cyanocephalus		x	x	x	
MAMMALS						
Insectivora						
Masked Shrew*	Sorex cinereus				x	x
Preble's Shrew*	Sorex preblei				x	x
Dwarf Shrew*	Sorex nanus				x	x
Hayden's Shrew*	Sorex haydeni				x	x
Chiroptera						
Little brown Myotis	Myotis lucifugus	x	x	x	x	x
Yuma Myotis*	Myotis yumanensis	x	x	x	x	x
Long-eared Myotis*	Myotis evotis	x	x	x	x	x
Western small-footed Myotis*	Myotis ciliolabrum	x	x	x	x	x
Silver-haired Bat	Lasionycteris noctivagans	x	x	x	x	x
Big Brown Bat*	Eptesicus fuscus	x	x	x	x	x
Red Bat*	Lasiurus borealis	x	x	x	x	x
Lagomorpha						
Mountain Cottontail	Sylvilagus nutalli				x	x
Desert Cottontail	Sylvilagus audubonii				x	x
White-tailed Jackrabbit	Lepus townsendii				x	x
Rodentia						
Yellow-bellied Marmot	Marmota flaviventris	x	x	x	x	x
Richardson's Ground Squirrel	Spermophilus richardsonii					x
Thirteen-lined Ground Squirrel	Spermophilus tricdecelineatus					x
Northern Pocket Gopher	Thomomys talpoides					x
Olive-backed Pocket Mouse*	Perognathus fasciatus					x
Western Harvest Mouse*	Reithrodontomys magalotis					x
Deer Mouse	Peromyscus maniculatus				x	x
Northern Grasshopper Mouse	Onychomys leucogater				x	x
Bushy-tailed Woodrat*	Neotoma cinera					x
Meadow Vole	Microtus pennsylvanicus		x	x	x	x
Prairie Vole*	Microtus orchrogaster			x	x	x
Muskrat	Ondatra zibethicus	x	x			
House Mouse	Mus musculus				x	x
Western Jumping Mouse*	Zapus princeps					x
Porcupine	Erethizon dorsatum					WD
Carnivora						
Coyote	Canis latrans	x	x	x	x	x
Red Fox	Vulpes vulpes			x	x	x
Swift Fox	Vulpes velox					x
Raccoon	Procyon lotor	x	x	x	x	x
Least Weasel	Mustela nivalis	x	x	x	x	x
Long-tailed Weasel	Mustela frenata	x	x	x	x	x
Mink	Mustela vision	x	x	x	x	
Badger	Taxidea taxus					x
Skunk	Mephitis mephitis				x	x

Appendix B. (cont'd)

Common Name	Scientific Name	Habitats				
		Robust Emergent	Sedge/ Rush	Seasonal Herbaceous	Wet Grassland	Upland Grassland
Artiodactyla						
Mule deer	Odocoileus hemionus	x	x	x	x	x
White-tailed Deer	Odocoileus virginianus	x	x	x	x	x
Pronghorn Antelope	Antilocarpa Americana				x	x