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

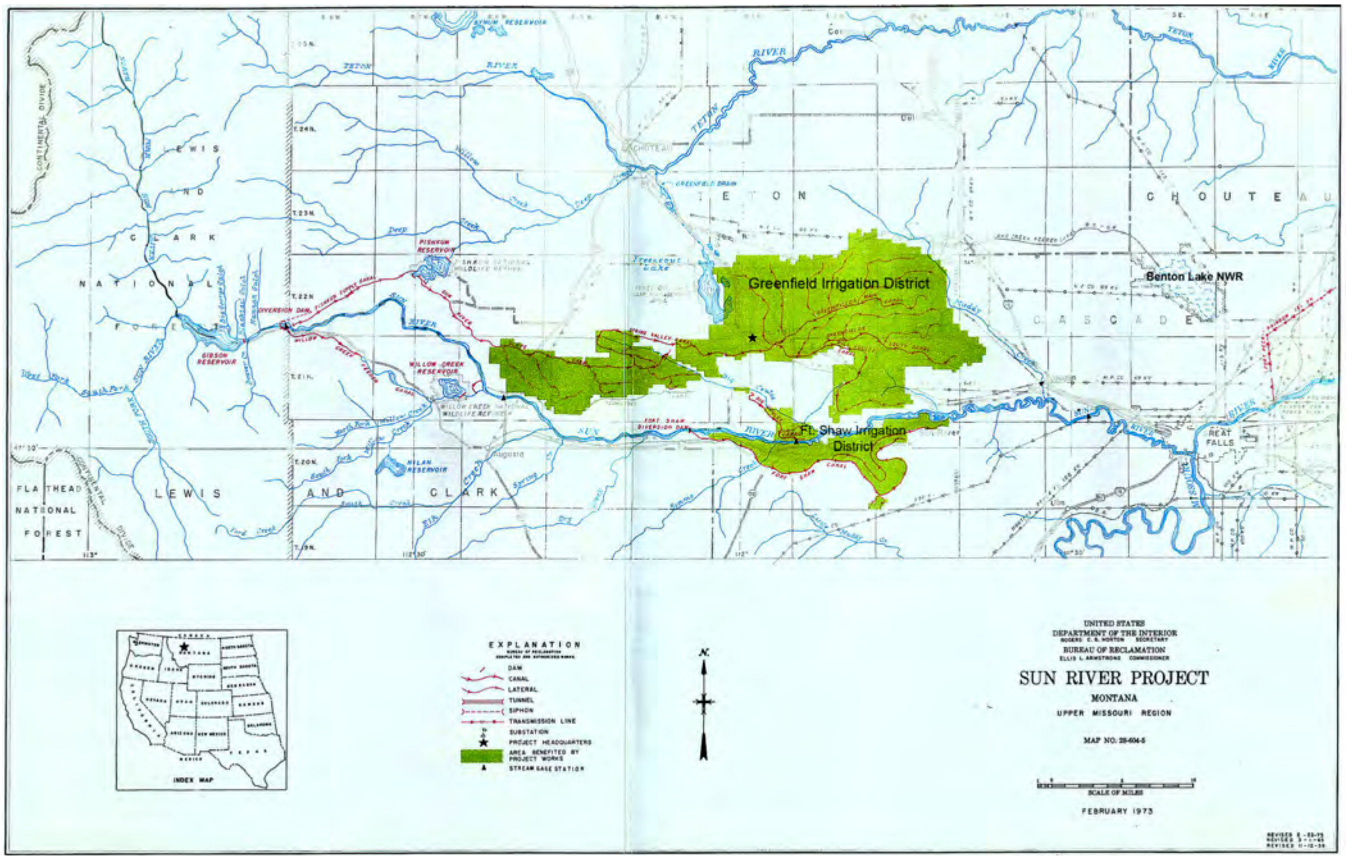

Figure 15. Map of the Sun River Irrigation Project.

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 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.

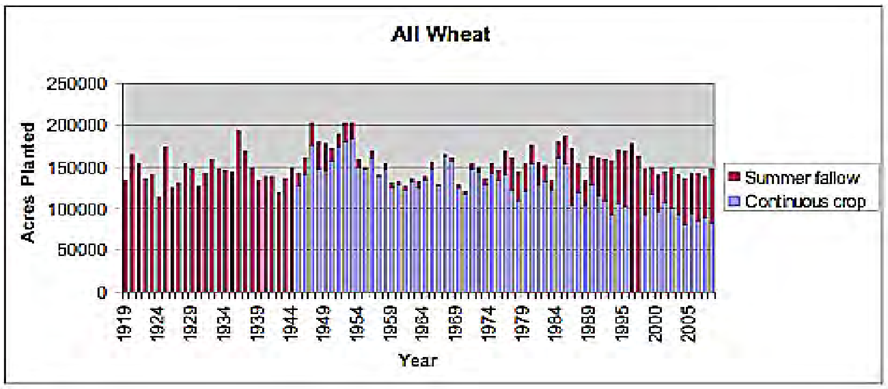

Figure 16. Total acres planted to wheat in Cascade County and portion of those acres following a summer fallow. Fallow data was not reported prior to 1945 and in 1996-1997. Almost all acres of wheat planted in Cascade County are non-irrigated (NASS 2009)

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

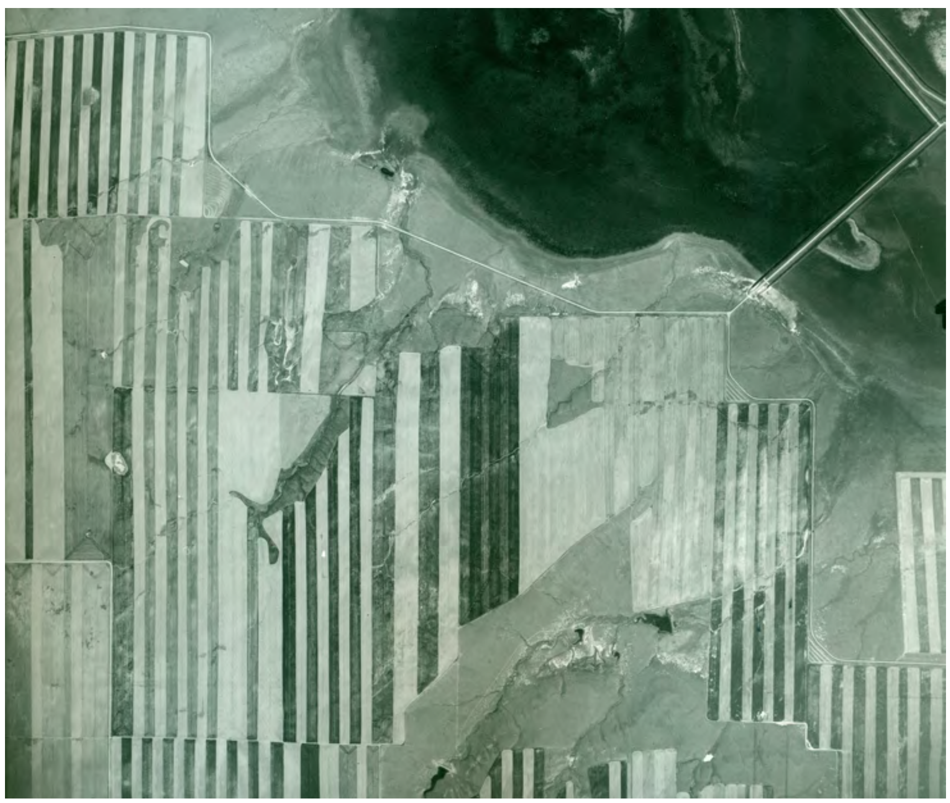

Figure 17. Crop-fallow agricultural fields in Benton Lake region.

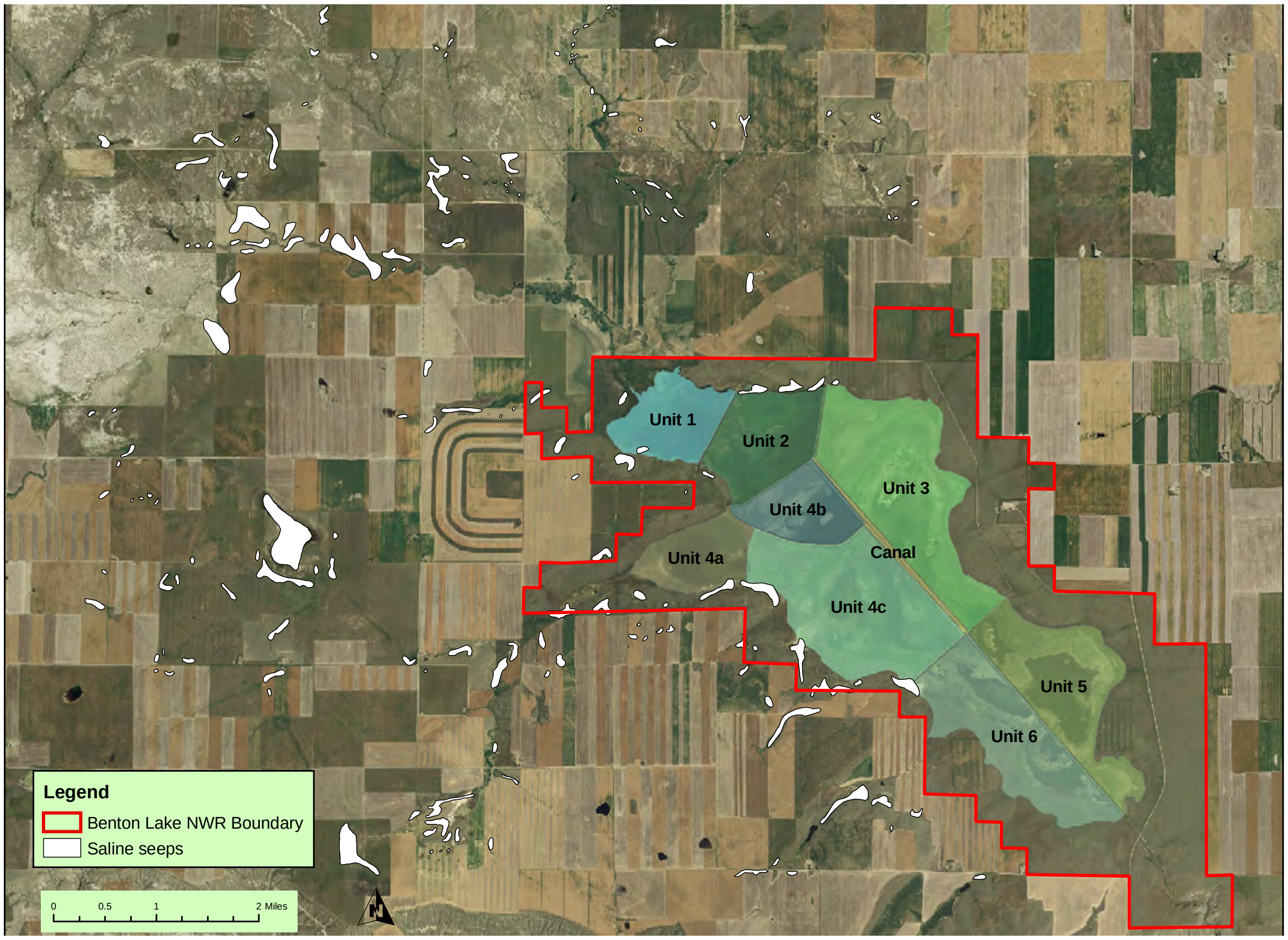

Figure 18. Saline seeps in the Benton Lake region.

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-

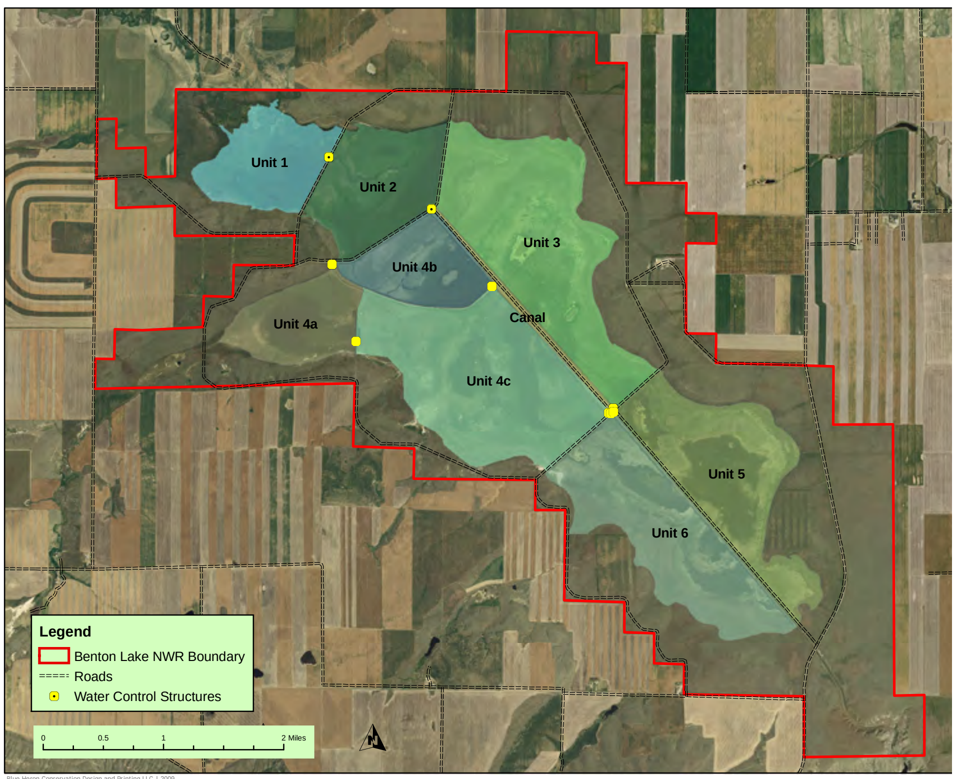

Figure 20. Water management pools on Benton on Benton Lake National Wildlife Refuge.

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

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

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

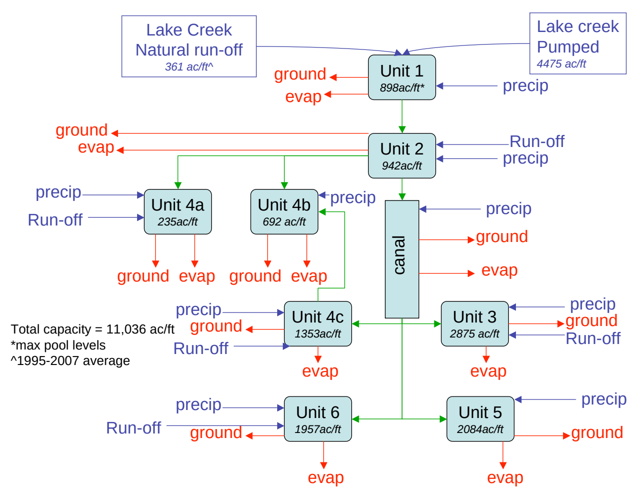

Figure 22. Flow chart of water source, storage, and movement in Benton Lake pools (data from 1970-97 records, USFWS, Benton Lake National Wildlife Refuge, unpublished files).

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.

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

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

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.

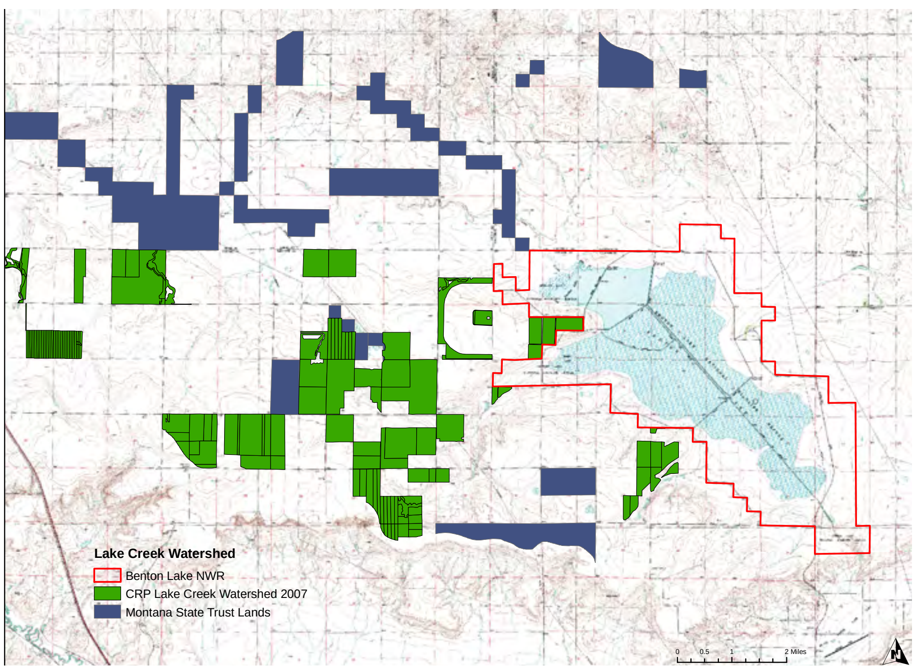

Figure 23. Map of Conservation Reserve Program (CRP) lands in the Benton Lake region (from U.S. Department of Agriculture, Natural Resources Conservation Service).

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).

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

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

Number and percent of species per category in each area

UNIT		Trees	Shrubs	Graminoids	Forbs	All Plants
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

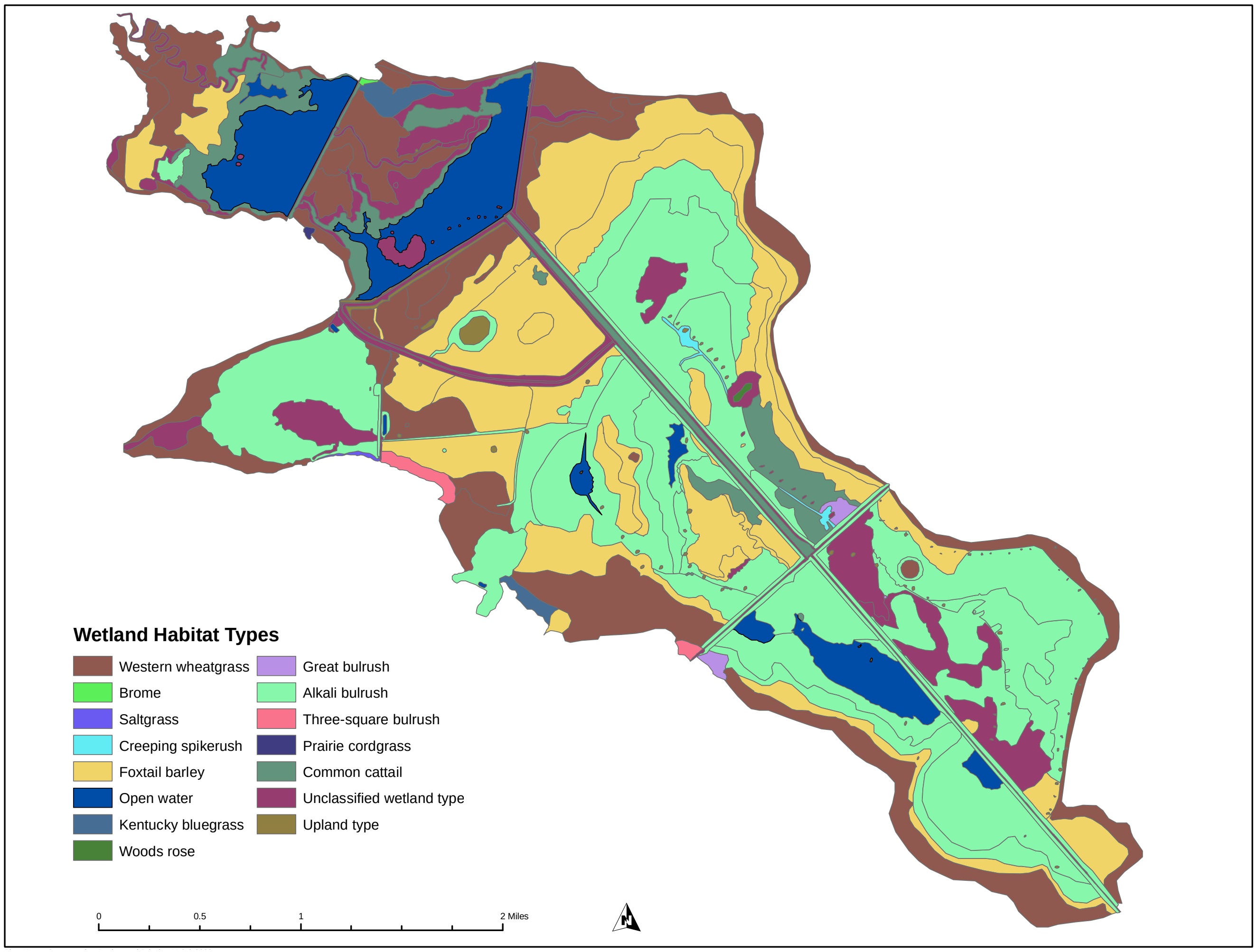

Figure 24. Distribution of major vegetation communities on Benton Lake National Wildlife Refuge, 2002 (adapted from Thompson and Hansen 2002).

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

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.

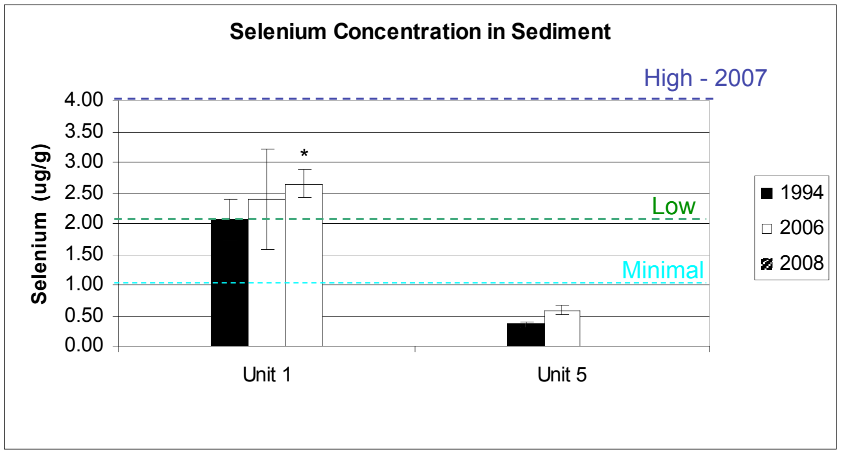

Figure 25. Selenium concentration in sediment in Units 1 and 5 on Benton Lake National Wildlife Refuge 1994, 2006, and 2008.

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.

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