Collapse of Waterbird Populations at Utah's Locomotive Springs Waterfowl Management Area

MICHAEL R. CONOVER[1,*], LAUREN J. HEAD[1], KIRSTIE A. KANDARIS[1], EMILY R. JONES[1], REBECCA J. THORLEY[1], AUSTIN A. POPE[1]

[1]Department of Wildland Resources, Utah State University, Logan Utah 84322-5230. U.S.A

[*]Corresponding author; Email: Mike.Conover@usu.edu

ACKNOWLEDGEMENTS

This study would not have been possible without the generous help and advice from employees from several state agencies including T. J. Clark-Wolf, Chad Cranney, Becka Downard, Chelsea Duke, Faith Jolley, William Johnson, John Luft, Therese Meyers, John Neill, Christine Rumsey. Funds for this research were provided by Utah State University's Ecology Center and Utah Agricultural Experiment Station (journal number 9922).

Abstract.—Locomotive Springs Waterfowl Management Area is located in Great Salt Lake Desert and has historically provided a freshwater oasis for large numbers of waterbirds and shorebirds prior to the 1970s, but the springs no longer do so. We used historical and recent records to investigate which waterbird species were impacted, when the decline occurred, and what caused it. We found that the collapse of waterbird populations was not sudden but occurred over decades. During 1973, an average of 10,659 ducks were counted daily at Locomotive Springs Waterfowl Management Area. Average waterfowl numbers had declined to only 1,001 ducks during 1997–2001 and 222 during 2016–2022. There were significant declines in all but one waterbird and shorebird species between 1997–2001 and 2016–2022. The apparent reason for the declining populations was a reduction in water discharge from the six Locomotive Springs, which state officials determined resulted from water extraction from its aquifer for the purposes of crop irrigation. Total water discharge from all Locomotive Springs was 4,000 m3/hr in 1939, 3,000 during 1939-1971, 2,500 during 1982, and only 218 during 2003. All springs were dry during August 2025. Locomotive Springs provides an important case study in how the pumping of water from an aquifer can have detrimental impacts on waterbird populations.

Keywords.—Curlew Valley, ducks, Great Salt Lake, groundwater, history, shorebirds, water development, water discharge, waterfowl, wetlands

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Across the world, waterbirds and shorebirds that live in arid regions must contend with high rates of environmental changes due to the diversion of freshwater for human activities and climate change (Smith et al. 2023). Chen et al. (2011), Mayor *et al.* (2017), Petrauski *et al.* (2023), have warned that bird populations have declined in response to diversion of freshwater for human uses and climate change linked to shifts in species distributions, altered migration, and a reduction in waterbird populations. Migratory species are particularly vulnerable to environmental change because they experience a wide range of conditions across their annual cycle and migratory routes (Newton 2023, Suthar *et al.* 2025). Research indicates growing conservation concern for migratory shorebirds, which accounted for 18 of the 26 (69%) species that recently were placed in a higher threat category (Wold 2026).

The arid Intermountain West is an important region for shorebirds migrating through the interior portion of the Pacific Americas Flyway and the western part of the Midcontinent Americas Flyway (Senner et al. 2016, MSCI 2025). Wetlands represent <1% of land cover in this region but still provide vital habitat for millions of shorebirds annually (Senner *et al.* 2016; Donnelly *et al.* 2022, 2026). Wetlands within the Intermountain West have faced increasing pressures over the last few decades, primarily related to drought and diversion of freshwater for agriculture, and urban development.

Great Salt Lake (GSL) lies within the Intermountain West and is the largest hypersaline lake in North America. It is similar to hypersaline lakes across the world in that it has been shrinking for decades due to human diversion of freshwater from the rivers that flow into it for irrigation. Water elevation of GSL is 3.6 m lower from what it would have been without human diversion of water (Wurtsbaugh *et al.* 2016). Great Salt Lake Desert lies to the north and west of GSL in northern Utah and receives little precipitation. Worldwide, diversion of freshwater for human uses has reduced the water discharge of springs located in deserts.

Locomotive Springs is a freshwater oasis in this desert and situated along the northern edge of GSL (Fig. 1). Water from Locomotive Springs flows a short distance south before reaching GSL. In that short distance, the springs create shallow, inundated open-water marshes that offer important habitat to both resident and migratory birds due to the scarcity of freshwater habitat in deserts of the West (Lamb 1912). In 1931, the state of Utah bought 70 ha that included the six Locomotive Springs and took steps to enhance the area as a wetland habitat for waterbirds by constructing dams, canals, and roads to improve habitat conditions for ducks and better access for hunters. Utah built two east-west dams to impound the slightly saline water flowing from the springs and create two impoundments: East Lake and West Lake (Fig. 2). The purpose of these shallow impoundments was to attract waterfowl for waterfowl hunters. Utah officially designated the area as a conservation area to preserve the freshwater habitat into perpetuity and provide access for waterfowl hunters. The state named the purchased land Locomotive Springs Waterfowl Management Area (WMA; McCollough 1951, Baker 1974, Kirby *et al.* 2005). Utah also acquired the water rights for 6,242 m^3/hr from the springs during 1934. In 1950, Locomotive Springs WMA had 486 ha of open water and 1,036 ha of marsh and stream-channel edges (McCullough 1951). By 2018, the WMA had increased to 7,608 ha and consisted of Locomotive Springs, the surrounding uplands, land below the springs, and East and West impoundments (Neill 2019).

Sometime after its establishment, areas covered by surface water at Locomotive Springs WMA began to shrink in size. In this paper, we examine the extent of declines in waterbird populations, identify which waterbird species were impacted, and determine when and why waterfowl were impacted. We then compiled historic and current discharge measurements for the watershed of Locomotive Springs between 1934 and 2025 and reviewed literature from the area to document comprehensively the timeline and causes of surface-water depletions. We assessed when water discharge declined by accessing public and private records and the scientific literature. We used remotely sensed datasets from Locomotive Springs to evaluate surface water changes since 1934. We tested the hypothesis that a reduction in water discharge from the springs was responsible for the waterbird decline by comparing whether a reduction in waterbird numbers occurred concomitantly with a decrease in waterflow from the springs.

METHODS

Study Area

Locomotive Springs (41.7074º, -112.9192º) consists of six springs: Sparks, Off, Teal, Bar M, Baker, and West Locomotive (Fig. 3). The springs occur in a curved line 5.6 km in length (Mundorff 1971). The water source for Locomotive Springs is groundwater from the Holbrook-Curlew flow system (hereafter, referred to as the Locomotive Springs aquifer) which is beneath the eastern side of Curlew Valley. Locomotive Springs is located at the southern edge of the aquifer. The climate of Curlew Valley is semi-arid and includes cold winters and warm, dry summers. The valley floor is arid with annual precipitation of only 0.2 m. More precipitation falls on the hills and mountains that surround the northern side of the valley (Bloke and Price 1969).

Curlew Valley is largely unsettled with its largest town, Snowville, having a population of only 163 during 2020. The 3,100 km^2 watershed of Locomotive Springs is beneath the Curlew Valley. The valley has a broad flat valley sloping downhill in a southern direction. The six Locomotive Springs are at the southern end of the valley and were approximately 10-13 m above the normal elevation of GSL. The actual distance water from the springs has to travel to reach GSL varies annually due to GSL's annual change in surface level; however, in that distance, the springs create shallow open water, and inundated marshes (Baker 1974, Hurlow and Burk 2008).

Field Methods

We checked the scientific literature and files belonging to Utah State University, Utah Division of Wildlife Resources (DWR), Utah Department of Water Resources, Utah Geological Survey, and Idaho Geological Survey for any information about Locomotive Springs and it's aquifer. We were particularly interested in populations of waterfowl, other waterbirds, and shorebirds at Locomotive Springs WMA. We searched for historical and current records about the waterflow from each of the six springs. We contacted Utah Division of Water Rights and Idaho Department of Water Resources for information about when people started to withdraw water from the aquifer, and how the amount of water withdrawal from the aquifer changed over the decades.

Waterbird populations and hunter counts. Counts of all waterbirds, including all ducks, at Locomotive Spring WMA occurred throughout the year in 1973, 1997-2001 and 2016-2022 and were made by trained biologists employed by Utah Division of Wildlife Resources. Counts were conducted by many different people; this variation in who made the counts provided a measure of independence to the data. The focus for 1973 was ducks, and sampled species included Cinnamon Teal (*Anas cyanoptera*), Green-winged Teal (*Anas carolinensis*), American Wigeon (*Anas americana*), Mallard (*Anas platyrhynchos*), Northern Shoveler (*Anas clypeata*), Northern Pintail (*Anas acuta*), Gadwall (*Anas strepera*), Canvasback (*Aythya valisineria*), Redhead (*Aythya americana*), Ruddy Duck (*Oxlyura jamaicensis*), Canada Goose (*Branta canadensis*), and American Coot (*Fulica americana*). These and other waterbird species were also counted numerous times during 1997–2001 and 2016–2022. It was difficult for observers to distinguish between female Green-winged Teal and Cinnamon Teal, so we combined data for these two species into a single group called both teal species. Numbers of waterbirds at Locomotive Springs WMA varied widely by season because few waterbirds were present during the middle of winter and summer, while large numbers were at Locomotive WMA during early spring and early fall. We used surveys that occurred between March 1 and September 30 because that was when most historic surveys were conducted. Bird abundance varied seasonally. To avoid this seasonal variation, we paired 1973 counts with counts from 1999-2002 and 2016–2022. In all comparisons, we paired data in one period to data in another period that occurred within two weeks of each other; mean difference in days between the paired counts was seven days. We analyzed the data using a General Linear Model ANOVA to locate statistically significant differences between 1973 and 1997-2001, 1973 and 2016-2022, and 1997-2001 and 2016-2022 ($P \leq 0.05$).

In addition to ducks, all species of waterbirds and shorebirds were included in counts made during both 1997–2001 and 2016–2022. We compared these two time periods for all waterbird and shorebird species where >10 birds were counted during both time periods. The species that met these criteria included Double-crested Cormorant (*Phalacrocorax auritus*), Common Merganser (*Mergus merganser*), American White Pelican (*Pelecanus erythrorhychos*), California Gull (*Laurus californicus*), Franklin's Gull (*Larus pipixcan*), Caspian Tern (*Sterna caspia*), Forester's Tern (*Sterna forteri*), Great Blue Heron (*Ardea herodias*), Black-crowned Night-heron (*Nycticorax nycticorax*), White-faced Ibis (*Plegadis chihi*), American Avocet (*Recurvirostra americana*), Black-necked Stilt (*Himantopus mexicanus*), Snowy Plover (*Anarhynchus nivosus*), Killdeer (*Charadrius vociferus*), Marbled Godwit (*Limosa fedoa*), Willet (*Catoptrophorus semipalmatus*), Greater Yellowlegs (*Tringa melanoleuca*), Lesser Yellowlegs (*Tringa flavipes*), Wilson's Phalarope (*Phalaropus tricolor*), Long-billed Dowitcher (*Limnodromus scolopaceus*), and Western Sandpiper (*Calidris mauri*). We again used a General

Linear Model ANOVA to analyze the data for statistically significant differences between these two time periods.

Starting in 1983, DWR employees counted the number of duck hunters at Locomotive Spring WMA on the opening day of the duck hunting season, which occurred during early October. We included these data because yearly changes in the number of duck hunters provide an independent measure of annual changes in duck number during the fall. This is based on the assumption that if duck populations crash, the number of duck hunters will also crash.

Water availability. We searched published and unpublished records for information on waterflow from individual springs and for all springs combined. Many sources noted that there was little seasonal change in water discharge from Locomotive Springs (McCullough 1951, Owsley 2009). Fortunately, this made comparisons across years more reliable. Unfortunately, there was little consistency among surveyors about the day when they made their measurements and which springs they measured. This made comparisons of water discharge across years less reliable.

The discharge rate of Locomotive Springs became more difficult to measure as the rate declined, and there was less interest in measuring small flows. For these reasons, discharge rates were not recorded by Utah Geological Survey after 2003. Fortunately, from 1984-2025, we were able to monitor changes in average spring discharge rates indirectly by using satellite imagery of Locomotive Springs WMA to calculate how many hectares of open water were present during each August. August was selected as the month for visualization to maintain consistency and to represent a period when both waterfowl and shorebirds should be abundant at the WMA. We exported these data directly from the Intermountain West Joint Venture's Wetland Evaluation

Tool Surface Water Module (Intermountain West Joint Venture 2025). Surface water averages for each decade were then visualized using the ggplot2 package in program R (Wickham 2016, R Core Team 2025).

Anyone who wants to use water in Utah and Idaho for personal use, including from an aquifer, must apply to the state for permission to do so. Both states maintain meticulous records on water rights. The records include the year, identity of the permittee, the location, where water was going to be removed, the amount of water to be withdrawn, and the purpose of the water removal. We searched state records for Locomotive Springs' aquifer and talked to state officials to determine when water was first withdrawn from the aquifer, where the water rights were located, the number of permittees, and the amount of water withdrawn changed over time. Data on water withdrawn (m^3/hour) from the Locomotive Springs aquifer for human uses from 1963-2003 came from Birken (2019). We used a regression analysis to determine how the annual amount of water withdrawn from the aquifer changed over years, how annual amount of water withdrawn from impacted the discharge of water from Locomotive Springs, and how annual amount of water withdrawn impacted the number of duck hunters.

RESULTS

Waterbirds populations and waterfowl hunters

Paired counts of waterfowl populations at Locomotive Springs were significantly higher during 1973 than the period of 1997–2001 for both teal species, American Wigeon, Northern Pintail, Redhead, and American Coot (Table 1). When paired counts of waterfowl during 1973 were compared to those made between 2016–2022, all species of waterfowl were more numerous during 1973 than the later counts (Table 2). Differences were significant for both teal species, American Wigeon, Mallard, Northern Pintail, Gadwall, Redhead, Canada Goose, and American Coot. During 1973, 10,108 waterfowl were counted during paired surveys versus 1,001 during 1997–2001, and only 222 during surveys that were conducted between 2016–2022.

Between 1997–2001 and 2016–2022, paired counts of waterfowl numbers declined by 83%, other waterbirds by 81%, and shorebirds by 79% (Table 3). Statistically significant differences between the two time periods occurred in both teal species, American Widgeon, Mallard, Northern Pintail, Gadwall, Canada Goose, and American Coot, Double-crested Cormorant, American White Pelican, California Gull, Caspian Tern, Forester's Tern, Great Blue Heron, Black-crowned Night-heron, White-faced Ibis, American Avocet, Black-necked Stilt, Willet, Greater Yellowlegs, and Wilson's Phalarope. Only Snowy Plovers exhibited similar numbers between the time periods.

There were 303 waterfowl hunters at Locomotive Springs WMA during the opening day of the 1983 waterfowl hunting season. Numbers of duck hunters declined after that (Fig. 4). There were 80 hunters during 1993, 20 during 2003, and only 5 during 2010. After 2010, DWR stopped surveying waterfowl hunters at Locomotive Springs WMA because there were too few hunters to make the trip worthwhile (Unpublished data from DWR files).

Water Discharge from Locomotive Springs

The earliest record of water discharge from Locomotive Springs was made in 1934 when Utah acquired the water rights to all six of the springs (6,242 m^3/hr). Baker (1974) reported the total water discharge from the springs was 4,080 m3/hr in 1939 (Table 4). Right before the first waterbird counts in 1973, discharge from all Locomotive Springs was 2,616 m^3/hr. Thereafter, yearly discharge from each spring consistently declined. Total discharge from all Locomotive Springs averaged 505 m^3/hr during 2000–2002 when the second waterbird count occurred. Off, Sparks, and West Locomotive springs were dry during 2003, and all springs were dry in August 2025.

Although discharge data from Locomotive Spring were no longer collected after 2003, satellite imagery provided an indirect method to assess yearly changes in discharge from each spring. The open water created by each spring can be calculated yearly starting in 1984, because the amount of open water created by each spring can be seen in satellite imagery (Fig. 3). From 1984–1994, discharge was sufficient to create an average of 36 km^2 of open water during the month of August, but this had declined to a mean of 2 km^2 during 1995–2004, and only 0.3 km^2 2015–2024. There was no longer any open water during August 2025.

Use of Water from the Curlew Valley Aquifer for Irrigation

Most irrigation in Curlew Valley took place at the northern end of Curlew Valley, 35 km north of Locomotive Springs (Baker 1974, Owsley 2009). From 1978 to 2008, the water table declined by up to 24 m in the agricultural areas of the aquifer (Hurlow and Burk 2008), and it continued to drop by 0.2 m annually (Owsley 2009). Aerial photos showed 188 pivots in the Locomotive Springs aquifer during 2025, and these irrigated 7,300 ha of land (Irrigation Rights Finder 2025).

During 1963, humans withdrew 141 m^2/hr from the Locomotive Springs, primarily for crop irrigation. This increased to 2,675 m^2/hr during 1973 when the first waterbird counts were made and 4,962 m^2/hr during 1999 when the second waterbird counts were made (Fig. 5). From the entire period (1963 to 2017), the annual rate of water removal increased (r = 0.80), and the correlation was significant ($F_{(1, 50)} = 89.02$, $P < 0.0001$). Water withdrawal from the aquifer for human uses occurred at the same time when discharge from Locomotive Springs was dropping (r = -0.81), but the results were not significant ($F_{(1, 3)} = 5.56$, $P < 0.10$) due to variation among years and small sample sizes. Water withdrawal from the aquifer occurred when duck hunter numbers at Locomotive Springs declined (r = -0.47); the correlation was significant ($F_{(1, 21)} = 6.01$, $P < 0.02$).

Average (± SD) annual precipitation in Locomotive Springs aquifer from 1930 through 2025 was 30.1 ± 7.8 cm (Fig. 6). Precipitation increased slightly over this time period (r = 0.24), but the correlation was not significant ($F_{(1, 94)} = 0.44$, $P = 0.51$). Clearly, the reduction of waterflow from Locomotive Springs since 1930 was not due to a decline in precipitation.

Discussion

The collapse of waterfowl populations at Locomotive Springs WMA was not sudden but occurred over decades. Duck numbers were down 90% between 1973 and 1997–2001 and another 78% between the latter period and 2016–2022. We also found indirect evidence for a collapse in waterfowl numbers at Locomotive Springs WMA because there were 80 duck hunters during 1993 which declined to five by 2010. This probably occurred because duck hunters did not think they would harvest enough waterfowl to make the trip worthwhile.

We cannot determine if shorebirds or other waterbird species, other than waterfowl, declined before 1997, but waterbirds declined by 81% and shorebirds by 79% between 1997–2001 and 2016–2022 at Locomotive Springs WMA. Our results show that the reduction in waterbird numbers coincided with a reduction in discharge from the springs, which reduced the amount of surface water available to waterbirds. We note that in August 2025 there was no open water at Locomotive Springs. This does not mean, however, that were is no outlet for water from the aquifer because groundwater still flows through the sediment into GSL (Zamora and Inkenbrandt 2024).

We did not make the conclusion that diminishing waterflow rates at Locomotive Springs was due to human withdrawals from the watershed. This conclusion was made by U. S. Geological Survey (Bloke and Price 1969), Idaho Department of Water Resources (Owsley 2009), Utah Geological Survey (Hurlow and Burk 2008), and Utah Division of Water Rights (Atkin 1998, Allen 2004). Our interest was whether the human removal of water from the watershed was correlated with the decline of water discharge from Locomotive Springs and whether the decline in spring discharge was correlated with a decline in numbers of waterbirds.

Additionally, the entire watershed of GSL has experienced droughts during the last decade, including Curlew Valley, and this also contributed to any decline in waterbird numbers from Locomotive Springs in the last few years (Baxter and Butler 2020).

Human extraction of water for irrigation and other uses was not limited to Curlew Valley but occurred throughout the arid Great Basin. Concomitantly, many springs in the region have either stopped flowing or their discharge declined. For example, Clear Lake WMA is located in central Utah, and the source of the refuge's water is Clear Lake Springs. Discharge from the springs was 2,110 m3/hr during 1960–1964 and was sufficient to sustain 20 km^2 lakes and marshes within the refuge. Mower (1967) noted that the discharge of Clear Lake springs was declining and that water extraction for irrigation in the vicinity of the springs was at least partially responsible. Concomitantly, Utah's Severe Lake became ephemeral or dry owing to water diversion by people (Conover and Bell 2020).

An interesting question is why Utah Department of Wildlife Resources, which were the owners and managers of Locomotive Springs WMA did not appeal to the Utah Division of Water Rights and the Idaho Department of Water Resources to stop farmers from withdrawing water from the Locomotive Springs aquifer, given their prior water rights. The problem that both state agencies faced was that aquifers are large and not visible like a stream or river, groundwater travels more slowly than surface water, and their water rights are administered differently than streams. The watershed of Locomotive Springs consists of 3,100 km^2, and most of the irrigation wells were located over 32 km from Locomotive Springs WMA. The number of wells drilled into the aquifer jumped significantly between 1965 and 1980 (Oaks 2004), but each well only accounted for a fraction of the water withdrawn from the aquifer. Once the substantial drop in discharge was identified in the 1970s and 1980s, there was no single water user that could be identified as responsible for drawing down the aquifer. Rather, it was a death by a thousand cuts: dozens of wells were drilled into the aquifer and were cumulatively extracting water from the aquifer at a higher rate than precipitation was able to recharge it. This created a long-term decline in the water level of the aquifer. Declines due to pumping were further exacerbated by years with poor precipitation, which also decreased the amount of water recharging the aquifer (Becka Downard, Wetland Section Manager, Utah Department of Natural Resources, personal communication).

The decline in waterfowl and other waterbirds populations seems to be limited to Locomotive Springs, rather than being a national phenomenon. During 2025, population declines of 229 avian species in the U.S. were of moderate or high concern (U. S. Committee of North American Conservation Initiative 2005). There are only two avian groups that were stable or increasing; these were waterfowl and waterbirds: the subjects of this study. Since 1970, waterfowl and waterbird populations in the U.S. are up 24% and 16%, respectively. Shorebirds are not doing as well; their populations were down by 33% in the U.S. However, populations of waterbirds and shorebirds in Utah have been increasing or are stable. Tavernia *et al.* (2023) tracked population trends of 37 shorebird, waterfowl, and other waterbird species or groups on GSL and its associated wetlands over a 21-year period (1997–2017). Of the 37 species or groups that were surveyed, 36 exhibited increasing or stable populations for the time period. The only exception was Redhead.

From a practical standpoint, Locomotive Springs have ceased to exist except as a ephemeral source of water during the spring or when there is a wet year in Curlew Valley. The collapse of waterfowl and shorebird populations at Locomotive Springs WMA is a cautionary tale about what can happen when people withdraw water from an aquifer for irrigation without considering the consequences for local springs. The number of waterfowl or shorebirds lost at Locomotive Springs WMA is inconsequential to continental bird populations. However, Locomotive Springs created one of the largest areas of open freshwater and wetlands in Great Salt Lake Desert, and its loss is significant. We need to be more alert to the inadvertent damage to the environment by withdrawing water from aquifers, especially in arid regions.

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Table 1. Waterfowl counts made in a single day at Utah Division of Wildlife Resources (DWR) Waterfowl Management Area, Utah, U.S. by DWR employees throughout the years of 1973 and 1997–2001. Counts from 1973 were paired with 1997–2001 counts made within two weeks of each other to reduce the impact of seasonal changes in waterfowl numbers. Data shown are the means ($\bar{x}$) and standard error (SE); data were analyzed using a General Linear Model ANOVA (df = 1, 8).

Species	1973		1997–2001		*F*	*P*
	$\bar{x}$	SE	$\bar{x}$	SE		
Both teal species	1,995	784	228	67	5.97	0.04
American Wigeon	2,009	738	101	65	8.47	0.02
Mallard	204	35	143	23	3.12	0.11
Northern Shoveler	116	43	67	21	2.46	0.16
Northern Pintail	4,033	1,353	121	47	8.86	0.02
Gadwall	174	52	107	31	1.35	0.28
Canvasback	3	2	23	9	4.23	0.07
Redhead	133	18	71	25	7.88	0.02
Canada Goose	43	8	22	7	3.55	0.10
American Coot	1,397	386	116	82	13.03	0.007
Total (all waterfowl species)	10,108		1,001			

Table 2. Waterfowl counts made in a single day at Utah department of Wildlife Resources (DWR) Locomotive Springs Waterfowl Management Area, Utah, U.S. by DWR employees throughout the years of 1973 and 2016–2022. Counts from 1973 were paired with 2016–2022 counts made within two weeks of each other to reduce the impact of seasonal changes in waterfowl numbers. Data shown are the means ($\bar{x}$) and standard error (SE); data were analyzed using a General Linear Model ANOVA (df = 1, 8).

Species	1973		2016–2022		*F*	*P*
	$\bar{x}$	SE	$\bar{x}$	SE		
Both teal species	1,995	784	78	30	6.31	0.04
American Wigeon	2,009	738	3	2	8.93	0.02
Mallard	204	35	21	4	24.70	0.001
Northern Shoveler	116	43	57	26	4.64	0.06
Northern Pintail	4,033	1,353	11	5	8.87	0.02
Gadwall	174	52	32	10	6.01	0.04
Canvasback	3	2	2	2	—	—
Redhead	133	18	1	1	51.17	0.0001
Canada Goose	43	8	11	4	8.42	0.02
American Coot	1,397	386	6	3	13.10	0.01
Total (all waterfowl species)	10,108		222			

Table 3. Waterfowl, waterbirds (other than waterfowl), and shorebird counts made in a single day at Utah Division of Wildlife Resources (DWR) Locomotive Springs Waterfowl Management Area, Utah, U.S. by DWR employees throughout the years of 1997–2001 and 2016–2022. Counts from 1997–2001 were paired with 2016–2022 counts made within two weeks of each other to reduce the impact of seasonal changes in waterfowl numbers. Data shown are the means ($\bar{x}$) and standard error (SE); data were analyzed using a General Linear Model ANOVA (df = 1, 14).

Species	1997–2001		2016–2022		*F*	*P*
	$\bar{x}$	SE	$\bar{x}$	SE		
Both teal species	217	51	72	21	19.92	0.001
American Wigeon	95	43	3	2	4.62	0.049
Mallard	163	23	25	6	32.08	0.0001
Northern Shoveler	70	17	55	25	0.92	0.35
Northern Pintail	84	30	11	4	6.44	0.02
Gadwall	114	27	28	8	16.73	0.001
Canvasback	121	71	2	1	2.81	0.12
Redhead	246	120	3	2	4.04	0.06
Canada Goose	33	8	12	4	20.62	0.001
American Coot	171	71	10	5	5.69	0.03
Total (waterfowl)	1,314		221			
Double-crested Cormorant	8	3	1	0	4.60	0.05
Common Merganser	6	3	0	0	3.34	0.09
American White Pelican	28	10	4	1	6.42	0.02

California Gull	31	11	7	3	5.25	0.04
Franklin's Gull	5	3	1	1	1.09	0.31
Caspian Tern	2	1	0	0	5.30	0.04
Forster's Tern	9	4	1	0	4.71	0.05
Great Blue Heron	9	1	2	1	61.02	0.001
Black-crowned Night-Heron	2	1	0	0	6.27	0.03
White-faced Ibis	41	12	11	5	4.50	0.05
Total (waterbirds other than waterfowl)	141		27			
Shorebirds						
American Avocet	121	37	42	11	7.97	0.01
Black-necked Stilt	47	14	4	1	8.45	0.01
Snowy Plover	33	13	32	16	0.00	0.95
Killdeer	14	6	7	7	0.46	0.55
Marbled Godwit	4	2	2	2	1.24	0.28
Willet	43	14	21	7	5.00	0.04
Greater Yellowlegs	5	1	1	0	13.50	0.002
Lesser Yellowlegs	7	3	3	1	1.36	0.26
Wilson's Phalarope	43	13	3	1	9.91	0.007
Long-billed Dowitcher	32	13	15	9	4.26	0.06
Western Sandpiper	35	14	13	7	3.12	0.10
Total (shorebirds)	384		143			
Grand total (all birds)	1,839		391			

Table 4. Water discharge (m^3/hr) from the six springs on Locomotive Springs Waterfowl Management Area from 1934 to 2003 (W. Loco. is West Locomotive Spring).

Year	Bar M	Teal	Off	Sparks	Baker	W. Loco.	Total	Date[1]	Source
1934	1,907	408	326	510	2,040	1,051	6,242	—	Taylor (1970)[2]
1939	1,519	—	235	235	—	—	—	20 Jul	W. H. Griffiths
1939	1,051	286	231	254	—	—	—	24 Mar	E. R. Morgan
1939	—	—	—	—	—	—	4,080	—	Baker (1974)
1951	551	530	337	—	—	581	2,693	various[3]	McCullough (1951)
1961	1,560	286	2,346	255	—	—	—	—	Taylor (1970)
1967	—	—	—	—	—	—	3,876	—	Owsley (2009)
1967	—	—	—	—	—	—	4,080	—	Bolke and Price (1969)
1969	1,132	143	—	153	—	1,805	3,134	every month	Baker (1974)
1969	1,134	—	143	143	31	1,683	3,223	daily[4]	Water Rights gauges
1970	1,163	143	—	153	—	1,805	3,264	every month	Baker (1974)
1970	1,132	—	129	150	335	1,513	3,259	daily[4]	Water Rights gauges
1971	1,001	—	136	148	349	1,774	3,408	daily[4]	Water Rights gauges
1972	997	—	130	116	346	1,027	2,616	daily[4]	Water Rights gauges
1973	965	—	126	122	—	—	—	daily[4]	Water Rights gauges
1974	918	—	112	133	—	—	—	daily[4]	Water Rights gauges
1975	893	—	134	141	—	—	—	daily[4]	Water Rights gauges
1976	824	—	117	134	—	—	—	daily[4]	Water Rights gauges

1977	673	—	98	114	—	—	—	daily[4]	Water Rights gauges
1978	590	—	79	65	—	—	—	daily[4]	Water Rights gauges
1979	558	—	86	80	—	—	—	daily[4]	Water Rights gauges
1994	356	150	42	0	44	644	1,236	7 Sep	Atkin (1998)
2000	418	—	439	0	97	163	683	daily[4]	Water Rights gauges
2001	259	—	367	0	71	306	570	daily[4]	Water Rights gauges
2002	245	—	0	0	18	0.1	263	daily[4]	Water Rights gauges
2003	187	—	0	0	31	0	218	daily[4]	Water Rights gauges

[1] This is the day when the measurements were made.

[2] These are water rights acquired by DWR when they bought them in 1934.

[3] These are the means of four measurements made during May-July, July-August, August-September, and October-May. The measurements were made at the springs.

[4] Means of all recorded daily flow measurements for year of interest logged by Utah Division of Water Rights gauges at Locomotive Springs.

Figure 1. Location of Locomotive Spring (41.7074^{o}, -112.9192^{o}) is northern Utah. The figure shows its location of the springs relative to the state, Great Salt Lake, and its watershed. The size of the black box marked as Locomotive Springs corresponds to the black area shown in Fig. 2 and the maps in Fig. 3.

Figure 2. Map of Locomotive Springs (41.7074^{o}, -112.9192^{o}) showing the location of the six springs (West Locomotive, Bakers, Bar M, Teal, Off and Sparks). The area shown in this figure corresponds to area contained in black box in Figure 1. Also shown are the streams from each spring and the two impoundments — West Lake and East Lake — built by Utah to store water from the springs for the benefit of waterfowl and waterfowl hunters. Figure is from McCullough (1951, public domain).

Figure 3. Satellite imagery of Locomotive Springs Waterfowl Management Area showing the amount of open water during the month of August. The satellite image corresponds to the area shown in Fig. 2. The figure shows that the surface of Great Salt Lake was lower during 2025 than earlier, and therefore, had retreated from Locomotive Springs and was no longer is visible in this figure. These data came directly from the Intermountain West Joint Venture's Wetland Evaluation Tool Surface Water Module (Intermountain West Joint Venture 2025, public domain).

Figure 4. Numbers of waterfowl hunters counted on the opening day of the hunting season in early October. Hunter counts stopped after 2010 because there were so few hunters that the Utah Division of Wildlife Resources no longer thought that it was worthwhile to count them.

Figure 5. Amount of water (m^3/hr) withdrawn annually from the Locomotive Springs aquifer from 1963 to 2003 for human uses, which consisted mainly of crop irrigation (Birkin 2019).

Figure 6. Annual precipitation in Curlew Valley from 1930 to 2025 (PRISM 2026).

Figure 1.

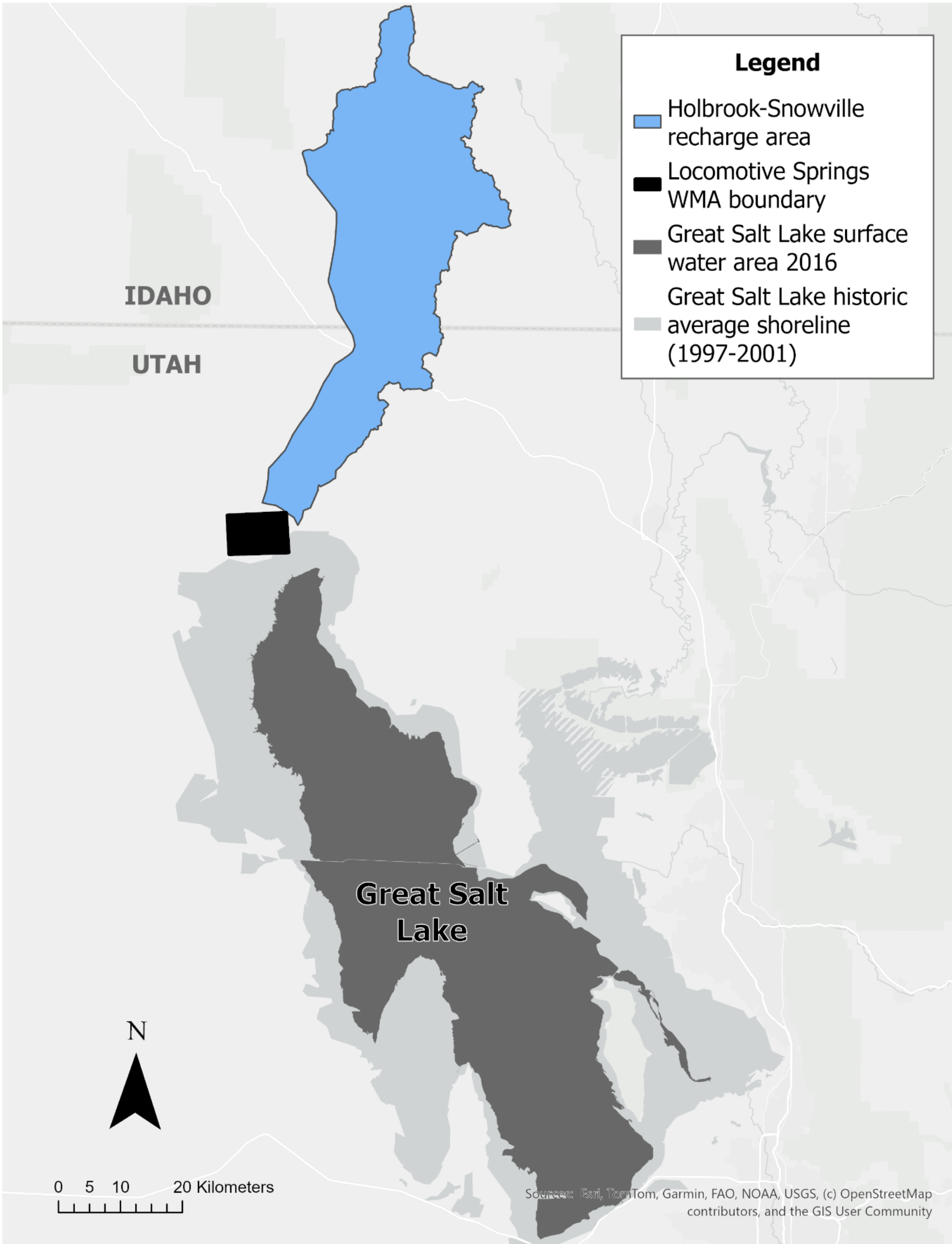

Legend
Holbrook-Snowville recharge area
Locomotive Springs WMA boundary
Great Salt Lake surface water area 2016
Great Salt Lake historic average shoreline (1997-2001)
IDAHO
UTAH
Great Salt Lake
N
0 5 10 20 Kilometers
Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.

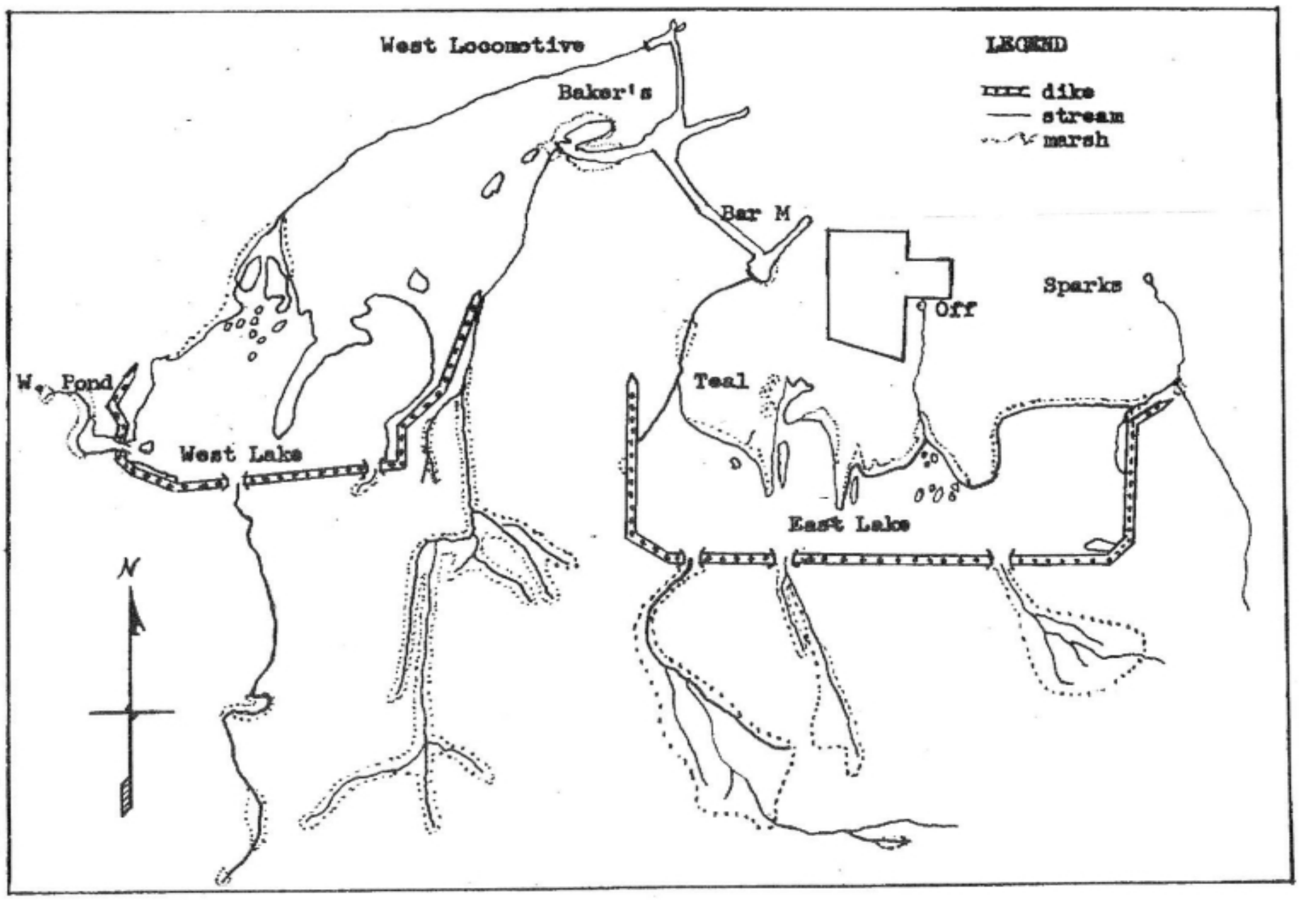

West Locomotive
Baker's
LEGEND
dike
stream
marsh
Bar M
Sparks
Off
W. Pond
Teal
West Lake
East Lake
N

Figure 3.

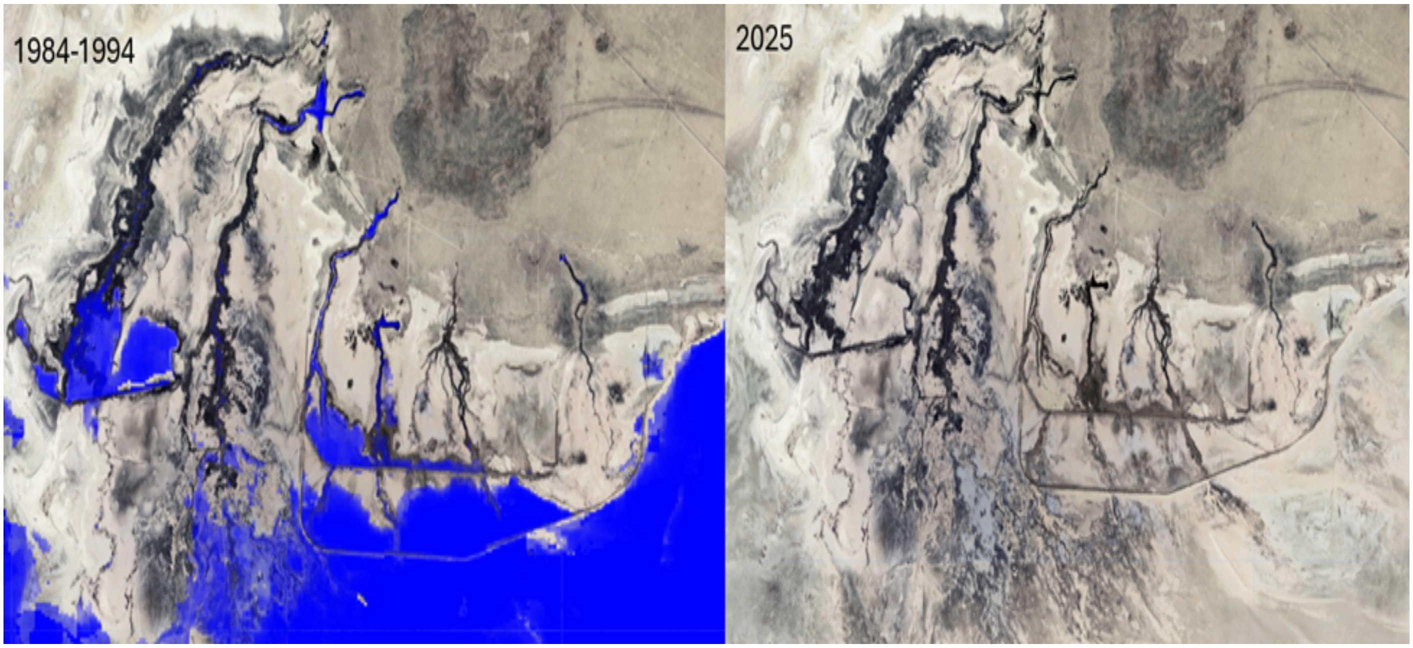


Figure 4.

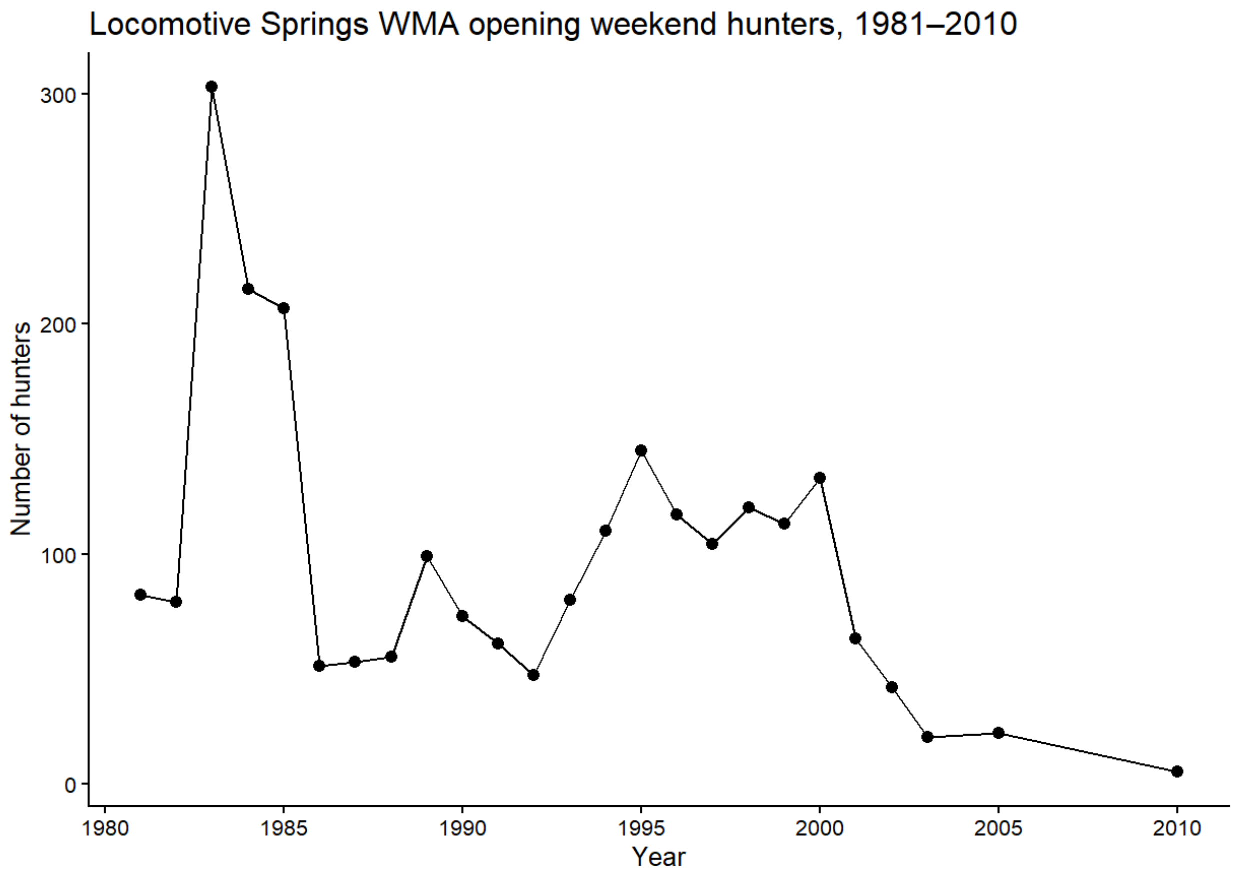

Locomotive Springs WMA opening weekend hunters, 1981–2010
Number of hunters
0
100
200
300
Year
1980
1985
1990
1995
2000
2005
2010

Fig. 5.

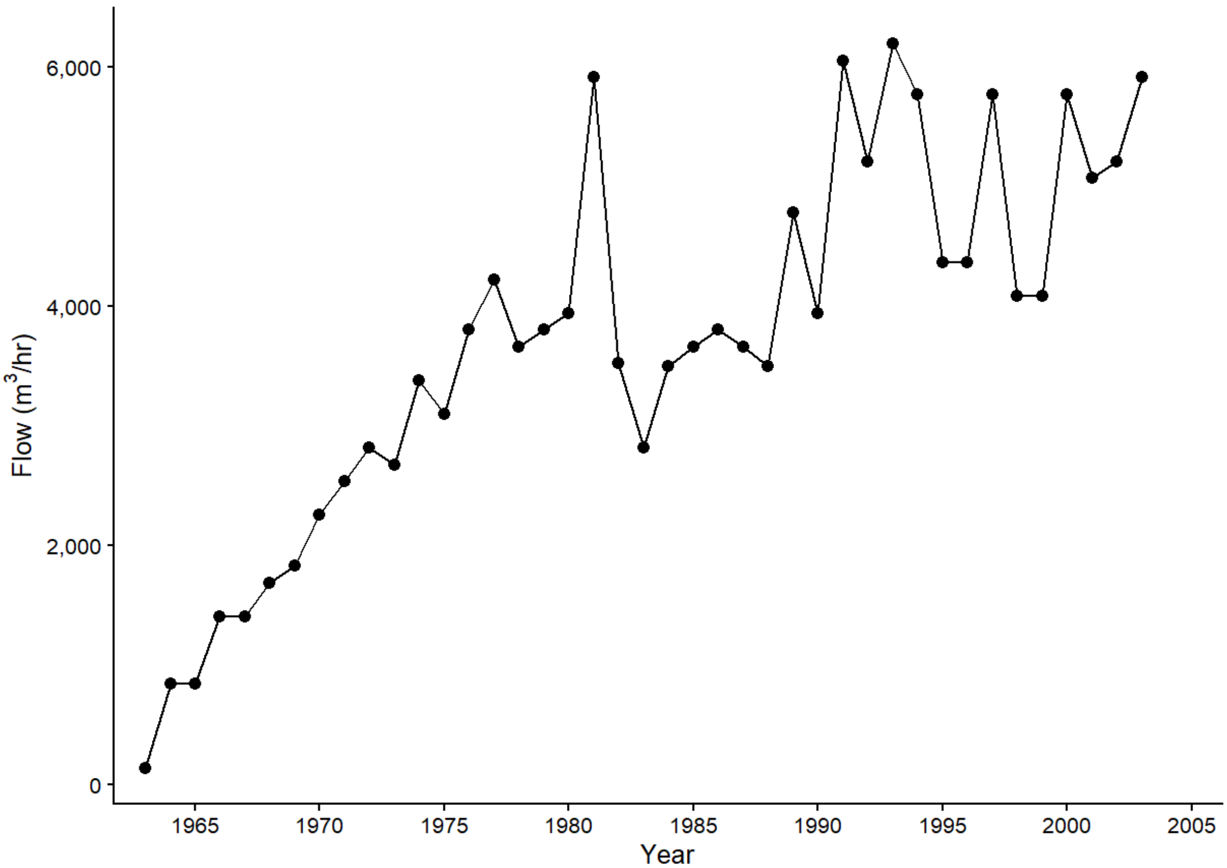
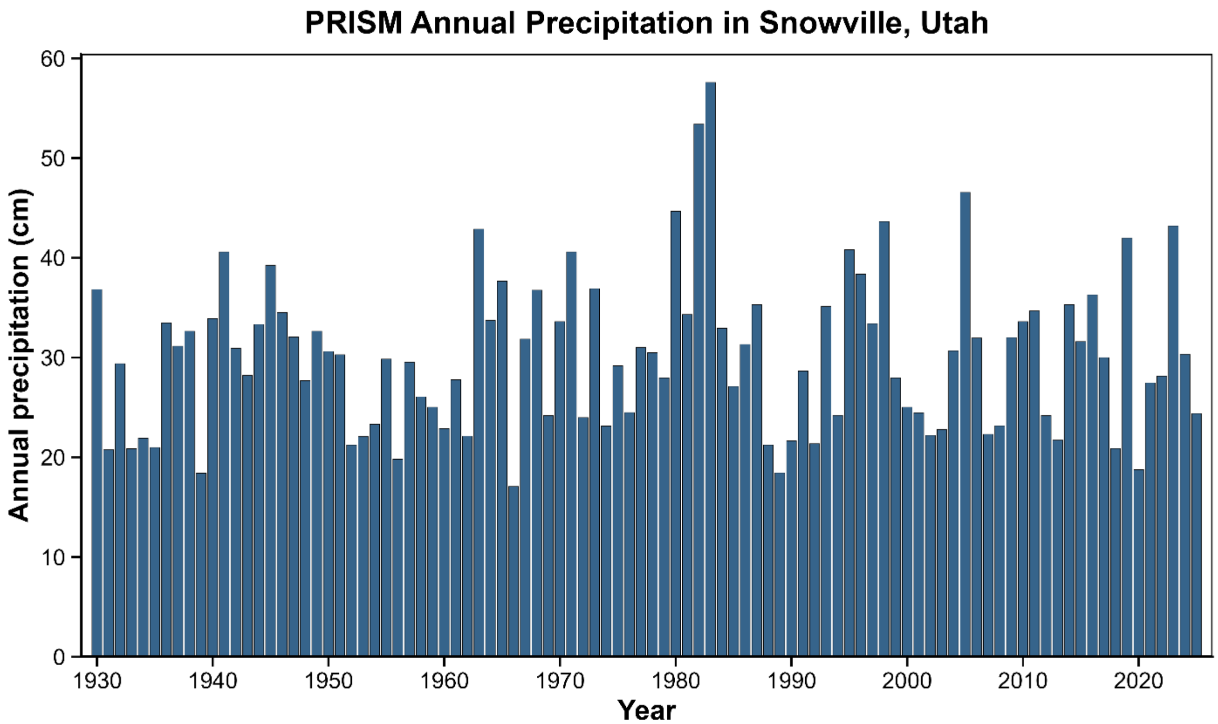

6,000
4,000
2,000
0
Flow (m3/hr)
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

Figure 6.


PRISM Annual Precipitation in Snowville, Utah
Annual precipitation (cm)
0
10
20
30
40
50
60
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year