Pahranagat National Wildlife Refuge

Hydrologic Analysis Report

June 2010

Upper Pahranagat Lake. October 2008.

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Front Cover: View of Upper Pahranagat Lake looking south. First filling of the lake after draining during the summer of 2008. October 2008.

Photo Credit: Malcolm Harris

Contents

Acknowledgements

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Fred Wurster, June 19, 2010

Chapter 1: Site Description, Geology, Hydrogeology, and Basic Hydrology

1) All surface water entering the refuge comes from Ash and Crystal springs. Approximately 80% of this water enters the refuge between November and April.

2) Ash and Crystal Springs are fed by a regional Paleozoic carbonate rock aquifer. The boundaries of this aquifer extend far beyond the boundaries of the Pahranagat Valley and are part of the White River regional groundwater flow system.

3) Since the 1960s, total annual inflows to the refuge from Ash and Crystal Springs have declined. This decline appears to be associated with a shorter annual period of inflows to the refuge. In the 1960s, inflows to the refuge lasted about 1 month longer than they do today.

4) The complex geology of the Pahranagat Shear Zone has a marked influence groundwater flow patterns and wetland habitat on the refuge.

Chapter 3: Wetland Habitat Distribution and Trends

1) There are about 1,970 acres of wetland habitat on the refuge.

2) About 90% of the wetlands are classified as palustrine emergent or lacustrine wetlands. The majority of this habitat is distributed between three areas: Upper Pahranagat Lake, Lower Pahranagat Lake, and the area between Dove Dike and Middle Marsh Dike.

3) Riparian wetlands in 2004 - 2006 covered approximately 87 acres, or 4% of the total wetland acreage. This is 2.5 times the riparian acreage on the refuge in 1965.

4) Manmade ponds in 2004 - 2006 covered approximately 87 acres, or 4% of the total wetland acreage. This is 9 times the pond acreage on the refuge in 1965.

5) Overall, the area covered by wetlands has declined slightly (~5%) since 1965. Most of this loss has occurred in the area between Lower Pahranagat Lake and Maynard Lake, which appears drier now than in 1965.

Chapter 4: Surface Water Hydrology

1) Upper Pahranagat Lake is the primary water management tool on the refuge. Water from Ash and Crystal Springs stored in the lake is the main water source for refuge wetlands.

2) A considerable amount of water is lost from the refuge's ditch system as it flows through the DU Project area. This is due to seepage from refuge ditches into the subsurface. At times seepage losses can be 70% or more of the releases from Upper Pahranagat Lake. This water seeps into the subsurface and recharges the alluvial groundwater aquifer.

3) Once surface water reaches Dove Dike, seepage losses decline considerably. Between Whin Dike and Middle Marsh Dike seepage losses from the water distribution system are insignificant.

4) In the Whin Dike/Middle Marsh area, groundwater discharge helps maintain year-round standing water. Therefore, these wetlands are less dependent on Upper Pahranagat Lake water for maintaining wetland habitat conditions than wetlands in the DU Project Area.

5) Flow from refuge springs is seasonal and a small fraction of the water supplied by Ash and Crystal Springs. Peak spring flows typically occur during the winter months. Maximum flow recorded at the refuge's largest spring, Cottonwood, was 35 gallons per minute; less than 1% of the flow at Ash Springs.

6) Refuge springs typically discharge enough water to maintain small pools. Only Cottonwood Spring discharge is large enough to maintain flow from the pool to surrounding wetlands.

7) Low flow volumes, water chemistry, and seasonal fluctuations suggest refuge springs are supported by groundwater flow paths that are different from those supporting Ash and Crystal Springs

Chapter 5: Groundwater Hydrology

1) Movement of shallow groundwater under the refuge is primarily from north to south with additional contributions from the east and west.

2) Areas where groundwater discharges to the ground surface are associated with faults of the Pahranagat Shear Zone.

3) Groundwater discharge occurs at the following refuge locations: the north end of Upper Pahranagat Lake, Whin Dike / Middle Marsh Dike areas, the west side of the meadow south of Dove Dike, south of Lower Pahranagat Lake, and the Maynard Springs area.

4) Depth to groundwater in the DU Project Area and Black Canyon suggest this is an area of high seepage loss from irrigation ditches.

5) Wetlands on the refuge are supported by a combination of surface water from Upper Pahranagat Lake and groundwater discharge. The relative importance of each source is dependent on groundwater flow paths and proximity to refuge irrigation ditches.

6) The water table under refuge wetlands fluctuates seasonally. Water table elevations are highest in the late winter/early spring and lowest in the late fall. Maximum seasonal fluctuations approached 10 ft during our study.

7) The volume of groundwater discharging into refuge wetlands is small in comparison to surface water contributions from Upper Pahranagat Lake. However, in some parts of the refuge and at certain times of the year, groundwater discharge is the only source of water for refuge wetlands.

Chapter 6: Water Quality

1) Water in spring pools tends to be cooler, fresher, and has a lower pH than water in irrigation ditches and lakes on the refuge.

2) Water chemistry analyses confirm that springs on the refuge have a different source than springs fed by the regional carbonate rock aquifer. The source of the spring water is probably alluvial groundwater that is recharged locally by precipitation inside the boundaries of the Pahranagat Valley.

3) Surface water entering the refuge is a 70:20:10 mix of Crystal Springs, Ash Springs, and groundwater with a chemical signature similar to Cottonwood and Maynard Springs.

4) Water collected from refuge wetlands is a mixture of surface water released from Upper Pahranagat Lake and groundwater with a chemical signature similar to Cottonwood and Maynard Springs.

5) Spring pools have lower concentrations of dissolved oxygen than surface water in the ditch system, presumably due to high rates of

biological activity, less surface area, and little oxygen-entraining turbulence.

Chapter 7: Historic Water Management

1) Beginning with the construction of Upper Pahranagat Lake, storage and distribution of the winter flows from Ash and Crystal Springs has gradually been concentrated in the northern third of the refuge over the last 80 years.

2) Water management since the refuge was established focused on maintaining a minimum pool in the Upper Lake. This has led to less water available for wetlands south of the headquarters and probably contributed to drying the wetlands in the southern third of the refuge since 1965.

Executive Summary

The Pahranagat Valley of southern Nevada is characterized by an arid climate and extensive spring discharge from the Regional Carbonate Rock Aquifer. The geology of the region promotes groundwater discharge into the valley from the regional aquifer. The geological faulting of the Pahranagat Shear Zone, in the southern end of the valley affects groundwater flow at a regional scale and locally on the Pahranagat National Wildlife Refuge. The displacement of rock layers at Shear Zone faults are barriers to ground water flow and promote groundwater discharge from the local alluvial aquifer and supports wetland habitat on the refuge.

Precipitation in the Pahranagat Valley is negligible and wetland habitat on the refuge is maintained almost exclusively by surface water flow from Ash and Crystal Springs. Water flowing from the two springs travels 12-15 miles south before reaching Upper Pahranagat Lake at the north end of the wildlife refuge. Eighty percent of the annual inflows to the refuge occur between November and April. Inflows to the refuge drop dramatically during the summer months because upstream irrigators divert surface water from the springs to flood fields and pasture north of the refuge. As a result, surface water inflow to the refuge tend to “start” near the end of October and “end” sometime around the beginning of May. During the intervening months inflows are negligible. Since the 1960s, the total annual volume of water entering the refuge has declined by 700 to 2,000 acre-feet.

Site Description

Pahranagat National Wildlife Refuge is located at the southern end of the Pahranagat Valley in south central Nevada, approximately 90 miles north of Las Vegas and 10 miles south of the town of Alamo, NV (Figure 1). The refuge was established 1964 with the purchase of the Gardner Ranch and includes approximately 5,380 acres of wet meadows, marsh, open water, grasslands, and upland deserts. Wetlands on the refuge provide habitat for over 230 species of migratory birds the majority of which are migratory waterfowl (USFWS 2008). The purpose of the refuge is derived from the Migratory Bird Conservation Act . . . “for the use as an inviolate sanctuary, or for any other management purposes, for migratory birds . . “.

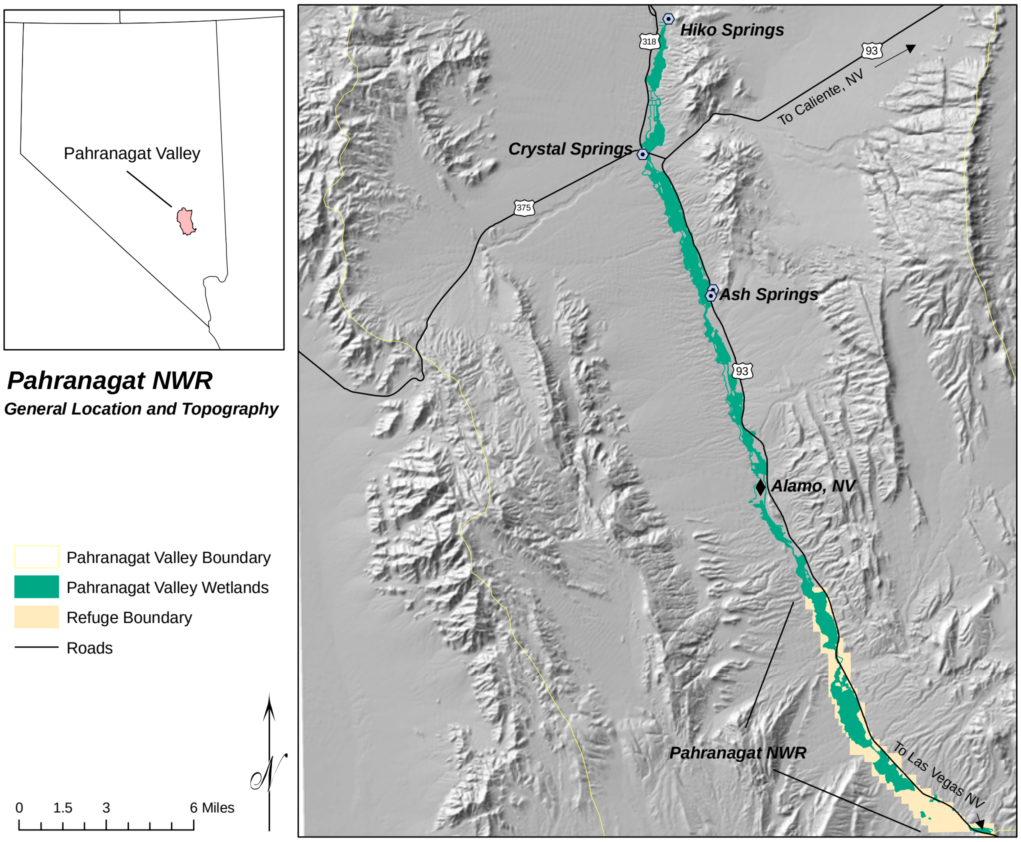


Figure 1: Location of Pahranagat Valley and Pahranagat National Wildlife Refuge, Nevada.

Pahranagat Valley Climate: Temperature & Precipitation

The climate of the Pahranagat Valley is arid, characterized by annual precipitation less than 10 inches, high potential evaporation with cold winters and hot summers. There are three climate monitoring sites in the valley: Pahranagat NWR headquarters, the Hiko COOP station, and the Alamo Community Environmental Monitoring Program (CEMP) station. Table 1 summarizes data from the Pahranagat NWR headquarters site.

Table 1: Monthly summary of climate records collected at the Pahranagat NWR COOP station. From Western Regional Climate Center Website. Period of Record: 3/31/1964-12/31/2008.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	53.1	58.3	64.7	72.1	82.2	92.0	98.5	96.4	89.1	77.5	63.2	52.8	75.0
Average Min. Temperature (F)	27.3	31.2	35.5	40.8	49.3	57.0	64.3	62.6	54.0	43.7	33.4	26.7	43.8
Average Total Precipitation (in.)	0.67	0.73	0.76	0.62	0.39	0.20	0.48	0.61	0.38	0.52	0.50	0.39	6.25
Average Total SnowFall (in.)	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	1.4

Monthly average precipitation totals are relatively uniform throughout the year. From Table 1, March has the highest precipitation total and June the lowest. Temperature maximums typically occur in July and can exceed 110° F. Minimum temperatures in the single digits are not uncommon in December and January. Daily temperature fluctuations can be as high as 30 degrees between daytime highs and nighttime lows.

In southern Nevada most precipitation falls in the winter and during the summer monsoon season. Winter precipitation is influenced by large frontal systems that originate in the Pacific Ocean and pass over the Sierra Nevada into Nevada's deserts. During the summer months, large convective thunderstorms associated with a monsoon-like weather pattern from the Gulf of California are the source of most moisture (Trimble 1989, Tyler et al. 1996). Climatic trends associated with El Nino South Oscillation may be important drivers of weather patterns at Pahranagat (Hevesi et al. 2003). In general, El Nino years are associated with more precipitation during the winter months while the La Nina winters tend to be drier.

Pahranagat Valley Climate: Evaporation

Southern Nevada has some of the highest evaporation rates in the United States (Dunne and Leopold 1978). During the last 10 years, numerous investigations have helped quantify evaporation and evapotranspiration rates for different habitat types in southern Nevada. (Laczniak et al. 1999, Berger et al. 2001, Reiner et al. 2002, DeMeo et al. 2003, and DeMeo et al. 2008). These reports indicate annual open water evaporation in central and southern Nevada ranges from 5.0 ft in Ruby Valley NWR to almost 8.0 ft at Ash Meadows NWR. During our study, Class A pan evaporation at Pahranagat NWR was about 6.0 ft/year. Comparing pan data with reference evapotranspiration rates calculated at the Alamo CEMP station, suggest open-water evaporation at Pahranagat approaches 5.5 ft/yr, almost 10 times the total annual precipitation of 6.25 inches. Open water evaporation rates range from 10 inches/month in July to 2 inches/month in December (Figure 2).

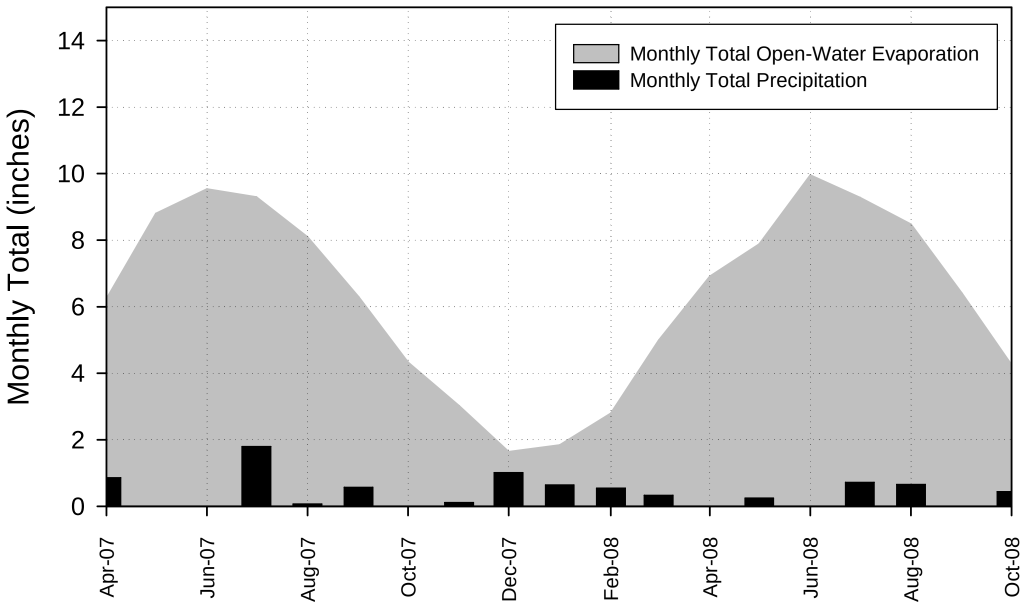


Figure 2: Estimated total monthly open water evaporation and precipitation at Pahranagat NWR.

Pahranagat Valley Geology

The Pahranagat Valley is a portion of a topographic low that runs roughly north-south along the path of the pre-historic White River. This trough includes the White River and Pahroc valleys to the north and Coyote Springs and Moapa Valley to the south. During the last glacial maxima, approximately 15,000 years ago, the White River flowed from the mountains near Lund, NV south through the Pahranagat Valley and eventually into the Muddy River near Moapa NWR (USFWS 1998, Eakin 1963).

The valley is approximately 44 miles long on its north-south axis and 7 miles wide from east to west. It is bordered by the Pahroc Range to the east and the Pahranagat Range to the west. Elevations on the valley floor are approximately 3,900 to 3,100 ft, from north to south, and high points in the surrounding mountains exceed 7,000 ft. Sand, gravel, and silt deposited by the pre-historic White River occupy a ¼ to ½ mile wide “floodplain” near the center of the valley. These deposits are the focus of agricultural development in the valley and the location of valley’s wetlands.

Pahranagat Valley Hydrogeology

The movement of surface water and groundwater in this portion of southern Nevada is controlled by the complex geology of the region. Different rock units have different water bearing properties and faulting of the rock layers influences groundwater movement between them. Three studies describing the geology of the Pahranagat Valley are particularly relevant to the current investigation: Eakin’s (1963) reconnaissance investigation of Pahranagat Valley hydrogeology, Jayko’s (1990) study of “shallow crustal deformations", or faults, of the southern Pahranagat Valley, and Jayko's (2007) geologic map of the Pahranagat Valley. Eakin's (1963) report on the valley's hydrogeology recognizes two aquifers at Pahranagat: the Paleozoic carbonate rock aquifer and the shallow alluvial aquifer.

The Paleozoic rock aquifer is composed of sedimentary limestone rocks. The rock formations were formed through the accumulation of coral and the shells of marine organisms in shallow, warm oceans during the Paleozoic era, 300-400 million years ago (Eakin 1963, Jayko 2007). These rocks form a large regional aquifer that extends as far north as Great Basin National Park and south to Death Valley and Lake Mead. Because rainwater dissolves limestone, the rock layers develop numerous cracks over time. Precipitation falling on the exposed limestone percolates into the cracks in the limestone, creating the carbonate rock aquifer. Water moving through the aquifer eventually discharges at the large springs in the Moapa Valley, Ash Meadows, Death Valley, and Pahranagat Valley (Eakin 1966) (Figure 3).

Above the Paleozoic carbonate rocks is a layer of volcanic ash-flow layers deposited 15-35 million years ago, during the Tertiary period. Sources of these volcanic deposits are calderas to the northwest and east of Pahranagat Valley, near Caliente, NV. The Tertiary volcanic rocks that overly the carbonates are not believed to store significant quantities of water, except in places where they have been fractured considerably (Eakin 1963).

Widespread folding and faulting of the major rock layers near Pahranagat Valley appears to have occurred in the later Tertiary, about 5-10 million years ago. This fracturing created mountains and valleys in what had been a relatively low-relief area (Jayko personal comm.). Weathering of the mountain ranges filled the adjacent valleys, or basins, with alluvial deposits of sand and gravel. In alluvial aquifers, water is stored in the pore spaces between sediment particles. Eakin (1963) believed the alluvial sands and silts that make up the White River floodplain store a significant volume of water in the Pahranagat Valley.

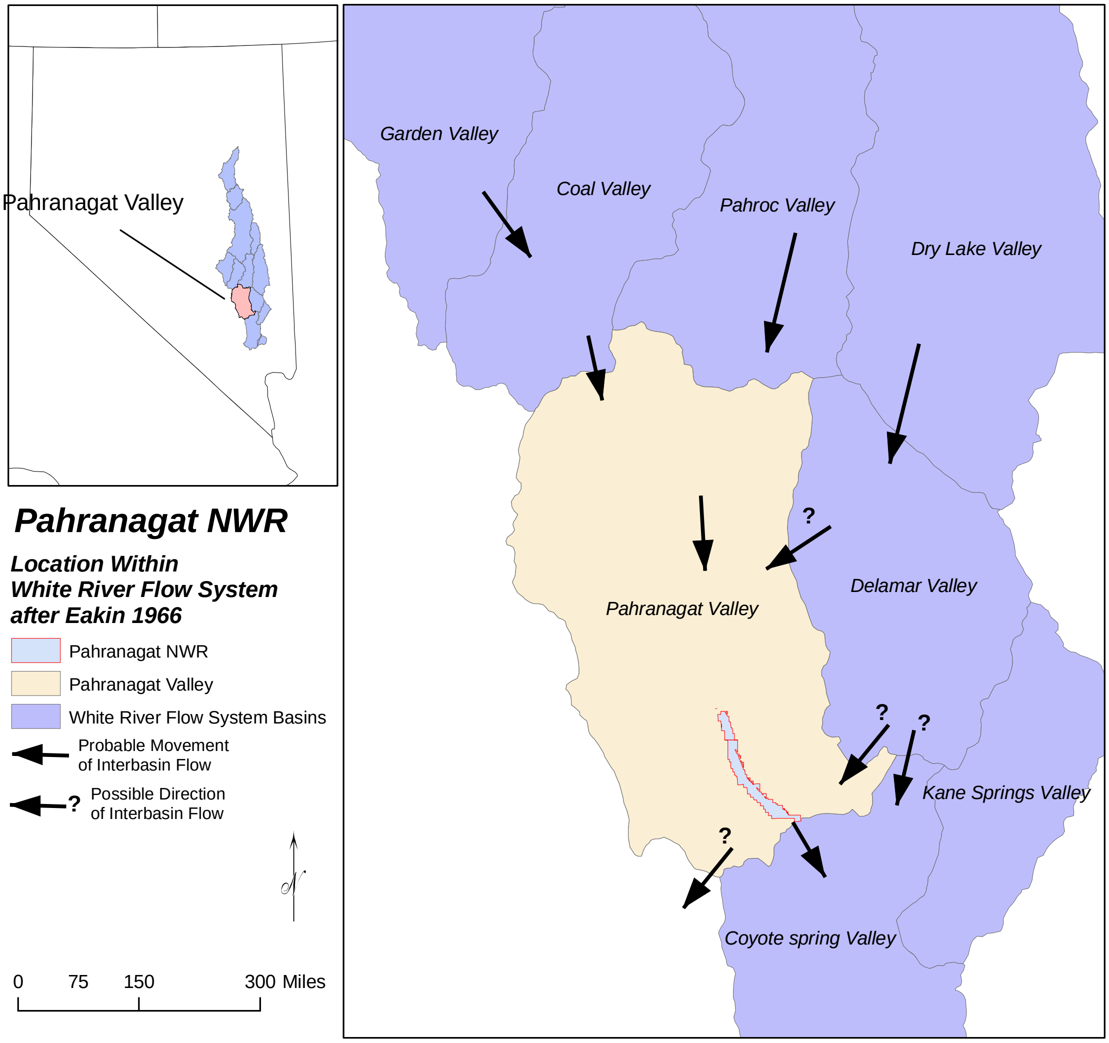


Figure 3: Approximation of groundwater movement in the Regional Paleozoic Carbonate Aquifer to the Pahranagat Valley. (Eakin 1963 and 1966).

Most of the discharge from the regional aquifer in Pahranagat Valley occurs at three springs; Hiko, Crystal, and Ash, located 18, 15, and 12 miles north of Pahranagat NWR, respectively. These springs are believed to provide nearly all the water supporting the lakes, wetlands, and irrigation activities in the Pahranagat Valley (Eakin 1963). Although, Eakin recognized " . . . additional [groundwater] discharge occurs by upward leakage from the carbonate rocks to the overlying younger valley fill [alluvium], " at present this process is not well defined at the relative contribution of upward leakage to the overlying alluvium is not quantified. Groundwater movement in the Paleozoic carbonate aquifer to Pahranagat Valley is thought to enter the valley from the north, northeast, and northwest (Figure 3).

The numerous faults that deformed the rock layers in southern Nevada are thought of as both conduits and barriers to groundwater movement in the regional carbonate aquifer. Deformation of the rock layers is particularly complex on the Pahranagat National

Wildlife Refuge in an area known as the Pahranagat Shear Zone (Jayko 1990). The faults of the shear zone are known as strike-slip faults, meaning the rock layers on either side of the fault move horizontally. Additionally, there is some tilting occurring, that causes the rock between the faults to tip downward to the southwest (Jayko 1990). The faults are aligned roughly perpendicular to the north-south axis of the Pahranagat Valley and are considered transfer faults that connect large north-south trending faults in the Dry Lake and Delamar Valleys with Desert Valley, or South Tikaboo, to the southwest of Pahranagat (Figure 4).

The Pahranagat Shear Zone is recognized as a significant barrier to groundwater movement in the north-south direction. As evidence, researchers often cite the 900 ft drop in the potentiometric surface between the southern Pahranagat Valley and northern Coyote Springs Valley (Eakin 1963, 1966). The cause of this process is vertical displacement of rock layers on either side of the shear zone faults. North of the faults, the rock is lower relative to the rock immediately south of a fault. This displacement places low permeability rock layers adjacent to the high permeability carbonates. In theory, the displacement effectively dams groundwater movement in the carbonates, causing water to “back up” behind, or upgradient, of the Shear Zone. This vertical displacement has implications for wetland habitat on Pahranagat NWR as well. Displacement around the shear zone faults may cause tertiary volcanics to “dam” groundwater movement in the alluvial aquifer of the valley’s floodplain. This may help create conditions that promote groundwater discharge into refuge wetlands.

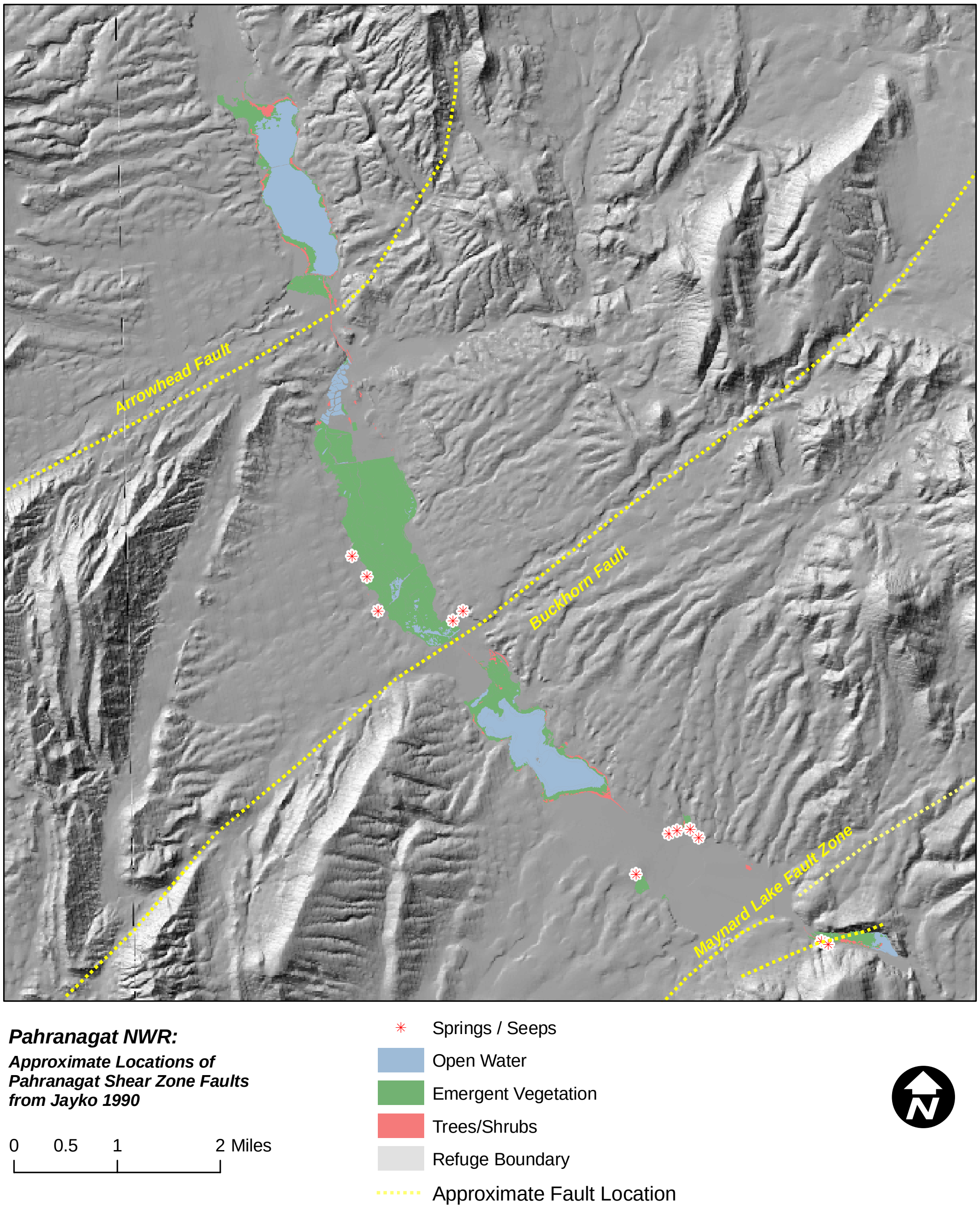


Figure 4: Approximate locations of Pahranagat Shear Zone faults at the southern end of the Pahranagat Valley. From Jayko (1990, 2007).

Pahranagat Valley Surface Water Hydrology

Three regional carbonate springs (Hiko, Crystal, and Ash) are the sources of most surface water in the Pahranagat Valley. Water from the three springs is used north of Pahranagat NWR to irrigate land for pasture and haying. Hiko Spring water remains north of

Highway 375 and supplies Frenchy and Nesbitt Lakes on the Key Pittman Wildlife Management Area. Ash and Crystal Springs provide water for lands south of Highway 375, including Pahranagat NWR (see Figure 1). After being applied to pasture lands, excess water from Ash and Crystal springs collects in a drain (Pahranagat Drain) at the center of the valley and flows south to Upper Pahranagat Lake. Spring flow at Ash and Crystal springs is monitored continuously by the U.S. Geological Survey (USGS) at the following stream gaging sites: 0941560, 09415639, 09415590, 095415589. Surface water entering Upper Pahranagat Lake via the Pahranagat Drain is measured by the U.S. Fish and Wildlife Service Water Resources Branch (WRB) (Figure 5).

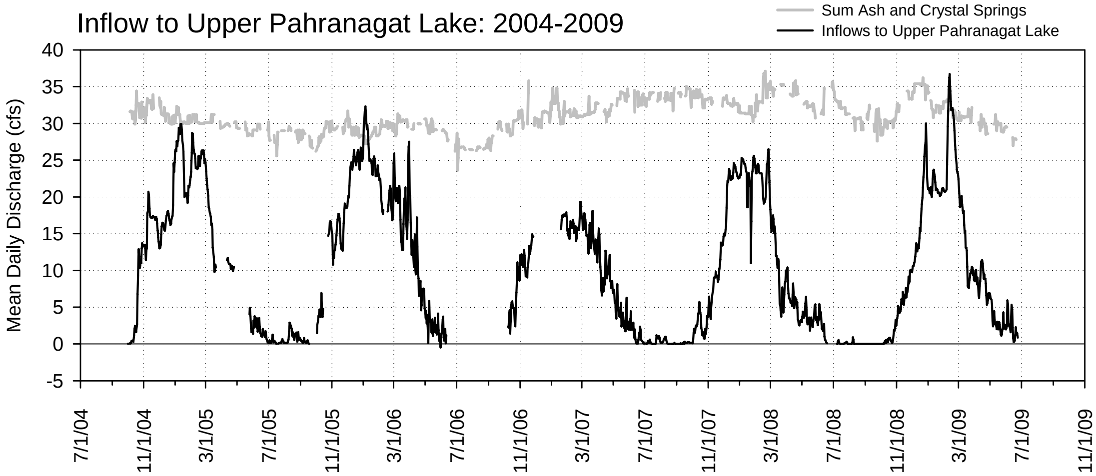


Figure 5: Mean daily combined discharge from Ash and Crystal Springs and discharge in the Pahranagat Drain above Upper Pahranagat Lake. October 2004-June 2009.

Combined Ash and Crystal flow from 2004 to 2009 is approximately 30 cfs (12 cfs from Crystal and 18 cfs from Ash). Although there is some variation over the period of record there do not appear to be any distinct seasonal trends. Hiko Spring only began being monitored in 2009 as part of the Cave, Dry Lake, and Delamar Valley Stipulated Agreement between the Department of Interior and Southern Nevada Water Authority (SNWA). Data are not available yet, but Eakin (1963) reported average daily discharge was approximately 6 cfs at the time of his study. Assuming Hiko discharge has not changed, combined flow of all three springs may approach 36 cfs. This agrees with estimates of spring flow made by Carpenter in 1915, which suggests flow from Hiko, Crystal, and Ash springs has been consistent for the last 95 years.

Surface Water Inflows to Pahranagat NWR

Unlike flows from Ash and Crystal Springs, inflows to the refuge have large seasonal fluctuations (Figure 5 & 6). In the summer months, when irrigation diversions upstream of the refuge are greatest, virtually no water from Ash or Crystal Springs reaches Upper Pahranagat Lake. Refuge inflows typically peak in January and February long after irrigation diversions from the springs have ended. Occasionally inflows match or exceed the combined spring discharge (Figure 6).

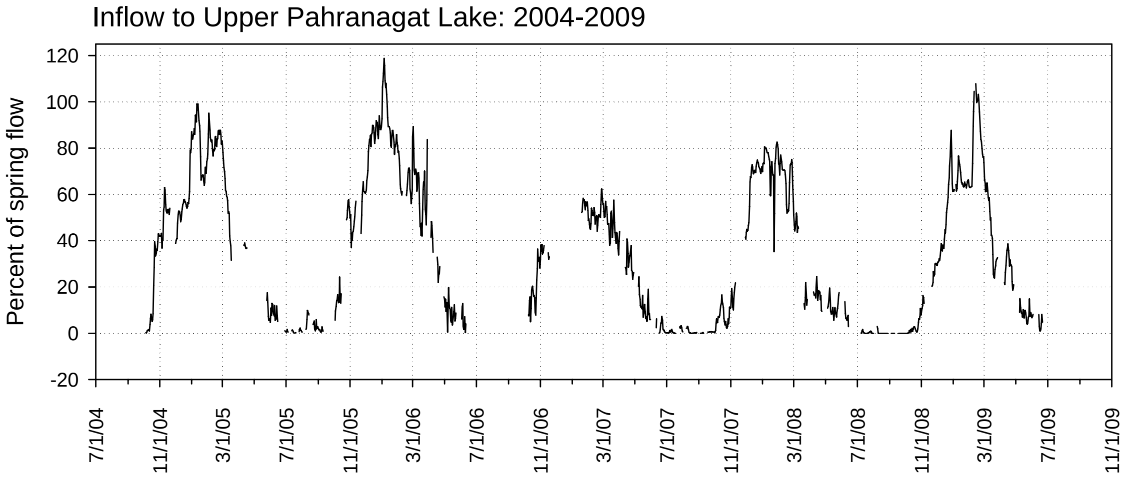


Figure 6: Inflows to Upper Pahranagat Lake as a percent of combined Ash and Crystal Spring mean daily discharge. October 2004 - June 2009.

The difference between winter and summer inflows are an important control on the refuge's ability to manage wetland habitat. Traditionally, refuge managers have focused on storing the winter flows from Ash and Crystal Springs in Upper Pahranagat Lake to maintain a bass fishery, irrigate cropland, and flood habitat for fall waterfowl migration (Brown 1990).

Historical Trends in Surface Water Inflows

Inflows to Upper Pahranagat Lake have been measured periodically since 1953. However, complete records for entire water years are only available between 1960-1969, 1990-1994, and 2004-2009 (Figure 7).

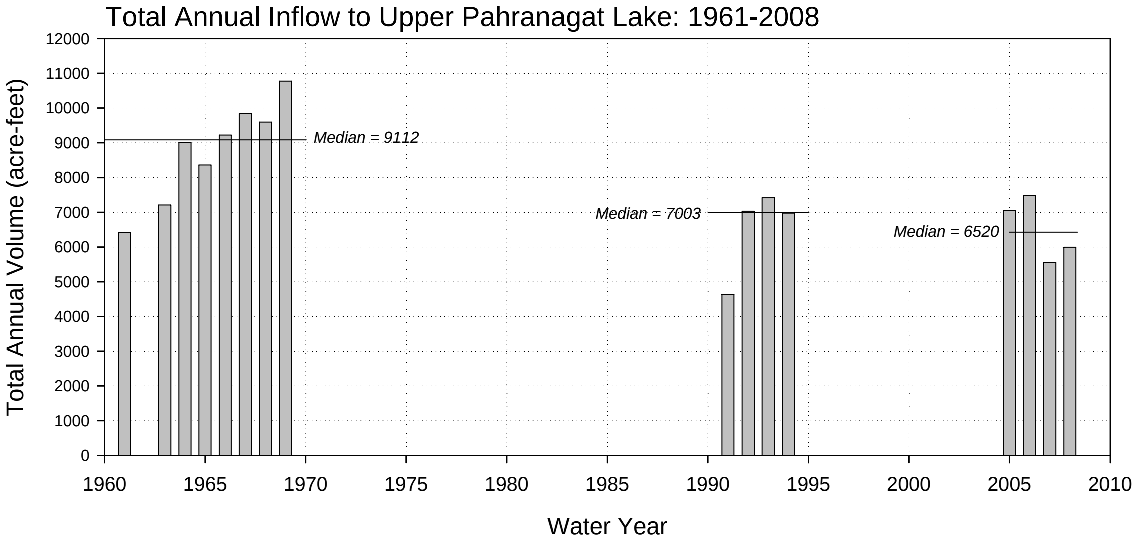


Figure 7: Total water year inflows to Upper Pahranagat Lake in acre-feet. Water years 1961-2008.

The median annual inflow from 1961 to 1969 was about 2,500 acre-feet greater than the median annual inflow from 2004 to 2008. This is a large difference that suggests considerable changes in the volume of water entering the refuge. However, much of the difference is driven by the relatively wet years between 1965 and 1969 when inflows were noticeably greater than the previous half of the 1960s. Between 1961 and 1965, the median annual inflow was 7,200 acre-feet, only 700 acre-ft more than the median value between 2004 and 2008. Therefore, the actual difference between 1960s and 2000s inflows may not be as dramatic as data from the second half of the 1960s suggest.

The timing of when water enters the refuge has changed since the 1960s (Figure 8). Inflows to the refuge have a well defined “start” and “end” date. For the purposes of this analysis, the start date is the first day when inflows exceeded 5 cubic feet per second (cfs) for 5 consecutive days. This typically occurs in the fall, when temperatures and irrigation diversions upstream begin to decrease. Once flows are consistently above 5 cfs they steadily increase through the winter until the refuge is receiving virtually all of the flow from Ash and Crystal Springs. The end date is defined as the first day when inflows drop below 5 cfs for 5 consecutive days. Once flows are consistently below 5 cfs they tend to continue dropping until they cease altogether in June or July. Between the start and end dates the refuge receives almost 90% of the total refuge inflows for the year.

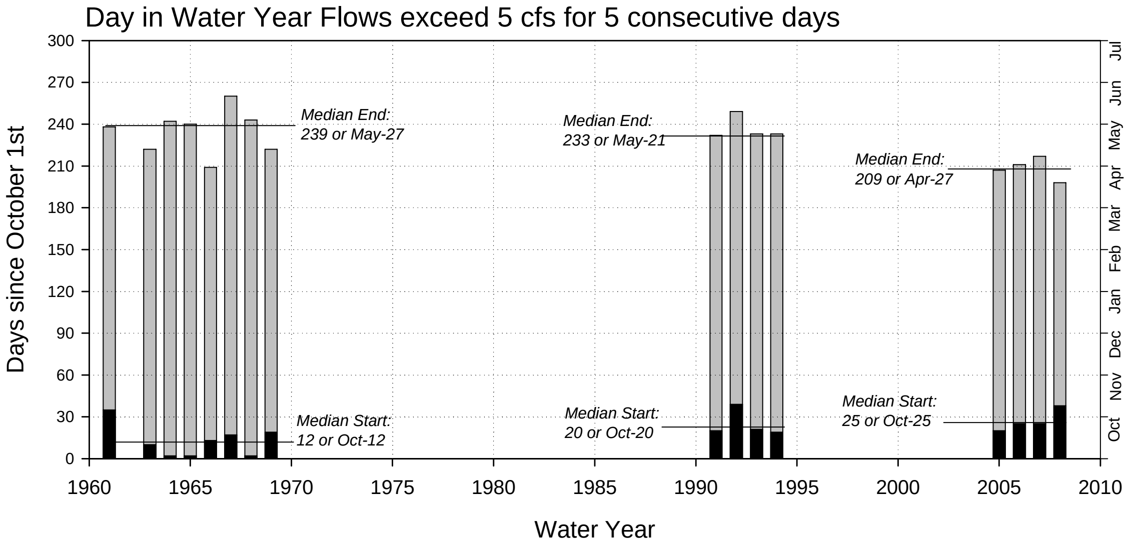


Figure 8: Day of water year when inflows exceed 5 cfs for 5 consecutive days (start) and when inflows drop below 5 cfs for 5 consecutive days (end). Black bars represent the start day and grey bars represent the end day.

The start day occurred approximately 2 weeks earlier in October during the 1960s than the 2000s. Additionally, inflows ended about 1 month later in the 1960s than they do today. Not only are the total inflows less but the duration of inflows above 5 cfs lasted 43 more days in the 1960s than the 2000s. The difference in start and end dates is statistically significant (alpha < 0.05) and represents an expansion of summer low flow conditions. Today the refuge relies on Upper Pahranagat Lake storage to meet its water supply needs for about 1 more month than it did in the 1960s.

There is no evidence to suggest flow from Ash and Crystal Springs has decreased appreciably since the 1960s. In fact, the reported discharge for Ash and Crystal springs in 1966 was 14 and 8 cfs, respectively, compared to today's 18 and 12 cfs. Given these changes, one might expect that refuge inflows would have increased slightly since the 1960s, yet the Service's inflow records clearly indicate they have not (Figures 7 and 8).

Assuming spring flows have slightly increased or remained constant over the last 50 years, there are several activities that could contribute to decreased inflows to Upper Pahranagat Lake: 1) obstructions to flow in the central drain that delivers water to the refuge, 2) more land being irrigated upstream of refuge, 3) land being irrigated for longer periods because of warmer fall and spring temperatures, 4) less rigorous enforcement of water distribution, and 5) increased ground water use upstream of refuge. Unfortunately, a thorough evaluation of the causes behind the observed flow decline is beyond the scope of the current document.

References

Berger, D.L., Johnson, M.J., Turnbusch, M.L., and J. Mackay. 2001. Estimates of Evapotranspiration from the Ruby Lake National Wildlife Refuge Area, Ruby Valley, Northeastern Nevada, May 1999-October 2000. U.S. Geological Survey. Water Resources Investigations Report 01-4234.

Brown D. 1990. Water Management Plan: Pahranagat National Wildlife Refuge, Alamo, NV. Unpublished Report. U.S. Fish and Wildlife Service, Desert National Wildlife Refuge Complex, Las Vegas, NV.

Carpenter E. 1915. Groundwater in Southeastern Nevada.U.S. Geological Survey Water Supply Paper 365.

DeMeo, G.A., Lazniak, R.J., Boyd, R.A., Smith, J.L., and W.E. Nylund. 2003. Estimated Groundwater Discharge by Evapotranspiration from Death Valley, California, 1997-2001. U.S. Geological Survey. Water Resources Investigation Report. 03-4254.

DeMeo, G.A., Smith, J.L., Damar, N.A., and J. Darnell. 2008. Quantifying Groundwater and Surface water Discharge from Evapotranspiration Processes in 12 Hydrographic Areas of the Colorado Regional Groundwater Flow System, Nevada, Utah, and Arizona. U.S. Geological Survey. Scientific Investigations Report. 2008-5116,

Dunne, T. and L.B. Leopold. 1978. Water in environmental planning. W. H. Freeman and Company. New York.

Eakin, T.E. 1963. Groundwater appraisal of Pahranagat and Pahroc Valleys, Lincoln and Nye Counties, Nevada. Nevada Department of Conservation and Natural Resources Groundwater Resources Reconnaissance Series Report 21.

Eakin, T.E. 1966. A regional interbasin groundwater system in the White River Area, southeastern Nevada. Water Resources Research. Vol 2 (2). 251-271.

Havesi, J.A., Flint, A.L., and L.E. Flint. 2003. Simulation of Net Infiltration and Potential Recharge Using a Distributed-Parameter Watershed Model of the Death Valley Region, Nevada and California. U.S. Geological Survey. Water Resources Investigation Report 03-4090.

Lazniak, R.J., DeMeo, G.A., Reiner, S.R., Smith, J.L. and W.E. Nylund. 1999. Estimates of Groundwater Discharge as Determined from Measurements of Evapotranspiration, Ash Meadows area, Nye County, Nevada. U.S. Geological Survey. Water Resources Investigation Report 99-4079.

Jayko, A.S. 1990. Shallow crustal deformation in the Pahranagat area, southern Nevada. In Wernicke, B.P. ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Boulder, Colorado, Geological Society of America Memoir 176.

Jayko, A.S. 2007. Geologic Map of the Pahranagat Range 30’ x 60’ Quadrangle, Lincoln and Nye Counties, Nevada. Scientific Investigations Map 2904. U.S. Geological Survey. Reston, VA.

Reiner, S.R., Lazniak, R.J, DeMeo, G.A., Smith, J.L, Elliott, P.E., Nylund, W.E., and C.J. Fridrich. 2002. Groundwater Discharge Determined from Measurements of Evapotranspiration, Other Available Hydrologic Components, and Shallow Water-Level Changes, Oasis Valley, Nye County, Nevada. U.S. Geological Survey. Water Resources Investigation Report 01-4239.

Trimble. S. 1989. The Sagebrush Ocean: A natural history of the Great Basin. University of Nevada Press. Reno.

Tyler, S.W., Chapman, J.B., Conrad, S.H., Hammermeister, D.P., Blout, D.O., Miller,.J.J, Sully, M.J., and J.M. Ginanni. 1996. Soil-water flux in the southern Great Basin, United States: Temporal and spatial variations over the last 120,000 years. Water Resources Research. Vol 32 (6). 1481-1499

U.S. Fish and Wildlife Service (USFWS). 1998. Recovery Plan for the Aquatic and Riparian Species of Pahranagat Valley. U.S. Fish and Wildlife Service. Portland, OR.

U.S. Fish and Wildlife Service. 2009. Desert National Wildlife Refuge Complex Final Comprehensive Conservation Plan and Environmental Impact Statement. U.S. Fish and Wildlife Service. Sacramento, CA.

Scope and Data Collection

This study began in February 2007 with the goal of characterizing the hydrologic processes supporting wetland habitat on Pahranagat NWR. Specific objectives were to: 1) develop alternative water management strategies for refuge wetlands, 2) identify the areas where seepage from ditches influence the water table in wetland units, 3) identify areas where hydrologic conditions are conducive for supporting additional riparian or wetland habitat, 4) quantify long-term trends in the areal extent of wetlands and riparian forests on Pahranagat NWR, and 5) characterize hydrologic processes on existing wetland and riparian habitat units. To achieve these objectives we designed and implemented the following monitoring program:

1) Collected historic air photographs of the refuge and developed GIS-based maps of wetland and riparian habitat using 2004, 1999, 1981, and 1965 air photographs.

2) Installed 37 shallow groundwater monitoring wells in wetland and riparian habitats on the refuge. Monitoring wells were constructed from 1.25" pvc with 5 feet of 10 – slot screen (0.01 inch). Wells were installed by hand using a soil auger and completed following guidelines outlined by U.S. Army Corps of Engineers (2005) and Nevada Division of Environmental Protection (1996).

3) Operated and maintained existing surface water gaging stations at the inflow and outflow of Upper Pahranagat Lake. Additionally, we established 6 new surface water gaging stations at various points on the refuge's irrigation ditches.

4) Installed staff gages and monitored water levels in surface water features at North Marsh, Upper Pahranagat Lake, ADA Pond, Dove Dike trench, Whin Dike Ponds, Middle Marsh Ponds, Lower Pahranagat Lake, and 6 small spring pools.

5) Established a survey control network of 8 benchmarks throughout the refuge to facilitate future surveys. The control network was completed using RTK GPS techniques and Trimble 4700 GPS dual frequency receivers.

6) Collected elevation data using RTK GPS at more than 1,500 points on the refuge. These include; water measurement points on wells and staff gages, ground surface elevations in wetlands and irrigation ditches, ground surface elevations in the vicinity of refuge headquarters, and inverts of selected water control structures in the ditch system. All surveyed data points were collected in North American Datum (NAD) 1983 State Plane (Nevada East 2701) coordinate system. Horizontal accuracy is considered ± 1.0 feet. Vertical data is referenced to NAVD 1988. Vertical accuracy

of elevation data collected during this study is considered accurate to ± 0.25 ft.

7) Manual water level measurements at wells and staff gages were recorded bi-monthly. Continuous water level datalogging devices were installed in 4 monitoring wells and 5 surface water gaging stations.

8) Forty-seven water chemistry samples were collected four times in 2007 and 2008 at the following locations: Ash, Crystal, and Hiko Springs, 3 locations on the Pahranagat Drain upstream of the refuge, inflows and outflows to Upper Pahranagat Lake, 3 locations on the refuge's ditch system, 4 shallow groundwater monitoring sites, and 4 small seeps and springs on Pahranagat NWR. Data from these samples were used to characterize the source of surface water, shallow groundwater, and springs on the refuge.

9) Identified individual plant species every 0.5 m on a 30 m transect at 34 sites in wetland and riparian habitat on the refuge.

10) Described the texture, color, and structure of soil layers at 12 locations in wetland and riparian habitat following protocols outlined by the Natural Resources Conservation Service (Schoeneberger et al. 2002). Forty-seven soil samples from the 12 locations were analyzed at the Utah State Analytical lab for: pH, Conductivity, texture, % organic matter, and % Carbonate. Additional analyses on 19 layers included Cation Exchange Capacity, particle size by hydrometer, and concentrations of Cl, Mg, Na, K, B and S.

11) Measured soil redox potential, pH, conductivity, temperature, percent moisture, and percent carbonate approximately every 3 months at 12 locations near shallow monitoring wells on the refuge. We sampled redox potential and percent carbonate following the protocols outlined by Vepraskas and Faulkner (2001) and Holmgren (1973).

12) Observations of pan evaporation, precipitation totals, and maximum and minimum temperatures were recorded daily.

Data collection during the study was carried out by two hydrologic technicians stationed at Pahranagat between April 2007 and June 2009. Regional Office hydrologists provided support and made numerous field visits between 2007 and 2009. The results from parts 1-8 and 12 of this study are summarized in this report. Reports summarizing refuge soil information and wetland plant distribution are pending.

Pahranagat NWR Management Units

For the purpose of familiarizing the reader with the different wetland units on the refuge, the following section briefly describes each wetland area, water delivery infrastructure, and generalizations about each area's hydrology.

The primary water management strategy for Pahranagat NWR over the years has been: 1) store winter flow from Ash and Crystal Springs in Upper Pahranagat Lake and 2) release Upper Pahranagat Lake water in the summer and fall to irrigate fields, flood wetlands, and fill Lower Pahranagat Lake.

All surface water entering the refuge remains on the refuge, either infiltrating into the subsurface or evaporating/transpiring to the atmosphere. Surface water from Ash and Crystal Springs enters the refuge and fills the North Marsh and Upper Pahranagat Lake. From there it is released into the main irrigation supply ditch to points south, eventually collecting in Lower Pahranagat Lake, which is essentially the terminus of the refuge's managed water delivery system.

I. Gooding's Willow Forest / Southwestern Willow Flycatcher Habitat

Southwest Willow Flycatcher habitat is a 9.5 acre stand of mature Gooding's Willows, Cottonwoods, and Coyote Willow at the north end of the North Marsh near the mouth of the Pahranagat Drain (Figure 1). The willow stand is an important riparian resource on the refuge and supports one of the largest nesting populations of southwestern willow flycatchers in the Lower Colorado River watershed (SWCA 2006).

There are no active surface water diversions into the willow forest. Saturated soil conditions appear to be maintained through a combination of groundwater discharge and water levels in the North Marsh.

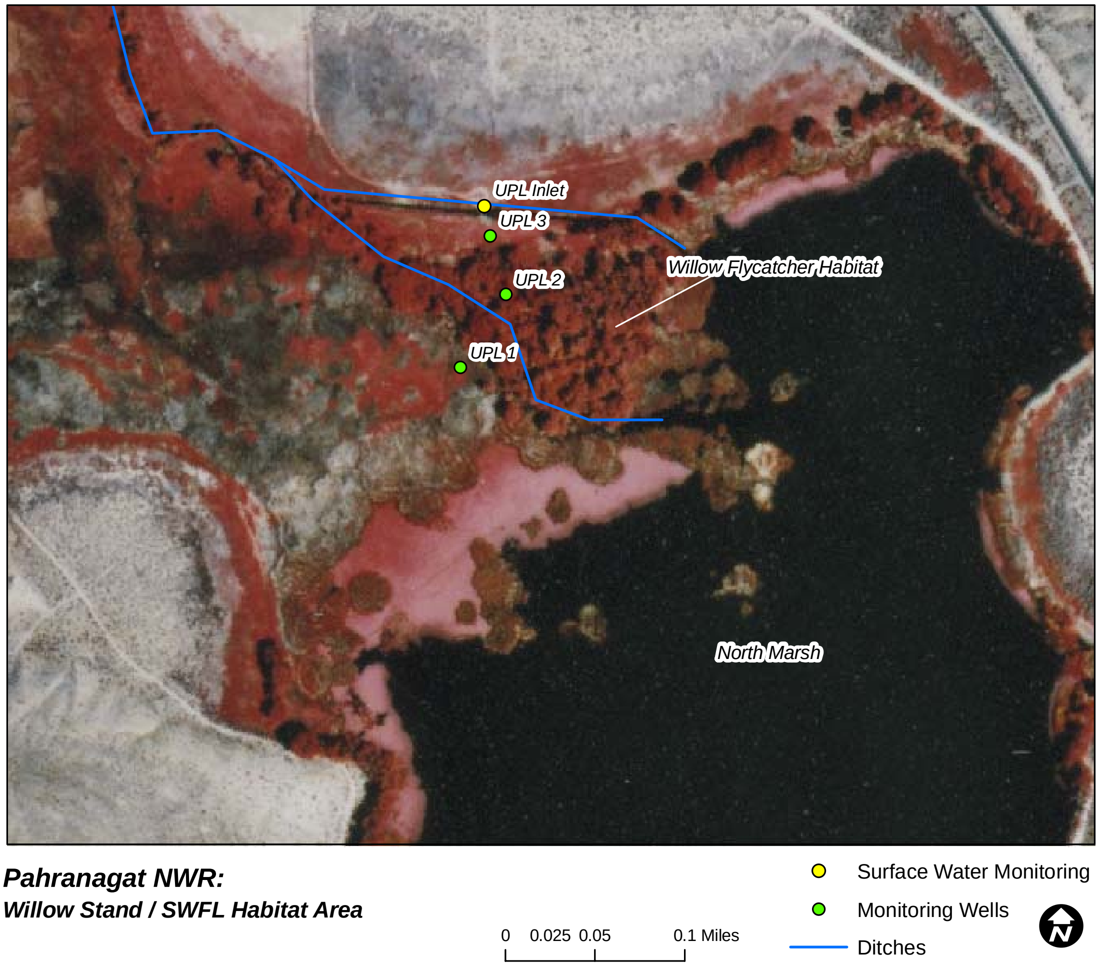


Figure 1: Willow stand supporting nesting populations of southwestern willow flycatchers at the north end of Pahranagat National Wildlife Refuge. Background is 2004 color infrared aerial photograph.

II. North Marsh / Upper Pahranagat Lake

Upper Pahranagat Lake, formerly known as Gardner Reservoir, was constructed in the early 1930s by the Civilian Conservation Corps to impound water from Ash and Crystal Springs. The dam creating the reservoir is about 15 feet (ft) high and extends 1,500 ft across the Pahranagat Valley floodplain. In 1979, FWS replaced the original outlet control structure and built a dike across the northern third of the reservoir (cross dike). Both water bodies are commonly referred to as Upper Pahranagat Lake (Figure 2). The pool north of the cross dike is also known as the North Marsh. When the lake level rises to the elevation of its Upper Pahranagat Lake's emergency spillway the combined surface area of the North Marsh and Upper Pahranagat Lake is approximately 450 acres. At this level maximum lake depth is 13 feet and the volume of water stored is about 3,200 acre-ft.

Ash and Crystal Springs water enters the North Marsh unit via the Pahranagat Drain. We have observed groundwater seeping into the northwest corner of the lake but do not believe it is a major contributor to the North Marsh's water supply. Water levels in the North Marsh are controlled by two 36-inch, 3.75 ft wide stop-log water control structures in the cross dike. Upper Pahranagat Lake water levels are controlled by a 26-inch screw gate water control structure. Two 18-inch culverts and two 4-ft supplemental spillways allow for uncontrolled releases from the lake when water levels rise above 3,352 ft, about 10 ft above the lake's outlet.

Under historic operating conditions, the lake provides open-water habitat, typically in excess of 3 feet deep. A fringe of cattails, bulrush, and cottonwood provide some habitat along the lake edge. South of the Upper Pahranagat Lake Dam is a 30 acre wet meadow complex with scattered riparian cottonwoods. When lake levels exceed 3,352 ft this area is flooded by uncontrolled spills from the two 18-inch culverts at the west end of the dam.

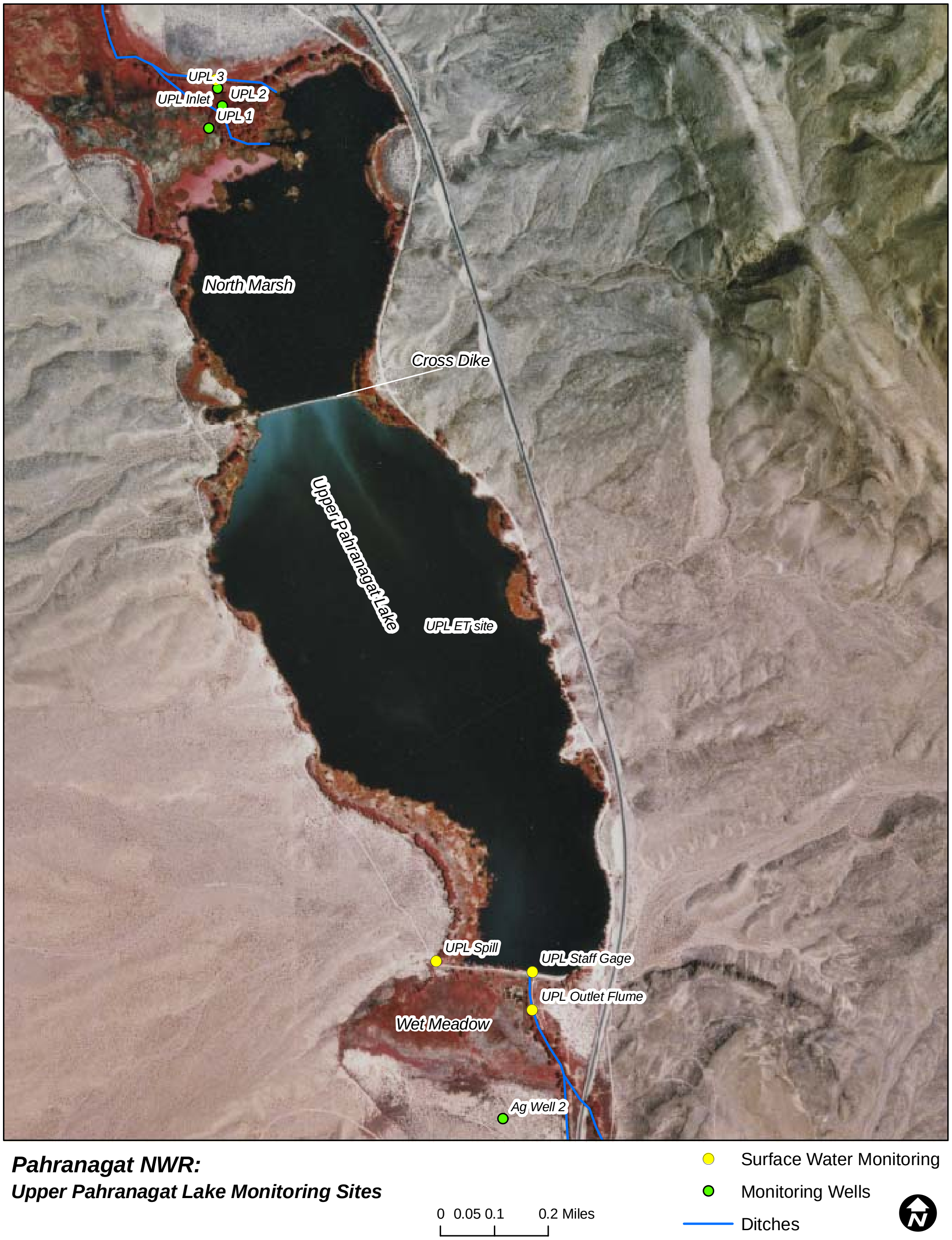


Figure 2: Upper Pahranagat Lake and North Marsh detail, Pahranagat NWR. 2004 Color infrared photo.

III. Black Canyon Unit

The Black Canyon Unit is located approximately 0.4 miles south of Upper Pahranagat Lake Dam on the east side of Highway 93 (Figure 3). The area includes 26 acres of floodplain deposits carved through the Kane Wash Tuff by the pre-historic White River. As recently as 2000, the area was actively farmed through cooperative agreements with local farmers. Vegetation in the area is dominated by invasive Russian knapweed which the refuge is actively trying to control through various techniques. Water is diverted into Black Canyon through a 24-inch screw gate water control structure on the main irrigation ditch south of Upper Pahranagat Lake. To reach the fields in Black Canyon, diverted water passes through a 24-inch culvert under Highway 93 and a bridge at the old highway before splitting into two earthen ditches on the east and west edges of the canyon. Under the current hydrologic regime there is no groundwater discharge into Black Canyon. Surface water diverted into Black Canyon ponds behind a low head dike at the south end of the unit to create seasonal wetland habitat.

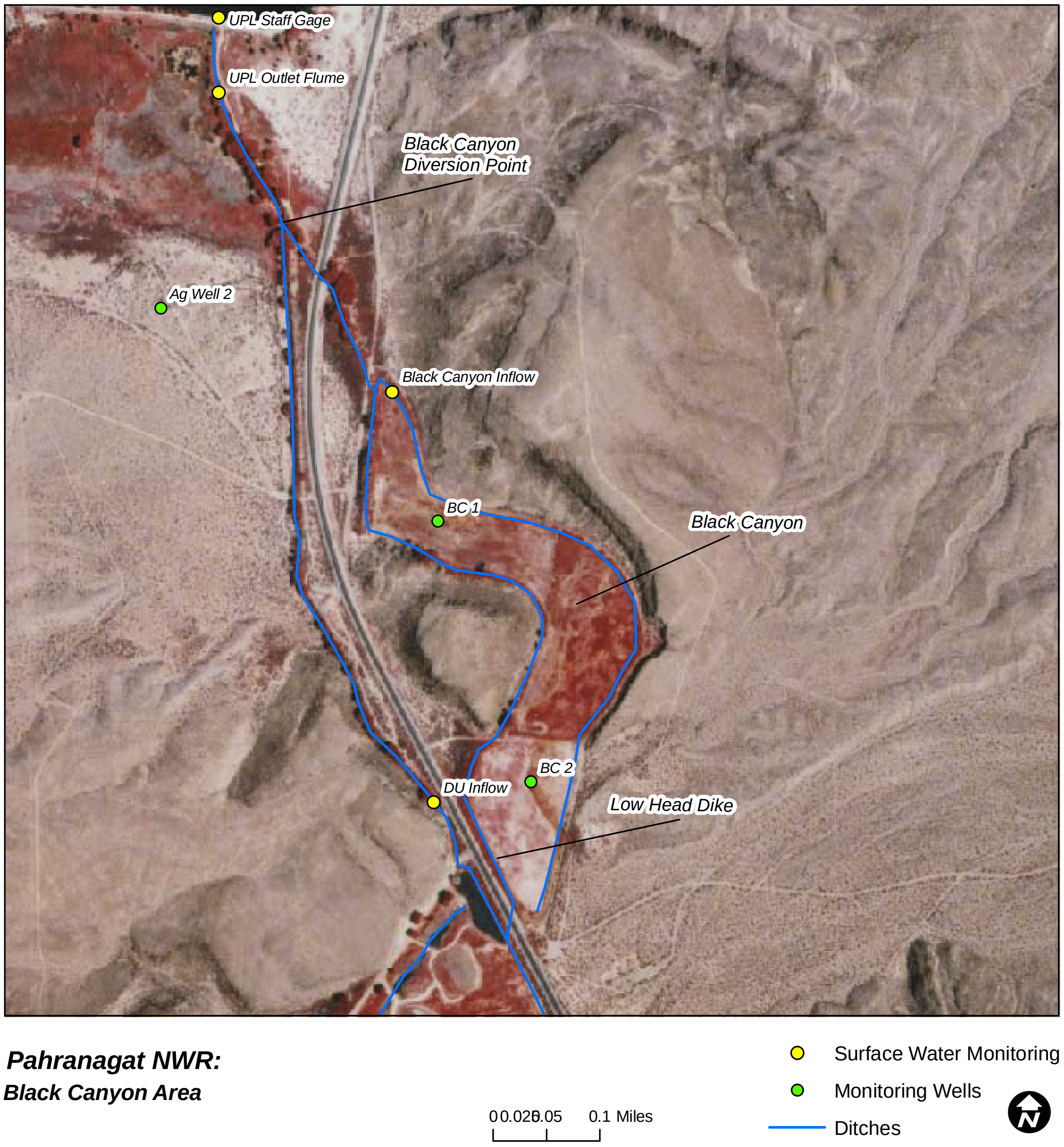


Figure 3: Detail of the Black Canyon area of Pahranagat NWR. 2004 Color-infrared photo.

IV. Ducks Unlimited Project

This area includes 36 acres of constructed wetland cells designed by Ducks Unlimited and built in 2001 and 2002 (Figure 4). Constructed wetlands were designed to allow for active water level management to promote different wetland habitat types. The project has not proven successful and many of the ponds are filled with invasive weeds. Cottonwoods planted on the water supply ditches in the project area are becoming established and provide some riparian habitat.

From the Black Canyon diversion point, water released from Upper Pahranagat Lake travels approximately 0.6 miles down the 5 ft wide Main Ditch west of Highway 93.

From the Head Pond, refuge staff move water through the DU Project to points further south using the Meandering Stream or Supply Ditch 2. The Meandering Stream is a broad earthen ditch about 20 ft wide, 2-3 ft deep, and 1.3 miles long that winds between wetland cells. Supply Ditch 2 is a trapezoidal, cement ditch about 8 ft wide, 3 ft deep, and 0.7 miles long. Water moves from the Head Pond into the Meandering Stream where it is diverted into wetland cells or Supply Ditch 2. Stop-log water control structures are used to manipulate water levels in the DU project cells and the Meandering Stream. In Supply Ditch 2 trapezoidal and rectangular slide gates facilitate diversions into adjacent fields.

Ag Wells 1 and 2 provide an additional source of water to the DU project area. Ag well 2 is south of Upper Pahranagat Lake (see Figure 2) and pumps directly into the Main Ditch above the DU Project. AG Well 1, pumps into one of the wetland cells in the DU project area. During our study, these wells were typically turned on during the summer months when there was no water available from Upper Pahranagat Lake. Ag Well 2 produces approximately 350 gpm and Ag Well 1 produces 270 gpm (0.7 and 0.6 cfs, respectively). Based on field observations, the pumping rate for Ag Well 2 is sufficient to maintain about 0.5 ft of water in the main ditch above the Head Pond. However, it was not sufficient to maintain flowing water in the Meandering Channel below the Head Pond. The Ag Well 1, pumping rate maintained saturated soil conditions and about 0.5 ft of water in a small area (<0.25 acres) near the well during 2008.

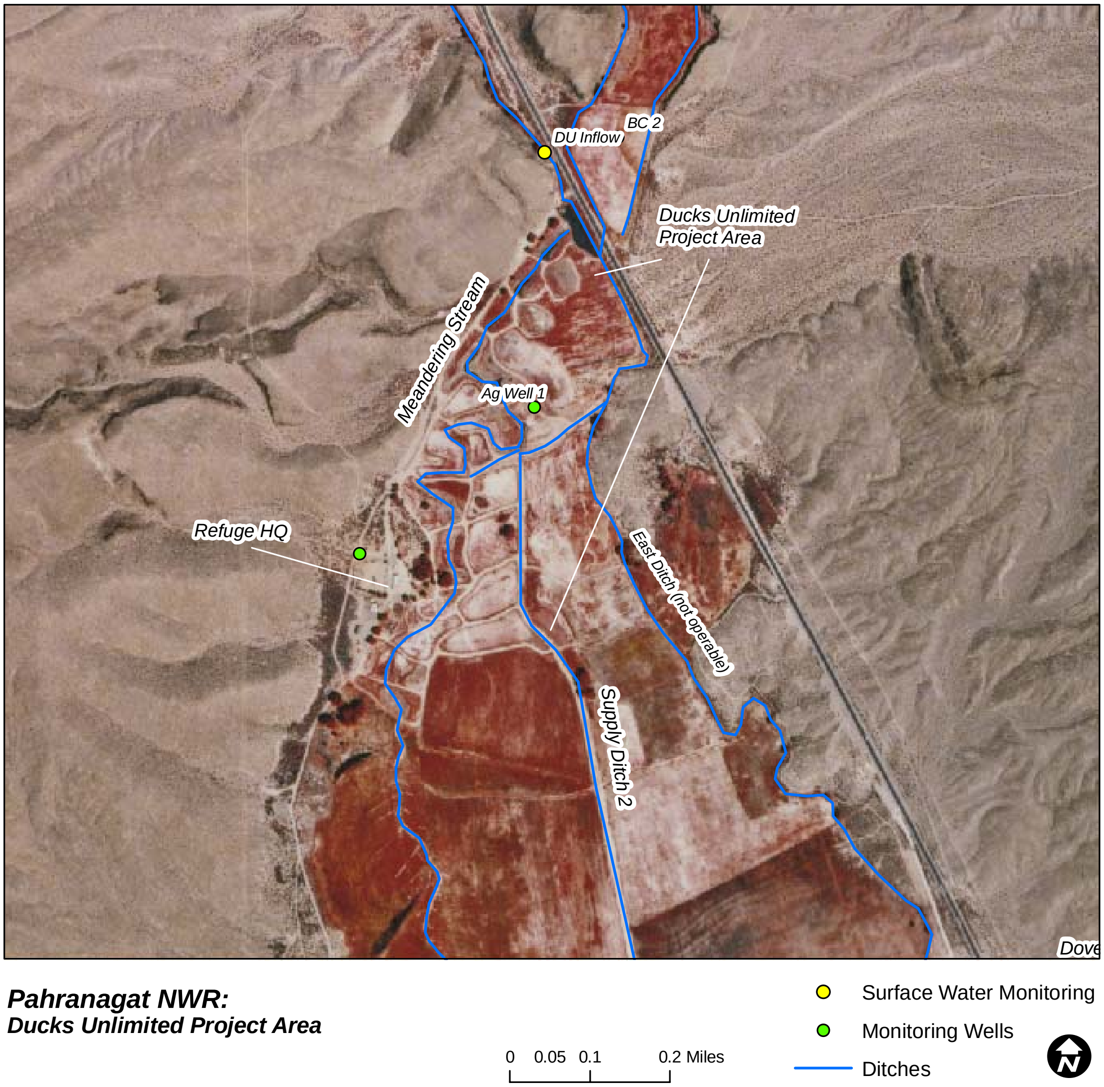


Figure 4: Detail of the Ducks Unlimited Project Area at Pahranagat NWR. 2004 color-infrared photo.

V. Dove Dike to Whin Dike Area

South of the DU project there are approximately 490 acres of wet meadow habitat between Dove Dike and Whin Dike (Figure 5). The meadow has not been farmed although it has been grazed in the past. Wetland habitat in the meadow ranges from grassland vegetation communities dominated by saltgrass and alkali sacaton to permanently flooded cattail and bulrush wetlands. Several small dikes have been built in the meadow over the years to create small seasonal ponds.

Water delivery to Dove Dike is through the Meandering Stream on the west side of the Valley and Supply Ditch 2 (SD2) near the center of the valley. Immediately south of Dove Dike, a 20 ft wide, 2-3 ft deep trench running the length of the ½ mile dike helps distribute water in the meadow. Water from the Meandering Stream and SD2 pass under Dove Dike and fill the trench. Once full, water in the trench finds its way south through

3 different ditches or by sheet flow across low lying areas of the meadow. Surface water flowing south eventually ponds behind Whin Dike about 1 mile south of Dove Dike.

In addition to the surface water from refuge irrigation ditches, there is sufficient groundwater discharge into the meadow to maintain standing water behind Whin Dike year round. Groundwater discharge processes south of Dove Dike are discussed in Section 5 of this document in more detail.

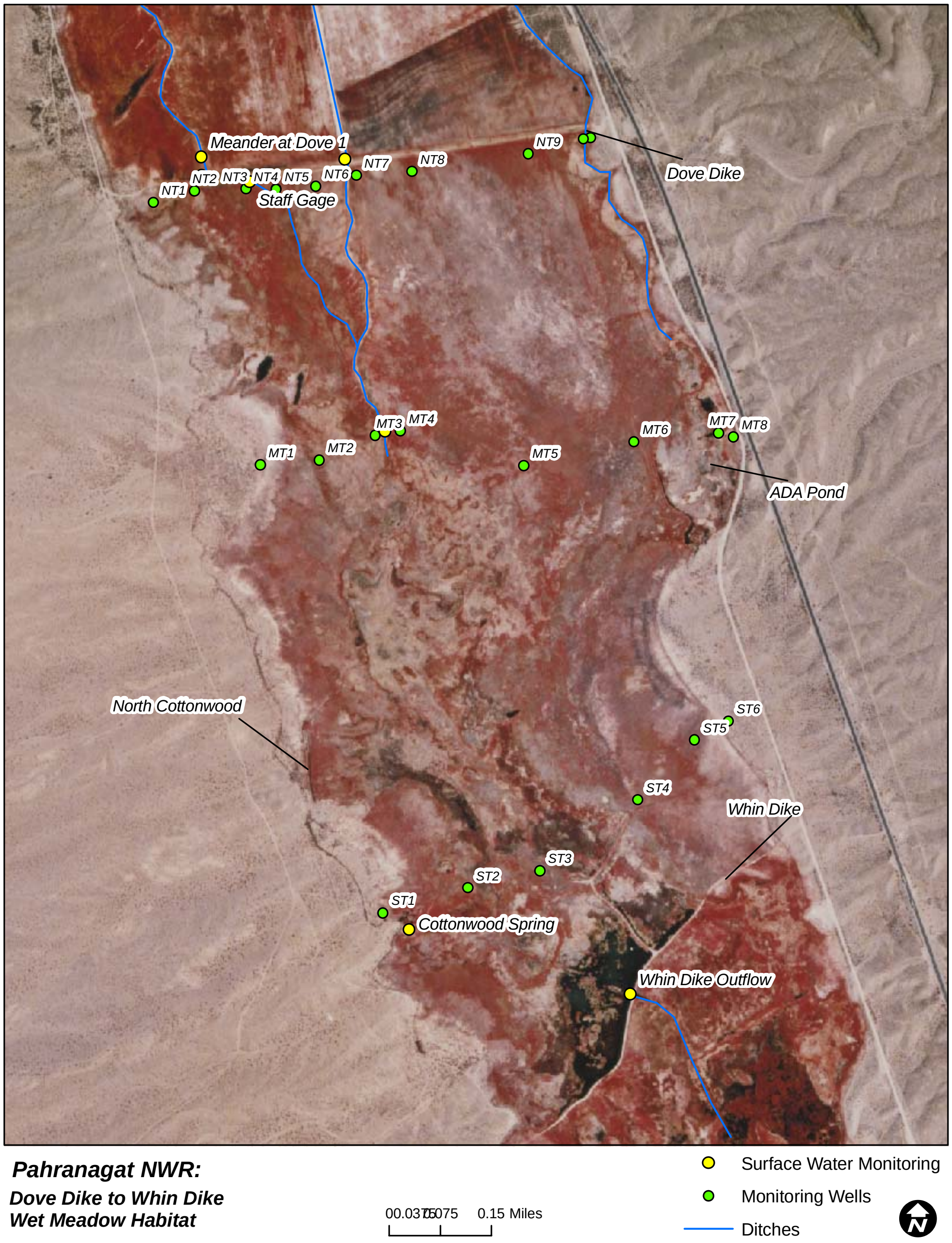


Figure 5: Detail of meadow habitat between Dove Dike and Whin Dike at Pahranagat NWR. 2004 color infrared photo.

VI. Middle Marsh

Between Whin Dike and Middle Marsh Dike are 162 acres of open-water, tall emergent wetlands (cattail/bulrush), and seasonally flooded emergent wetlands (juncus and sedges) known as Middle Marsh (Figure 6). The wetland system is created by water that ponds behind the 4 ft high Middle Marsh dike, located 0.70 miles south of Whin Dike.

Surface water fills Middle Marsh through a 2.7 ft wide stop-log structure and two culverts at Whin Dike. The refuge can control water levels in the Middle Marsh by manipulating a 3.5 ft wide stop log structure in the Middle Marsh Dike. Groundwater discharge into the wetland appears to maintain year-round standing water behind Middle Marsh Dike.

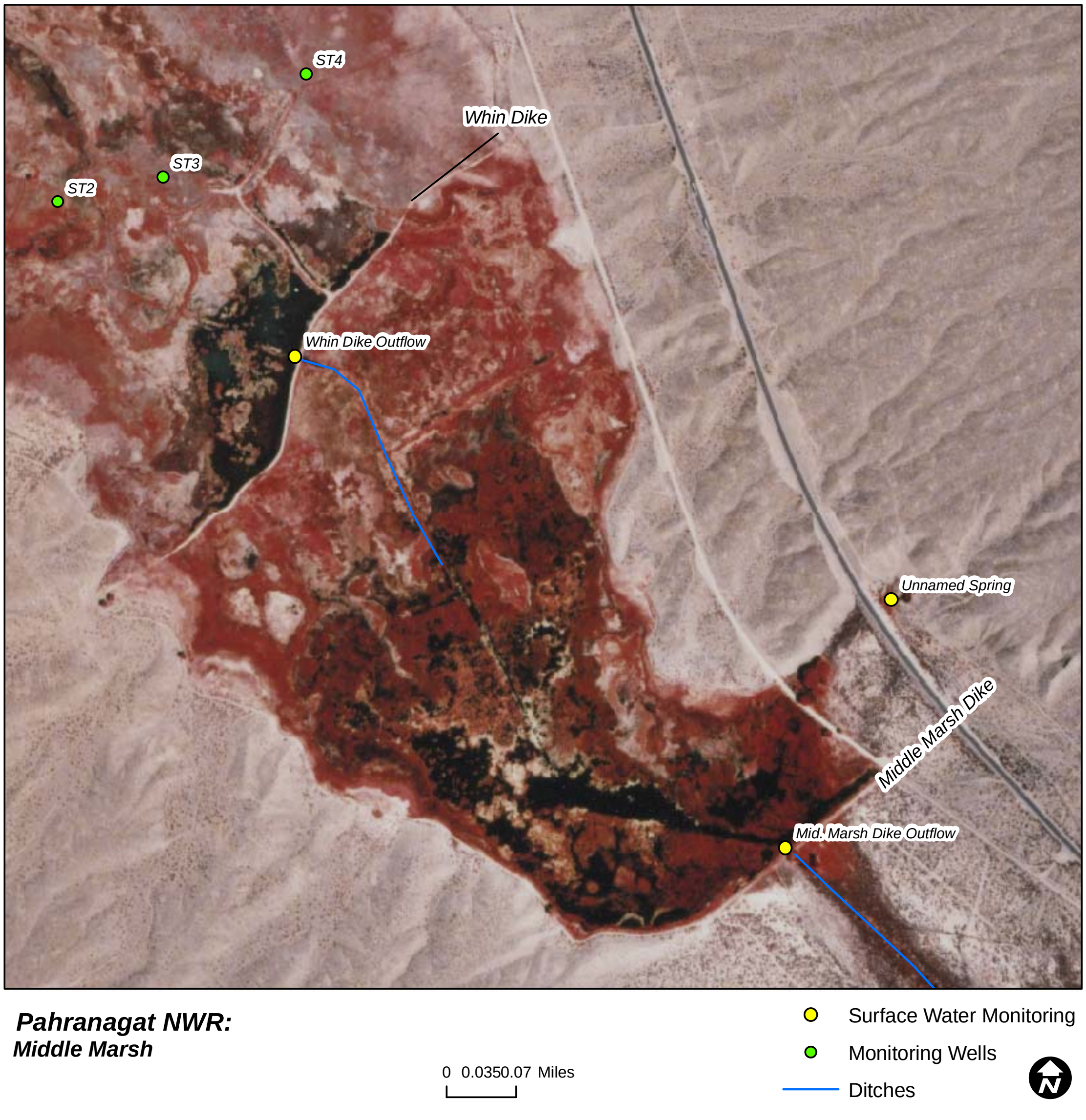


Figure 6: Middle Marsh Area detail at Pahranagat NWR. 2004 color-infrared photo.

VII. Lower Pahranagat Lake

Lower Pahranagat Lake is a 300 acre natural lake that has existed at this location for thousands of years (Wigand 1997). The lake is no deeper than 5 ft at high water levels and normally is less than 3 ft deep (Figure 7). Brown (1990) estimated the Lower Lake stores 750 acre-feet of water, approximately one quarter of the volume stored in Upper Pahranagat Lake. In 2008 Desert Complex staff attempted to collect additional information to better quantify the storage of Lower Pahranagat Lake. However, this work has not been completed at present.

Water enters the lake through an earthen ditch from Middle Marsh Dike. The ditch is 11 ft wide and deeply incised (> 20 ft) near Middle Marsh dike. When the lake's water level rises above 3,156 ft, water can be released from a 24-inch screwgate at the south end of Lower Pahranagat Lake.

Figure 7: Detail of Lower Pahranagat Lake at Pahranagat NWR.. 2004 color-infrared photo.

VIII. South of Lower Pahranagat Lake / North of Maynard Lake

South of the Lower Lake are several hundred acres of salt flats, rabbit brush, and small wet meadows (Figure 8). Above 3,156 ft, water can be released from Lower Pahranagat Lake but the ditches south of the lake are in poor condition and do not distribute water in the area effectively. At least two 3-4 ft tall dikes extend across portions of the valley floodplain between the Lower Lake and Maynard Lake. Water released from Lower Pahranagat Lake ponded behind these dikes temporarily in 2009 but did not create more than 100 square feet of open water habitat. Following particularly wet periods, larger areas of water may pond in the depressions behind these dikes.

There are approximately 8 small seeps or springs found in this portion of the refuge. They reflect the modest amount of groundwater discharge that occurs in the area. Because surface water rarely reaches this part of the refuge, any wetland vegetation or fauna is found in the vicinity of these seeps.

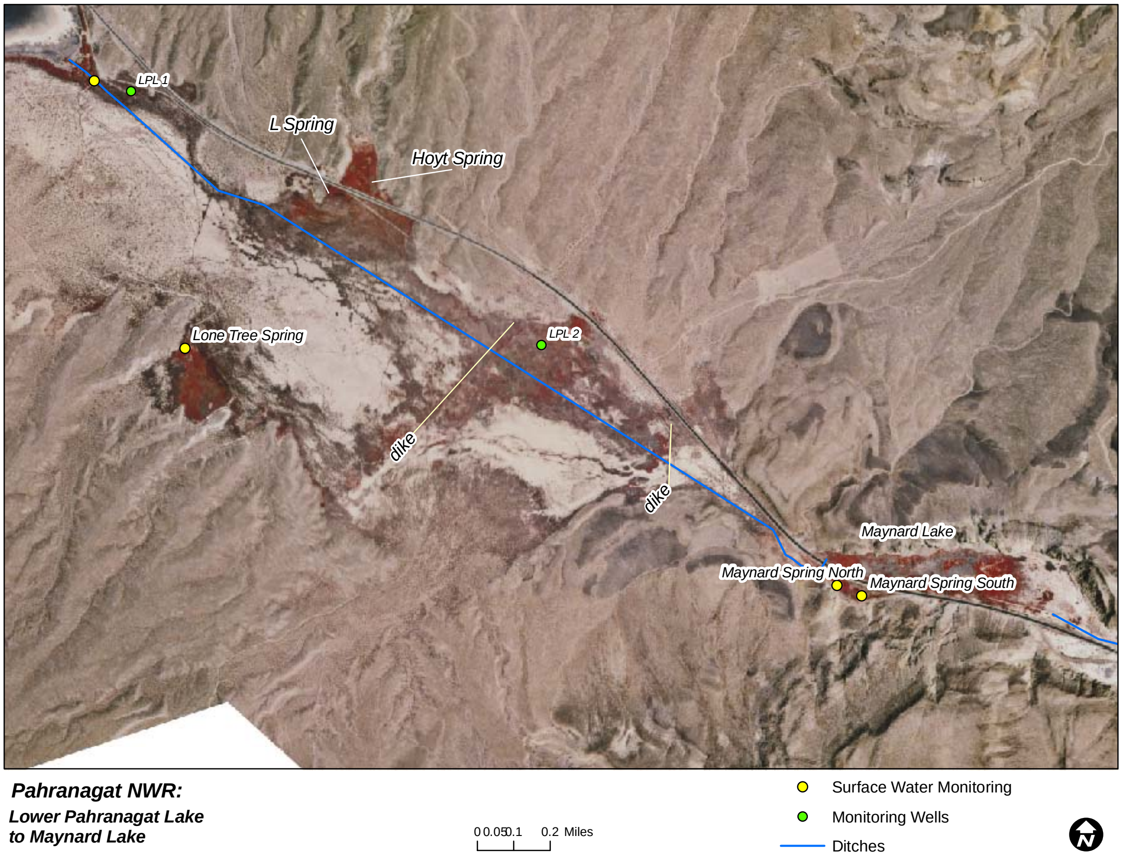


Figure 8: Wetland areas between Lower Pahranagat Lake and Maynard Lake at Pahranagat NWR. 2004 color-infrared photo.

IX. Maynard Lake

Maynard Lake is the terminus of the prehistoric wetland system in the Pahranagat Valley. Although a lake existed here as recently as the 1930s, there probably has not been significant water in the lake bed since the 1940s (USFWS 1998). The lake bed is approximately 28 acres of un-vegetated sediment, tamarisk, and other invasive weeds. A high water mark near 3,144 ft on adjacent cliffs indicate the maximum depth of the lake was about 28 ft. Stories from local ranchers suggest the lake was at swimmable depths in the 1920s (Docktor pers comm.) A ditch was dug in the east end of Maynard Lake at some point in the past, presumably to drain the lake.

Surface water has not been released from Lower Pahranagat Lake to flood Maynard Lake for many years. The only standing water in the Maynard Lake area is found at North and South Maynard Springs (Figure 8). There is enough flow in the springs to support shallow pools of water, but not enough to maintain flowing water from the spring pools.

References

Brown D. 1990. Water Management Plan: Pahranagat National Wildlife Refuge, Alamo, NV. Unpublished Report. U.S. Fish and Wildlife Service, Desert National Wildlife Refuge Complex, Las Vegas, NV.

Holmgren, G.S. 1973. Quantitative Calcium Carbonate Equivalent Determination in the Field. Soil Science Society of America Proceedings. Vol 37. pp. 304-307.

Nevada Division of Environmental Protection. 1996. Guidance Document for Design of Groundwater Monitoring Wells. WTS-4 (http://ndep.nv.gov/BWPC/wts-4.pdf)

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. 2002. Field book for describing and sampling soils Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

U.S. Army Corps of Engineers (USACE). 2005. Technical Standards for Water table Monitoring of Potential Wetland Sites. ERDC TN-WRAP-05-2. U.S. Army Engineer Research and Development Center, Vicksburg, MS. (http://el.erdc.usace.army.mil/elpubs/pdf/tnwrap05-2.pdf)

U.S. Fish and Wildlife Service (USFWS). 1998. Recovery Plan for the Aquatic and Riparian Species of Pahranagat Valley. U.S. Fish and Wildlife Service. Portland, OR.

Vepraskas, M.J., and S.P. Faulkner. 2001. Redox Chemistry of Hydric Soils. in Vepraskas, M.J. and J.L. Richardson (eds) Wetland Soils: Genesis, Hydrology, Landscapes and Classification. Chapter 4. Lewis Publishers pp. 85-105

Wigand, P.E. 1997. A late-Holocene pollen record from Lower Pahranagat Lake, southern Nevada, USA: High resolution paleoclimate records and analysis of Environmental Responses to Climate Change. In. C.M. Isaacs and V.L. Tharp (eds) Proceedings of the thirteenth annual pacific climate workshop (PACLIM). April 15-18. 1996. Interagency Ecological Program. Technical Report 53. California Department of Water Resources.

Executive Summary

Wetland habitat at Pahranagat NWR was mapped using the National Wetland Inventory's classification system from current and historic air photographs of Pahranagat NWR collected between 1965 and 2004. Analyses of the wetland habitat maps indicate 90% of the refuge's wetlands are lacustrine or palustrine wetlands. Meaning the majority of the refuge's wetlands are either lakes or wet meadows. There was approximately 100 more acres of wetlands in 1965 than in 2004, suggesting the refuge may have been wetter in the past. The greatest loss of wetland habitat appears to be south of Lower Pahranagat Lake while the greatest gain is in the DU Project and North Marsh areas. Additionally, there has been a net gain in riparian forested and shrub wetlands since 1965.

The National Wetland Inventory

The National Wetland Inventory (NWI) is a branch of the U.S. Fish and Wildlife Service established in 1974 to provide information on the extent of the nation's wetlands (Tiner 1984). The NWI produces maps of wetland habitat as well as reports on the status and trends of the nation's wetlands. Using the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin et al. 1979) wetlands have been inventoried and classified for approximately 90% of the conterminous United States and approximately 34% of Alaska. Cowardin's classification places all wetlands and deepwater habitats into 5 "systems": marine, estuarine, riverine, lacustrine, and palustrine. Most of the wetlands in the United States are either estuarine or palustrine (Tiner 1984). The two predominant wetland classes at Pahranagat NWR are defined in Cowardin et al. (1979) as:

> **Lacustrine:** the Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: 1) situated in a topographic depression or a dammed river channel; 2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and 3) total area exceeds 8 ha (20 acres). . . . Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than $0.5^{o}/_{oo.}$
>
> **Palustrine**: the Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean derived salts is below $0.5^{o}/_{oo}$ (e.g., inland marshes, bogs, fens, and swamps)

The different systems can be broken down into subsystems, classes and hydrologic regimes based on the wetland's position in the landscape, dominant vegetation type, and hydrology.

Wetland Mapping Methods

Wetland and deepwater habitat boundaries were interpreted using aerial photographs and digital imagery taken in 2006, 2004, 1999, 1981, and 1965. Wetland boundaries were delineated on-screen for each photo year in a "heads-up" environment using ArcInfo GIS

Version 9.2 and digital, geo-referenced images of Pahranagat NWR. These tools facilitated zooming in on individual wetlands of less than one acre with boundary accuracies of approximately ± 15 ft. Wetland vegetation signatures identified in 2004 color-infrared and 2006 natural color imagery were field verified in February 2007 and March 2008.

The Cowardin system (1979) was used to delineate and classify wetland habitat in different air photographs. Table 1 lists the Cowardin wetland habitat classifications used at Pahranagat NWR.

Table 1: Cowardin et al. (1979) wetland classifications and descriptions used at Pahranagat NWR.

WETLAND ATTRIBUTE	DESCRIPTION	WETLAND ATTRIBUTE	DESCRIPTION
L2EMAh	Temporarily flooded Lacustrine fringe wetland with erect, rooted, herbaceous hydrophytes. Supported or created by an impoundment (e.g., reservoir fringe)	**PFO/SSA**	Temporarily flooded depressions and floodplains characterized by a matrix of forested and scrub-shrub vegetation.
L2EMCh	Seasonally flooded Lacustrine fringe wetland with erect, rooted, herbaceous hydrophytes. Supported or created by an impoundment (e.g., reservoir fringe)	**PFOA**	Temporarily flooded depressions and floodplains dominated by forested vegetation.
L2UBFh	Semi-permanently flooded, open water habitat extending from the shoreward boundary to a depth of 2 meters that is supported or created by an impoundment (e.g., reservoir).	**PFOB**	Saturated forested wetland usually associated with springs. Common tree species include willow and cottonwood.
L2UBHh	Permanently flooded, open water habitat extending from the shoreward boundary to a depth of 2 meters that is supported or created by an impoundment (e.g., reservoir).	**PFOC**	Seasonally flooded depressions and floodplains dominated by forested vegetation.
L2USCh	Seasonally flooded Lacustrine fringe unvegetated wetland with less than 30 percent cover of erect, rooted, herbaceous hydrophytes. Supported or created by an impoundment (e.g., reservoir fringe)	**PSS/FOA**	Temporarily flooded depressions and floodplains characterized by a matrix of scrub-shrub and forested vegetation.
PEM/SSC	Seasonally flooded depressions and floodplains characterized by a matrix of herbaceous and scrub-shrub vegetation.	**PSSA**	Temporarily flooded scrub-shrub wetland usually located in drainages.
PEMA	Temporarily flooded wetlands dominated by herbaceous vegetation.	**PSSB**	Saturated scrub-shrub wetland usually associated with springs.
PEMB	Wetlands dominated by herbaceous vegetation in depressions or below springs where the water table is usually at or near the surface.	**PSSC**	Seasonally flooded scrub-shrub wetland usually located in drainages.
PEMC	Seasonally flooded wetlands dominated by herbaceous vegetation.	**PUBF**	Semi-permanently flooded ponds.
PEMF	Semi-permanently flooded depressions dominated by herbaceous vegetation.	**PUBHh**	Permanently flooded pond created behind an impoundment.
PUBHx	Permanently flooded pond created by excavation.	**R2UBH**	Permanently flowing lower perennial rivers.
PUBKr	Artificially flooded pond with an artificial substrate (e.g. sewage detention pond).	**R2USC**	Seasonally flooded unconsolidated substrate associated with lower perennial riverine systems.
PUSA	Temporarily flooded basins with little or no vegetation.	**R4SBA**	Temporarily flowing riverine channels.
PUSC	Seasonally flooded basins with little or no vegetation.	**R4SBC**	Seasonally flowing riverine channels.
		R4SBJrx	Intermittently flooded streambeds or canal systems where the channel has been excavated and the substrate is not natural

Wetland Mapping Results

Of the 5,480 acres included in the original boundary of Pahranagat NWR, approximately 36% (1,970 acres) is considered wetland habitat under the Cowardin (1979) classification. About 33 % of the wetland habitat (650 acres) are lacustrine and the remaining 70% (1,320 acres) is palustrine (Table 2).

Table 2: Percent distribution of wetland habitat identified at Pahranagat. Data values are in percent of total wetland acreage for each mapped photo year.

Description	**NWI Code**	**2004**	**1999**	**1981**	**1965**
Lakes	L2	33	33	35	25
Emergent wetlands	PE	58	60	59	73
Forested Wetlands	PF	2	2	2	<1
Shrub Wetlands	PS	2	2	1	1
Ponds	PU	4	3	1	<1
Ditches/Channels	R2/R4	<1	<1	<1	1
Total Acreage		1,970	1,950	1,930	2,090

More than 90% of the refuge's wetlands are either lakes (LU) or palustrine emergent (PE) wetlands in all photo years (Table 2). The lake habitat covers about 650 acres in 2004 and is occupied entirely by deepwater sections of Upper Pahranagat and Lower Pahranagat Lakes. Palustrine emergent (PE) wetlands include 1140 acres in 2004 where the dominant herbaceous vegetation is cattail (*Typha domingensis*), bulrush (*Scirpus americanus*), juncus (*Juncus balticus*), yerba mansa (*Anemopsis californica*), alkali sacaton (*Sporobolus airoides*), and saltgrass (*Distichlis spicata*). Riparian habitat (PF or PS) and constructed ponds (PU) both make up 160 acres, or 4%, of the refuge wetlands.

In a general, the refuge's wetlands are either lake's or wet meadows. Upper Pahranagat Lake, Lower Pahranagat Lake, and wet meadow wetlands account for approximately 71% (1399 acres) of all wetlands on the refuge in 2004. The definition of a wet meadow is a "grassland with waterlogged soil near the surface but without standing water for most of the year." (Mitsch and Gosselink 2000). Using the Cowardin system, this habitat type is classified as PEMA, PEMB, or PEMC. (Palustrine Emergent Temporarily Flooded, Saturated, or Seasonally Flooded, respectively). About 39% (760 acres) of the wetland habitat at Pahranagat in 2004 is considered wet meadow.

Wetland Habitat Trends

The distribution of Lacustrine, Palustrine, and Riverine wetland habitat for different air photo years is presented in Figure 1. Since 1981, there has been little change in the total wetland acreage (Table 2). However, there have been changes in the extent of different wetland habitat types. Most notably, the percentage of PE wetlands dropped about 14% between 1965 and 1981. Analysis of the historic air photographs suggest this change is due to dike construction in the Middle Marsh area. Between these air photo years, the area was converted from a PE wetland to a LU wetland when Middle Marsh dike was constructed. The change accounts for the relatively large increase in Lacustrine wetlands between 1965 and 1981. Since 1981, the Middle Marsh has returned to Palustrine habitat as bulrush and cattails have gradually encroached into the pond area.

There has been a general increase in wetland habitat identified as riparian, or PF and PS, since the refuge was established (Table 2). At the time of the 2004 and 2006 photographs, this habitat included willows (*Salix goodingii*) at the north end of Upper Pahranagat Lake, cottonwoods (*Populus fremontii*) around the upper lake and refuge irrigation ditches, and salt-cedar (*Tamarix ramosissima*) on the shore of Lower Pahranagat Lake.

The acreage of wetlands identified as ponds (PU) has increased since 1965. Although the total area covered by these communities today is modest (about 4 % or 87 acres in 2004), there has been an increase in this habitat type since 1965. This habitat class includes man-made ponds like those in the Ducks Unlimited project and areas where water accumulates behind other small dikes scattered around the refuge. The largest contribution to this classification was created by the construction of Whin and Middle Marsh Dikes between 1965 and 1981. After 1981, the increase in pond acreage is related to the transition from lake (LU) to pond (PU) habitat at Middle Marsh. In 1981, open-water at Middle Marsh dike was large enough to be considered a lake under Cowardin's classification. Since then, vegetation encroachment has reduced the open-water acreage in the Middle Marsh and it is now considered a pond (PU). The increase in open-water habitat reflects the management strategies that emphasized more open-water habitat on the refuge. This was a common strategy at upland desert refuges managed by the Service in the era when Pahranagat NWR was established (Broyles 1995).

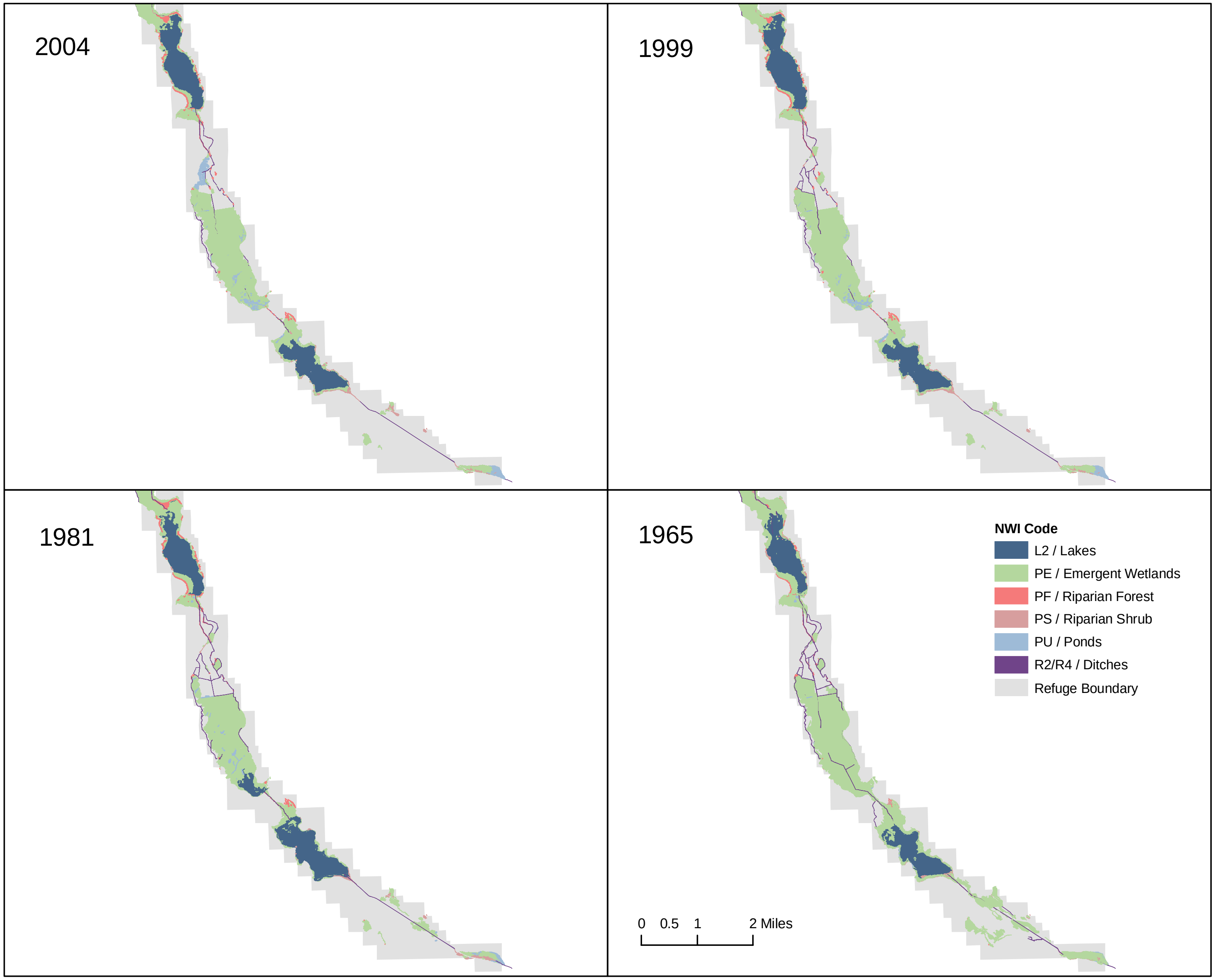


Figure 1: Extent of Wetland habitat for different air photograph years 2004 -1965. Wetland habitat classified using Cowardin et al. (1979) system.

Wetland Hydrology

The Cowardin system includes water regime modifiers that describe the hydrology of a wetland. Figure 2, includes maps of Pahranagat NWR wetlands classified by water regime. Interpreting hydrologic conditions from aerial photographs is an approximation of conditions at the time the photo was taken. Existing hydrologic information helped air photograph interpreters classify wetland water regimes for modern conditions at Pahranagat. Because hydrologic processes supporting existing wetland plant communities are the same processes that supported those communities in the past; modern hydrologic information was used to interpret wetland water in historic air photographs. Although these analyses are, by their nature, sensitive to the interpretations of the remote sensing specialist they serve as a useful proxy of historic hydrologic conditions on Pahranagat NWR (Table 3).

Table 3: Percent of the total wetland acreage at Pahranagat NWR grouped by Cowardin hydrologic regime.

Description	**Code**	**2004**	**1999**	**1981**	**1965**
Temporarily Flooded	A	8	9	11	15
Saturated	B	21	21	10	40
Seasonally Flooded	C	16	15	20	19
Semipermanently Flooded	F	6	8	6	1
Permanently Flooded	H	9	9	18	10
Intermittently Flooded	J	3	3	--	--
Impounded	H	35	33	33	14
Total Acreage		1,970	1,950	1,930	2,090

In general, conditions appear wetter in 1965 and 1981 air photographs than 1999 and 2004 imagery. In particular the area south of Lower Pahranagat Lake appears to be much drier at present than in 1965 (Figure 2).

The interpretation of wetter conditions at Lower Pahranagat Lake in 1981 and 1965 explain the higher percentage of permanently flooded habitat in those years (Table 3). Most permanently flooded (H) wetland habitat on the refuge is in Lower Pahranagat Lake in 1981 and 1965. However, in 1999 and 2004 Lower Pahranagat Lake was often dry in the fall of each year and more of the lake was classified seasonally flooded (C) or temporarily flooded (A).

Construction of Middle Marsh Dike helps explain some of the change in saturated (B) wetland habitat between 1965 and 1981 (Table 3). In 1965, prior to constructing the dike, the Middle Marsh was considered a PEMB (Palustrine Emergent Saturated) wetland. PEMB wetlands at Pahranagat are dominated by a yerba/juncus vegetation community and near-saturated soil conditions for most of the year. The 1981 photograph reveals that impounding water at Middle Marsh effectively removed a large area of PEMB wetland habitat and replaced it with lacustrine, impounded habitat. Since 1981, vegetation expansion into the Middle Marsh has transformed it back into a palustrine wetland, but the hydrologic regime is no longer considered saturated. Instead, it is classified as impounded.

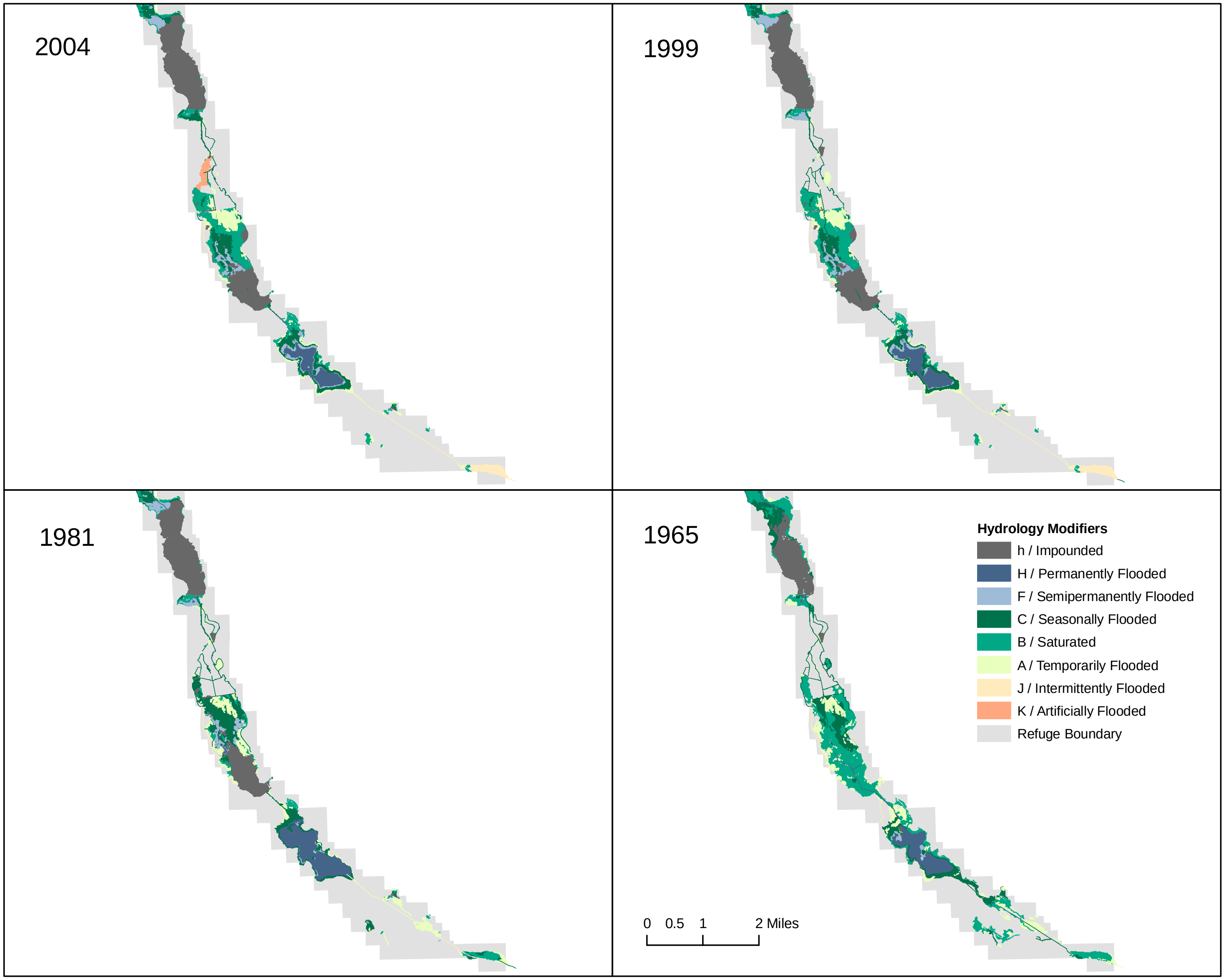


Figure 2: Distribution of wetland habitat based on hydrologic regime in four different air photograph years. Based on Cowardin et al. 1979.

Changes prior to 1965

Although wetland habitat maps for aerial photographs taken in 1953 and 1938 were not completed, the images have been reviewed to identify other major changes in wetland distribution. Table 4 highlights observed changes between air photographs for different wetland units on the refuge. This review is reconnaissance level only. Additional review of the historic images should be undertaken before implementing any management actions based on this information.

Table 4: List of observed changes between air photographs for different wetland units on Pahranagat NWR. Notes represent changes observed between the older and more recent photograph. Each column contains notes on changes that occurred in wetland units during the air photograph era.

ERA	**Maynard Lake**	**South of LPL**	**LPL**	**Middle Marsh**	**Dove to Whin Dike**	**DU Project**	**Black Canyon**	**South of UPL**	**UPL**	**North Marsh**	**SWFL Willows**
1938-1953	Water in lake ‘38 More veg. growth west end of lake in ‘53	None	Lake very full in ‘38. No obvious ditch from Mid Marsh. More veg on lake edge in ‘53	No trees at NDOT rest area. More water in ‘38.	None	None	None	Slightly wetter in ‘38	More trees in ‘53	None	Trees obvious in ‘53. Trees not obvious in ’38. Ditch on west side of Sharp property added in ‘53.
1953-1965	Veg covers most of lake bed in ‘65	More standing water @ Lone Tree Spring. More grass @ S. end of lake	More shrubs in ‘65. More water in ‘65. Ditch from Mid Mrsh obvious. New Highway 93 grade.	New drainage ditch through Mid Marsh in ‘65. Standing water in Mid Marsh ‘53	New highway. New ditch near Whin. Obvious ditch S. of Dove.	Farm fields S. of cabin added in ‘65.	New ditch W. of highway in ‘65. New Highway grade in ‘65	Ponds dug S. of UPL before ‘65. Drier S. of UPL in ‘53. New highway in ‘65	None	Inflows to Lake in ’65 approximately same location as present.	Noticeably less trees than present in ‘53 and ‘65.
1965-1981	New highway. Veg growth about the same	Looks wetter in ‘81	Less water in ‘65.	Mid Marsh and Whin dike built before ‘81. Farmed south of Mid Marsh in ‘65?	ADA and small ponds built. Dove Dike built. Cottonwood North dug	Terraces added to Cutler Field. Dikes built south of cabin before ‘81	More trees in ‘81	More trees on ditches in ‘81. Ponds filled with emergents.	Cross Dike built before ‘81	Cross Dike built. Higher water in ‘81	More trees or thicker canopies.
1981-2004	Saltcedar area expands.	Looks drier	Lake level lower. More emergents in ‘81. More tamarisk in ‘04	More water in ‘81. Less open water & more emergents in ‘04.	Drier in ‘04. Ditch S. of Supply Ditch 2 obvious.	DU project built. Meandering stream built before ‘04.	None. Bigger trees.	Bigger trees.	More water in lake ‘04. Less tall emergents on west side.	Fish screen ditch built before ‘04. Less tall emergents in N. Marsh.	More trees, or thicker canopies

Abbreviations: ERA: period between two air photograph years / Maynard: Maynard Lake area / South of LPL: meadow habitat between Lower Pahranagat Lake and Maynard Lake / LPL: Lower Pahranagat Lake / Mid Marsh: Middle Marsh area / Dove to Whin Dike: Meadow habitat between Dove and Whin Dikes / DU Project: area occupied by Ducks Unlimited Project near refuge headquarters / Black Canyon: Fields located in Black Canyon / South of UPL: meadow habitat immediately south of Upper Pahranagat Lake dam / UPL: Upper Pahranagat Lake. North Marsh: north end of Upper Pahranagat Lake / SWFL Willow: Gooding’s willow habitat where inflows from Ash and Crystal Springs enter North Marsh. NOTE: This is a reconnaissance level of analysis completed by reviewing air photographs for each wetland unit.

Conclusions

The analysis of historic aerial photographs at Pahranagat NWR suggests the following trends regarding wetland habitat at the refuge:

1) The area south of Lower Pahranagat Lake is drier now than it was between the 1930s and 1960s.

2) There appears to be more open-water habitat on the refuge in 2004 than prior to 1965.

3) Upper Pahranagat Lake/North Marsh is larger now than it was in 1965 due to water management and construction of the cross dike.

4) There are more trees and shrubs on the refuge in 2004 than prior to 1965.

References

Brown, D. 1990. Water Management Plan: Pahranagat National Wildlife Refuge, Alamo, NV. Unpublished Report. U.S. Fish and Wildlife Service, Desert National Wildlife Refuge Complex.

Broyles, B. 1995. Desert Wildlife Water Developments: Questioning use in the Southwest. Wildlife Society Bulletin. 23(4): 663-675.

Cowardin, L.M., Carter, V., Golet, F.C., and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. 3rd Edition. John Wiley and Sons.

Tiner, R.W. 1984. Wetlands of the United States: Current Status and Recent Trends. U.S. Fish and Wildlife Service. National Wetland Inventory.

Executive Summary

Surface water is distributed between Upper Pahranagat Lake and Lower Pahranagat Lake using a network of irrigation ditches. The ditch system was originally built by ranchers for the purpose of irrigating pasture or growing crops. In some of the wetter areas of the refuge, ditches were dug to drain wetlands. Today, ditches carry water from Upper Pahranagat Lake to flood wetlands and ponds on the refuge. Flow monitoring in the water delivery system began in April 2007 and continued through June 2009. Data collected during this period provides a record of water management and surface water conditions at the refuge during the last 2.5 years.

Surface water monitoring data help identify areas that are poorly suited to maintaining wetland habitat due to high rates of seepage through the irrigation ditches. Additionally, they identify areas where groundwater discharge into wetlands helps maintain surface water long after releases from Upper Pahranagat Lake have ceased.

Surface water monitoring also took place at the numerous small springs on the refuge. The majority of the refuge springs are capable of maintaining small spring pools with little, or no, flow from the pools. Low flow volumes and seasonal variation imply the source water for refuge springs is different from Ash and Crystal Springs.

Water Management: 2007-2009

Surface water flow from Ash and Crystal springs enters Upper Pahranagat Lake at the northern end of the refuge. The Service has no control over the amount of water entering the refuge in a given year. Instead, inflows to the refuge are controlled by weather and irrigation practices upstream of the refuge. Once Ash and Crystal springs water reaches the refuge it is stored in Upper Pahranagat Lake. From there it is released to flood wetland habitat to the south, eventually reaching Lower Pahranagat Lake. Surface water rarely travels south of Lower Pahranagat Lake except in particularly wet years. On rare occasions, when the Lower Lake is full, refuge personnel open the outlet structure on its south end so water can enter the ditch system below the Lower Lake.

The primary surface water management tool on the refuge is Upper Pahranagat Lake. In the past, management of the lake has revolved around how much standing water needs to be kept in the reservoir. Because it is the principle source of water for the refuge’s ditch system from June to October, management decisions affecting the lake affect wetland habitat on the entire refuge. Storing as much water as possible demands limiting releases but keeping the lake level low, requires releasing as much water as possible. This study covered both types of management scenarios. In 2007, water management focused on keeping water in the lake but in 2008 and 2009, the lake was managed so it would be dry by July of both years. The affect of these management strategies on water releases from the lake are summarized in Table 1.

Table 1: Total annual releases and inflows (acre-feet) to Upper Pahranagat Lake: Water Years 2007-2009.

Water Year (Oct-Sept)	**2007**	**2008**	**2009 (Thru June 24)**
Releases (ac-ft)	3300	5300	4500
UPL Inflows (ac-ft)	5500	6000	6000
Precip Totals (in)	4.74	4.86	4.59

Although total annual inflows were similar in all 3 years, releases from the lake in 2008 and 2009 were much greater than 2007 releases (Table 1). The cause for the difference is draining Upper Pahranagat Lake in 2008 and 2009 to create suitable conditions for repairing the lake's outlet structure. 2007 releases reflect water management strategies that might be considered "typical" prior to 2008. Management of the lake during the last 25 years has focused on filling the lake to capacity during the winter months, followed by moderate releases during the summer to irrigate wetlands and fields (Brown 1990).

Hydrographs of flow from the lake are presented in Figure 1. In early 2007, little water was released from Upper Pahranagat Lake. An uncontrolled release in February 2007 prompted concern over the integrity of the dam and releases were further reduced in March 2007. Between March and June of 2007, all releases from Upper Pahranagat Lake were diverted to Black Canyon or the ponds in the DU Project. After June 2007, the refuge continuously released water from the lake until June 2008.

Draining the lake in 2008 and 2009 dried the lake completely and there was no surface water available for refuge wetlands between July and December in 2008 and 2009. To drain the lake, most water needed to be released during the winter months. Consequently, wetlands south of the headquarters received more water during the winters of 2008 and 2009 than 2007.

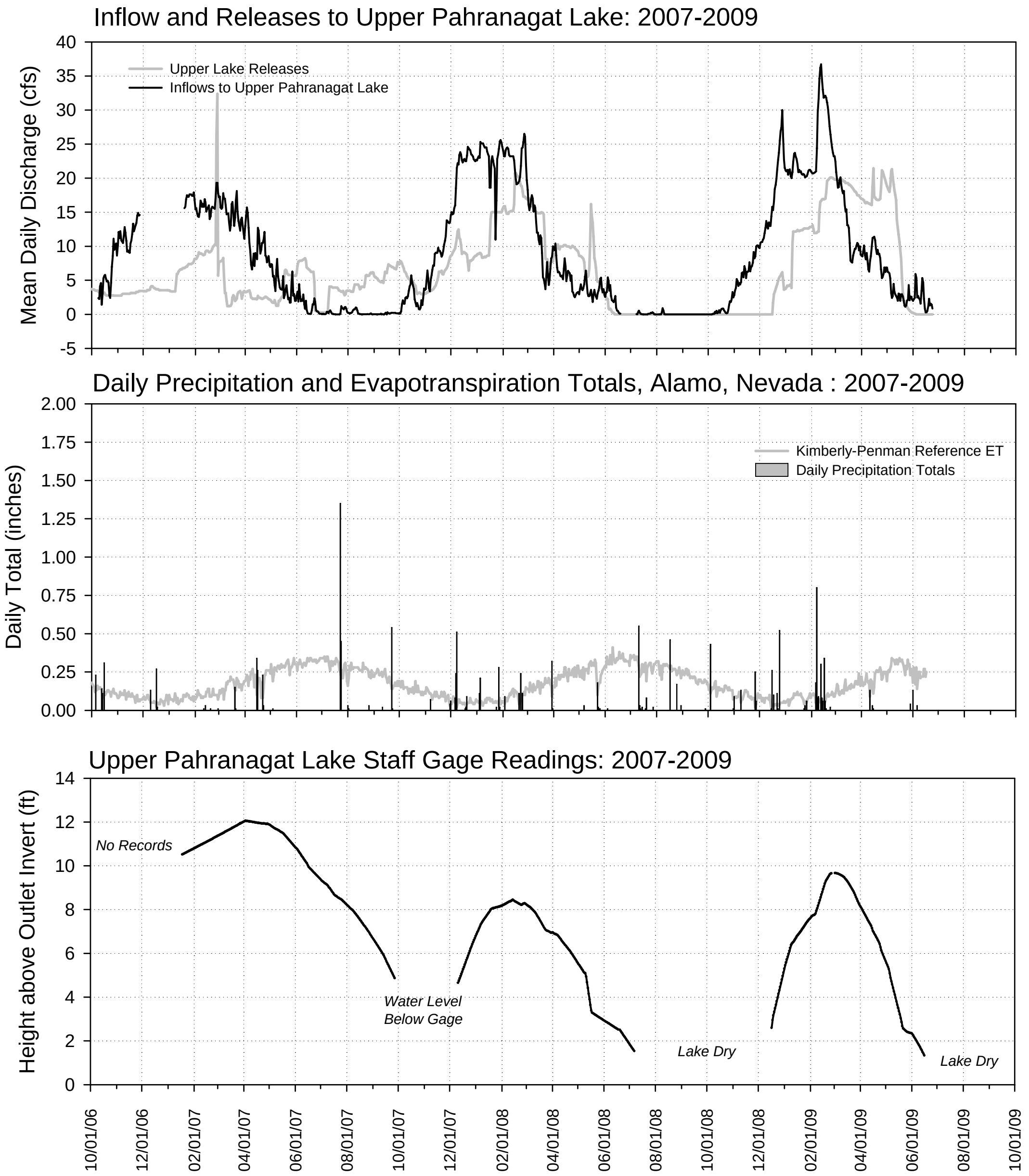


Figure 1: Summary of Inflow and Outflow measurements at Upper Pahranagat Lake. Precipitation and reference evapotranspiration totals. Upper Pahranagat Lake level readings. 2007 to 2009.

Seepage Losses in the Ditch System

During this study flow in the refuge’s irrigation network was monitored to evaluate the fate of surface water once it leaves Upper Pahranagat Lake. A day in the field at Pahranagat reveals the basic layout of the irrigation network: after leaving the Upper Lake, water flows south through a series of impoundment type wetlands, eventually collecting in Lower Pahranagat Lake. Monitoring surface water flow at various locations in the ditch system help quantify areas where ditches lose water to the subsurface (losing reaches) or areas where the groundwater flows into ditches (gaining reaches). If the flow volume in the ditch increases downstream, the ditch is considered gaining. If the flow volume decreases, the ditch is considered losing.

To quantify gaining and losing reaches in the ditch system, we compared flow upstream and downstream of 4 reaches in the irrigation network (Figure 2). From upstream to downstream these are: Upper Pahranagat Lake to the DU Project, Du Project to Dove Dike, Dove Dike to Whin Dike, and Whin Dike to Middle Marsh Dike.

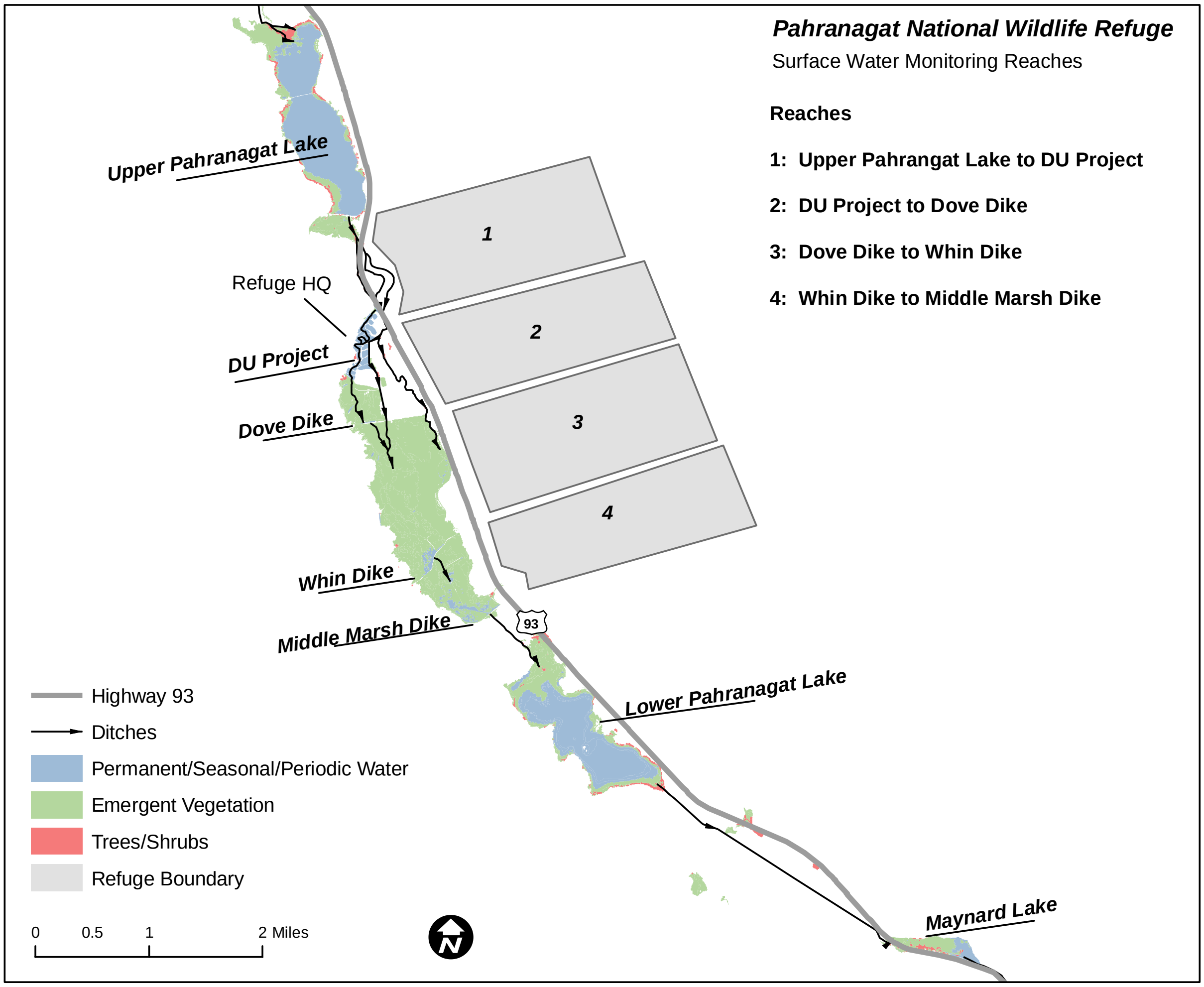


Figure 2: Location of surface water monitoring reaches on Pahranagat National Wildlife Refuge. Reaches are in the ditch system to the left of the grey blocks.

Upper Pahranagat Lake to the DU Project

Water released from Upper Pahranagat Lake travels south 0.9 miles through the main water supply ditch to the DU Project (see Figure 2). Comparing flow in the ditch at the DU Project and below Upper Pahranagat Lake reveals that seepage losses across this reach are minor (Figure 3).

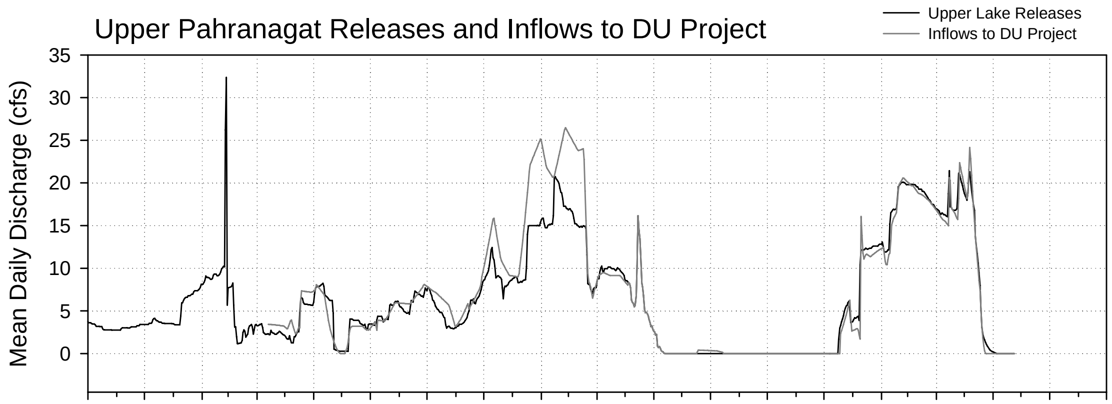


Figure 3: Mean daily discharge (cfs) at flume below Upper Pahranagat Lake and at a monitoring site upstream of the DU project.

Total monthly flow into the DU project is typically about 90% of the flow below Upper Pahranagat Lake. In 2008 releases from the upper lake overwhelmed the ditch system and spilled around the outlet flume. Flow downstream at the DU project was up to 50% higher because the outlet flume did not measure all the water leaving the lake.

DU Project to Dove Dike

Once Upper Pahranagat Lake releases enter the DU project, water passes through a series of channels and 36 acres of wetland management units on its way to Dove Dike. Comparisons of discharge upstream and downstream of the DU Project suggest at least 30% of the water flowing into the DU project in 2008 and 2009 was lost to seepage, evaporation, and storage in the wetland units before reaching Dove Dike (Figure 4).

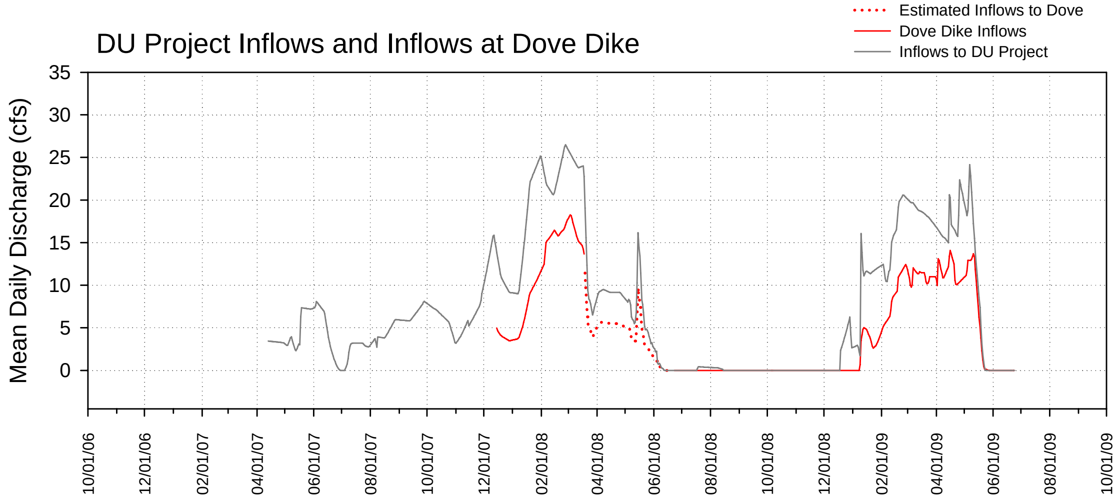


Figure 4: Mean daily discharge upstream of the DU Project and discharge measured at Dove Dike (Meandering Stream plus Supply Ditch 2 flows).

During the data collection period, water was actively diverted through most wetland cells in 2007. However, in 2008 and 2009, little water was diverted into wetland cells to avoid mobilizing pesticides that had been applied to treat Russian knapweed. Therefore, it is likely the difference in flow at the two sites reflects seepage losses from the ditch system, rather than changes driven by increased evaporation or water diverted from the ditch system.

The amount of water lost between the DU Project and Dove Dike tends to decrease over time. In January 2008 and 2009, 60-70% of the total monthly flow into the DU project did not reach Dove Dike. However, in the subsequent months, losses stabilize near 35% (Figure 5).

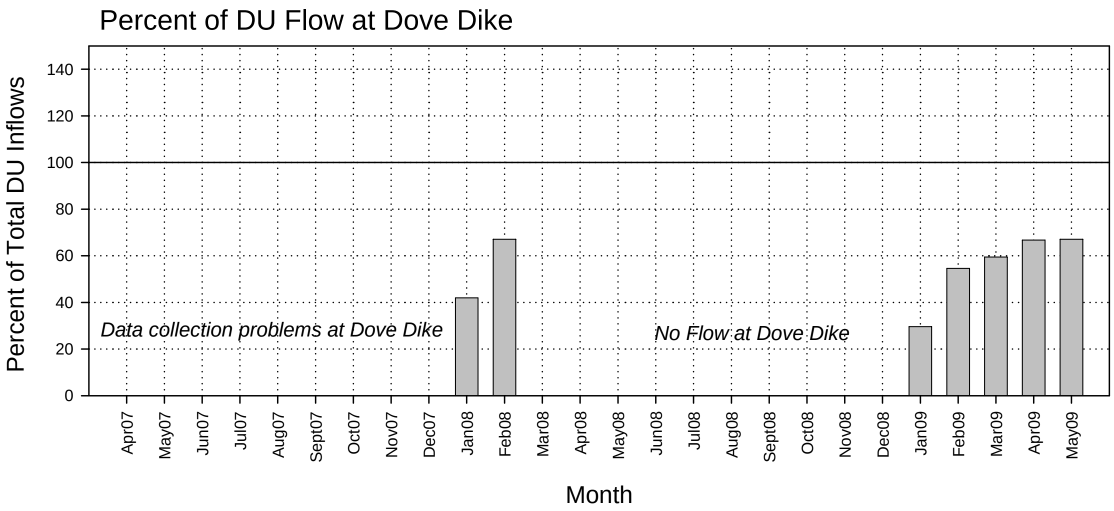


Figure 5: Percent of the monthly surface water inflows to the DU Project that are measured at Dove Dike.

The observed differences between inflow to and outflow from the DU Project are best explained by seepage losses. Although evaporation might explain some of the losses observed in Figure 3, it cannot explain the dramatic differences presented in Figure 4. Evidence of this can be found in the large differences between inflows and outflows that occur during the winter months, when evaporation is at its lowest. This pattern agrees with the discussions in the literature showing that infiltration tends to be highest when water is applied to a dry ditch or pond but approaches a near constant rate once soil becomes saturated (Dunne and Leopold 1978, Burt 1995).

Dove Dike to Whin Dike

Surface water data from south of the DU Project area indicate little water is lost in the Meadow between Dove and Whin Dike (Figure 6).

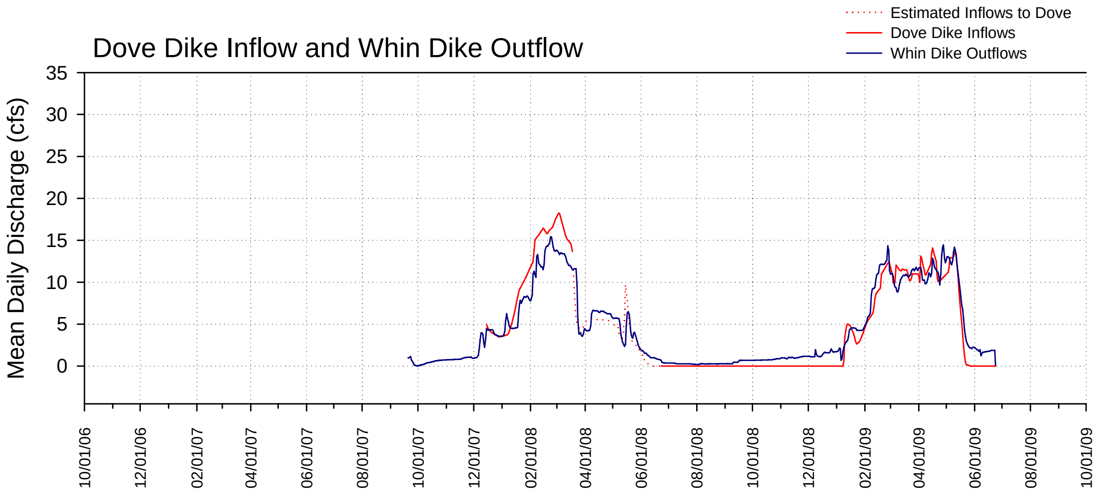


Figure 6: Combined mean daily discharge measured in Meandering Channel and Supply Ditch 2 at Dove Dike (red) and mean daily discharge spilling at Whin Dike.

Total monthly flow at Whin Dike's outlet is about 10% less than the flow measured upstream at Dove Dike. Given the inaccuracies of the data collection techniques, we consider this close agreement between the two records as evidence that little water seeps into the subsurface between the two gages. In contrast to the DU project, the area near Whin Dike appears to be one where groundwater is flowing into the ditch system.

Between June 2008 and December 2008, Whin Dike spilled 1-2 cfs long after Upper Pahranagat Lake releases stopped reaching Dove Dike. The steady spill is evidence there are other water sources contributing to the meadow during the summer months. The source of the additional water is groundwater that flows into the ditch system and refuge wetlands. This process, known as "groundwater discharge" helps keep the water table near the ground surface during the summer months which helps minimizes surface water seepage losses and supports wetland plant species near Whin Dike.

Whin Dike to Middle Marsh Dike

There is little change in flow conditions between Whin Dike and Middle Marsh dike, indicating seepage losses between the two sites are minor (Figure 7). Like the flow records above and below Whin Dike, this information is interpreted as evidence that groundwater discharge occurs in Middle Marsh. Further evidence of this was the presence of extensive standing water during the summers of 2008 and 2009, long after releases from Upper Pahranagat Lake had ceased.

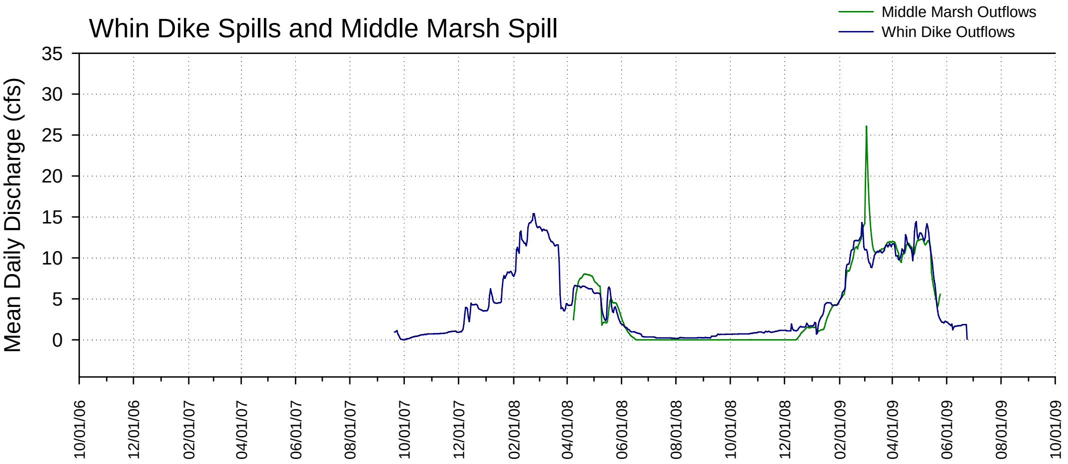


Figure 7: Mean daily discharge of spills at Whin Dike (blue) and Middle Marsh Dike (green).

Spring Hydrology

There are eight reliable springs on Pahranagat NWR (see Figures 13-16 in Part 2). In parts of the refuge springs are important resources for wildlife because they often provide the only year-round water. Cottonwood Spring is the largest on the refuge and the only one that maintains a steady flow from its spring pool. Flow from the others is enough to preserve shallow pools of permanent water but not enough for water to flow out of the pools.

Due to an absence of flowing water, vertical hydraulic gradients were monitored at six of the eight springs as a proxy for flow. A vertical hydraulic gradient is the energy driving water from the ground into the spring pool. Vertical gradients can be measured using mini-piezometers: 5 ft lengths of 1-inch diameter PVC tubes driven approximately 3-4 ft below the bed of the spring pool. The PVC is open on one end so shallow groundwater can flow up into it. The magnitude of the vertical hydraulic gradient at springs was calculated using Equation 1 (Simonds et al. 2004).

1) $I_v = dh / dl$

Where

I_v = vertical hydraulic gradient (unitless)
dh = Measured difference between water level inside the mini-piezometer and in the spring pool.
dl = vertical distance between bottom of spring pool and the opening at the bottom of the mini-piezometer

When water levels inside the mini-piezometer are higher than spring pool levels, there is a positive hydraulic gradient and the spring pool is considered “gaining” or groundwater is flowing into the spring pool. When water levels inside the mini-piezometer are lower than spring pool levels, there is a negative hydraulic gradient and the spring pool is “losing.” In situations with “losing”conditions, surface water in the pool is flowing into the shallow ground water aquifer below the pool (Simonds et al. 2004).

Mini-piezometers were installed around the periphery of the Cottonwood, North Cottonwood, Maynard North, Maynard South, Lone Tree, and Unnamed spring pools. Measurements at the piezometers were collected approximately monthly during our study (Figure 8).

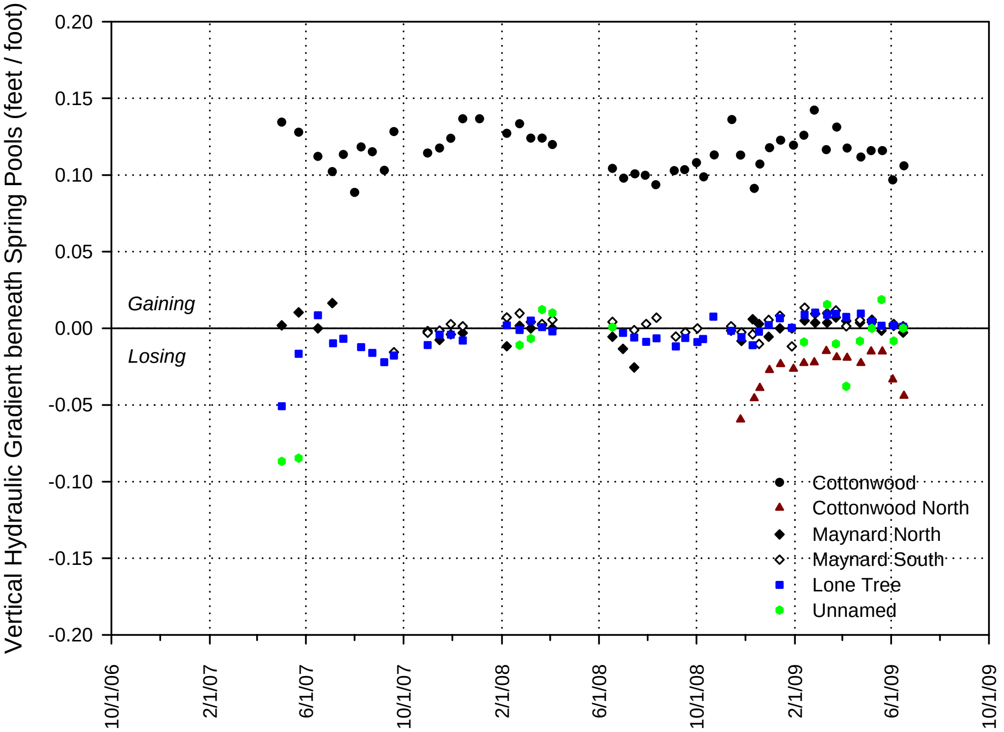


Figure 8: Vertical hydraulic gradients between shallow groundwater and spring pools at Pahranagat NWR. Data are median values calculated from 3 – 4 mini-piezometers installed at spring pool edges.

The volume of water moving between shallow groundwater and the spring pool is proportional to the measured vertical gradients. Larger gradients indicate more vertical movement, smaller gradients mean less vertical movement. Cottonwood Spring has the highest vertical gradient which contributes to the year-round flow from the spring. The vertical gradients at the other sites are near zero. These springs are slightly gaining or slightly losing depending on the time of the year. Spring pools at these sites are smaller than Cottonwood’s and water levels in the pools fluctuate more. Additionally they do not support flowing water from the spring pools. Because of the weak hydraulic gradients, the smaller spring pools are more akin to seeps than springs. They are capable of maintaining a small area of open water habitat and saturated soil conditions. However, it is unlikely that they can support larger spring pools or channels with flowing water.

Water Levels at Cottonwood Springs fluctuate about 0.10 ft over the course of the year (approximately 1.2 inches). Flow from the spring and vertical gradients at the spring mirror this seasonal fluctuation (Figure 9).

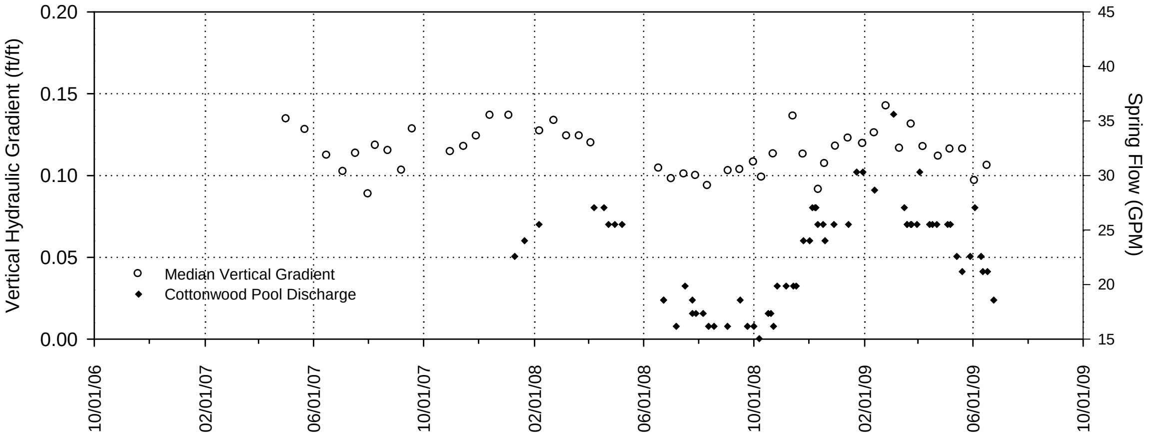


Figure 9: Vertical Hydraulic Gradients and measured spring flow at Cottonwood Springs, Pahranagat NWR.

Maximum flow (30-35 gpm) from the spring coincides with the maximum vertical gradients (0.12 - 0.14) in February or March. The lowest flow rates (15 - 17 gpm) and lowest gradients (0.09 – 0.10) occur in July and August.

Spring Source Waters

A spring’s aquifer is analogous to a stream’s watershed. Water from precipitation infiltrates into the subsurface, is stored and moves underground in an aquifer, and eventually discharges at the spring. The flow, temperature, and chemistry of the spring reflect the extent and geology of the groundwater aquifer feeding it. The time it takes for precipitation falling on land to travel through an aquifer to a spring head is related to the size of the aquifer, its rock type, and the elevation gradient in the aquifer. Water from springs fed by large, regional aquifers may take hundreds or thousands of years to travel hundreds of miles between the areas where precipitation enters the aquifer to discharge points at spring heads. Because the distances are great and the movement of groundwater is slow, regional spring flow and temperature fluctuate less than in springs fed by local aquifers. The distance between recharge areas and discharge areas in local springs may be a few miles or a few tens of miles. Travel times for water in local aquifers may be over years or decades, rather than centuries. The shorter travel time in local aquifers manifests as seasonal fluctuations in spring flow and temperatures that mimic seasonal variations in precipitation and temperature of the area.

Flow at the springs near Pahranagat NWR are different from the regional carbonate springs further north in the Pahranagat Valley. The small vertical hydraulic gradients and lack of spring discharge suggest refuge springs are fed by local groundwater from the Pahrangat Valley, rather than regional groundwater from the Paleozoic carbonate rocks. Because refuge springs are found on the edge of the valley and above the valley floodplain their source water may originate in the surrounding mountains, rather than the water passing through the valley’s floodplain.

References

Bassett, R.L. 2003. Evaluation of Spring and Aquifer Isotopic Data Associated with the Muddy River Springs Geographic Area, Southeastern Nevada. Unpublished report. Geochemical Technologies Corporation. Wheat Ridge, CO.

Burt, C.M. 1995. The Surface Irrigation Manual. Waterman Industries. Exeter, CA.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company. New York.

Simonds, F.W., Longpre, C.I., and G.B. Justin. 2004. Groundwater system in the Chimacum Creek Basin and Surface Water/Groundwater Interaction in Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers, Eastern Jefferson County, Washington. U.S. Geological Survey. Scientific Investigations Report 2004-5058.

Executive Summary

Monitoring wells were used to evaluate the dynamics of shallow groundwater in refuge wetlands. The majority of these wells were installed in the meadow south of Dove Dike (Meadow), consequently this section of the report focuses heavily on groundwater processes there. Although other parts of the refuge have not been evaluated in as much detail, shallow groundwater dynamics throughout the refuge are thought to be similar to those found in the Meadow.

Shallow groundwater on the refuge is found in the alluvial sands and gravels overlying deeper rock layers. The depth of alluvial sediments is not well defined at present but is thought to be hundreds of feet thick. Groundwater movement in the alluvial sediments is primarily from north to south. However, there is also groundwater flowing towards the center of the valley from the east and west. The Pahranagat Shear Zone faults affect groundwater discharge on the refuge by impeding north-south subsurface flow in the alluvial sediments of the valley's floodplain. Groundwater discharge areas are characterized by year-round shallow depths to water, saturated soil conditions, or standing water.

There are two sources of water for wetlands south of Upper Pahranagat Lake: 1) surface water released from Upper Pahranagat Lake and 2) groundwater discharge from the alluvial aquifer. Of the two, surface water releases from the lake are the largest but their spatial distribution is limited to wetlands near irrigation ditches and wetland impoundments. Additionally, surface water is rarely available in adequate quantities to flood all refuge wetlands after June or July. Groundwater discharge occurs year round but the volume of water is small compared to the Upper Lake releases and only occurs in suitable geomorphic settings. In some parts of the refuge, far from irrigation ditches, groundwater discharge is the only source of water for wetlands.

Pahranagat NWR Groundwater Aquifers

Precipitation in this portion of Nevada is too low to be a significant water source for wetland resources in the valley. Instead, groundwater discharge is the water source for all the wetlands, lakes, and streams in the Pahranagat Valley. Groundwater in the valley originates in one of two aquifers: a regional Paleozoic carbonate-rock aquifer or a local alluvial aquifer.

The regional aquifer is composed of sedimentary limestone deposited during the Paleozoic era, 300-400 million years ago (Eakin 1963). The aquifer is considered regional because the rock layers extend north to Great Basin National Park, east into Utah, and south to Death Valley and Lake Mead (See Figure 3, Chapter 1). In the Pahranagat Valley, outcrops of regional aquifer rocks are found north of the town of Alamo. The close proximity of Ash, Crystal, and Hiko springs to these outcrops and the chemical characteristics of the spring water is evidence that groundwater discharging from the springs is from the regional aquifer. After leaving the springs, water is diked, dammed, or diverted to irrigate pasture and flood wetlands in the valley floodplain.

The local alluvial aquifer is composed of sands, gravels, and silts that have accumulated in the Pahranagat Valley through the weathering of the adjacent mountains. These fine grained sediments known as "alluvium" have filled the valley bottom over the millennia and in places can be several hundred feet thick. Water is stored in the pore space between the sediment particles and the aquifer as a whole may store a significant volume of water (Eakin 1963). Water in the alluvial aquifer originates as precipitation falling in the Pahranagat Valley or surface water from the regional springs that seep into the subsurface. Water originating from local precipitation or regional springs mixes in the alluvium and moves south towards Maynard Lake. The alluvial aquifer can be considered "local" because water stored in it originates within the boundaries of the Pahranagat Valley.

Although Eakin (1963) suggested there was probably upwelling from the regional aquifer into the local alluvial aquifer, the dynamics of this process have not been quantified. If this is occurring some percentage of the groundwater in the alluvium is derived from upwelling from the carbonate rocks.

The importance of groundwater to Pahranagat NWR cannot be understated. Ultimately, all the water available for the refuge's wetlands is from regional or local groundwater. The proposed plans for development of the regional groundwater aquifer are a potential threat to the flow from Ash, Crystal, and Hiko Springs. Groundwater development in the regional aquifer has the potential to reduce flow from these springs which could lead to less surface water entering the refuge and less surface water seeping into the alluvial aquifer. Because the refuge is located at the downstream end of the valley's surface water and groundwater flow systems, it is likely the effects of less regional spring flow will be felt at the refuge before other areas of the Pahranagat Valley. These effects could manifest as reduced inflows to Upper Pahranagat Lake and reduced groundwater discharge from the alluvial aquifer into refuge wetlands.

Scope of Groundwater Monitoring

The focus of groundwater monitoring was limited to the local alluvial groundwater aquifer. Water levels in monitoring wells were used to quantify the range of water level fluctuations in refuge wetlands and help illustrate how shallow groundwater moves on the refuge and interacts with refuge irrigation ditches.

Most groundwater monitoring on the refuge took place in the wet meadow habitat between Dove Dike and Whin Dike. This area was chosen because it was large (450 acres) and relatively undisturbed by grazing or farming. The wet meadow community south of Dove Dike includes a range of vegetation types and water regimes. Therefore, the groundwater monitoring in this area is thought to be applicable to similar wetland communities on other parts of the refuge.

North – South Groundwater Movement

At the refuge scale, a longitudinal profile of the ground surface and water table elevation is a simple way of presenting some of the groundwater information from the well network (Figure 1).

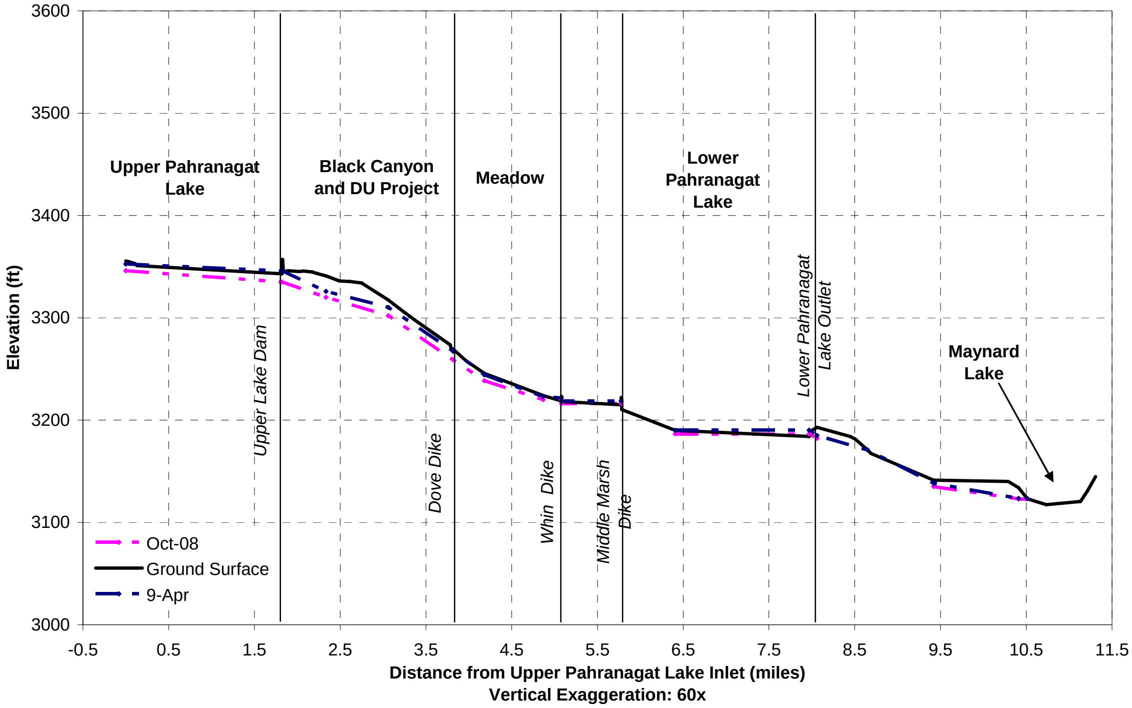


Figure 1: Longitudinal profile of Pahranagat NWR. Based on ground surface and water table elevations at selected locations near the center of the valley floodplain. Dashed lines are approximate water table elevations on October 2008 and April 2009. Vertical lines represent the location of dikes spanning the valley's floodplain.

In unconfined groundwater aquifers like the local alluvial aquifer, water moves from high water table elevations to low elevations. The slope of the water table reflects the velocity and magnitude of groundwater movement as well as the physical characteristics of the aquifer it is moving through (Fetter 1994). In Figure 1, the movement of groundwater is from left to right, which is north to south on the refuge. The profile of the water table mimics the ground surface through the refuge and drops 200 ft in 11 miles. This equates to an average water table slope of 0.3 % across the entire refuge.

Areas where the water table approaches the ground surface are known as zones of groundwater discharge. Often, these zones are found at transitions between steep and flat sections of the valley profile (Winter 1998). Evidence of groundwater discharge includes seeps, springs and year-round saturated soil conditions (Mitsch and Gosselink 2000). From Figure 1 and observations in the field, the primary groundwater discharge areas on the refuge are found at the north end of Upper Pahranagat Lake, at Whin Dike, in Middle Marsh, the north end of Lower Pahranagat Lake, south of Lower Pahranagat Lake, and the north end of Maynard Lake.

Areas where the water table is far from the ground surface are often considered zones of groundwater recharge. These are zones where surface water infiltrates and recharges the underlying groundwater aquifer. The portion of the refuge between the Black Canyon and DU project areas stand out because the water table is more than 15 ft below the ground surface while depth to groundwater in other sections of the refuge is rarely more than 10 feet. Because infiltration rates are highest in dry, unsaturated soils like those found in the Black Canyon/DU Project area, surface water applied in this area will recharge the underlying groundwater aquifer. This is consistent with surface water records presented in Chapter 4 that show seepage losses are high through the DU project.

Water that seeps into the subsurface in the DU Project/Black Canyon area is incorporated into the alluvial aquifer and slowly moves downgradient, which is south on the refuge. Groundwater recharge in the DU Project has the potential to increase the volume of groundwater discharging in the Whin Dike / Middle Marsh area. However, this leads to a loss of surface water in the DU Project area, limiting the refuge’s ability to maintain wetland habitat there. The implication for some of the proposed wetland and riparian restoration plans is that Black Canyon and the DU Project area may not be suitable locations for establishing and maintaining wetland habitat.

Influence of the Pahranagat Shear Zone

Longitudinal profiles of river channels in homogenous substrate typically develop a concave appearance. Convex channel profiles, like Pahranagat’s, are evidence of geologic features resistant to erosion (Knighton 1984). The longitudinal profile on the refuge appears to be affected by the three faults of the Pahranagat Shear Zone described by Jayko (1990, 2007) (Figure 2). Transitions in the valley’s slope, or slope breaks, are found near these faults. These slope breaks are clearly visible in Figure 2, where north of the faults the valley profile is flatter than the slope south of the faults.

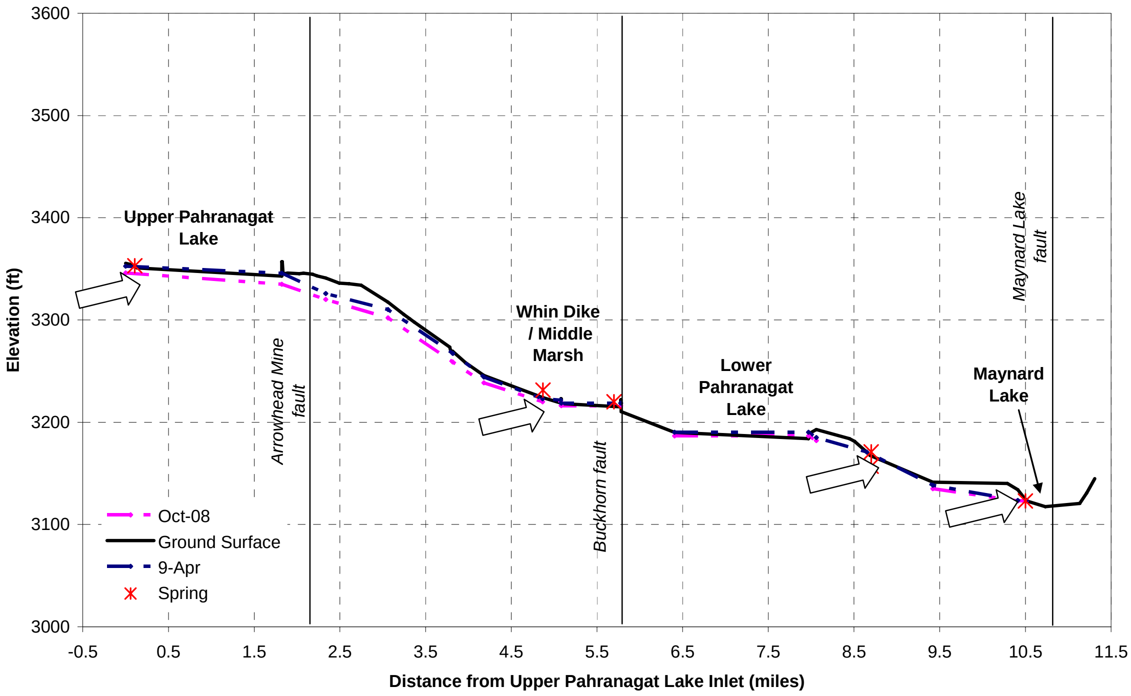


Figure 2: Longitudinal profile of Pahranagat NWR with approximate locations of principle Pahranagat Shear Zone faults. Asterisk represent the approximate locations and elevations of refuge springs. Arrows represent areas of inferred groundwater discharge based on field observations, water table depth, and spring locations.

The Pahranagat Shear Zone faults displace rock layers in the valley vertically and horizontally. Tertiary volcanic rocks and Paleozoic carbonate rocks north of the faults are lower relative to similar rock layers south of the faults. On a regional scale, the Pahranagat Shear Zone is considered a barrier to north-south groundwater movement in the White River flow system of the Paleozoic carbonate aquifer described by Eakin (1966).

Sand, gravel, and silt that has weathered from the surrounding mountains has accumulated above the volcanic and carbonate rock layers. Except for hard rock outcrops, the top of the alluvium is the surface of the ground in the Pahranagat Valley. Eakin (1963) considered the alluvium in the Pahranagat Valley a local groundwater aquifer. Displacement of the rock layers at shear zone faults may place low-permeability volcanic tuff in contact with the alluvium, creating a barrier to the southward movement of alluvial groundwater (Jayko pers comm.). This scenario would promote groundwater discharge north of the shear zone faults. Field observations of shallow depths to groundwater, springs, and wetlands north of the faults support the hypothesis that rock displacement in the shear zone creates groundwater discharge from the alluvial aquifer.

East-West Groundwater Movement

Figures 1 and 2 present the north-south component of groundwater movement across the entire refuge. Cross section profiles of the water table and ground surface in the meadow south of Dove Dike (Meadow) illustrate east-west or west-east groundwater movement (Figure 3).

Cross section profiles in Figure 3 illustrate horizontal hydraulic gradients of the water table south of Dove Dike (Figure 3A), in the middle of the Meadow (3B), and just north of Whin Dike (3C). Water table elevations at wells NT1, MT1, and ST1 are evidence of groundwater movement from the western edge of the Meadow to the center of the valley. Similarly, water table elevations at wells NT11, MT8, and ST6 are evidence of groundwater movement from the east edge of the Meadow to the center of the valley (See Figure 4 for well locations).

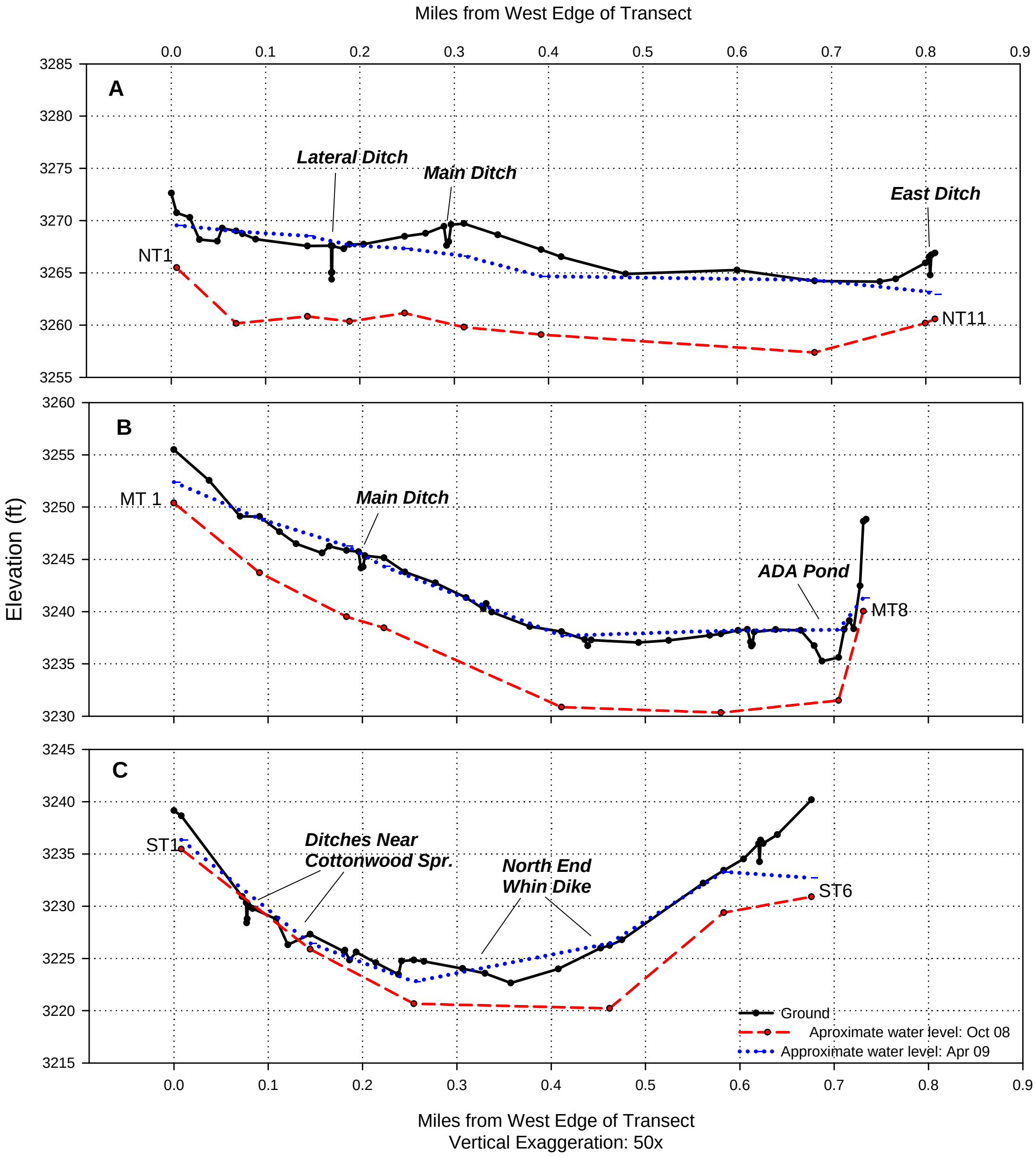


Figure 3: Cross section profiles of ground surface and approximate water levels in October 2008 and April 2009 in the meadow between Dove Dike and Whin Dike. Water levels above the ground surface represent approximate areas where standing water may occur but do not approximate the depth of water. See Chapter 2, Figure 5, for well locations.

Water Table Contours

Data presented in Figures 1 through 3 can be integrated into a two-dimensional map of the water table surface under the Meadow (Figure 4). Water table contour maps were generated for October 2008 and April 2009, the highest and lowest water levels observed during the data collection period. The seasonal fluctuations are related to changing patterns of water release from Upper Pahranagat Lake and different rates of evapotranspiration from the meadow's wetland vegetation. In 2008 and 2009, water was released from the lake during the winter months but ceased during the summer months, because the lake had been drained for outlet work construction (see Chapter 4 of this report for more details). October 2008 water levels are low because they follow several months of no surface water inputs and high evaporation rates. April 2009 water levels are high because they follow several months of surface water inputs and low evaporation.

Water table contour maps (Figure 4) show that groundwater moves primarily from north to south through the Meadow and also from the west and east towards the center of the valley. The distribution of water table contours in Figure 4 is similar to those observed near "gaining" streams (Winter 1998) and evidence that groundwater is discharging into the southern half of the Meadow. Groundwater could discharge from the aquifer at this location for several reasons, including: narrowing of the valley floodplain, changes in the valley slope near ADA pond, or displacement of rock layers at the Buckhorn fault (see Figure 4 in Chapter 1).

Seasonal Water Table Fluctuations

The difference between October 2008 and April 2009 water levels in Figure 4 is greatest near the center of the well transects and smaller at the valley edges (Figure 5). Wells with the least amount of variability were on the west side of the southern transect near Cottonwood Spring. Additionally, the influence of east-west gradients is stronger in October 2008, while the north-south component is more significant in April 2009. The difference is related to surface water inflow from Upper Pahranagat Lake that floods the Meadow from the north during the winter. When releases from Upper Pahranagat Lake reach Dove Dike they spread out across the Meadow in a thin layer of water that does not concentrate into distinct channels. This flow pattern is often referred to as "sheet flow" (Wilson and Moore 1998) and occurs primarily during the winter months when releases from Upper Pahranagat Lake are greatest. During periods with widespread sheet flow the alluvial aquifer is recharged and the water table rises. As the water table rises, the north-south component of groundwater movement becomes the dominant direction of groundwater flow in the Meadow. Later in the year, when plants are transpiring and there is no surface water recharging the alluvial aquifer, the north-south direction of groundwater movement is less dominant and the east-west components become more important to refuge wetlands.

The greatest differences in well water levels between October 2008 and April 2009 are in the vicinity of the ADA Pond and Dove Dike (Figure 5). In the north half of the Meadow, the water table was more than 6 ft lower in October 2008 than in April 2009. The large variations indicate groundwater recharge to the meadow from “sheet flow” is greatest north of ADA pond. South and west of ADA pond the difference in water levels decreases with proximity to the groundwater discharge zone on the western edge of the Meadow. This suggests groundwater discharge on the western edge of the Meadow helps offset summer water table declines due to evapotranspiration.

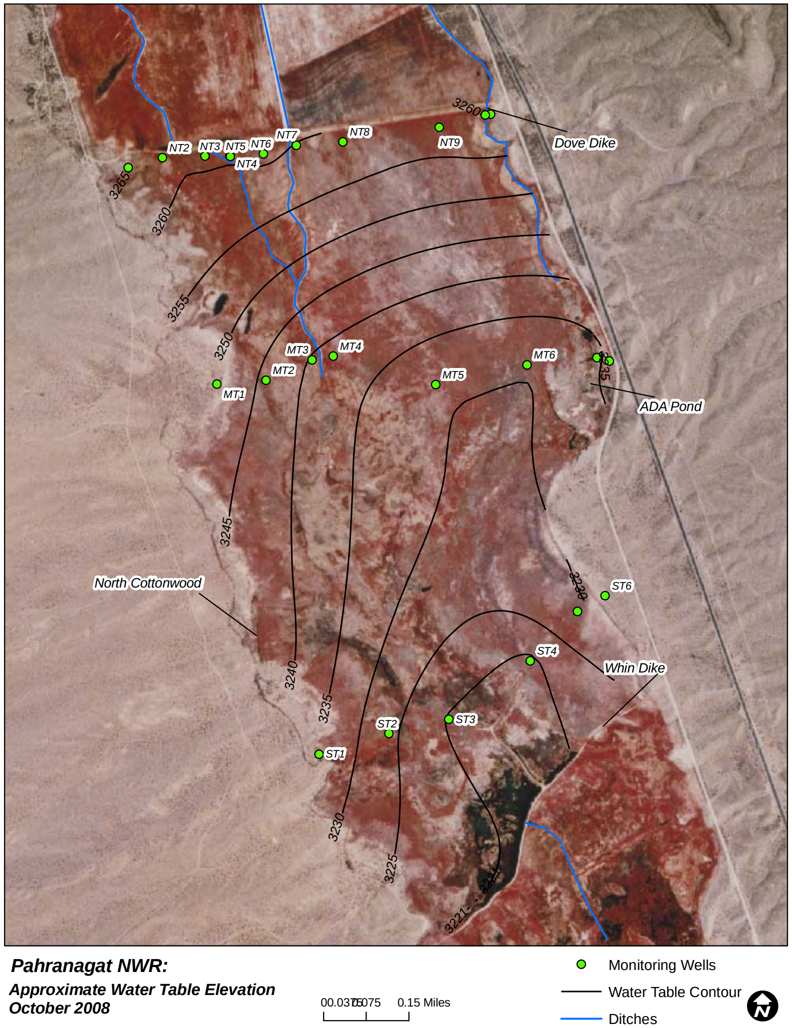


Figure 4A: Approximate water table elevation south of Dove Dike in October 2008. 5 ft contour intervals. Background photo taken in June 2004.

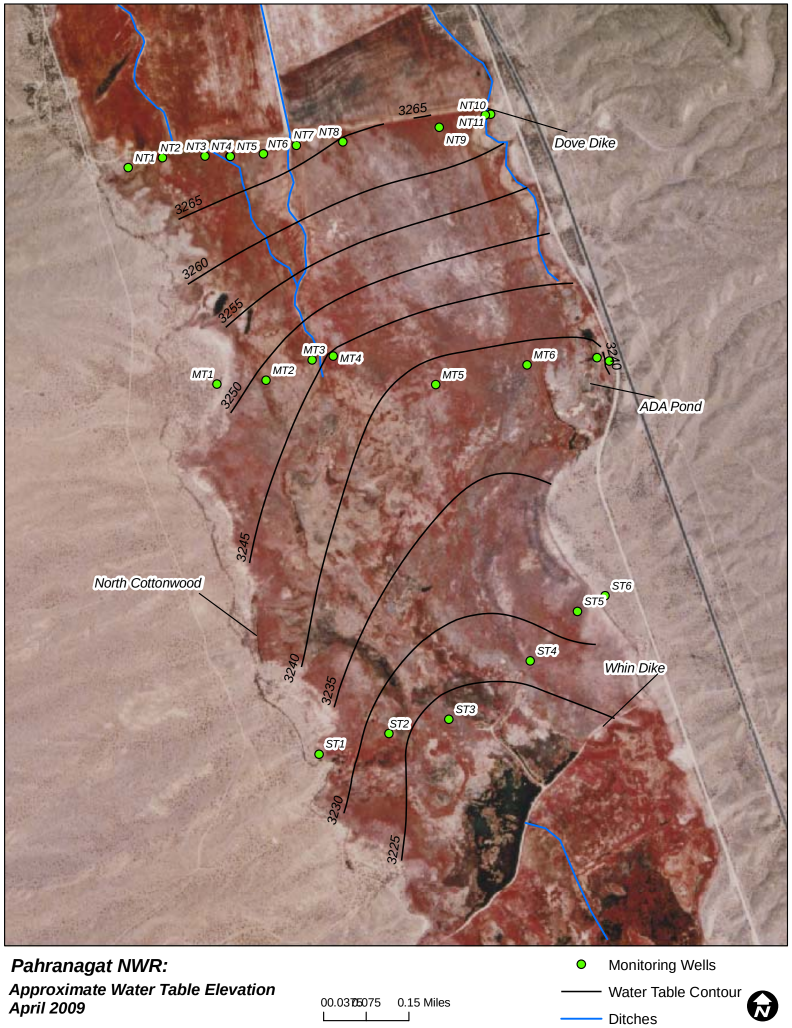


Figure 4B: Approximate water table elevations south of Dove Dike in April 2009. 5 ft contour intervals.

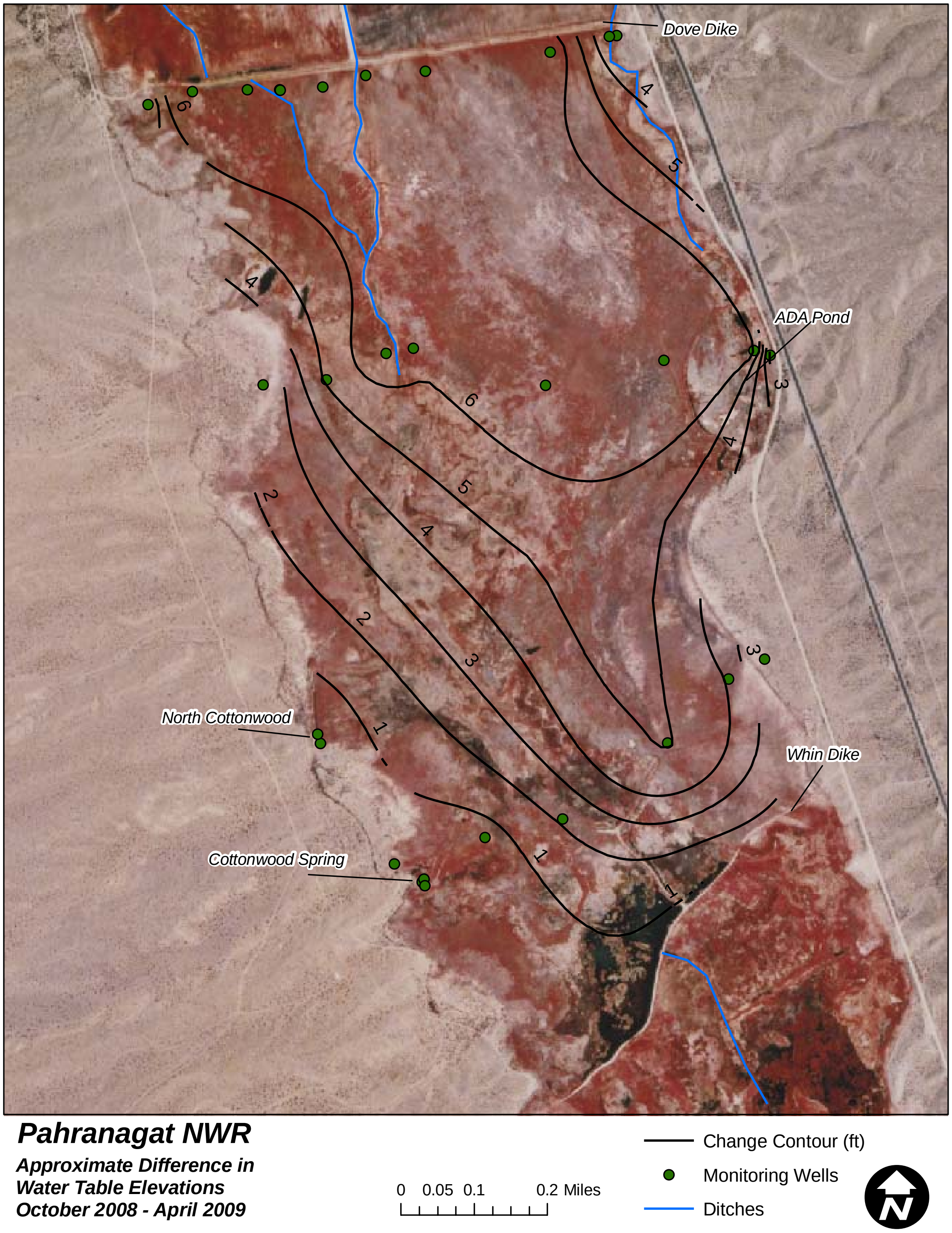


Figure 5: Net increase in water table elevations (feet) between October 2008 and April 2009. Exampple: the elevation of the water table was 6 ft higher in April 2009 than October 2008 along the 6 ft contour.

Water Level Fluctuations at Individual Wells

Figure 5 presents the spatial distribution of water level fluctuations in the Meadow between October 2008 and April 2009. Hydrographs of water level fluctuations emphasize the relative importance of groundwater recharge and discharge on groundwater dynamics in the Meadow. The water levels in the Meadow's wells fluctuated between 1 and 9 feet during the study period (Figure 6). Water levels dropped during the summer months, reaching their lowest elevations in early October, and peaked during winter in February or March. In addition to seasonal variations there are differences in the magnitude of the seasonal fluctuations depending on a wells proximity to additional sources of water.

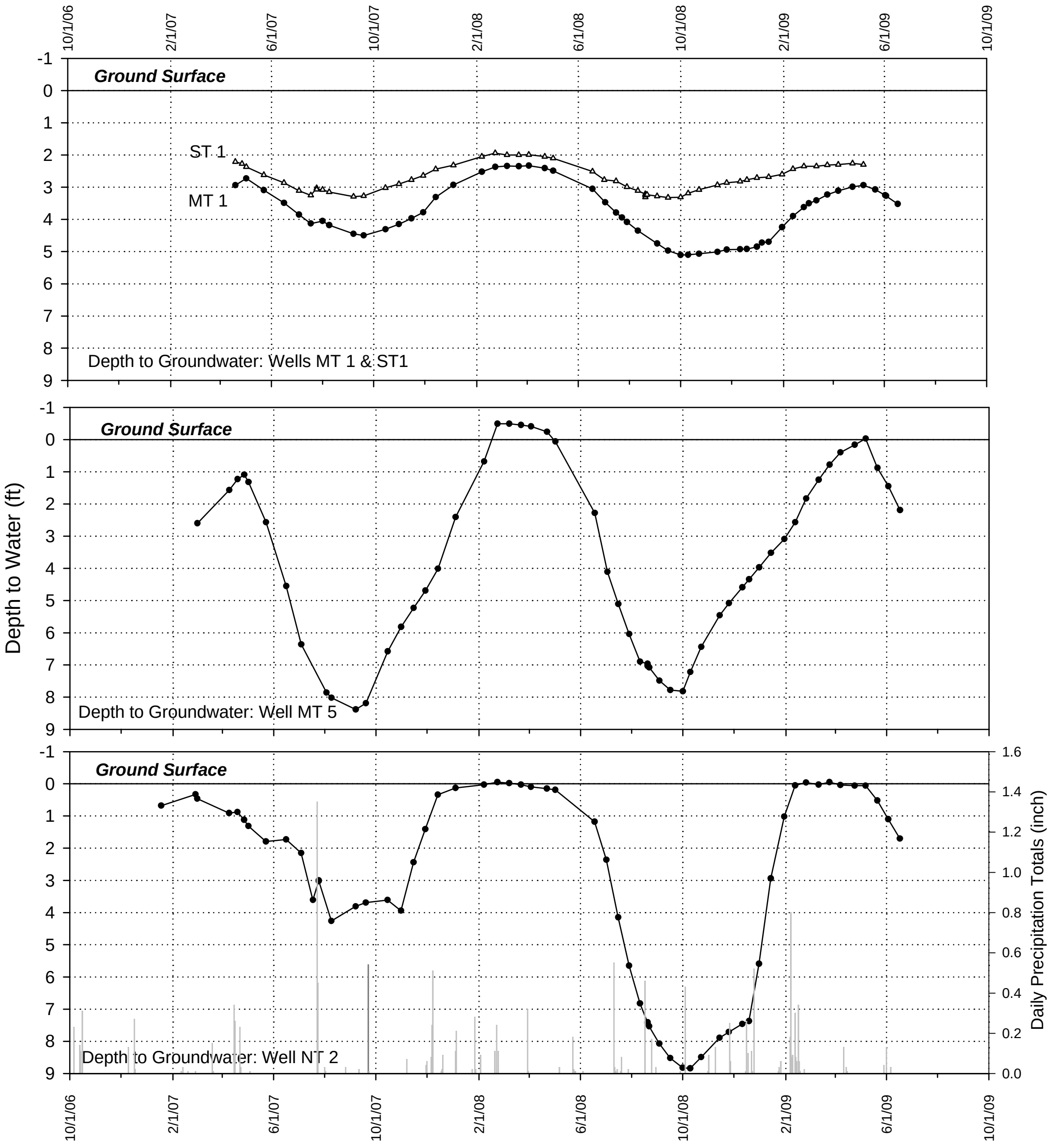


Figure 6: Depth to groundwater hydrographs for 4 wells in the wet meadow south of Dove Dike. Daily precipitation totals in inches measured at CEMP station in Alamo, NV. See Figure 4 for well locations.

Wells MT1 and ST1 are on the Meadow's edge and fluctuate 1 to 2 feet annually. Near the center of the valley, at MT5, the water table fluctuates 8 to 9 ft. The observed water table decline during the summer months is not surprising. Similar seasonal fluctuations at wells in southern Nevada's Oasis Valley were attributed to evapotranspiration by wetland plants (Reiner et al. 2002). Reiner also noted that water levels in wells close to water sources like springs, streams, or irrigation ditches dropped less than wells far from these sources. The additional water sources recharged shallow groundwater enough to offset the water table decline caused by evapotranspiration. Water levels in Well NT2 illustrate that similar processes occur near irrigation ditches at Pahranagat (Figure 6).

Releases from Upper Pahranagat Lake fill a shallow trench immediately south of Dove Dike and only a few yards from well NT2. Between June and September 2007, the trench was filled with water and water levels in NT2 rose accordingly. In 2008, Upper Pahranagat Lake releases ceased in June, the trench near NT2 dried up, and water levels in NT2 dropped 5 ft below the minimum observed in 2007. These data highlight how the local alluvial aquifer is recharged by surface water in the trench. In 2007 this recharge was enough to offset the water table decline caused by evapotranspiration. Other wells near the trench and other irrigation ditches responded similarly while water was released during the summer of 2007.

The fluctuations at ST1 and MT1 appear small in comparison to the large variations at MT5 and NT2 (Figure 6). Assuming evapotranspiration rates are similar throughout the Meadow, the small seasonal fluctuations are evidence that evapotranspiration is continuously offset at these sites. Irrigation ditches do not bring surface water into these areas and the only source capable of continuously offsetting transpiration is groundwater discharge. Water table contours in Figure 4 clearly show groundwater moving into the Meadow from the west and east. This groundwater movement does not always manifest itself as discreet springs like Cottonwood. Instead, groundwater flow from the alluvial fans on the west and east edges of the Meadow moves in a diffuse and broad front over a large area. Therefore, continuous groundwater inflow to the Meadow offsets evapotranspiration and helps keep the water table high in the southern half of the Meadow year-round.

Influence of Upper Pahranagat Lake Releases

Surface water releases from Upper Pahranagat Lake recharge the shallow alluvial aquifer under the Meadow. Data collection for this study spanned two radically different water management strategies for Upper Pahranagat Lake. In 2007, winter releases from the lake were relatively modest and only reached Dove Dike between January and March. In contrast, Upper Pahranagat Lake was completely drained in 2008 and 2009 to repair the lake's outlet structure, causing considerably more water to flow south of Dove Dike during the winter months. The effects of the two different operational schemes can be seen in well hydrographs from Figure 7.

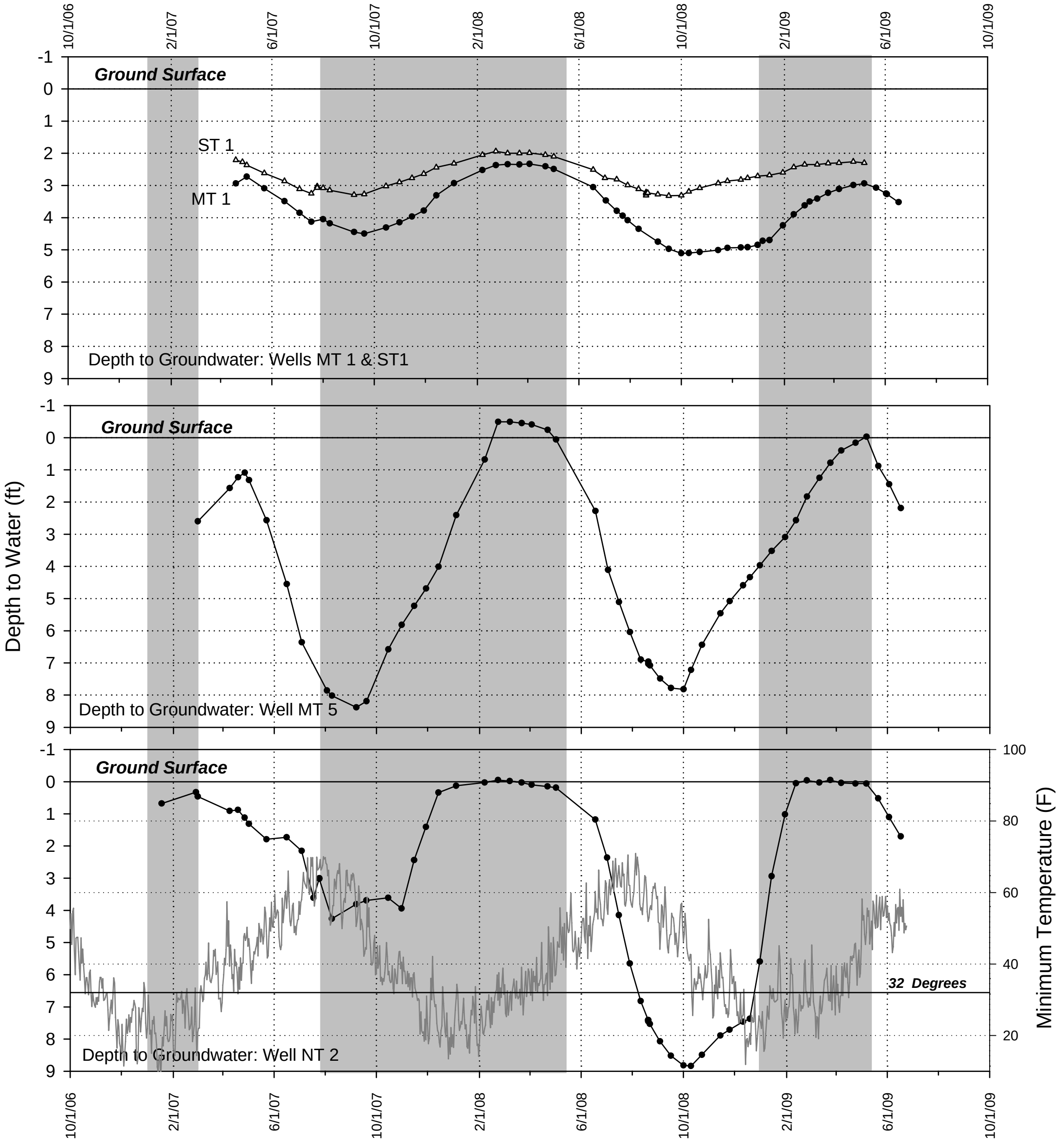


Figure 7: Hydrographs of depth to water at selected wells in meadow south of Dove Dike at Pahranagat NWR. Shaded regions are periods when releases from Upper Pahranagat Lake reached Dove Dike. The grey line in the plot of NT 2 water levels is the minimum daily air temperatures measured at the Alamo CEMP station.

When releases from Upper Pahranagat Lake reach Dove Dike, they fill a shallow trench south of the dike and spill out into the Meadow. Because the slope of the Meadow is nearly 1%, water spilling at the trench spreads out across the Meadow eventually collecting behind Whin Dike. The duration and spatial extent of this sheet flow phenomenon depends on the amount of water reaching Dove Dike and manipulation of the stop-log control structures south of the dike.

Water that reaches Dove Dike via the Meandering Channel contributes to sheet flow conditions on the western side of the Meadow. To create sheet flow conditions on the east side of the Meadow, water needs to reach Dove Dike via Supply Ditch 2. Based on surface water monitoring data presented in Chapter 4, the minimum flow needed to generate sheet flow on both sides of Supply Ditch 2 is approximately 10 cfs. Due to seepage losses in the DU project area, releases from Upper Pahranagat Lake need to be about 13 cfs to translate into 10 cfs at Dove Dike. Because of the trench's elevation it is not physically possible to generate sheet flow on the east side of the Meadow unless water is running in Supply Ditch 2. Thus, when the extent of sheet flow is at its maximum surface water will reach wells MT 5 and NT2 but will never reach ST1 or MT1.

During sheet flow events, surface water recharges the alluvial aquifer which keeps the water table at or near the ground surface until the sheet flow ceases. Draining Upper Pahranagat Lake in 2008 and 2009 maintained sheet flow conditions south of Dove Dike until late May of both years. This regime kept the water table 1.5 feet higher at MT5 and 0.5 ft higher at NT2 in June 2008 and 2009 than in June 2007 (Figure 7). Although the difference is small, it may be significant for certain wetland plants at critical times in the growing season. For example, water management actions that mirror 2007, when no sheet flow occurred, would be more beneficial to meadow plants that prefer drier conditions while management that promotes extensive sheet flow, like 2008 and 2009, would benefit plants that prefer wetter conditions.

Precipitation Influence and Plant Dormancy

Precipitation events appear to have little direct influence on water table elevations in monitoring wells at Pahranagat NWR (Figure 6). Instead, groundwater discharge to the Meadow and surface water releases from Upper Pahranagat Lake are the most important source of water for wetlands south of Dove Dike. Evapotranspiration is the dominant process removing water from the Meadow during the summer months and only begins to decrease as colder temperatures and longer nights trigger dormancy in wetland plants (Figure 7). The water table in the Meadow rises because hydrologic inputs to the meadow exceed the outputs. In the fall of 2008, when minimum temperatures approached 32 degrees, the water table began to rise. This occurred 2 months before any water was released from Upper Pahranagat Lake (Figure 7) and is probably related to the onset of dormancy in the wetland plants on the refuge. In the absence of lake releases, groundwater flowing into the Meadow from the north, west, and east is the only other source capable of raising the water table in Pahranagat NWR wetlands.

Conclusions

Although the bulk of this analysis was focused on conditions in the Meadow south of Dove Dike, the hydrologic processes play out in similar fashions across the refuge. Ultimately there are two sources of water for all wetlands on the refuge: surface water releases from Upper Pahranagat Lake and groundwater that discharges from the local aquifer. The importance of either for a particular wetland unit depends on the ability to deliver water from the lake to that unit. One would expect groundwater discharge to be more influential at sites far from irrigation ditches than at sites close to ditches. Likewise, groundwater discharge becomes more important to wetlands during the summer months, when flow in the ditches has ceased.

References

Eakin, T.E. 1963. Groundwater appraisal of Pahranagat and Pahroc Valleys, Lincoln and Nye Counties, Nevada. Nevada Department of Conservation and Natural Resources Groundwater Resources Reconnaissance Series Report 21.

Eakin, T.E. 1966. A regional interbasin groundwater system in the White River Area, southeastern Nevada. Water Resources Research. Vol 2 (2). 251-271.

Jayko, A.S. 1990. Shallow crustal deformation in the Pahranagat area, southern Nevada. In Wernicke, B.P. ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Boulder, Colorado, Geological Society of America Memoir 176.

Jayko, A.S. 2007. Geologic Map of the Pahranagat Range 30' x 60' Quadrangle, Lincoln and Nye Counties, Nevada. Scientific Investigations Map 2904. U.S. Geological Survey. Reston, VA.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. 3rd Edition. John Wiley and Sons.

Wilson, W.E. and J.E. Moore. 1998. Glossary of Hydrology. American Geological Institute. Alexandria, VA.

Winter, T.C., Harvey, J.W., Franke, O.L., and W.M. Alley. 1998. Groundwater and Surface Water: A Single Resource. U.S. Geological Survey Circular 1139.

Executive Summary

Water in spring pools is cooler, fresher, and has a lower pH than surface water in Upper Pahranagat Lake and in refuge irrigation ditches. Shallow groundwater in the meadow south of Dove Dike (Meadow) is a mixture of Upper Pahranagat Lake surface water and shallow groundwater from the alluvial aquifer. Analyses of radiogenic isotopes suggest there are three sources of water for refuge wetlands: Ash Springs, Crystal Springs, and groundwater that resembles Cottonwood and Maynard Springs water.

Continuous Monitoring

Multi-parameter water quality sensors were used to measure pH, electrical conductivity, dissolved oxygen, and temperature in selected surface water features on the refuge. Sensors were deployed in the field during suitable conditions approximately every 4 months between July 2007 and April 2009. Typical field deployments lasted 3 to 4 days, with data recorded hourly. Sensors were installed in 4 springs (Cottonwood, Lone Tree, Maynard, and Unnamed) and 5 surface water sites (Inlet to Upper Pahranagat Lake, Outlet from Upper Pahranagat Lake, Supply Ditch 2 at Dove Dike, Outlet of Whin Dike, and Lower Pahranagat Lake). The distribution of median values for each deployment between July 2007 and April 2009 are presented in Figures 1 through 4 below.

Temperature

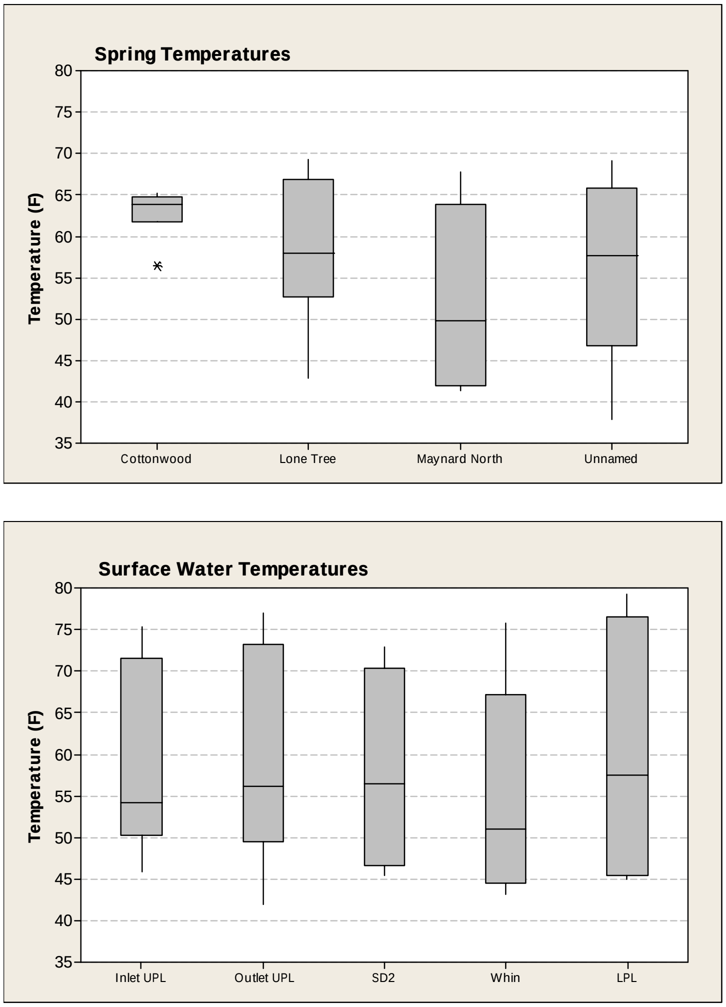


Figure 1: Distribution of median temperatures for each deployment at spring and surface water sites: July 2007 – April 2009. Abbreviations for this and all other figures: Cottonwood = Cottonwood Springs / Lone Tree = Lone Tree Springs / Maynard South = Maynard Springs South / Unnamed = Unnamed Springs / Inlet UPL = Inlet to Upper Pahranagat Lake / Outlet UPL = Outlet to Upper Pahranagat Lake / SD2 = Supply Ditch 2 and Dove Dike / Whin = Outflow at Whin Dike / LPL = Lower Pahranagat Lake.

Water temperatures in springs and surface water fluctuate seasonally. Highest temperatures occur during the summer months and lowest temperatures during the winter months. Water temperatures fluctuated more at surface water locations than spring locations (Figure 1). Spring sites remained below 70 ^{0}F during the data collection period but surface water sites often exceeded 75 ^{0}F during the summer months. Cottonwood Springs showed the least amount of water temperature fluctuation of any site, usually staying between 60 and 65 ^{0}F, throughout the year.

Dissolved Oxygen

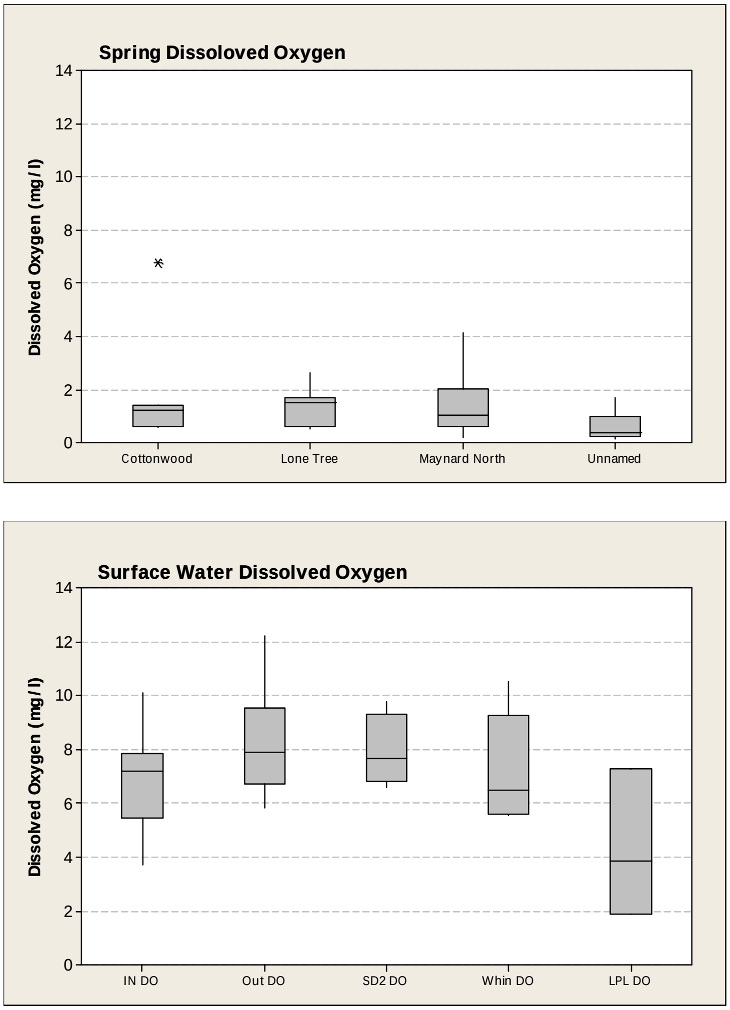
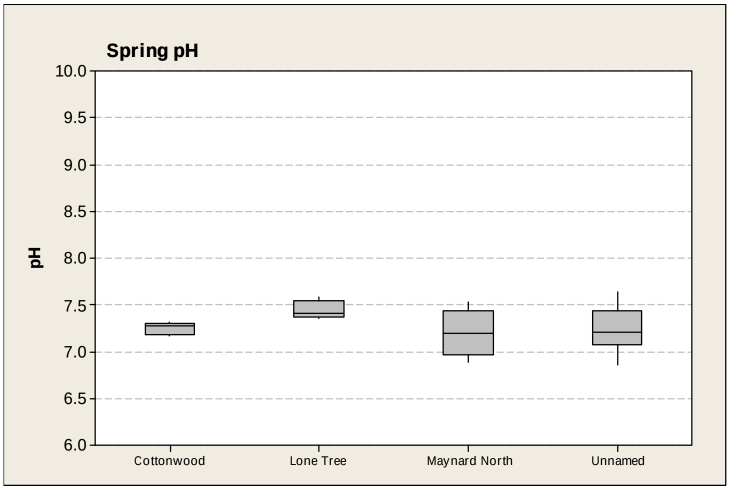


Figure 2: Distribution of median dissolved oxygen concentrations for each deployment at spring and surface water sites: July 2007 – April 2009. Abbreviations: In DO= Inlet to Upper Pahranagat Lake / Out DO = Outflow from Upper Pahranagat Lake.

Dissolved oxygen concentration reflects the availability of oxygen for aquatic life at the measurement locations. Dissolved oxygen concentrations were consistently higher at surface water measurement locations than spring locations (Figure 2). Surface water data were typically collected from moving water in refuge irrigation ditches. In contrast, waters in shallow spring pools are stagnant, with dense cattail growth and thick accumulation of organic material. Under these conditions, biological activity requiring oxygen is high. Combined with low flow volumes and little water movement that entrains oxygen, spring pools are areas of low dissolved oxygen concentrations compared to the surface water in refuge irrigation ditches (Figure 2).

pH



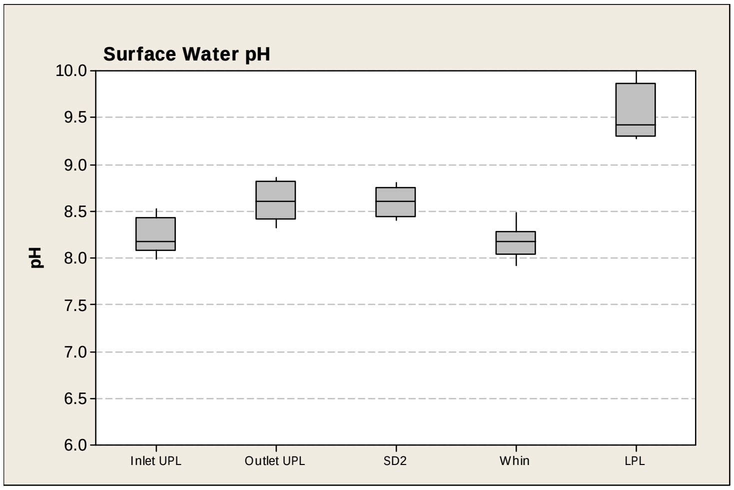


Figure 3: Distribution of median pH values for each deployment at spring and surface water sites: July 2007-April 2009.

pH is a measure of hydrogen ion activity in a water body and is one of the most common properties measured in natural waters (Hem 1985). At Pahranagat surface waters are nearly 1 pH unit higher than spring waters (Figure 3). Higher pH indicates a lower concentration of positive hydrogen ions in the water. Both biologic and chemical processes can remove hydrogen ions from solution. Most surface water on the refuge is derived from Ash and Crystal Springs discharge. Because these springs are fed by a Paleozoic carbonate rock aquifer, their waters contain high concentrations of bicarbonate (HCO_3) and carbonate (CO_3). These chemicals react with hydrogen to form carbonic acid (H_2CO_3). The reactions creating carbonic acid in Pahranagat NWR surface water reduce the hydrogen ion activity in the water, causing pH to rise (Freeze and Cherry

1979). Because the pH of Pahranagat NWR springs is lower than the pH of surface waters it is unlikely the two features share the same water source. .

Electrical Conductivity

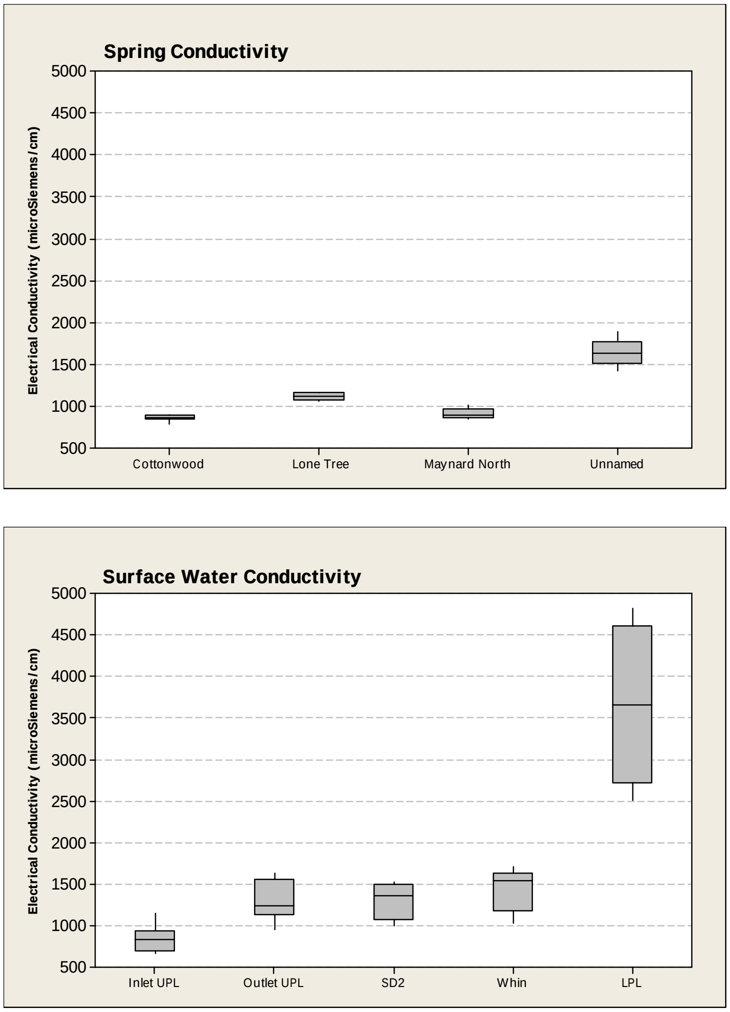


Figure 4: Distribution of median electrical conductivity at spring and surface water sites: July 2007 – April 2009.

Electrical conductivity is a measure of a liquid's ability to conduct an electrical charge. Higher charges are associated with higher concentrations of solutes in the water (Hem 1985). Cottonwood and Maynard North springs have the lowest conductivity, consistently less than 1000 microSiemens/cm (uS/cm). Water at other springs and surface water sites were higher, between 1000 and 1500 uS/cm. Lower Pahranagat Lake stands out with the highest conductivities (Figure 4). This gradation of electrical conductivity is directly related to water movement on the refuge. As surface water moves downstream conductivity increases as more minerals are dissolved and transported in the water. The conductivity at Lower Pahranagat Lake is exceptionally high because the lake is at the terminus of the surface water flow system and evaporation removes water and concentrates minerals in the lake.

Water Chemistry Sampling

In addition to continuous monitoring using multi-parameter sensors, grab samples were collected from Ash and Crystal Springs and sites on the refuge to help characterize source waters for refuge wetlands and springs. Forty three samples were collected on 4 occasions from the sites in Table 1.

Table 1: Locations of water chemistry sampling sites. See Figures 1-6 in Part 2 for site locations.

Ash Springs	Crystal Springs
Inlet to Upper Pahranagat Lake	Outlet to Upper Pahranagat Lake
Main Ditch near well MT 3	Outlet to Whin Dike
Cottonwood Spring	Lone Tree Spring
Maynard Spring North	Unnamed Spring
Well NT 11	Well MT4
Well ST3	Well ST6

Sample collection and processing followed USGS water quality sampling guidelines (USGS 2005). Samples were filtered and preserved at Pahranagat NWR before shipping overnight to the USGS Yucca Mountain Laboratory in Denver, Colorado for analysis. Samples were analyzed for concentrations of the following constituents:

1) Major cations and anions (Ca, Mg, Na, K, NH_4, Cl, SO_4, NO_3, NO_2, F, Br, PO_4. SiO_2).
2) Trace Elements: (Li, Be, B, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Sr, Rb, Mo, Ag, Cd, Sb, Ba, Pb, Th, U).
3) Isotopic ratios of Oxygen, Hydrogen, Sulfur, Strontium, and Uranium

Major Cations and Anions

Piper diagrams were prepared to present the distribution of water samples based on the proportion of major cations (positively charged chemicals) and anions (negatively charged chemicals) (Figure 5). The position of a sample on the Piper diagram helps characterize the sample's water type (Drever 1997).

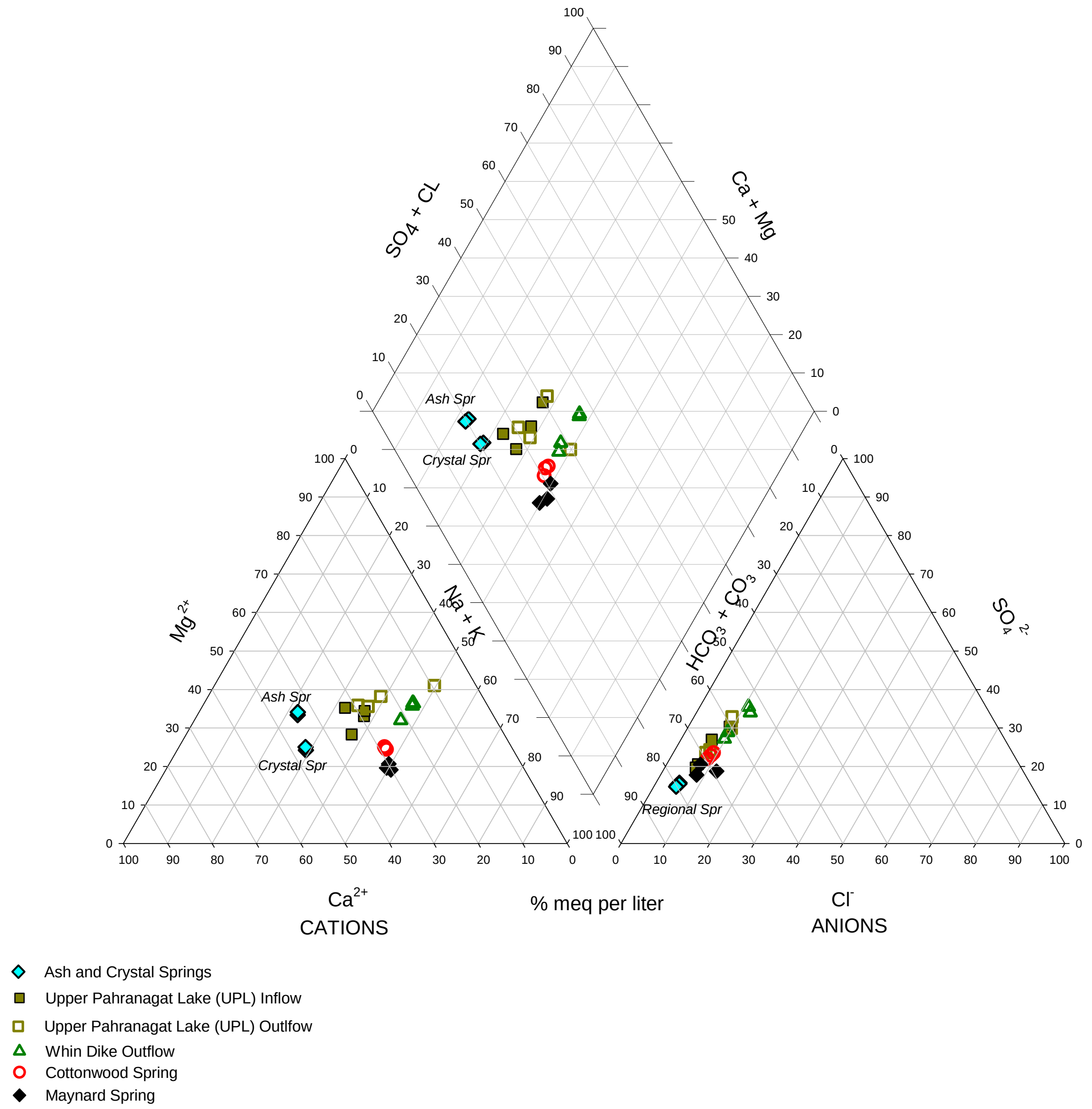


Figure 5: Piper Diagram of Ash and Crystal Springs, Refuge surface water, and selected springs at Pahranagat NWR.

Because Ash and Crystal Springs are the source of most surface water that reaches the refuge, characteristics of those waters should be reflected in samples collected on refuge wetlands.

Samples collected at Ash and Crystal Springs clearly stand out in Figure 5. The anions in the water are dominated by bicarbonate (HCO_3) and carbonate (CO_3), whereas the cations are predominantly calcium (Ca) and magnesium (Mg).

Surface water becomes modified chemically as it moves downstream through the Pahranagat Valley to the refuge. This is most obvious in the lower left corner of Figure 5: refuge surface water samples have a higher proportion of sodium (Na) cations than the regional springs. In the anion triangle, the higher proportion of chlorine (Cl) in refuge surface waters is further evidence of mineral accumulation in water as it flows downstream of Ash and Crystal springs.

Like regional carbonate springs, Cottonwood and Maynard Spring waters are also dominated by the bicarbonate and carbonate anions. However the relative proportion is less than those measured in the springs of the regional carbonate aquifer (Figure 5). The close proximity of Cottonwood and Maynard springs samples in the plot suggest they share source waters. Given the two springs are approximately 6 miles from each other the similarity in their chemical compositions is somewhat surprising. .

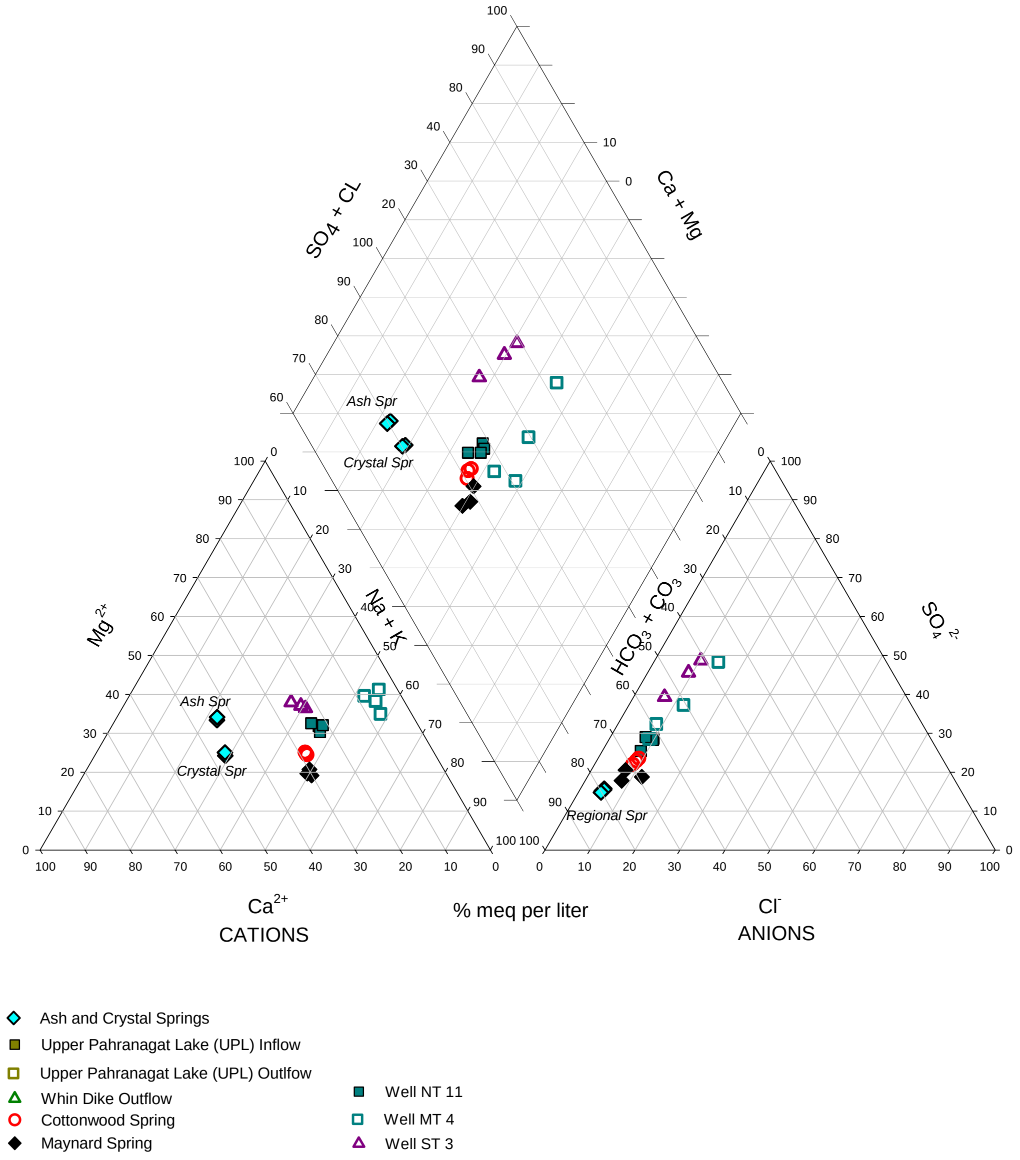


Figure 6: Piper diagram of Ash and Crystal Springs, Cottonwood and Maynard Springs, and shallow groundwater at Pahranagat NWR.

The proportion of Cl and Na ions in shallow groundwater are considerably higher than what is found in Cottonwood and Maynard springs or surface water samples collected on the refuge (Figure 6). The difference is related to the slow travel time of water in wetland soils. Contact with soil particles increases the concentration of dissolved solutes in the groundwater as it moves downstream through refuge wetlands.

Source water identification based on chemical concentrations alone is challenging because of the variability in the chemical signatures of surface water and shallow groundwater. Isotopic composition analysis provides additional information that can be used to help identify source waters for refuge wetlands and springs.

Stable Isotopes

Water samples collected at Pahranagat NWR were analyzed for their isotopic ratios of oxygen and hydrogen (Figure 7) to evaluate wetland source waters. Terrestrial waters are ultimately derived from moisture that originates in the oceans and falls as snow or rain on land. The ratio of oxygen (δ^{18}O) and hydrogen (δ^{2}H) isotopes in precipitation varies the further an air mass travels from the ocean. As moisture travels over land, precipitation preferentially removes heavier isotopes from the air mass and the remaining moisture is depleted of the heavy oxygen and hydrogen isotopes. Evaporation has the opposite effect and preferentially removes lighter isotopes from a water body (Clark and Fritz 1997). Therefore, the isotopic composition of waters can be used to distinguish between water sources and evaluate the processes influencing wetlands on the refuge.

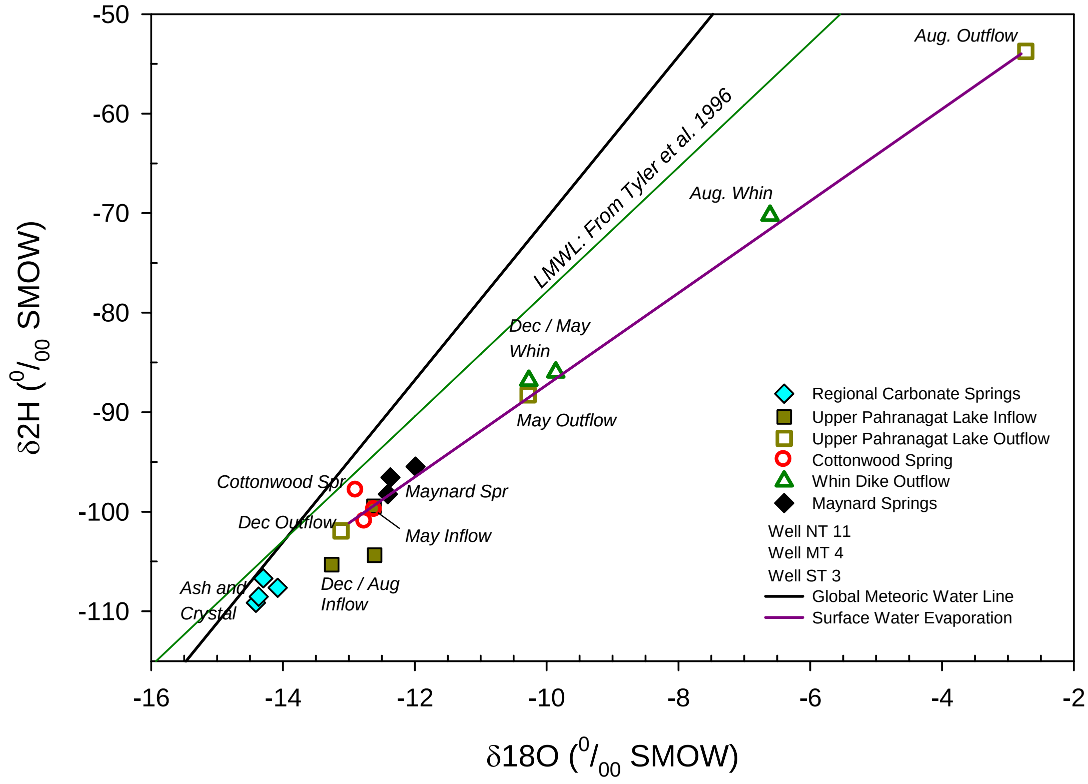


Figure 7: Plot of isotopic composition of waters at or near Pahranagat NWR. Samples collected from regional carbonate springs, Pahranagat NWR springs and surface water. Includes Global Meteoric Water Line and a Local Meteoric Line developed by Tyler et al. 1996.

At the global scale, precipitation has δ^2H and δ^{18}O compositions that form a systematic trend known as the Global Meteoric Water Line (GWML). The GWML approximates isotopic ratios of precipitation around the globe, but local precipitation usually varies from the global trend (Clark and Fritz 1997). Tyler et al. (1996), calculated a Local Meteoric Water Line (LMWL) for precipitation samples collected in southern Nevada. The LMWL is based on winter and summer precipitation collected near the Nevada Test Site, west of Pahranagat NWR. The LMWL should reflect the isotopic ratios of modern local precipitation better than the GWML.

On plots of δ^2H vs. δ^{18}O, water subject to evaporative enrichment of heavier isotopes falls on a line with a slope that is less than the GWML (Tyler et al. 1996). The position of Pahranagat surface waters on a line with a slope of 4.6 indicates these samples have been enriched by evaporation (Figure 7). The intersection of the refuge samples' line and the GWML, or LWML, should approximate the composition of the evaporated water's source. The location of Ash and Crystal Springs very near this intersection is consistent with our understanding that most surface water on the refuge is derived from Ash and Crystal Springs. The isotopically heavy sample collected at the outlet of Upper Pahranagat Lake in August 2007 emphasizes the degree of evaporation from the lake during the summer.

Cottonwood and North Maynard Springs isotopic signatures are similar to each other, yet different from Ash and Crystal Springs (Figure 7). Although the samples appear to have experienced some evaporative enrichment, their location above the December surface water samples suggests a source independent of Ash and Crystal Springs. Because the regional spring's signatures are depleted in heavy isotopes it is likely precipitation feeding Ash and Crystal may have fallen during winter months, at higher latitudes, or during colder past climate regimes. Cottonwood and Maynard Springs' water is isotopically lighter which suggests a warmer recharge source than the regional springs (Clark and Fritz 1997).

The isotopic composition of shallow groundwater illustrates the strong influence of evaporation on the water in refuge wetlands. Isotopic enrichment via evaporation affects surface water, which them mixes with shallow groundwater and positions those samples to the right of the meteoric water lines (Figure 8).

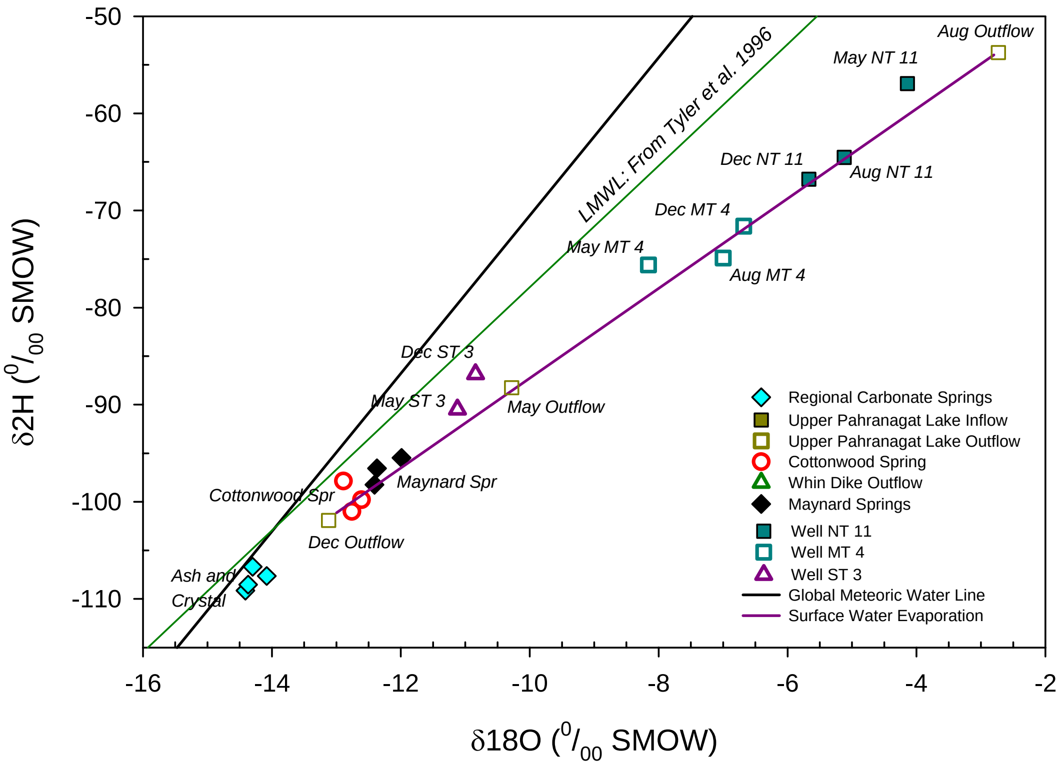


Figure 8: Plot of isotopic composition of waters at or near Pahranagat NWR. Samples collected from regional carbonate springs, Pahranagat NWR springs, surface water, and shallow groundwater.

South of Dove Dike, source waters for wetlands are a combination of surface water released from Upper Pahranagat Lake and groundwater discharge from nearby mountains. Shallow groundwater samples plot along the evaporative trend line of refuge surface waters, which suggests that the source of this shallow groundwater is surface water from Ash and Crystal Springs. However, all groundwater samples are depleted relative to August releases from Upper Pahranagat Lake. Because the groundwater discharging into the Meadow has a different chemical and isotopic signature from the surface water, it is likely the depletion of shallow groundwater samples reflects mixing between surface water releases and groundwater that discharges into the Meadow.

Radiogenic Isotopes

Chemical concentrations and stable isotopic ratios of samples collected at Pahranagat are strongly influenced by evaporative processes. To eliminate the influence of evaporative processes on a sample requires analysis of elements that are conservative with respect to evaporation. The isotopic ratio of strontium (Sr) and uranium (U) isotopes is well suited to this task because it does not change due to evaporation like stable isotopes of oxygen and hydrogen (Clark and Fritz 1997). Instead, isotopic ratios Sr and U change due to chemical reactions between water and rock. Therefore, the ratio of $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{234}\text{U}/^{238}\text{U}$ in a sample is unique to the aquifer discharging to the surface. Analyses of radiogenic isotopic ratios were used to differentiate between water from the regional carbonate-rock aquifer water (represented by Ash and Crystal Springs) and groundwater discharging on Pahranagat NWR (represented by Cottonwood and Maynard Springs) (Figure 9).

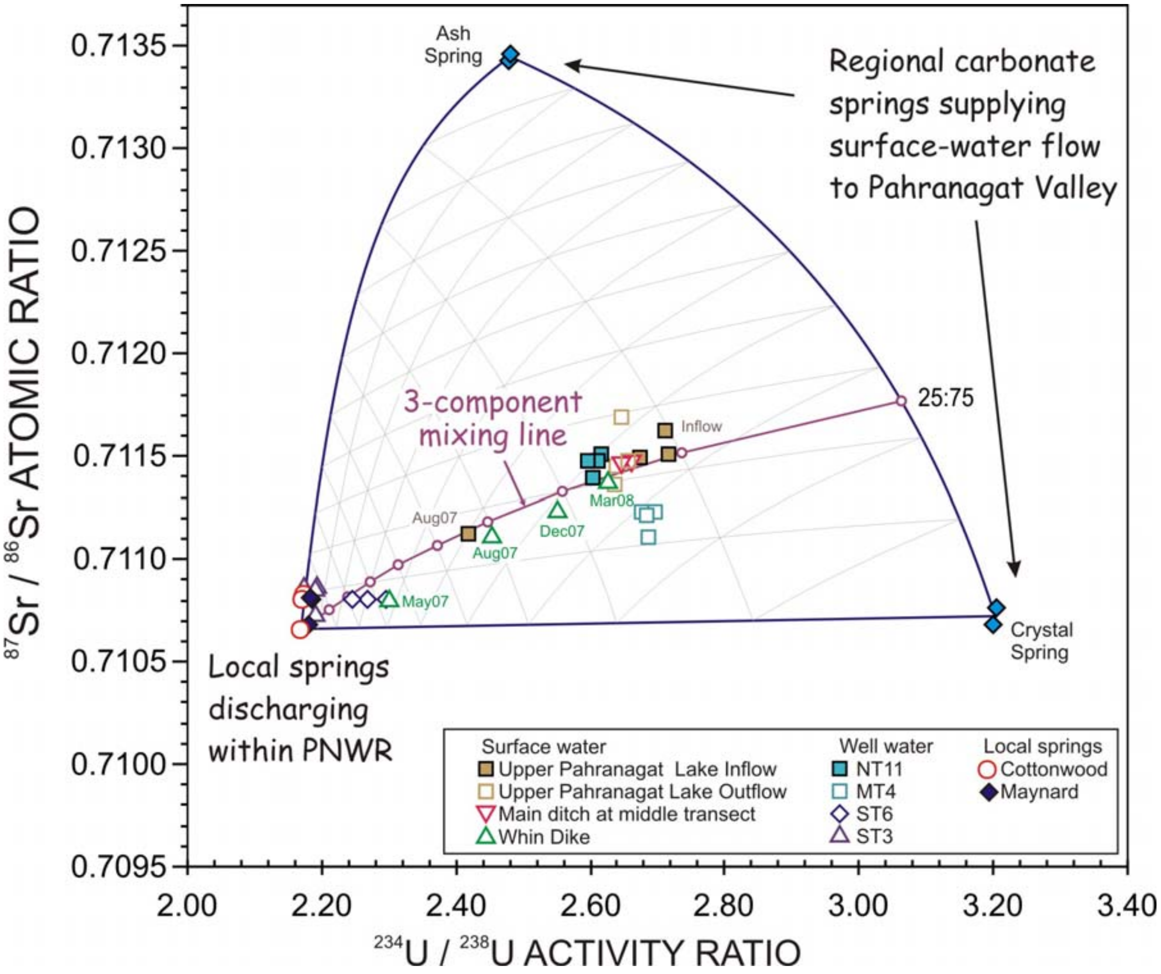


Figure 9: Three-component mixing model of water samples collected at Pahranagat NWR.

Although the carbonate aquifer water discharging at Ash and Crystal Springs has similar chemical and stable-isotope compositions, the ^{87}Sr/^{86}Sr and ^{234}U/^{238}U activity ratios (AR) of the two springs are distinct (Figure 9). The difference is somewhat surprising because the two springs are thought to originate from the same regional carbonate aquifer. These data suggest that water from the two springs follows different flow paths within the regional carbonate aquifer.

Based on flow patterns (See Chapter 4), temperature, and stable isotope concentrations the source water of Cottonwood and Maynard springs is thought to originate locally, as precipitation that falls inside the boundaries of the Pahranagat Valley. The difference between Cottonwood and Maynard springs' ARs and Ash and Crystal Springs ARs seems to support this conclusion. Additionally, the similarity in ^{87}Sr/^{86}Sr and ^{234}U/^{238}U ARs implies Cottonwood and Maynard waters share the same source water.

In summary, isotopic activity ratios support the hypothesis that there are three sources of water for wetlands at Pahranagat: 1) water from Ash Springs, 2) water from Crystal Springs, and 3) water from "local" groundwater sources.

A three-parameter mixing model suggests surface water entering the refuge between May 2007 and March 2008 is a 70:20:10 mixture of Crystal, Ash, and local groundwater. This is the composition of the water stored in Upper Pahranagat Lake before it is released to flood wetlands south of the lake. In the meadow south of Dove Dike, shallow groundwater samples were a mixture of water released from Upper Pahranagat Lake and local ground water. The proportions of Upper Pahranagat Lake water to local groundwater varies with proximity to refuge springs and refuge irrigation ditches. Close to irrigation ditches, shallow groundwater closely resembles Upper Pahranagat Lake water. Further from ditches, shallow groundwater more closely resembles local groundwater. The difference in the two ARs at Whin Dike helped track water management changes on the refuge during 2007 (Figure 10).

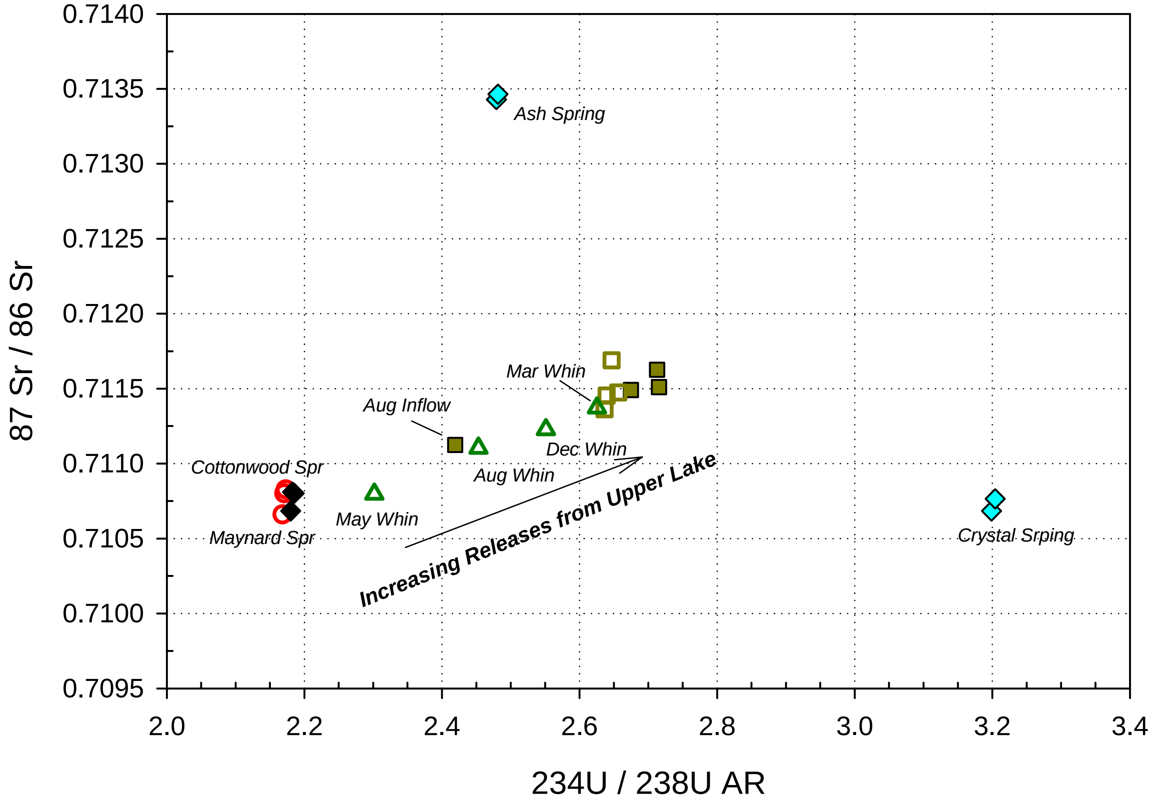


Figure 10: Strontium and uranium activity ratios at selected sites on Pahranagat NWR. Includes samples collected at Whin Dike at different times of the year.

The transition in Whin Dike water chemistry corroborates our observations of water management on the refuge. Prior to flooding the Meadow, water sampled at Whin Dike's outflow consisted of ~50% ground water derived from the local aquifer and 50% Ash and Crystal spring water. After 4 months of continuous flood irrigation, Sr and U ARs indicated that samples from the same site became dominated (>90%) by water from Upper Pahranagat Lake.

The information in Figure 9 and 10 illustrate how ARs can be used to distinguish between source waters at Pahranagat NWR wetlands. During months when little or no water is released from Upper Pahranagat Lake, these data suggest almost 50% of the water at Whin Dike is from groundwater that discharges into the wetland (See Chapter 5). Without this groundwater discharge, wetland habitat at Whin Dike could not exist in its current state. In other parts of the refuge, groundwater discharge plays a similarly important role in maintaining wetland habitat during the summer months. Groundwater discharge areas at Pahranagat NWR are: the north end of Upper Pahranagat Lake, the meadow habitat between ADA Pond and Middle Marsh Dike, small seeps south of Lower Pahranagat Lake, Lone Tree springs, Maynard Springs North and South.

References

Clark, I.D., and P. Fritz. 1997. Environmental Isotopes in Hydrogeology. Lewis Publishers

Drever, J.I. 1997. The Geochemistry of Natural Waters. Third Edition. Prentice Hall.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prentice Hall

Hem. J.D. 1985. Study and Interpretation of the Chemical Characteristics of Natural Waters. Third Edition. U.S. Geological Survey. Water Supply Paper 2254.

Tyler, S.W., Chapman, J.B., Conrad, S.H., Hammermeister, D.P., Blout, D.O., Miller,.J.J, Sully, M.J., and J.M. Ginanni. 1996. Soil-water flux in the southern Great Basin, United States: Temporal and spatial variations over the last 120,000 years. Water Resources Research. Vol 32 (6). 1481-1499

Executive Summary

Over the last 25 years water management at Pahranagat NWR concentrated the water received from Ash and Crystal Springs in the northern third of the refuge. Maintaining more water in the northern third meant less water reached the wetlands and lakes in the southern two-thirds of the refuge. Therefore, it is not surprising the Lower Lake was often dry by October of all but the wettest years and there was rarely water available to flood meadows south of the Lower Lake.

Most of the wetland habitat on the refuge is either wet meadow or open-water. In general more water is needed to maintain open-water habitat than meadow habitat. Not only do meadows require less water to saturate soil, but the rate of evapotranspiration from wetland plants is roughly 40-80% of open-water evaporation. Therefore, more water is required to maintain the open-water dominated habitat in the northern third of the refuge than is required to maintain the meadow dominated habitat of the southern two-thirds.

Beginning with the construction of Upper Pahranagat Lake, storage and distribution of the winter flows from Ash and Crystal Springs has gradually been concentrated in the northern third of the refuge over the last 80 years. We suspect this has gradually led to drying conditions in Lower Pahranagat Lake and may help explain the apparent loss of wetland habitat south of Lower Pahranagat Lake.

Historic Water Management

The last water management plan for the refuge was developed in 1990 by Dave Brown, then project leader at the Desert National Wildlife Refuge Complex. The primary goal of water management at the time of Brown’s report was maintaining minimum water levels in Upper Pahranagat Lake and the North Marsh to support an introduced bass fishery. Secondary objectives included using Upper Pahranagat Lake water to irrigate pasture and croplands in the DU Project Area and Black Canyon. Upper Pahranagat Lake staff gage readings collected between 1984 and 2009 indicate the management strategies outlined by Brown (1990) have been remarkably consistent for the last 25 years (Figure 1).

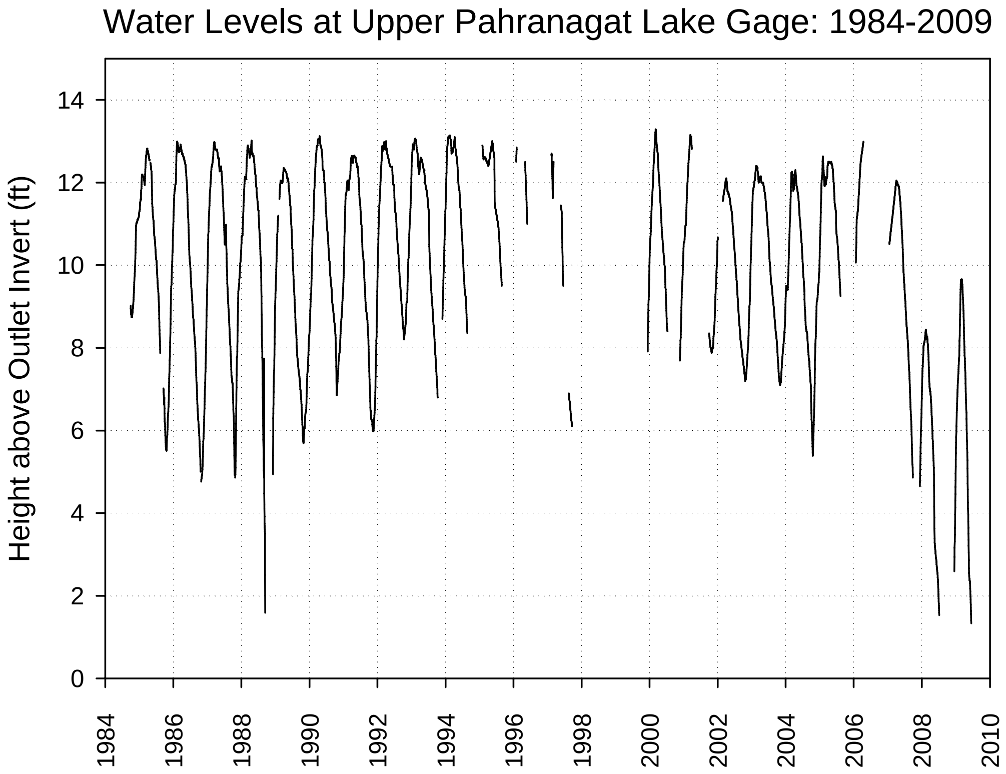


Figure 1: Water levels measured at the Upper Pahranagat Lake staff gage.

Lake levels peak during the winter months when inflows from Ash and Crystal Springs fill the reservoir. The lowest water levels occur in the fall, after months of little surface water inflows and high evaporation rates. The lake has been drained 5 times in the last 25 years (1988, 1996, 2007, 2008, and 2009). For the remaining 20 years, water levels were seldom lower than 3.5 ft on the lake's staff gage. This water level is based on a 1990 agreement between the Service and Nevada Department of Wildlife (NDOW) which set the minimum pool at 4.0 ft on the old staff gage, or 5.5 ft above the bottom of the lake's outlet.

The primary surface water management tool on the refuge is Upper Pahranagat Lake. Because the lake is the principle source of water for the refuge's ditch system between June and October, management decisions affecting the lake affect wetland habitat on the entire refuge. Management of Upper Pahranagat Lake following Brown's plan left water in the lake in order to maintain a minimum pool. Maintaining a minimum pool meant at least 500 acre-ft was not available to flood wetlands further south. However, the total amount of unavailable water exceeded 500 acre-ft because evaporation from the surface of the pool during the summer months would have been lost to refuge wetlands also.

Wetland Water Requirements

The water requirements of a wetland can be defined as the volume of water needed to maintain conditions that support wetland plants, saturated soils, or standing water in the wetland. Determining how much water a wetland needs requires knowing how much water is used by wetland plants; how much water fills a wetland unit; or how much water saturates wetland soils. Hydrologists often try to quantify how much water is needed to maintain wetland systems by developing a water budget. Water budgets attempt to account for all the hydrologic inputs and outputs to a particular wetland and can be written in the form of an equation:

1) Inputs – Outputs = Change in Storage

where inputs are the hydrologic processes bringing water into a particular storage reservoir and the outputs are the processes removing water from that reservoir. In this case a reservoir is any well defined area where water can be stored. Examples include lakes, wetlands, groundwater aquifers, or rivers. If inputs and outputs are equal then there will be no change in storage. When inputs exceed outputs, storage increases and when outputs exceed inputs, storage decreases. Theoretically if all components of the water budget are accurately measured then both sides of Equation 1 will be equal. In practice, accounting for all the parameters of a water budget is not possible and the two sides of equation 1 are rarely equal.

A simple water budget for Pahranagat NWR wetlands can be written in the following form:

2) (Inflow + Precip+ GWin) – (Releases + GWOut + EvapOut) = Change in Storage

Where:
Inflow = Flow from Ash and Crystal springs or refuge irrigation ditches.
Precip = Precipitation falling on the wetland
GWin = groundwater flowing into the wetland from the subsurface.
Releases = water released from the wetland using water control structures.
EvapOut = Water that evaporates from the water surface or is transpired by wetland plants.
GWOut = groundwater that flows from the wetland to the subsurface.
Change in storage is the change in the volume of water stored in the wetland.

NOTE: For the purposes of this discussion reservoirs like Upper Pahranagat Lake are considered wetlands.

The different components of the water budget are quantified by measuring their volume in acre-feet, cubic feet, cubic meters, gallons, etc. The amount of water “needed” by the wetland is the volume of inputs needed to offset the outputs. Both input and output volumes vary throughout the year. Input volumes are greatest during the winter months, when surface water from Ash and Crystal Springs enters the refuge (Figure 2). Outputs are greatest during the summer months when evapotranspiration increases with warmer temperatures and longer days (Figure 3).

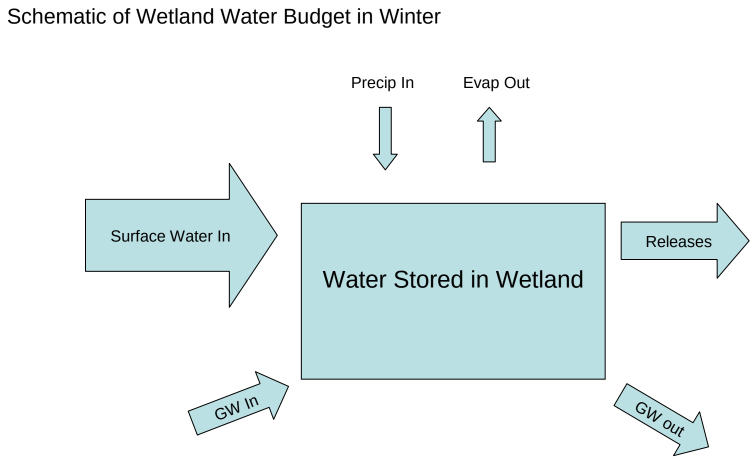


Figure 2: Schematic of winter water budget for Pahranagat NWR wetlands. Arrow size represents relative contribution of each component of the water budget.

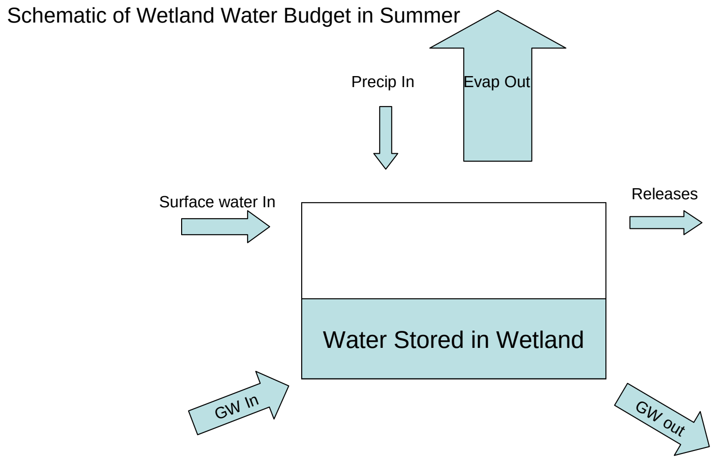


Figure 3: Schematic of summer water budget for Pahranagat NWR wetlands. Arrow size represents relative contribution of each component of the water budget.

The challenge of water management at Pahranagat NWR is the dichotomy between inputs and outputs. Inputs capable of offsetting outputs simply aren't available during the summer months. Instead wetland plants get most of the water they need by removing it from storage. Therefore, water management on the refuge needs to focus on strategies that store the winter inputs in wetlands. Doing so maximizes the available storage, making water available for wetland plants during the summer months. For obvious reasons, if wetland vegetation does not have enough water to survive the habitat will transition to upland plant species and cease to function as a wetland.

As discussed earlier, past water management at Pahranagat has emphasized water storage in Upper Pahranagat Lake, primarily to provide habitat for an introduced bass fishery and irrigation water for crops in Black Canyon and fields near the refuge headquarters. To evaluate the hydrologic “cost” of those management decisions the remainder of this chapter compares water budget components of the two largest wetland units on the refuge: Upper Pahranagat Lake and the meadow between Dove Dike and Whin Dike (Meadow). The Meadow is the single largest wetland unit on the refuge (490 acres) and is characteristic of wet meadow communities in the southern Great Basin (Castelli 2000, Reiner et al 2002). Historic air photographs suggest the Meadow has never been farmed, therefore it may be a close approximation of the wetland habitat in the valley prior to European-American settlement. In contrast, Upper Pahranagat Lake is a man-made open-water wetland. When full, the lake covers 450 acres but the habitat value of the reservoir is questionable since it serves as a refuge for carp and portions of it are easily overgrown with cattails and bulrush.

Open Water Evaporation vs. Transpiration

Comparisons of the rates of evaporation and transpiration for different habitat types provide some perspective of how much water different wetland habitat use. Rates of evaporation and transpiration near Pahranagat NWR are summarized in Table 1.

Table 1: Annual evaporation rates (inches/year) per acre for given wetland habitat types in southern Nevada.

Habitat Type	Ruby Lake NWR (in)[1]	Ash Meadows NWR (in)[2]	Oasis Valley (in)[3]	Moapa Valley (in)[4]
Open Water	66	103	80	59
Dense Wetland Veg. Flooded year-round (bulrush)	50	47	47	47
Dense meadow vegetation. Seasonally flooded (juncus)	38	41	40	Not calculated
Dense grassland vegetation. Water below ground surface	28	42	38	Not calculated

1: From Berger et al. 2001
2: Lazniak et al 1999
3: Reiner et al. 2002
4: DeMeo et al. 2008

Transpiration rates from wetland vegetation communities are 40 – 80% of open water evaporation rates. The highest rates are found in permanently flooded bulrush communities while the lowest rates are in seasonally flooded wet-meadow or grassland habitat where the water table is typically below the ground surface. One would expect evapotranspiration rates at Pahranagat to fall somewhere in between the Ruby Valley, to the north, and Ash Meadows to the south. Interestingly, transpiration rates from wetland plant communities are nearly the same for each study yet open-water evaporation rates for the studies range between 60 and 100 inches per year.

We estimated the open-water evaporation rate for Pahranagat NWR using data collected at a Class A evaporation pan at the refuge and reference evaporation rates calculated at the Alamo CEMP station (Table 2).

Table 2: Estimate of total monthly open-water evaporation at Pahranagat NWR. Median monthly values of reference evaporation estimates from the Alamo CEMP station between 2005 and 2008.

Month	**Total open-water evaporation for the month (inches)**	**Percent of total annual evaporation**
January	2.2	3.3
February	2.7	4.0
March	4.6	6.8
April	6.3	9.4
May	8.6	12.8
June	9.7	14.4
July	9.6	14.3
August	8.4	12.5
September	6.5	9.7
October	4.2	6.2
November	2.7	4.0
December	1.8	2.7
Total	***67.3***	***100***

Estimates presented in Table 1 are based on reference evaporation rates calculated at the Alamo CEMP station north of the refuge. Comparing these values with Class A pan evaporation rates indicate they are a good approximation of open-water evaporation on the refuge. If transpiration from Pahranagat NWR wetlands is similar to the rates presented in Table 1, one can expect wetland habitat requires about 60% to 75% of the water of open-water habitat. All other factors being equal, it will take more water to meet the evaporation demands of an acre of open-water than the transpiration demands of an acre of wetland habitat. This fact has profound implications for water management and wetland restoration at Pahranagat NWR because past management has focused on maintaining open-water habitat (Upper Pahranagat Lake) or building more open-water habitat on the refuge (i.e. Ducks Unlimited Project).

Water Storage in Wetlands and Reservoirs

Hydrologic inputs to wetlands help offset evapotranspiration demands and fill available storage. In this context, storage, is the space where water can be stored for use by wetland vegetation. Water is stored both above and below the ground surface in wetlands. When water is above the ground surface it is typically in a pond or reservoir and held in place by earthen dikes or dams. Below the ground surface, water is stored in the pore space between soil particles. Although the two storage zones are separated for the purpose of this discussion, in reality the two are usually interconnected.

Because very little surface water from Ash and Crystal Springs reaches Pahranagat NWR in the summer months, wetland habitat on the refuge relies on stored water to meet its water needs during the growing season. Most of the stored water in the refuge is found in Upper Pahranagat Lake, Lower Pahranagat Lake, and the wetland soils between Dove Dike and Middle Marsh Dike.

Upper Pahranagat Lake Storage

If Upper Pahranagat Lake could fill to the top of its dam the total storage is 3,900 acre-feet (Figure 4). This includes the North Marsh, which stores approximately 570 acre-feet when full. An acre-foot is the amount of water capable of covering an acre of land with one foot of water; equivalent to 325,851 gallons.

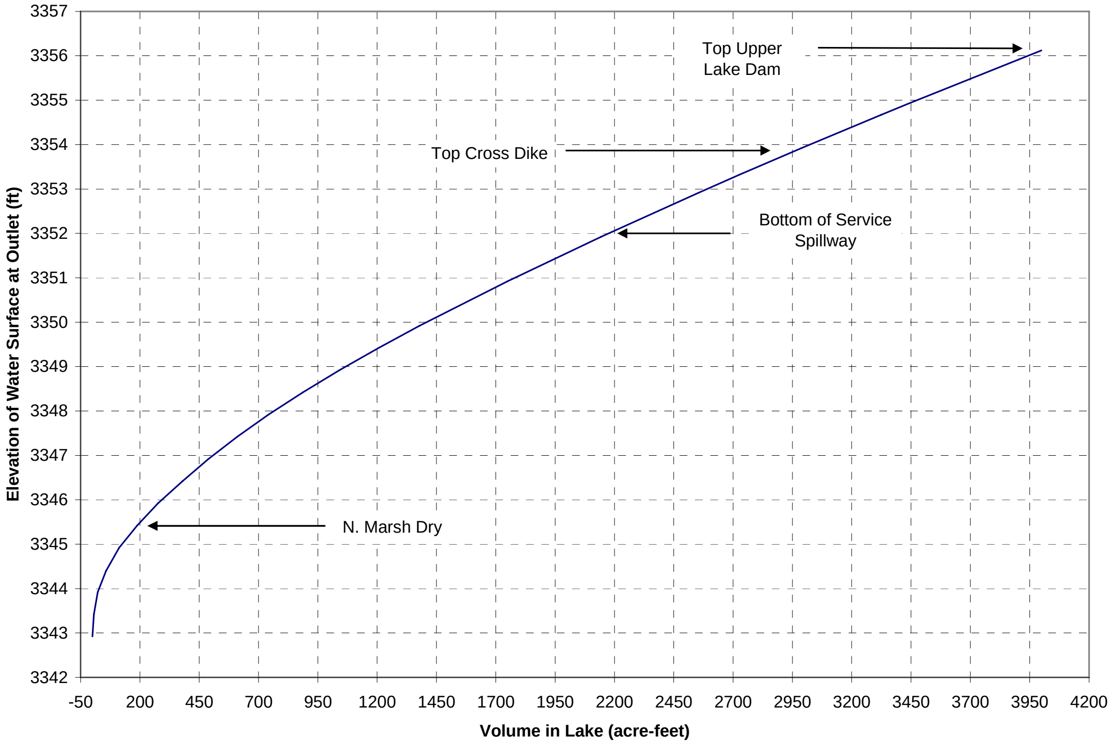


Figure 4: Elevation – capacity curve for Upper Pahranagat Lake. Includes storage in Upper Pahranagat Lake and the North Marsh.

In reality the water level is limited by a service spillway from rising above the 3352 ft elevation. Storage at these water levels is about 2200 acre-ft which is 33% of the median annual inflows (6700 acre-ft) from Ash and Crystal Springs. Therefore, most of the water entering the refuge cannot physically be stored in the lake and must be passed on to wetland areas further south. Water kept in the lake can be released during the summer months to help saturate soils or fill smaller ponds after inflows to the refuge have ceased.

Lower Pahranagat Lake Storage

The other major surface water storage area on the refuge is in Lower Pahranagat Lake. Brown (1990) estimated that available storage in Lower Pahranagat Lake is 750 acre-ft, however this volume has not been verified. Water can be released from storage in Lower Pahranagat Lake to the ditch system south of the lake, however this has not been done frequently. For all practical purposes the lower lake is the terminus of the surface water flow system on the refuge. The water stored there either evaporates or seeps into the subsurface.

Dove Dike to Middle Marsh Dike Storage

Estimating the volume of water stored between Dove Dike and Middle Marsh Dike is complicated because much of the storage area is below ground and the extent of the groundwater reservoir is poorly defined. Other than a few small ponds, the only area for storing surface water is immediately north of Whin Dike, the area between Whin Dike and Middle Marsh Dike, and ADA pond. Combined, these areas probably account for about 400 acre-ft when completely full. The remaining storage area is the pore space of the wetland soils, which can be estimated using the following equation:

3) $S = dV * P$

Where:

S = Available subsurface storage
dV = Change in volume between water table surface at the lowest and highest points of the hydrograph
P = effective porosity of the soil. Estimated 30% for Meadow soils.

Soil texture and soil bulk density from samples collected at 4 wells were used to estimate effective porosity of the wetland soils. For the silt loams we sampled, effective porosity was approximately 30%. Meaning, 30% of the soil profile is capable of storing water and the remaining 70% is occupied by soil particles and residual water bound to the particles. Using Equation 3 and an effective porosity of 30%, the subsurface storage between Dove Dike and Whin Dike is approximately 600 – 700 acre-feet. Unfortunately we did not collect information on water table depths south of Whin Dike and are unable to quantify subsurface storage in the Middle Marsh area. However, observations of year-round standing water suggest the subsurface remains saturated year-round and most of the available storage is above ground in the Middle Marsh.

Both surface water storage and subsurface storage between Dove Dike and Middle Marsh dike is probably more than ½ (1300 acre-ft) of the water that can be stored in the Upper Lake and approximately 20% of the median annual inflows to the refuge. This available storage can fill relatively quickly during the winter months, when releases from the lake reach their maximum. Once the soils and ponds are full, most of the surface water reaching Dove Dike will no longer infiltrate into the subsurface and flow south to the Middle Marsh and Lower Pahranagat Lake. In the summer, when surface water inputs are less than the plant's transpiration, the water table drops as the plants use water stored in the subsurface.

Groundwater Outflows

Groundwater outflows are not considered a significant component of the water requirements of Upper Pahranagat Lake or the wet meadow south of Dove Dike. If water entering a wetland is flowing out of the wetland in large enough quantities to be significant, then the area probably is not a wetland. Wetlands are usually found in poorly drained areas where water does not move quickly into the subsurface. Therefore, it is not surprising that groundwater data collected at the Meadow (see Chapter 5) indicates the wetland has a considerable amount of groundwater flowing into it, rather than out. Observations of seepage and permanent standing water around Upper Pahranagat Lake suggest it too is in an area where the dominant movement of groundwater is into the wetland. Groundwater outflow seems to be more of an issue in the DU Project area. In that area there is no evidence of groundwater flowing into constructed wetlands. Instead, groundwater outflows are significant and the ponds dry up quickly (2-3 days) after surface water is applied. The losses of the surface water are significant (see Chapter 4) and have implications for water availability for refuge wetlands under the management scenarios outlined by Brown in 1990.

Effects of Past Management: Evaporation

Water level data collected in 2007 and 2008 help quantify how much more water evaporates from Upper Pahranagat Lake when water management mirrors those outlined by Brown (1990). The volume of water evaporated from the lake was calculated by multiplying the Pahranagat NWR open-water evaporation rate by the surface area of the lake for two periods in 2007 and 2008 (Table 3).

Table 3: Estimated open-water evaporation based on lake levels in 2007 and 2008. All data are in acre-feet.

	1/19/07 – 8/19/07	**1/19/08 – 8/19/08**
Total volume of open water Evaporation (acre-ft)	1650	600
Total days	213	213
Evaporation rate (acre-ft/day)	7.7	2.8

Evaporation from the lake increases with the surface area of the lake. Consequently, higher lake levels will lead to more evaporation because the lake's surface area is greater. 2008 lake levels were lower than in 2007 because the reservoir was drained to create conditions suitable for repairing the outlet structure. As a result, the volume of water that evaporated from the lake between 1/19/07 and 8/19/07 was more than double the amount for the same period in 2008 (Table 3).

It is important to remember that Pahranagat NWR receives a fixed amount of surface water from Ash and Crystal Springs each year. Because all the inflows to the refuge are stored in Upper Pahranagat Lake, any water that evaporates from the lake is water that is not available for wetland habitat south of the lake. In 2007, total inflows to the lake from Ash and Crystal springs were about 5500 acre-ft. Evaporation between 1/19/07 and 8/19/07 removed the equivalent of 30% of the surface water inflows to the refuge. One advantage of allowing the lake level to drop more than it did in 2007, is less of the surface water inflows are “lost” to evaporation. Because past water management was similar to water management in 2007, the management strategies outlined by Brown (1990) have probably contributed to generally less water being available south of Upper Pahranagat Lake for at least 25 years.

Effects of Past Management: Seepage Losses

In addition to maintaining minimum pool levels, refuge managers used lake water to irrigate 25 acres of cropland in Black Canyon and 125 acres of crops and pasture in the DU project area. Surface water monitoring in 2007 and 2008 suggest 40 to 60% of the water applied to these areas infiltrates into the subsurface (see Chapter 4). Assuming seepage losses in the DU Project were similar in the past, much of the water used to irrigate crops would have infiltrated into the subsurface making it unavailable to wetlands further south. Some of this water is not completely lost from the system because it recharges the alluvial aquifer and ultimately discharges into wetlands in the Whin Dike area after several months or years. However, the short term effect is less surface water available to flood wetlands south of the DU Project area.

Effects of Past Management: Subsurface Storage

To maximize subsurface storage in wetland soils, the area must be flooded so the water table is at or above the ground surface at the beginning of the growing season. Flooding the meadow habitat south of Dove Dike requires releases from Upper Pahranagat Lake between 10 and 15 cfs for 1-2 months. To make sure this flooding occurs at the beginning of the growing season, releases of this scale need to occur in late April and May. Past water management minimized releases during this time period in an effort to fill the Upper Lake as much as possible prior to summer. Therefore, it is likely the available storage in the wetland soils was rarely maximized in the last 25 years and wetland plants in this portion of the refuge were water stressed in the past. Furthermore, less water released from Upper Pahranagat Lake means less water was available to fill Lower Pahranagat Lake, which would probably contributed to it being dry in the fall of most years.

Historic Hydrology and Effects of Past Water Management

There is little information available on hydrologic conditions at Pahranagat NWR prior to establishing the refuge and even less information on conditions prior to constructing Upper Pahranagat Lake. However, enough information exists to piece together a rough idea of how the hydrology of the refuge has changed in the last 100 years.

Based on flow estimates included in the Pahranagat Lake Decree and Carpenter's 1915 report, flow from Ash and Crystal Springs has not changed more than a few cfs in the last 95 years. Due to high evapotranspiration rates during the summer, one can assume there has always been more surface water on refuge lands during the winter months than the summer months. Although flow from Ash and Crystal Springs has not changed, the amount of water from the springs reaching the refuge probably has decreased as more land north of the refuge has been put into production for irrigated agriculture.

Prior to building Upper Pahranagat Lake most of the winter flow from Ash and Crystal Springs would have collected in Lower Pahranagat Lake. Therefore, the wetlands between Dove Dike and the Lower Lake would have been flooded with surface water at least every winter. After the Lower Lake filled any additional water entering it would have spilled out and flowed south into Maynard Lake. The frequency of these spills is unknown and probably did not occur every year. However, because early reports from the valley mention water in Maynard Lake (Carpenter 1915) and local residents in their 80s remember swimming in the Maynard Lake as children (Docktor pers. Comm.), one can assume spill from the Lower Lake occurred into the 1920s.

Building the Upper Lake created a new storage area which allowed ranchers to irrigate crops in the Black Canyon and DU project areas and would have reduced the amount of winter water flowing through the wetlands south of Dove Dike and into Lower Pahranagat Lake. It is likely the frequency of spills to Maynard Lake were reduced or stopped altogether after construction of Upper Pahranagat Lake.

Prior to establishing the refuge, ranchers drained Upper Pahranagat Lake each year in order to use the reservoir's stored water to irrigate crops. Although much of this released water was used in what is now the DU Project Area or Black Canyon, some percentage of it would find its way to the wetlands south of Dove Dike and eventually Lower Pahranagat Lake. After the land was turned over to the Fish and Wildlife Service, still more of the winter flows from Ash and Crystal Springs were stored in Upper Pahranagat Lake due to the minimum lake-level agreement between the Service and the Nevada Department of Wildlife. Building the Cross Dike in 1979 further increased the amount of water stored in Upper Pahranagat Lake.

Over the last 100 years, there has been a progressive shift in how the winter flows from Ash and Crystal Springs are stored and utilized on the lands occupied on the refuge. In general the shift has been from the south end of the refuge to the north end of the refuge; or from Lower Pahranagat Lake to Upper Pahranagat Lake. Not only is the water stored in the Upper Lake unavailable for wetlands further south but a considerable amount of the stored water is lost to evaporation. Additional water was made unavailable by applying it to well drained areas to irrigate crops in Black Canyon and the DU Project Area. The shift in water storage partially explains why there appears to be less wetland habitat south of the Lower Lake today than in 1965 or 1938 (See Chapter 3).

References

Berger, D.L. Johnson, M.J., Turnbusch, M.L., and J. Mackay. 2001. Estimates of Evapotranspiration from the Ruby Lake National Wildlife Refuge Area, Ruby Valley, Northeastern Nevada, May 1999-October 2000. U.S. Geological Survey. Water Resources Investigations Report 01-4234.

Brown D. 1990. Water Management Plan: Pahranagat National Wildlife Refuge, Alamo, NV. Unpublished Report. U.S. Fish and Wildlife Service, Desert National Wildlife Refuge Complex, Las Vegas, NV.

Carpenter, E.1915. Grondwater in southeastern Nevada. U.S. Geological Survey Water Supply Paper 365.

Castelli, R.M., Chambers, J.C., and R.J. Tausch. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian Meadows. Wetlands. Vol 20 (2) 251-266

DeMeo, G.A., Smith, J.L., Damar, N.A., and J. Darnell. 2008. Quantifying Groundwater and Surface water Discharge from Evapotranspiration Processes in 12 Hydrographic Areas of the Colorado Regional Groundwater Flow System, Nevada, Utah, and Arizona. U.S. Geological Survey. Scientific Investigations Report. 2008-5116

Fetter, C.W. 1994. Applied Hydrogeology, Third Edition. Prentice Hall

Lazniak, R.J., DeMeo, G.A., Reiner, S.R., Smith, J.L. and W.E. Nylund. 1999. Estimates of Groundwater Discharge as Determined from Measurements of Evapotranspiration, Ash Meadows area, Nye County, Nevada. U.S. Geological Survey. Water Resources Investigation Report 99-4079.

Reiner, S.R., Lazniak, R.J, DeMeo, G.A., Smith, J.L, Elliott, P.E., Nylund, W.E., and C.J. Fridrich. 2002. Groundwater Discharge Determined from Measurements of Evapotranspiration, Other Available Hydrologic Components, and Shallow Water-Level Changes, Oasis Valley, Nye County, Nevada. U.S. Geological Survey. Water Resources Investigation Report 01-4239.

Conclusions:

Chapter 1: Site Description, Geology, Hydrogeology, and Basic Hydrology

1) All surface water entering the refuge comes from Ash and Crystal springs. Approximately 80% of this water enters the refuge between November and April.

2) Ash and Crystal Springs are fed by a regional Paleozoic carbonate rock aquifer. The boundaries of this aquifer extend far beyond the boundaries of the Pahranagat Valley and are part of the White River regional groundwater flow system.

3) Since the 1960s, total annual inflows to the refuge from Ash and Crystal Springs have declined. This decline appears to be associated with a shorter annual period of inflows to the refuge. In the 1960s, inflows to the refuge lasted about 1 month longer than they do today.

4) The complex geology of the Pahranagat Shear Zone has a marked influence groundwater flow patterns and wetland habitat on the refuge.

Chapter 3: Wetland Habitat Distribution and Trends

1) There are about 1,970 acres of wetland habitat on the refuge.

2) About 90% of the wetlands are classified as palustrine emergent or lacustrine wetlands. The majority of this habitat is distributed between three areas: Upper Pahranagat Lake, Lower Pahranagat Lake, and the area between Dove Dike and Middle Marsh Dike.

3) Riparian wetlands in 2004 - 2006 covered approximately 87 acres, or 4% of the total wetland acreage. This is 2.5 times the riparian acreage on the refuge in 1965.

4) Manmade ponds in 2004 - 2006 covered approximately 87 acres, or 4% of the total wetland acreage. This is 9 times the pond acreage on the refuge in 1965.

5) Overall, the area covered by wetlands has declined slightly (~5%) since 1965. Most of this loss has occurred in the area between Lower Pahranagat Lake and Maynard Lake, which appears drier now than in 1965.

Chapter 4: Surface Water Hydrology

1) Upper Pahranagat Lake is the primary water management tool on the refuge. Water from Ash and Crystal Springs stored in the lake is the main water source for refuge wetlands.

2) A considerable amount of water is lost from the refuge's ditch system as it flows through the DU Project area. This is due to seepage from refuge ditches into the subsurface. At times seepage losses can be 70% or more of the releases from Upper Pahranagat Lake. This water seeps into the subsurface and recharges the alluvial groundwater aquifer.

3) Once surface water reaches Dove Dike, seepage losses decline considerably. Between Whin Dike and Middle Marsh Dike seepage losses from the water distribution system are insignificant.

4) In the Whin Dike/Middle Marsh area, groundwater discharge helps maintain year-round standing water. Therefore, these wetlands are less dependent on Upper Pahranagat Lake water for maintaining wetland habitat conditions than wetlands in the DU Project Area.

5) Flow from refuge springs is seasonal and a small fraction of the water supplied by Ash and Crystal Springs. Peak spring flows typically occur during the winter months. Maximum flow recorded at the refuge's largest spring, Cottonwood, was 35 gallons per minute; less than 1% of the flow at Ash Springs.

6) Refuge springs typically discharge enough water to maintain small pools. Only Cottonwood Spring discharge is large enough to maintain flow from the pool to surrounding wetlands.

7) Low flow volumes, water chemistry, and seasonal fluctuations suggest refuge springs are supported by groundwater flow paths that are different from those supporting Ash and Crystal Springs

Chapter 5: Groundwater Hydrology

1) Movement of shallow groundwater under the refuge is primarily from north to south with additional contributions from the east and west.

2) Areas where groundwater discharges to the ground surface are associated with faults of the Pahranagat Shear Zone.

3) Groundwater discharge occurs at the following refuge locations: the north end of Upper Pahranagat Lake, Whin Dike / Middle Marsh Dike areas, the west side of the meadow south of Dove Dike, south of Lower Pahranagat Lake, and the Maynard Springs area.

4) Depth to groundwater in the DU Project Area and Black Canyon suggest this is an area of high seepage loss from irrigation ditches.

5) Wetlands on the refuge are supported by a combination of surface water from Upper Pahranagat Lake and groundwater discharge. The relative importance of each source is dependent on groundwater flow paths and proximity to refuge irrigation ditches.

6) The water table under refuge wetlands fluctuates seasonally. Water table elevations are highest in the late winter/early spring and lowest in the late fall. Maximum seasonal fluctuations approached 10 ft during our study.

7) The volume of groundwater discharging into refuge wetlands is small in comparison to surface water contributions from Upper Pahranagat Lake. However, in some parts of the refuge and at certain times of the year, groundwater discharge is the only source of water for refuge wetlands.

Chapter 6: Water Quality

1) Water in spring pools tends to be cooler, fresher, and has a lower pH than water in irrigation ditches and lakes on the refuge.

2) Water chemistry analyses confirm that springs on the refuge have a different source than springs fed by the regional carbonate rock aquifer. The source of the spring water is probably alluvial groundwater that is recharged locally by precipitation inside the boundaries of the Pahranagat Valley.

3) Surface water entering the refuge is a 70:20:10 mix of Crystal Springs, Ash Springs, and groundwater with a chemical signature similar to Cottonwood and Maynard Springs.

4) Water collected from refuge wetlands is a mixture of surface water released from Upper Pahranagat Lake and groundwater with a chemical signature similar to Cottonwood and Maynard Springs.

5) Spring pools have lower concentrations of dissolved oxygen than surface water in the ditch system, presumably due to high rates of biological activity, less surface area, and little oxygen-entraining turbulence.

Chapter 7: Historic Water Management

1) Beginning with the construction of Upper Pahranagat Lake, storage and distribution of the winter flows from Ash and Crystal Springs has gradually been concentrated in the northern third of the refuge over the last 80 years.

2) Water management since the refuge was established focused on maintaining a minimum pool in the Upper Lake. This has led to less water available for wetlands south of the headquarters and probably contributed to drying the wetlands in the southern third of the refuge since 1965.

Water Management / Restoration Recommendations

General

The wetland mapping effort highlighted three major wetland habitat areas on the refuge: Upper Pahranagat Lake, Lower Pahranagat Lake, and wetlands between Dove Dike and Middle Marsh Dike. Each area exceeds 300 acres and combined, account for about 75% of the wetland acreage on the refuge. Past water management has kept most of the water from Ash and Crystal Springs in Upper Pahranagat Lake and the DU / Black Canyon area. Adjusting water management so there is a more equal distribution between the three major wetland areas should have the following effects:

Increased open-water habitat at Lower Pahranagat Lake;

Increased seasonally-flooded and saturated wetland habitat south of Dove Dike;

Reduced open-water habitat at Upper Pahranagat Lake;

More seasonal variation in wetland and lake water levels.

Pahranagat’s wetlands can be improved significantly without major infrastructure investments by fine tuning water management and managing the density of wetland plants with fire, heavy equipment, and herbicides.

Below are some water management and habitat management recommendations for different wetland units on the refuge.

Upper Pahranagat Lake / North Marsh

Consider managing the lake as a seasonally flooded wetland, with highest water levels in the late winter / early spring and shallow water or moist-soil in the fall. Allow for partial or complete drawdown occasionally (perhaps every 2-3 years) to promote mechanical vegetation control, moist-soil management and carp control. This will allow more water to be distributed to other wetland areas during the spring and early summer.

High water levels in the North Marsh will facilitate shallow depths to groundwater in the Gooding's Willow forest. Side effects of storing water in the North Marsh are less water available to wetlands south of the headquarters and more cattail growth in the North Marsh. Periodic drying of the North Marsh should not harm the Gooding's Willow forest because local groundwater discharge keeps the water table high enough to reach the root zone. To improve water availability and control cattail expansion, try periodically drying the North Marsh every 2-3 years. Drying the North Marsh should be done in years when higher water levels in the Lower Lake are desirable.

DU Project / Black Canyon

These areas are not well suited to maintaining or creating wetland habitat because seepage rates through the soils are high. Consider this part of the refuge a "flow-through" area where water in the ditch system passes through on its way south. These areas would be well-suited for establishing riparian trees and shrubs adjacent to ditches but trying to maintain an extensive network of flooded wetlands is not recommended.

Dove Dike to Whin Dike

Recommend adjusting stop-logs at Dove Dike to promote sheet-flow during late winter/early spring. If sheet-flow is maintained into May, the water table between Dove and Whin Dikes will be at or above the ground surface in most of the wetland at the beginning of the growing season. This should promote wetland plant growth (i.e sedges, eleocharis) and less upland plant species (i.e. saltgrass, alkali sacaton, great basin rye).

The largest extent of open-water habitat in this area is near Whin Dike. Groundwater discharge here supports standing water year-round. In the absence of dramatic water level fluctuations, the open-water habitat here has become overgrown with cattails and a haven for carp on the refuge.

Try introducing more seasonal water level fluctuations in the standing water behind Whin Dike. Winter / Spring releases from Upper Pahranagat Lake will raise the water level and create open-water habitat. Allow natural drawdown from evaporation during the summer. Groundwater discharge will maintain saturated soil conditions near Whin Dike and limited open water through the summer. Use mechanical and chemical management to keep cattails/bulrush and tamarisk in check.

Middle Marsh

The wetland between Whin Dike and Middle Marsh Dike was a large peat deposit as recently as 1953. At some point between 1953 and 1965 large ditches were dug through the peat to drain it. After 1965 dikes were built across the drainage ditches to create Middle Marsh Pond. Over time, steady water levels promoted cattail and bulrush growth, which reduced the open-water area in Middle Marsh.

Recommend introducing more seasonal water level fluctuations at Middle Marsh. Winter / Spring releases from Upper Pahranagat Lake will raise the water table and create open-water habitat. Allow for natural drawdown from evaporation during the summer. Groundwater discharge will maintain saturated soil conditions but with limited open water through the summer. Use mechanical and chemical management to keep cattails/bulrush and tamarisk in check.

Lower Pahranagat Lake

Water reaches Lower Pahranagat Lake easily when flows at Dove Dike are 10 cfs or greater. If the Upper Lake is managed to allow for more drawdown then water levels in the Lower Lake will be higher than during the previous 25 years. The natural variation in lake levels during the last 2 years appears to have been beneficial for waterfowl at both Upper and Lower Pahranagat Lakes. Higher water levels in the early summer would support seasonally flooded wetland habitat at the northern end of the lake and alkali bulrush on the lake's fringe. Year-round water promotes submerged aquatics like the macro-algae Chara, or muskgrass, on the lake bottom.

The salinity of the Lower Lake should limit expansion of cattails and hardstem bulrush, but will also limit the refuge's ability to establish riparian vegetation such as cottonwoods or willows. Based on review of the historic air photographs, the lake did not become an area for riparian vegetation until tamarisk became established in the 1960s. Consider focusing habitat management on maintaining periodically flooded short emergent vegetation (saltgrass, sea blight), seasonally-flooded to permanently-flooded tall emergents (alkali bulrush), exposed mudflats, and submerged aquatics.

If there is a need to drain the Lower Lake, I recommend doing it in the fall of the year. This follows the natural cycle of wetting and drying in the valley and is much easier to accomplish from a water management perspective. Refuge managers should open the outlet structure on the lake's south end in the spring of the year. This will ensure that the lake level does not rise above the bottom of the outlet structure in June, which will allow evaporation to dry the lake out by October.

South of Lower Pahranagat Lake

Small seeps and springs maintain some areas of wet meadow habitat and permanently flooded pools in this area. The remainder of the land between the lower lake and Maynard Lake is exposed soil, dense invasives (kosha), and dense shrub habitat (rabbitbrush, 4-wing saltbush). With the exception of the handful of springs and seeps the opportunities to create permanent wetlands in this area are limited.

Regular releases from Lower Pahranagat Lake could raise the water table in the vicinity of ditches and promote more seasonally flooded wet meadow habitat. However, to do this, the refuge would need to almost dry the Upper Lake each year. Alternatively, more active vegetation management could promote a balanced mix of upland grasses and shrubs and limit invasive plants.

There is clear evidence in the field and historic air photographs of a meandering channel originating south of the Lower Lake near L-spring area. Perhaps rehabilitation work could focus on creating a more “natural” outlet to the Lower Lake. Swales and weirs could be part of a constructed meandering channel to promote sheet flow and floodplain connection above certain flow rates when the lake is drained.

Maynard Lake

Getting water to Maynard Lake would require a few years of regular winter releases from Lower Pahranagat Lake and draining Upper Pahranagat Lake each year. Additionally, the trenches in the Maynard Lake bed would need to be filled and the ditch from Lower Pahranagat Lake would need to be cleared and rehabilitated Although, putting water in the Maynard Lake bed would be exciting, it is not a recommended management priority. Instead, it is more likely to be a byproduct of choosing to flood the area south of Lower Pahranagat Lake.

The extent of kosha in the lake bed appears to have expanded considerably during the last 2 years. Although the Maynard lake bed is no longer part of the Service’s property, it may be appropriate to consider it when developing burn plans and other invasive species management strategies.

Chub Refugium

The refuge’s ditch system is not well suited for establishing a Pahranagat Roundtailed Chub refugium. There is simply not enough water in Upper Pahranagat Lake to maintain adequate flow conditions in the ditch year-round. Additionally, production from the existing wells is not enough to maintain more than a small, shallow flow of water in the existing ditch.

If a pool-type refugium is suitable for the fish, then the best location is at Cottonwood Springs. Although flow at this spring fluctuates seasonally it is typically enough to maintain a relatively deep pool with a steady outflow of 15-30 gallons per minute. It is likely that the flow at the spring responds to climate variability in southern Nevada. Several years of drought would probably reduce flow into the spring and could cause the pool level to decline or the quality of the pool water to change. Cattails and invasive aquatic animals are important issues to address when designing a refugium at Cottonwood Springs.

Refuge Spring Pools

Refuge springs (Maynard, Lone Tree, L-spring, etc.) were excavated in the past to create small pools of year-round water. Refuge management of spring pools has focused on cleaning them out periodically to remove cattails and create more open-water habitat. Because the flow from the springs is so low, they are not well suited for creating channels from the pools, with the possible exception of Cottonwood Springs.

The Pahranagat PPP team may want to consider developing a conceptual design for spring pool restoration that addresses appropriate pool size, depth, and outlet shapes for the desired habitat effects.

Ditches in Wetlands

Ditches drain wetland soils when the water level in the ditch is lower than the water table in the surrounding wetland. Ditches can be beneficial because managing wetland vegetation requires periodic drying, particularly in permanently flooded areas where tall emergent vegetation dominates. However, in seasonally flooded wetlands, a ditch can prevent the water table from reaching the ground surface. This can promote the expansion of upland vegetation into areas that were once dominated by wet meadow vegetation.

Because ditches at Pahranagat tend to be dry during the summer months, they drain wetlands when the vegetation needs the water most. The refuge should avoid digging more ditches in Pahranagat wetlands and may want to consider filling some of the existing ditches so they no longer intercept groundwater. Only secondary ditches that are not necessary for delivering water to wetland units should be filled. The area between Dove Dike and Whin Dike has several small ditches that may be well suited for filling.

Wetland restoration design should evaluate the effectiveness of the outlet ditches at refuge wetlands to determine if they should be filled, widened or otherwise controlled. Ditches that are deeply incised and lower the water table can be found south of Middle Marsh, south of Lower Pahranagat Lake, and at the inlet to Upper Pahranagat Lake.

Conclusions

Two-thirds of the refuge’s wetlands are found south of the refuge headquarters yet past management focused on keeping the Upper Lake full and the Black Canyon/DU Project area irrigated. Managing water in this fashion contributed to drying large wetlands south of Dove Dike and at Lower Pahranagat Lake. The habitat for migratory birds at Pahranagat NWR can be improved significantly by: 1) distributing water more equally between the refuge’s major wetland units, and 2) expanding on the invasive species and vegetation management the refuge is already doing. Although, the existing irrigation infrastructure is not ideal, with some minor adjustments it can meet most of the refuge’s needs.

The best thing the refuge can do to improve the distribution of water is to draw Upper Pahranagat Lake down to 1 or 2 feet above the lake’s outlet each fall (3343 or 3344 ft). Removing water from storage in the lake will significantly increase the amount of water to other wetlands, and conserve the water supply by reducing the amount of evaporation from the lake. Although this limits the amount of water available to flood small impoundments during fall migration, there would still be 200 to 400 acres of open-water habitat available between Upper Pahranagat and Lower Pahranagat Lake each fall.