US Fish and Wildlife Service

ASH MEADOWS

NATIONAL WILDLIFE REFUGE

Water Resource Inventory and Assessment
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1 Executive Summary

1.1 Findings

1) The Ash Meadows National Wildlife Refuge, established in 1984, comprises about 24,000 acres of spring-fed wetlands and upland desert in the Mojave Desert portion of the Great Basin in southern Nevada. The Refuge is an area of exceptional biological diversity resulting from a unique combination of limited water resources, endemic species, and an isolated desert environment.

2) The Ash Meadows area is in the Ash Meadows Groundwater sub-basin, which is one of several groundwater sub-basins in the Death Valley regional groundwater system, a 15,800 square mile area underlying southwestern Nevada. The regional groundwater system is composed of a highly transmissive regional carbonate aquifer overlain with numerous local basin-fill aquifers. Groundwater is recharged through rainfall and snowmelt in the higher mountain ranges and mesas in the northern and eastern part of the regional flow system. Regional hydraulic gradients, as well as isotope and other chemical data, indicate that the water moves away from these recharge areas several hundred miles to the southwest towards Ash Meadows and Death Valley. The springflow that emerges at Ash Meadows is in transit underground for hundreds or thousands of years before reaching the Refuge and it circulates deeply enough in the Earth to warm considerably.

3) The Refuge has seven major springs that discharge > 500 gallons per minute (gpm) or 1.1 cubic feet per second (cfs) and at least 25 other minor springs that discharge < 500 gpm or 1.1 cfs. Combined, all these springs discharge an average about 23.5 cfs or 17,000 acre-feet (af) annually. The only perennial streams on the Refuge are those flowing from springs. Spring outflow supports streams of several miles, depending on the size of the spring. Eventually, streams dry up as the water is either consumed through evapotranspiration or lost to seepage. There is no perennial flow off of the Refuge. Several intermittent or ephemeral drainages on or near the Refuge, including Carson Slough, only flow in winter or after significant rainfall, although their flow can be considerable and flooding is an issue.

4) The Service currently holds 60 state appropriative water rights for 17,024 acre-feet per year (afy) on the Refuge, 56 permits for surface water (spring discharge) and 4 for groundwater. Most of the water rights were acquired from The Nature Conservancy (TNC) with the property in 1984 or have been appurtenant to more recent property acquisitions. The priority dates of the water rights range from 1886 to 1979. The surface water rights are essentially in-stream flow rights for the spring outflows. The total volume of water appropriated under the Service's surface water rights for springs is 17,014 afy.

1.2 Recommendations

The major recommendations for water resources at the Refuge are:

1) Continue the long-term monitoring of springflows and groundwater levels that is jointly conducted by Water Resources Branch (WRB) and the Refuge. This monitoring was started about 20 years ago to comply with water right permit conditions and to collect baseline data on springflows and water levels at the Refuge. Of particular interest are these springs and wells in the northern part of the Refuge, as a result of declines in springflow and water levels that may be occurring there recently.

2) Continue to work with the National Parks Service, the Nevada State Engineer, and other agencies and entities to defend the Refuges water rights and water resources from water right applications or changes that may injure those rights or threaten those resources. This may involve participating with other Federal agencies in the legal defense of Order 1197. It may also involve filing protests and participating in administrative hearings related to water right protests or seeking a hearing where the Service's water rights are being injured by existing pumping.

2 Introduction

Water Resources Inventory and Assessments (WRIA) are being developed by the National Water Team of the U.S. Fish and Wildlife Service (Service). The purpose of these assessments is to provide reconnaissance level information on water resources at National Wildlife Refuges and National Fish Hatcheries. The assessments provide a basic understanding of water resource issues that are important to the facility and assess the potential threats to those resources.

Data collected in the WRIAs are being incorporated into a national database, which is currently under development. Once the WRIA interactive online database is complete, the information contained within this report and supporting documents will be entered into the national database for storage, online access, and consistency with future WRIA's. Much of the water resource and water right information on the Refuge is available in three files maintained by the Water Resources Branch (WRB): the Ash Meadows NWR Water Monitoring Plan (Mayer, 2000), the Ash Meadows Water Rights Microsoft Access database (Mayer, 2010), and the WRB's Regional Water Monitoring Sites Network Microsoft Access database. Much of the information in the water monitoring plan is referenced rather than repeated here. The files were all updated in process of completing this WRIA.

3 Facility Information

Ash Meadows National Wildlife Refuge (Refuge), established in 1984, comprises about 24,000 acres of spring-fed wetlands and upland desert in southern Nevada. The Refuge is located about 90 miles west of Las Vegas, just a few miles northeast of the California border (Map 1), and is one of four refuges in the Desert National Wildlife Refuge Complex. The Refuge is in the Mojave Desert portion of the Great Basin and Range province and is part of the Desert Landscape Conservation Cooperative or LCC. The Refuge is adjacent to Death Valley National Park in California and the approved Refuge boundary encompasses Devils Hole, a 40-acre detached unit of Death Valley National Park that predates the establishment of the Refuge.

The Ash Meadows NWR was established on June 18, 1984, through the purchase of 11,177 acres of former private, agricultural lands from The Nature Conservancy (TNC). Most of the remaining acreage on the Refuge was transferred to the Service from Bureau of Land Management. According to the Service's 1984 Environmental Assessment: "Proposed Acquisition to Establish Ash Meadows National Wildlife Refuge," the purpose of the acquisition was ". . . to protect the endemic, endangered, and rare organisms (plants and animals) found in Ash Meadows . . ." The Ash Meadows NWR derives its purpose from the ESA, which authorized its creation:

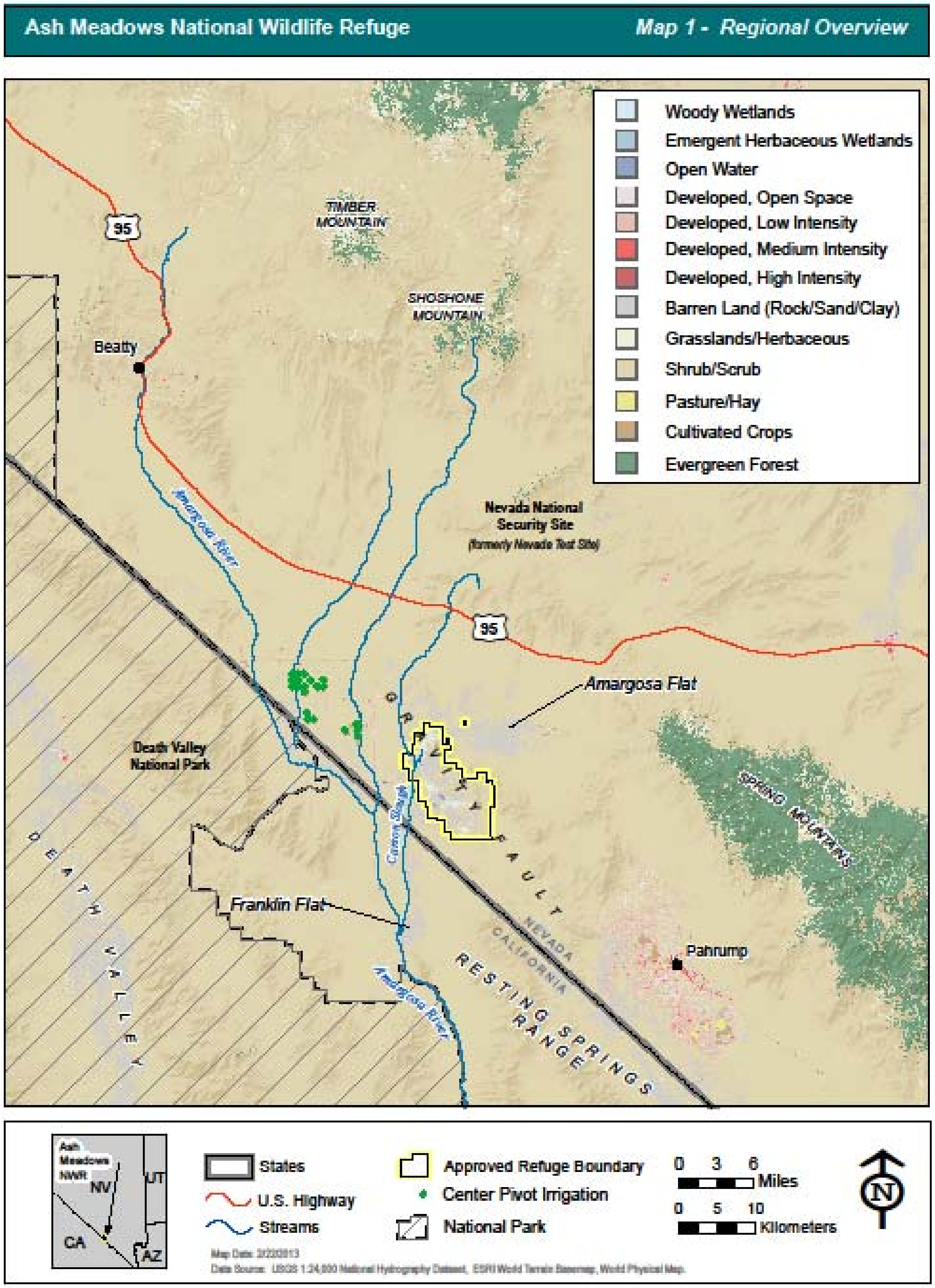
"...*to conserve (A) fish or wildlife which are listed as endangered species or threatened species...or (B) plants*..." (16 USC Sec. 1534).

The Refuge was created to conserve and protect the habitats and populations of endemic, resident, and migratory species. The Refuge is an area of exceptional biological diversity resulting from a unique combination of limited water resources and an isolated desert environment (Adams et al., 2000). At least twenty-five species of plants and animals are restricted to the local geographic area, one of the highest concentrations of endemic species found in the United States.

The Refuge currently provides habitat used by seven listed species: southwestern willow flycatcher (endangered), Yuma clapper rail (endangered), Devils Hole pupfish (endangered), Ash Meadows Amargosa pupfish (endangered), Warm Springs pupfish (endangered), Ash Meadows speckled dace (endangered), and Ash Meadows naucorid (threatened). The last five listed species are endemic to the Refuge (USFWS, 2013).

Almost all species at Ash Meadows are critically dependent on the water resources of the Refuge. The Refuge has seven major springs (discharge > 500 gpm or 1.1 cfs) and at least 25 other minor springs (discharge < 500 gpm or 1.1 cfs). The Service, recognizing the importance of the water resources to the Refuge, holds water rights for almost all of the springs and monitors spring discharge and groundwater levels regularly.

Map 1 – Regional Overview of Ash Meadows NWR



4 Natural Setting

4.1 Topography, Landforms, and Land Use

The Refuge is located at the southern end of the Amargosa Valley and is bordered to the north, south, and west by the Amargosa Desert and to the east by the Devils Hole Hills. The Refuge itself is entirely in Nevada but the Amargosa Valley extends into neighboring California. Most of the Amargosa Valley is dry desert or irrigated agriculture. The Amargosa River flows free and undammed for its entire length of 125 miles through the valley, along and across the boundary of Nevada and California, terminating at Badwater in Death Valley National Park (Map 1). The river is principally fed by regional springflow thought to originate over a vast region ranging across Nevada to Utah. The river does not flow through the Refuge but Carson Slough, an intermittent surface drainage that is tributary to the river, flows across the northern part of the Refuge.

The Refuge's numerous springs lie along a N. 20˚ to 25˚ W. trending line that extends about 10 miles and parallels the trend of the topographic ridge that borders most of the Refuge to the east. The ridge, called the Devils Hole Hills, have an elevation of approximately 3,100 feet above mean sea level (msl). The valley floor of the Refuge slopes gently to the southwest and has an average elevation of 2,060 feet above msl. The elevations of springs on the Refuge range from 2,200 to 2,345 ft, with the highest springs on the east side closest to the Devils Hole Hills (Winnograd and Thordarson, 1975). The pre-pumping elevation of the water surface at Devils Hole, a cavernous sinkhole, was 2,359 ft above msl in the early 1960s, which is higher than any of the springs on the Refuge (Winnograd and Thordarson, 1975).

A large playa, Amargosa Flat, is located northwest of the Refuge and collects runoff from adjacent uplands to the north. The elevation of the playa is 2,331 ft above mean sea level (msl) and the surrounding ridges range from 3,000 to 6,000 ft above msl (Winnograd and Thordarson, 1975). The playa drains to the southwest into the Refuge via a tributary of Carson Slough, which empties into the Amargosa River. Carson Slough seldom flows through its entire extent except after infrequent storms. Mud Lake dam and reservoir, located in Carson Slough, northeast of the Refuge, was constructed in the 1960s and was used to collect runoff from Amargosa Flat for agricultural irrigation prior to the Refuge. The dam has been breached in recent years and is in serious disrepair. A smaller playa, Franklin Flat, is located along the southern boundary and collects runoff from Devils Hole Hills located to the east, from the Resting Spring Range located to the south, and from several springs located along the southeast corner of the Refuge.

The population in portions of the Amargosa Valley region, especially in the rural Nevada community of Pahrump, has soared. For the last several decades, southern Nevada, including the Las Vegas Valley, just to the south and east of the Amargosa watershed, has been one of the fastest growing areas in the nation. Future increases are expected on both sides of the California-Nevada border, all dependent on the limited groundwater resources in the Amargosa region. Currently, agriculture in the Nevada portion of the Amargosa watershed is a very large user of groundwater, with wells servicing large dairies and alfalfa fields (Christian and James, 2007).

4.2 Geology

The Great Basin consists mostly of bedrock and sedimentary basin fill. Bedrock is exposed in mountains or underlies basin fill deposits throughout much of central and southeastern Nevada. The bedrock is either consolidated carbonate rock (such as limestone) or noncarbonate rock (including gneiss or schist, granite, shale and volcanic deposits). The overlying basin fill deposits consist largely of material eroded from the mountains (such as sand, gravel and clay) (Walker and Eakin, 1963).

The valley floor of the Refuge is underlain primarily by alluvial fan and playa deposits of Quaternary age (1.8 million years ago [mya] to present). Tertiary age (65 to 1.8 mya) sedimentary rocks are exposed near the southwestern boundary and central portion of the western boundary. The alluvial fan deposits consist of gravel and rubble near the highlands and grade downward into sand and silt playa deposits in the valley bottoms. The total thickness of the Quaternary sediments in the Ash Meadows area is unknown. Data collected from several water well drilling logs at a ranch located a few miles northwest of the Refuge indicate that gravel and clay are encountered to depths in excess of 700 feet (Winnograd and Thordarson, 1975).

The eastern boundary of the Refuge is formed of limestone and dolomite ridges from the Cambrian period (545 to 490 mya). This boundary contains carbonate hills and ridges as a result of bedrock being dropped down along the Ash Meadows fault system.

As recently as 15,000 years ago, during the colder and wetter geologic time known as the Pleistocene, or Ice Ages, the Ash Meadows area, along with much of the Great Basin, was humid and temperate. Lakes filled many of the valleys, including Death Valley, and rivers connected the region with the Colorado River and the Gulf of California. As the climate warmed, the region turned to desert and surface waters gradually disappeared. Perennial surface water became isolated and confined to a series of springs and seeps in the area of the Refuge and elsewhere. Isolated fish and other organisms in the spring pools and surrounding area evolved into unique species, producing the rich diversity of endemic species that characterize the Refuge today. Their isolation and preferred habitat makes them particularly vulnerable to extinction (Winnograd and Thordarson, 1975; Adams et al., 2000).

4.3 Soils

Soils in the Refuge are forming in alluvial landforms and parent material typical of Great Basin valley fill deposits. At times, coarse alluvium overlies finer lacustrine deposits. Weathering of the surrounding mountains brings a mixture of carbonate or silica rich sediments onto the basin floor.

Soils in arid regions are dry most of the year and have limited leaching due to insufficient precipitation. Low precipitation combined with high evapotranspiration rates draws naturally occurring salts in the soil upward - accumulating close to the surface. The minerals sodium and calcium are two minerals that commonly collect in soils of arid regions. The concentration of soil salts creates both chemical and physical conditions that limit soil permeability and drainage. The desert soils at Ash Meadows are affected to varying degrees by calcium, sodium and other soluble salts.

Alkali soils are soils that have a pH of 7.0 or higher. Most of the soils in Ash Meadows have a pH in excess of 8.5. These higher pH soils reflect the presence of calcium and sodium in the soils. Calcium carbonate accumulations can form dense, impermeable layers that create perched water tables. Yurm soils have a lime-cemented hardpan below 16 inches and are found on alluvial flats throughout the Refuge. Strongly alkaline soils with pH greater than 8.5 tend to become sticky when wet and are nearly impermeable to water. When they dry, they become hard, cloddy and crusty.

Saline soils contain an excess of soluble salts such as chlorides and sulfates of sodium, calcium and magnesium. Only salt tolerant plant species can grow on these soils. Water infiltration is usually good through saline soils as water can flow through the pores formed by the aggregated clays. Casaga soils are moderately saline and are found on basin floors and toeslopes throughout the Refuge.

NRCS soil mapping within the Ash Meadows NWR consists of generalized groups of one or more soil types. In some groups, soil qualities of the minor components can be dissimilar and thus present different limitations than the major components. Maps of soil properties based on the generalized groups do not always illustrate the range of possible variability on site. Caution should be used when interpreting soil properties at the Refuge scale.

Map 2 shows the spatial distribution of soil map units on and around the Refuge and **Table 1** describes the acreage and summary characteristics of those units.

Map 2. Soil Map Units on and adjacent to the Refuge

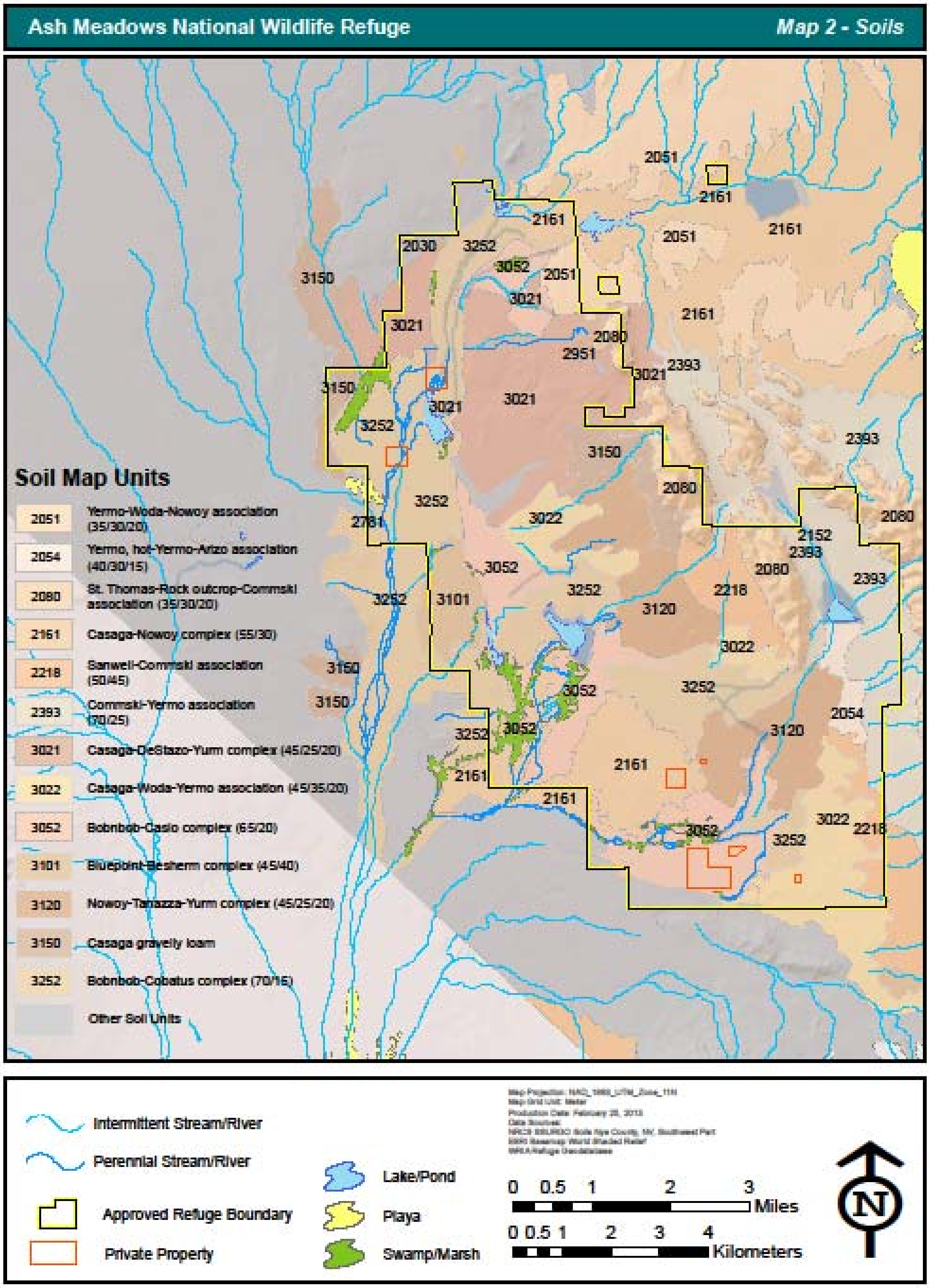


Table 1 Major Soil Types Found within the Approved Boundary of the Ash Meadows NWR (source NRCS)

SOIL MAP UNIT NAME and SUMMARY CHARACTERISTICS	**MAP SYMBOL**	**ACRES** (within approved boundary)	**pH Alkalinity** (Dominant Component Weighted average all layers)	**Salinity** (Dominant Component)
Bobnbob–Cobatus (70/ 15) complex 0 to 2 percent slopes Soils are very deep and somewhat poorly drained.	3252	4926	8.8 Strongly alkaline	Slight
Bobnbob–Caslo complex (65/20) 0 to 4 percent slopes Soils are very deep and somewhat poorly to poorly drained.	3052	3564	9.1 Very strongly alkaline	Slight
Casaga – DeStazo –Yurm complex (45/25/20) 2 to 8 percent slopes Casaga and DeStazo soils are very deep and well drained. Yurm soils are shallow to a calcium carbonate cemented hardpan.	3021	2760	8.6 Strongly alkaline	Moderate
Nowoy-Tanazza-Yurm association (45/25/20) Nowoy and Tanazza soils are very deep and well drained. Yurm soils are shallow to a calcium carbonate cemented hardpan.	3120	2550	8.6 Strongly alkaline	Slight
Casaga-Woda-Yermo association (45/35/20) Casaga and Yermo soils are very deep to deep and well drained. Woda soils are shallow to a calcium carbonate cemented hardpan.	3022	1910	8.6 Strongly alkaline	Moderate
Casaga-Nowoy complex (55/30) 2 to 4 percent slopes Soils are very deep and well drained. The surface is often covered by desert pavement of pebbles and cobbles.	2161	1802	8.6 Strongly alkaline	Moderate
Commski-Yermo association (70/25) Soils are very deep to deep and well drained.	2393	1530	8.5 Strongly alkaline	Slight
St. Thomas-Rock outcrop-Commski association (35/30/20) St. Thomas and Commski soils are well drained and very shallow to bedrock.	2080	1053	8.5 Strongly alkaline	Non Saline
Sanwell-Commski association (50/45) Soils are deep and well drained.	2218	1036	8.7 Strongly alkaline	Slight
Casaga gravelly loam 2 to 4 percent slopes This soil is deep and well drained.	3150	760	8.6 Strongly alkaline	Moderate
Bluepoint-Besherm complex (45/40) 2 to 15 percent slopes Soils are deep and somewhat excessively drained.	3101	582	8.5 Strongly alkaline	Non Saline to Moderately Saline
Yermo, hot-Yermo-Arizo association (40/30/15) Soils are deep and well drained.	2054	379	8.5 Strongly alkaline	Non Saline
Yermo-Woda-Nowoy association (35/30/20) 2 to 4 percent slopes Soils are very deep and well drained.	2051	316	8.5 Strongly alkaline	Non Saline

4.4 Hydro-Climate

The Ash Meadows area is typical of areas in the Mojave Desert with short mild winters, long hot summers, and low annual rainfall. There is strong surface heating during the day and rapid nighttime cooling because of the dry air, resulting in wide daily ranges in temperature. Even after the hottest days, the nights are usually cool. Daily ranges are larger in summer than the winter (Western Regional Climate Center, 2013). Summer temperatures above 100° F occur rather frequently in southern Nevada. Humidity is usually low. The freeze-free season is over over 225 days in southern Nevada.

Nevada lies on the eastern, lee side of the Sierra Nevada Range, a massive mountain barrier that markedly influences the climate. One of the largest precipitation gradients in the United States occurs between the western slopes of the Sierras in California and the valleys just to the east of this range. The prevailing winds are from the west, and as the warm moist air from the Pacific Ocean ascends the western slopes of the Sierra Range, the air cools, condensation takes place and most of the moisture falls as precipitation. As the air descends the eastern slope, it is warmed by compression, and very little precipitation occurs. The effects of this mountain barrier are felt not only in the west but throughout the state, with the result that the lowlands of Nevada are largely desert or steppes.

The PRISM (Parameter-elevation Regressions on Independent Slopes Model) uses available NWS, SNOTEL and other point measurements of climate variables and pairs these with a digital elevation model and expert knowledge to create a continuous digital grid of estimated climate parameters (Daly et al, 2008). PRISM offers a more complete picture of local climatology than traditional point data by spatially interpolating data across the landscape. Average monthly precipitation and maximum and minimum monthly temperature for the Refuge are presented in Table 2, using PRISM data for the period 1981-2010.

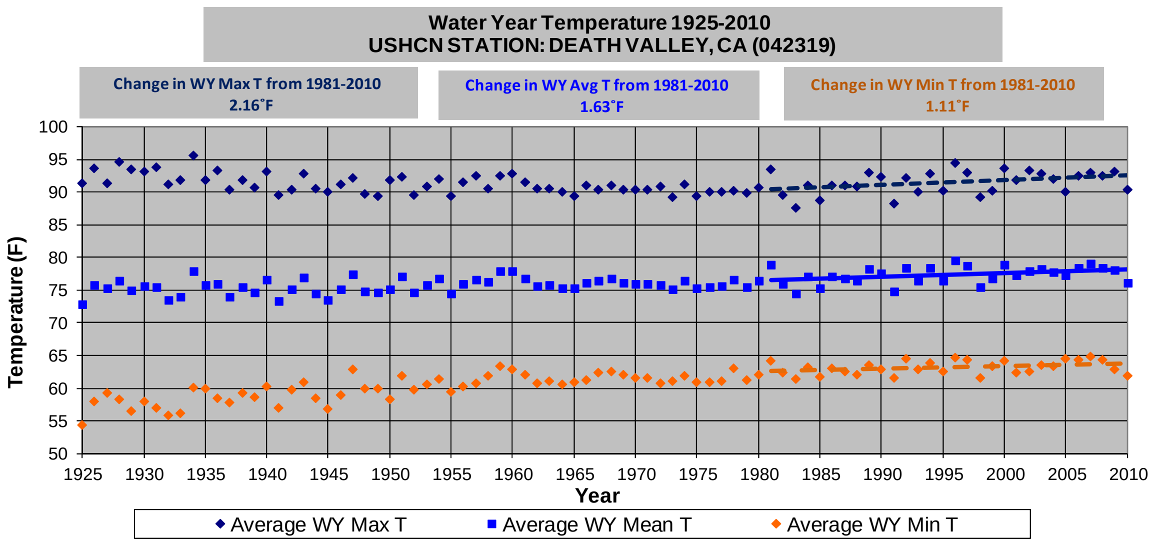
Mean annual precipitation and air temperature at the Refuge for 1981-2010 is 4.2 in/yr and 18.35˚C, respectively. Annual open water evaporation was estimated to be 6.2 to 6.8 ft/yr (Winnograd and Thordarson, 1975). Laczniak et al. (1999) measured a higher rate of open water evaporation of 8.6 ft/yr. The important point is that annual evaporation far exceeds annual precipitation in this environment.

While precipitation is slightly higher during the winter months, July through September can be fairly wet as well, due to the influence of the North American Monsoon. During the summer monsoon season, which extends from about mid-July to September, winds in the southwestern U.S. reverse direction and shift from the west or northwest to the south or southeast. These southerly winds bring moisture northward from the Pacific Ocean or the Gulf of Mexico, increasing precipitation in the southwestern US. Ash Meadows and Southern Nevada are at the northern end of the geographic area affected by the summer monsoon, so the increase in precipitation is not as great here. Nevertheless, some of the worst floods and most intense rainfall events in the Las Vegas area, 90 miles to the east of the Refuge, have occurred in the summer months, including a storm on July 8, 1999 with rainfall totals as high as 3.2 inches recorded in the Las Vegas valley.

Table 2 PRISM Monthly Normals (1981-2010) for Ash Meadows NWR. 800 m dataset (source PRISM Climate Group)

Month	Precipitation (in)	Min Temperature (C)	Max Temperature (C)
January	0.6	16.2	-0.2
February	0.8	17.9	1.6
March	0.5	22.3	4.8
April	0.2	25.6	8.1
May	0.1	29.7	13.1
June	0.1	35.6	17.6
July	0.3	40.0	21.3
August	0.4	39.1	20.4
September	0.3	35.1	15.7
October	0.2	28.5	9.4
November	0.3	20.8	3.1
December	0.5	15.6	-0.9
Total Precipitation	**4.2**		
Average Temperature		**27.2**	**9.5**

The US Historical Climatology Network (USHCN) is a network of climate monitoring sites maintained by the National Weather Service (Menne et al., 2011). Sites in the network are selected because their location and data quality make them well suited for evaluating long-term trends in regional climate. The closest USHCN station is at Death Valley National Park, which is considerably lower in elevation and hotter than Ash Meadows. However, trends and seasonal patterns at this site should be similar to Ash Meadows. Temperature data from Death Valley National Park show an increase during the most recent 30-year period (1.63˚F or 0.91˚C for average annual temperature, Figure 1). While minimum temperature have not increased as much as maximum temperature over the last 30 years, the increase in minimum temperatures appears to be constant over the entire period of record, consistent with other findings. Summer temperatures have risen more than at other times of the year (data not shown).



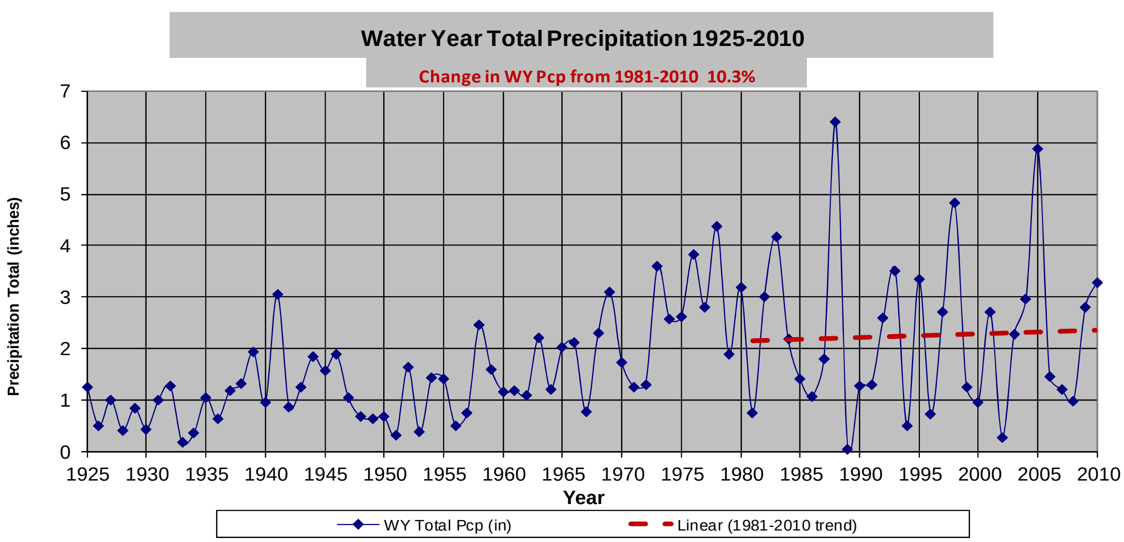


Figure 1. Average air temperature (top) and total precipitation (bottom) by water year from Death Valley National Park USHCN station for the period 1925-2010. Linear trends are shown for the last 30 years

Precipitation has also shown an increase in the last 30 years, although the 10% increase is not statistically significant because of the variability in precipitation over the same period. What is most striking is the general increase in precipitation since about the 1970s (Figure 1). While the site is very dry, with a mean annual precipitation of 2.3 in/yr from 1981-2010, precipitation is much greater during the most recent 50 years compared to the first half of the 20th century. Some of this increase may be related to increasing El Nino Southern Oscillation (ENSO) activity. The Desert Southwest, including the Death Valley area and Ash Meadows area, is very sensitive to ENSO. El Nino is typically associated with much greater precipitation in the region compared with La Nina (Figure 2).

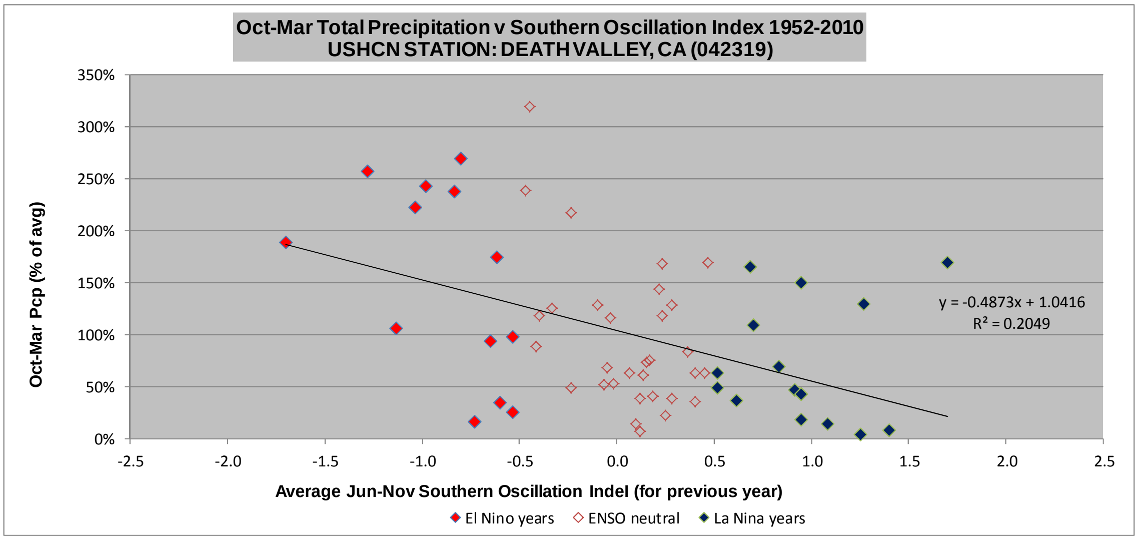


Figure 2. Winter (Oct-Mar) precipitation totals in relation to ENSO at Death Valley National Park USHCN station for the period 1952-2010

Time series of monthly precipitation and temperature data compiled for the entire state of Nevada are plotted and summarized on the Nevada Climate Tracker website http://www.wrcc.dri.edu/monitor/nev-mon/index.html . There are strong warming trends apparent in this temperature dataset as well over the last century. Mean annual temperatures have increased about 1 ˚C since 1895 and the rate of increase is greater for more recent periods. Minimum temperatures have increased more than maximum temperature and summer warming has been greater than winter warming. Precipitation trends are much weaker over the same period, showing a slight increase in annual precipitation over the 20th century (Western Regional Climate Center, 2013).

4.5 Climate Change

A broad scientific consensus based on basic theory, climate model simulations, and observations, has emerged to support the idea that humans are changing the Earth's climate (IPCC, 2007; NAS 2008; GCRP 2009). Temperatures have increased between 0.3°C and 0.6°C across the Great Basin over the 20th century (Chambers, 2008). Climate models predict warming and a general drying trend with increasing air temperatures, increasing evapotranspiration, and decreasing precipitation (Hughson et al., 2011). Model projections for the Great Basin and Mojave Desert region show temperature increases of 1.3˚C by the early 21st century, 2.8˚ C by mid-21st century and 3.8˚C by the late 21st century, relative to 1971-2000 (Redmond, 2010). Model projections indicate that there will be drier conditions in the south trending towards average precipitation in the northern parts of the Great Basin (Redmond, 2010). Summer warms slightly more, and winter slightly less, than the annual mean temperature warms, and spring and fall changes are close to the annual change. ENSO has a strong effect in southern parts of the Great Basin, but the impact of climate change on ENSO is not known (Collins et al., 2010).

The combined effect of simultaneous temperature and precipitation has an effect on hydrologic function (Redmond 2010). All other factors held constant, cooler weather precipitation is more effective at recharging soil moisture than is warmer weather precipitation (e.g., Winograd et al., 1998). Cool weather precipitation often falls as snow, melts at near freezing temperatures, and percolates into the substrate at a steady rate. In contrast, warmer weather precipitation, falling on warm or hot surfaces, encounters significant evaporation and a major fraction returns to the atmosphere relatively quickly. So warmer temperatures with no change in precipitation can in effect act like a slight decrease in precipitation due to a decrease in infiltration and recharge, depending on the temperature increase.

A general drying trend coupled with a variable precipitation regime is likely to severely alter the hydrologic cycle and stress human water delivery systems. In addition to lower snowpack and earlier spring melt, both extreme flood events and extreme drought are likely. Decreased runoff and increased evaporation on the Colorado River system imply that current regional water demands will not be met in the future, increasing the pressure to develop scarce groundwater resources. Decreased flows combined with increasing urban populations will require that water managers seek other sources for water supplies. Reduced recharge from decreased snowpack and increased ET may eventually impact regional spring flow at the Refuge, although it may take many years before measureable impacts are observed.

5 Inventory Summary and Discussion

5.1 Water Resources

5.1.1 Hydrogeology

In the Great Basin, most groundwater originates from rain and snow that falls on the higher mountains. Runoff from the rain and snow directly enters fractures in the bedrock that comprises the mountains, or flows down from the mountains in streams and percolates into the sedimentary fill that comprises the valleys (Prudic et al., 1993). Water that percolates downward and reaches the water table is commonly referred to as “recharge.” The water table is the point where the subsurface material is saturated—that is, all of the space between the subsurface materials is occupied by water. The water-bearing basin-fill and carbonate rock into which the runoff percolates are called aquifers. Considered together, the carbonate rock and linked basin fill deposits constitute the principal regional aquifer system. Non-carbonate rocks are often much less permeable than carbonate rock or basin fill sediments, posing a barrier to groundwater movement.

The Ash Meadows area is in the Ash Meadows Groundwater sub-basin, which is one of several groundwater sub-basins in the Death Valley regional groundwater system, a 15,800 square mile area underlying southwestern Nevada. The regional groundwater system is composed of a highly transmissive regional carbonate aquifer overlain with numerous local basin fill aquifers. The exact boundary of the regional flow system is still being debated but we know that it extends several hundred miles north and northeast of the Refuge (Winnograd and Thordarson, 1975; Prudic et al., 1993; Thomas et al., 1996; Koonce et al., 2006). Groundwater is recharged through rainfall and snowmelt in the higher mountain ranges and mesas in the northern and eastern part of the regional flow system. Regional hydraulic gradients, as well as isotope and other chemical data, indicate that the water moves away from these recharge areas several hundred miles to the southwest towards Ash Meadows and Death Valley (Winnograd and Thordarson, 1975; Prudic et al., 1993; Thomas et al., 1996; Koonce et al., 2006). The water that emerges at Ash Meadows is in transit underground for hundreds or thousands of years before reaching the Refuge and it circulates deeply enough in the Earth to warm considerably (Winnograd and Thordarson, 1975).

Spring discharge at Ash Meadows is thought to be supported mainly from recharge on the Spring Mountains to the east and but also from the other mountain ranges to the north and northeast (Map 1). There is very little subsurface flow from the Pahrump Valley to Ash Meadows (Winnograd and Thordardson, 1975, Prudic et al., 1993) or from the central Amargosa Valley and southwestern Jackass Flats to Ash Meadows (Winnograd and Thordardson, 1975).

5.1.2 Rivers/Streams/Creeks

The only perennial streams on the Refuge are those flowing from springs. Spring outflow supports streams of several miles, depending on the size of the spring. Eventually, streams dry up and disappear as the water is either consumed through evapotranspiration or lost to seepage. No perennial streams flow off of the Refuge (Map 3).

As discussed above, Carson Slough is the largest of several ephemeral drainages on or near the Refuge. As is typical in desert environments, these streams only flow after significant rainfall, although their flow can be considerable and flooding is an issue.

5.1.3 Canals and Drainage Ditches

There are a number of canals and ditches associated with irrigation activities that predate the Refuge. The outflows from many of the springs were collected and channelized for farming and irrigation. Few of these canals are still functional but there are remnants and sections of canals scattered throughout the Refuge, mostly in disrepair. The Refuge has completed restoration of several natural stream channels including Crystal Springs, Kings Pool and Point of Rocks, Fairbanks Spring, Schoolhouse Springs, and the Warm Springs complex. The next major restoration project, involving the outflows from Longstreet and Rogers Springs, is scheduled to begin in 2013.

5.1.4 Reservoirs

There are two major reservoirs on the Refuge: Peterson reservoir and Crystal reservoir (Map 3). These reservoirs predate the Refuge and were constructed for irrigation supply. Springflow is diverted and collected in the impoundments. Seepage and outflow from the reservoirs have created wetland habitat downstream of the reservoirs. Both dams are in poor shape.

Mud Lake dam and reservoir, located in Carson Slough, northeast of the Refuge, was constructed in the 1960s and was used to collect runoff from Amargosa Flat for agricultural irrigation. The dam has been breached in recent years and is also in serious disrepair.

5.1.4 Springs

Spring discharge in the Ash Meadows area results from one or more buried faults oriented northwest to southeast along a 10-mile line known as the Gravity Fault. Lake beds and bedded tuff on the west side of these faults act as an aquitard to restrict the lateral flow of groundwater in the area, forcing it to discharge at the surface (Winnograd and Thordardson, 1975; Dudley and Larson, 1976). Approximately thirty springs (Map 3) collectively discharge about 23.5 cfs or 17,000 acre-feet/year (afy) (Walker and Eakin, 1963). The total number of springs on the Refuge is difficult to quantify there are numerous areas of obvious seepage or high water table that have no surface water but do support water-dependent vegetation. Springs have been categorized into major springs (those having average discharge > 500 gpm or 1.1 cfs) and minor springs (those with average discharge < 500 gpm or 1.1 cfs). The seven major springs, from north to south, are Fairbanks, Rogers, Longstreet, Crystal, Kings Pool, Jackrabbit, and Big Springs.

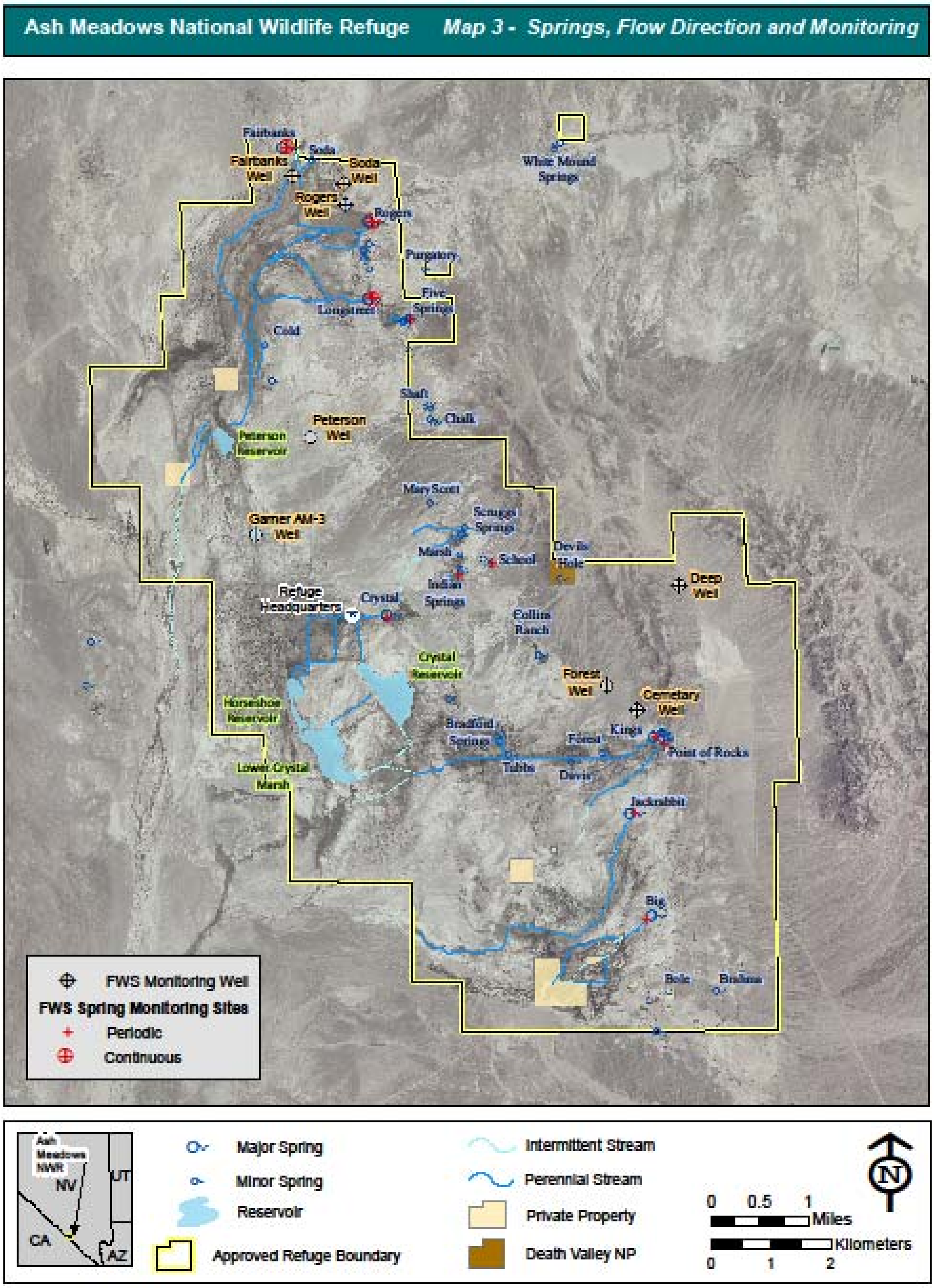
About 90% of the total spring discharge comes from the seven major springs. Although long-term continuous discharge measurements are not available at every spring and seep, generally, the total spring discharge has been fairly constant over the past several decades (Laczniak et al., 1999; Fenelon and Moreo, 2002). All the major springs emerge from circular pools, are relatively warm, and discharge at a fairly constant rate. The consistency and large volume of flow, the vertical head gradients, the water temperatures well above mean annual air temperature, and the uniform water chemistry indicate that the majority of spring discharge at Ash Meadows originates from the regional carbonate aquifer (Winnograd and Thordarson, 1975). Present-day climate conditions are extremely arid at the Refuge, and recharge on the adjacent Devils Hole Hills to the east cannot sustain such high spring discharge.

5.1.4 Groundwater

Ash Meadows NWR lies within the Amargosa Valley Hydrographic Basin (Basin 230; see NDWR website http://water.nv.gov/mapping/maps/designated_basinmap.pdf). The Refuge is underlain by a regional carbonate aquifer and a local valley-fill aquifer (Winograd, 1975; Dudley and Larson, 1976). Almost all of the springs are sourced from the carbonate aquifer. At Point of Rocks, springs appear to discharge directly from the carbonate aquifer because of the carbonate rock outcrop. Other springs on the Refuge discharge from the valley-fill aquifer, which is derived from and connected to the carbonate aquifer. The valley-fill aquifer is fed by regional groundwater through direct flows and surface water percolation of springflow.

Total spring discharge from the Ash Meadows area is currently about 17,000 afy (Laczniak et al., 1999), the same as the estimate from 40 to 50 years ago (Walker and Eakin, 1963). Service water rights for springs total 17,014 afy; essentially protecting all the spring discharge. Total groundwater discharge, based on phreatophyte ET measurements, is 18,000 to 21,000 afy (Laczniak et al., 1999). Since the range of phreatophyte ET exceeds the total spring discharge, this indicates that all the spring discharge on the refuge is consumed through ET and there is no spring discharge leaving the area and returning to the groundwater system (Laczniak et al., 1999). This means that none of the 17,000 afy of spring discharge is available for subsequent appropriation elsewhere in the basin.

Map 3 – Springs, Monitoring Sites, and Flow Direction at Ash Meadows NWR



Map Projection: NAD 1983 UTM Zone 11N
Map Date: 10/18/2013
Data Source: USFWS cadastral database (boundaries), USFWS field data collection (springs, wells, streams), USDA NAIP 2010 Aerial Imagery (basemap)

Shallow groundwater is usually 1˚ to 2˚C above mean annual temperature (Heath, 1983). Mean annual air temperature for the Refuge is 18.4˚C, as discussed above in the Hydro-Climate section. Water in the shallow upper basin fill wells on the Refuge is about 19.5˚C, slightly higher than mean annual air temperature, and water in the deep carbonate aquifer is 33.5˚C to 34˚C.

A heat gradient exists between the two aquifers. Most of the springs on the Refuge are well above mean annual air temperature, indicating they are sourced from the deeper carbonate aquifer, but there is some variation in water temperatures across the Refuge. Springs near the carbonate ridges on the east side of the Refuge, where the carbonate aquifer is shallowest, have little time to cool as they reach the surface and they all are hot (Winnograd and Thordarson, 1975). For example, water temperatures at Devils Hole and one spring at Point of Rocks (which discharges directly from carbonate) are 33.5˚C and 34˚C, respectively. Springs within ½ mile of the ridge that borders the Refuge on the northeast have temperatures > 32˚C, regardless of their discharge. However, at greater distances from the ridge, where the carbonate aquifer is buried deeper, there is more time to cool as the water flows to the surface. The temperature of larger springs remains fairly warm further from the carbonate ridge (27˚C to 34.5˚C), but the smaller discharge springs are cooler than this. The small discharge at Cold Spring (19.5˚C) apparently spends enough time in transit to approximate the mean annual air temperature. Three major springs on the north part of the Refuge (Fairbanks, Rogers, and Longstreet) are relatively cool (27˚C to 29˚C), considering their proximity to the carbonate ridge and their large discharges, and this fact has led some researchers to suggest that they may be fed by shallower flow paths from the north or northeast (Dudley and Larson, 1976).

5.2 Water Quality

5.2.1 Surface Water Quality

Under section 303(d) of the Clean Water Act, the state of Nevada is required to develop a list of waters in the state that fail to meet water quality standards. At this time, Nevada has not designated a beneficial use for any of the waters within the Death Valley Region, which includes Ash Meadows; therefore water quality standards have not been set (see NAC 445A.2232 and NAC 445A.2234).

The water chemistry of the major springs and Devils Hole is remarkably uniform (Winnograd and Thordarson, 1975; Dudley and Larson, 1976). Sodium is typically about 40% of the total cations, followed by calcium, and then magnesium. Bicarbonate is about 70% of the total anions, followed by sulfate and chloride. Wells and smaller springs are more enriched in sodium, sulfate, and chloride, due to their longer period of residence in local aquifers (Koonce et al., 2006).

Groundwater is known to inherit the geochemical composition of the aquifer material through which it has flowed. The geochemical composition of the springs is very similar to most carbonate-derived groundwater throughout the Death Valley Flow System, but also shows the influence of volcanic-derived groundwater or basin-fill material (Koonce et al., 2006).

5.2.2 Water Quality of Groundwater

Military activities in the region have led to possible adverse effects on the Amargosa watershed. The Nevada National Security Site (formerly the Nevada Test Site), a 1,360 mi^2 area where hundreds of the nation's nuclear device tests occurred from the 1950s until the 1980s, is located in the Death Valley Groundwater Flow System. The Security Site currently also serves as a major low-level waste disposal facility low-level nuclear waste, generated on-site and off-site. Many of the underground tests were conducted beneath or near the water table, resulting in documented contamination of the groundwater aquifer. Some of the old waste sites are no longer in use and their exact location is not known. The extent and movement of groundwater contamination is still being determined.

Tritium is the most common and most mobile radionuclide found at the Security Site (Department of Energy, 2011). Tritium is the first constituent monitored for in groundwater samples because the presence of other contaminants is not expected when tritium concentrations are low. At this time, no proven, cost-effective technology exists that removes extensive tritium contamination from deep groundwater in complex geology. DOE has said it will leave the tritium in the ground and monitor movement instead of attempting to remediate the site. Monitoring at over 60 locations in and around the Security Site is conducted on a regular basis (DOE, 2011).

So far, tritium and other contaminants have not moved far from the underground testing sites, which are about 40 to 50 miles north of the Refuge. In 2009, tritium was detected for the first time in a monitoring well to the west of the Security Site, about 25 miles northeast of Beatty, Nevada. The eastern portion of the Security Site is encompassed by the Ash Meadows Groundwater sub-basin, with regional groundwater flow towards the Refuge. Groundwater contamination of Amargosa system water, including Ash Meadows, is a major concern but, to date, no contaminants have been found to the south of the Security Site, in the direction of the Refuge and the Amargosa Valley. Studies to define probable routes and the timing of the transport of contaminants through the Amargosa region are ongoing. Part of the motivation for the USGS ET groundwater discharge study described above (Laczniak et al., 1999) was to assist these studies and modeling efforts.

5.2.3 Other Water Quality Studies

The Service collected data on PCBs in water, sediment, and biota from the Refuge in 1997 (Meisner and Martinez, 1998) to investigate the potential for contamination from on-site electrical transformers. No contamination was found. The Service also collected data on metals and trace elements in water, sediment, and aquatic vegetation at the Refuge (Weimeyer, 2005). Samples were collected from Crystal Spring, Crystal Reservoir, Horseshoe Reservoir, Point of Rocks Springs, Jackrabbit Springs, Big Springs, Fairbanks Spring, Rogers Spring, Longstreet Spring, and Peterson Reservoir. Water samples were below the State of Nevada aquatic life standards, where applicable and available. Mercury concentrations in the sediment in Crystal Spring were high enough to be of concern and the study recommended additional sampling.

5.3 Water Monitoring

5.3.1 Spring Monitoring

Much of the following monitoring information is from the Ash Meadows Water Monitoring Plan produced by the WRB and updated most recently in January, 2013 (Mayer, 2000). Please refer to that document for more detail on the water monitoring at individual sites on the Refuge (Appendix A).

The US Geological Survey (USGS) conducted water monitoring in the area of the Refuge regularly until 2009. The first USGS measurements of springflow were made in 1953 (Walker and Eakin, 1963). From 1972 to 1990, the USGS monitoring was in cooperation with the National Park Service (NPS), because of the Park Service's concern over pumping effects on water levels in Devils Hole (described below). In 1990, NPS terminated their contract with the USGS and began their own monitoring program. At the same time, the USGS began a cooperative effort with the Department of Energy to monitor and model groundwater in the vicinity of Yucca Mountain. Several springs and wells on the Refuge were monitored regularly as part of this program, however, funding for this monitoring effort ended in 2009.

Much of the early monitoring efforts involved protection of the water level in Devil's Hole and evaluation of the effects of local groundwater pumping in the area. Presently, irrigation pumping has virtually ceased at the Refuge but increased pumping for irrigation from the local alluvial aquifer to the west of the Refuge and pumping from the regional carbonate aquifer elsewhere is a serious concern and a comprehensive monitoring effort is still essential.

About the same time that USGS began the cooperative monitoring effort with the DOE, the Service initiated monitoring at several sites on the Refuge. The Service was required to provide flow measurements on all certificated springs as part of the water right changes that the Service filed in the 1990s (described below). In addition, the Service has used the data to evaluate the status and trends of water resources on the Refuge. Methods and monitoring locations were coordinated among the USGS, NPS, and the Service to maintain data consistency and ensure complete records. NPS monitoring efforts are directed solely at protecting the level of the pool in Devils Hole. This site is monitored by NPS but the USGS does report the measurements on NWIS (USGS Site No 362532116172700).

Currently, the Service is the primary agency responsible for monitoring spring discharge and groundwater levels at the Refuge. All monitoring on the Refuge, with the exception of Devils Hole, is done by the Service. A total of 21 springs and 10 wells have been monitored regularly by the Service for varying periods since 1990 (Table 3 and 4). Most of this monitoring has been done by Refuge staff, with occasional periods covered by the WRB staff.

The name, number, period of record and average flow for these springs are given in Table 3. Currently there are seven **major springs** (outflows > 500 gpm or 1.1 cfs) and three other minor springs that are monitored. There have been a few changes in springflow related to spring restoration or to changes in the monitoring site location or measurement method. These are documented in the monitoring plan, updated regularly (Mayer, 2000).

Most of the minor springs, (outflows < 500 gpm or 1.1 cfs), are no longer monitored (with the exception of the three listed in Table 3), because of the level of staff time involved in monitoring these springs and challenges of measuring small discharges in natural stream channels. Monitoring and protecting the spring discharge at the major springs will also protect these minor springs because the ultimate source for all of these springs is likely the regional carbonate aquifer.

The data collected at springs and wells over this period represent an excellent baseline record of water conditions on the Refuge. Most of the springs and wells are fairly stable, with some seasonal changes but no long-term trends or changes. The one exception involves several of the springs and wells in the northern part of the Refuge, discussed further in the Water Resource Issues of Concern section of this report.

Several of the monitoring sites are included in the Amargosa Monitoring Network, a multi-agency monitoring network established, funded, and maintained by the Bureau of Land Management, NPS, USGS, the Service, Nye County Nevada Nye, and Inyo County California (BLM et al. 2013). Sites monitored by the Service and located on the Refuge include three springs (Fairbanks Springs, Crystal Springs, Big Springs) and five wells (Garner-AM-3 well, Devils Hole well, Point of Rocks North well. Point of Rocks South well, and Rogers Spring well). The purpose of this network is to identify, support, coordinate on, and share data from monitoring sites that are important in understanding groundwater flowpaths and groundwater level variability and change and to provide early warning of the effects of widespread groundwater withdrawals in the Amargosa Valley.

5.3.2 Groundwater Monitoring

The name, FWS site number, number of measurements, period of record, well depth, average water level depth and temperature, and aquifer for each monitoring well are given in Table 4. Groundwater levels are currently monitored in nine wells at the Refuge. Some of these are monitoring water levels in the carbonate aquifer and some are in the basin-fill aquifer, although the aquifer source is unknown for 4 of 9 wells. Water levels at most wells have been fairly stable. However, some small declines have been observed at several of the northern wells. The implications of these declines are discussed in the Assessment section of this report. In addition to these nine monitoring wells, there are four production wells on the Refuge that are monitored for reporting requirements associated with the water right permit conditions.

There are several other important groundwater wells that exist off the Refuge and are monitored by other agencies. These sites are important because they are located between the Refuge and some of the areas of concern that have been discussed, including the Amargosa Farms area and the Nevada Security Site. There are four wells (the GF wells, Table 4) located on the Gravity Fault between the Refuge and the Amargosa Farms area. These wells were all installed by the NPS in 2005, to monitor impacts from pumping in the Amargosa Farms area. Trends in water levels since that time are inconsistent among the wells. Three of the wells have declined since 2005 but AM-9 shows an increase in levels. The last well in Table 4, Tracer Well 3, is a USGS monitoring well that is located to the northeast and upgradient of the Refuge in Amargosa Flats. This well should respond to changes or impacts propagating from the north or northeast. Water levels in this well are very closely correlated with Devils Hole.

Table 3 Surface Water Monitoring Sites on Ash Meadows NWR

Major Springs							
Spring Name	**FWS Site Number**	**Measurement Method**	**Measurement Period**	**Number of Measurements**	**Average (cfs)**	**Average (gpm)**	**Relative Standard Deviation**
Fairbanks Spr	455403	Parshall flume	1993-present	continuous	3.90	1751	2%
Rogers Spr	455408	Parshall flume	1993-present	continuous	1.39	624	3%
Longstreet Spr	455405	Parshall flume	1993-present	continuous	2.33	1046	5%
Crystal Pool	455411	current meter	1996-present	122	6.36	2855	8%
Kings Pool	455412	current meter	1997-present	87	2.53	1136	11%
Jackrabbit Spr	455413	current meter	1990-present	162	1.38	619	12%
Big Sprs	455414	current meter	1990-present	154	2.31	1037	12%
Minor Springs							
Soda Spr	455417	current meter	1995-2002	31	0.09	40	52%
Bradford Sprs	455416	current meter	1995-2002	35	0.99	445	18%
Forest Spr	455406	current meter	1998-2002	16	0.58	258	40%
Cold Spr	455415	portable flume	1997-2002	20	0.08	36	6%
North Five Sprs	455418	portable flume	1997-2002	34	0.18	82	29%
Five Springs	USGS Site	volumetric	1996-2011	157	0.09	38	16%
Five Springs	455434	volumetric	2012 to present	4	0.06	26	4%
South Five Sprs	455419	portable flume	1997-2002	32	0.07	29	21%
North Scruggs Sprs	455402	v-notch weir	1992-1997	55	0.13	58	7%
North Scruggs Sprs	455402	portable flume	1997-2002	38	0.17	77	17%
South Scruggs Spr	455421	portable flume	1997-2002	32	0.16	74	17%
Marsh Sprs	455409	v-notch weir	1992-1997	55	0.12	54	9%
Marsh Spr	455409	portable flume	1998-2002	16	0.11	48	7%
School Spr	455420	portable flume	1997-2002	31	0.03	12	27%
School Spr	455420	volumetric	2009 to present	12	0.02	7	10%
North Indian Spr	455422	portable flume	1997-2002	32	0.12	53	16%
South Indian Spr	455423	portable flume	1997-2002	32	0.08	36	39%
Point of Rocks	455401	current meter	2005 to present	58	0.68	305	17%

Table 4 Ground Water Monitoring Sites on Ash Meadows NWR

Well monitoring sites located on the Refuge (monitored by FWS)								
Well Name[1]	**Site Number**	**Method**	**Period**	**Number of Measurements**	**Well Depth (ft)**	**Average Depth to Water (ft)**	**Water Temperature (C)[3]**	**Aquifer**
Soda Well	455410	float/datalogger	1994-2001	continuous	157			unknown
Soda Well	455410	well tape	2002 to present	54	157	4.1	27	unknown
Fairbanks Well	455432	well tape	2001 to present	53	18	6.5	17	unknown (likely basin-fill)
Rogers Well	455429	well tape	1990 to present	169	202	3.2	21	basin-fill
Peterson Well	455430	well tape	1992 to present	87	450	5.0	18	unknown (likely basin-fill)
Garner Well (AM-3)	USGS Site No 362755116190401	well tape	1992-2009	214	202	19.9	unknown	basin-fill
Garner Well (AM-3)	455433	well tape	2009 to present	13	202	20.3	unknown	basin-fill
Deep Well (Spring Meadows 12)	455425	well tape	1990 to present	178	265	74.4	27	unknown
Devils Hole Well (AM-5)	455426	well tape	1990 to present	4972	200	48.1	29	basin-fill
Cemetery Well (Point of Rocks South AM-7)	455427	well tape	1990 to present	177	586	8.5	29	carbonate
Forest Well (Point of Rocks North AM-6)	455428	well tape	1990 to present	179	500	21.4	29	basin-fill

Well monitoring sites located off the Refuge (monitored by NPS/USGS)								
Well Name[1]	**FWS Site Number**	**Method**	**Period**	**Number of Measurements**	**Well Depth (ft)**	**Average Depth to Water (ft)**	**Water Temperature (C)[3]**	**Aquifer**
Devils Hole (monitored by NPS)	USGS Site No 362532116172700	float/datalogger	1937 to present	continuous	NA	NA	33	carbonate
230 S17 E50 05ADCB1 GF-1 (AM-9)	USGS Site No 363012116214801	well tape	2005 to present	46	500	46.3	unknown	basin-fill
230 S17 E50 04CDAA2 GF-2A shallow (AM-10)	USGS Site No 362953116210102	well tape	2007 to present	66	510	30.4	unknown	basin-fill
230 S17 E50 04CDAA1 GF-2B deep (AM-11)	USGS Site No 362953116210101	well tape	2007 to present	66	510	32.6	unknown	carbonate
230 S17 E50 30ACCC1 GF-3 (AM-12)	USGS Site No 362649116225801	well tape	2005 to present	84	315	51.7	unknown	basin-fill
230 S16 E51 27BAA 3 Tracer Well 3 (AD-6)	USGS Site No 363213116133800	well tape	1966 to present	253	807	41.7	unknown	carbonate

1/ USGS name in parenthesis, if different from FWS name

2/ combined USFWS and USGS measurements over the period

3/ water temperature measurements collected by Water Resources Branch on 3/3/2008
Devils Hole water temperature from NPS http://www.nps.gov/deva/naturescience/devils-hole.htm

5.3.3 Spring Water Temperature Monitoring

In 2012, the Refuge began an effort to monitor water temperature continuously at the springheads of all the major springs. In addition, temperature is monitored along outflow streams, from the springheads in a downstream direction, in the following spring systems: Fairbanks, Soda, Rogers, Longstreet, Cold, South Scruggs and Indian Springs. These springs have been recently restored or are scheduled for restoration in the near future.

Measurements are made using the HOBO Pendant deployable dataloggers. These small units are placed on the bottom of the streambed or pool and covered with a weighted neoprene solar shield to eliminate diurnal influences on temperature. Data is recorded on an hourly basis and downloaded regularly.

The current temperature data are summarized for all springs in Table 5. Monitoring site locations are shown on Map 4. Generally, water temperatures are relatively stable, especially in the warmer temperature springs. Springs near the carbonate ridges on the east side of the Refuge, where the buried carbonate is shallowest, are warmest. However, the temperature of even these springs can vary due to precipitation and runoff. During an August 2012 rain event, the temperature throughout the South Scruggs and Indian Springs monitoring network recorded a temporary decrease in temperature of at least 10° C at all sites, with some sites recording a drop of up to 20°C. The cooler temperatures were related to runoff generated from the sizable precipitation event.

Water temperatures were also recorded semi-regularly by the Refuge from 1989 to 2002 at almost all the springs. The temperature data are in digital format and are available from WRB. There is no information on dates/times (beyond year), measurement methods, or locations (beyond spring name) therefore utility of this information may be limited. Nonetheless, a cursory comparison of the temperatures in that dataset with those presented here show no major discrepancies among spring temperatures between the two datasets.

5.3.4 Evapotranspiration Monitoring

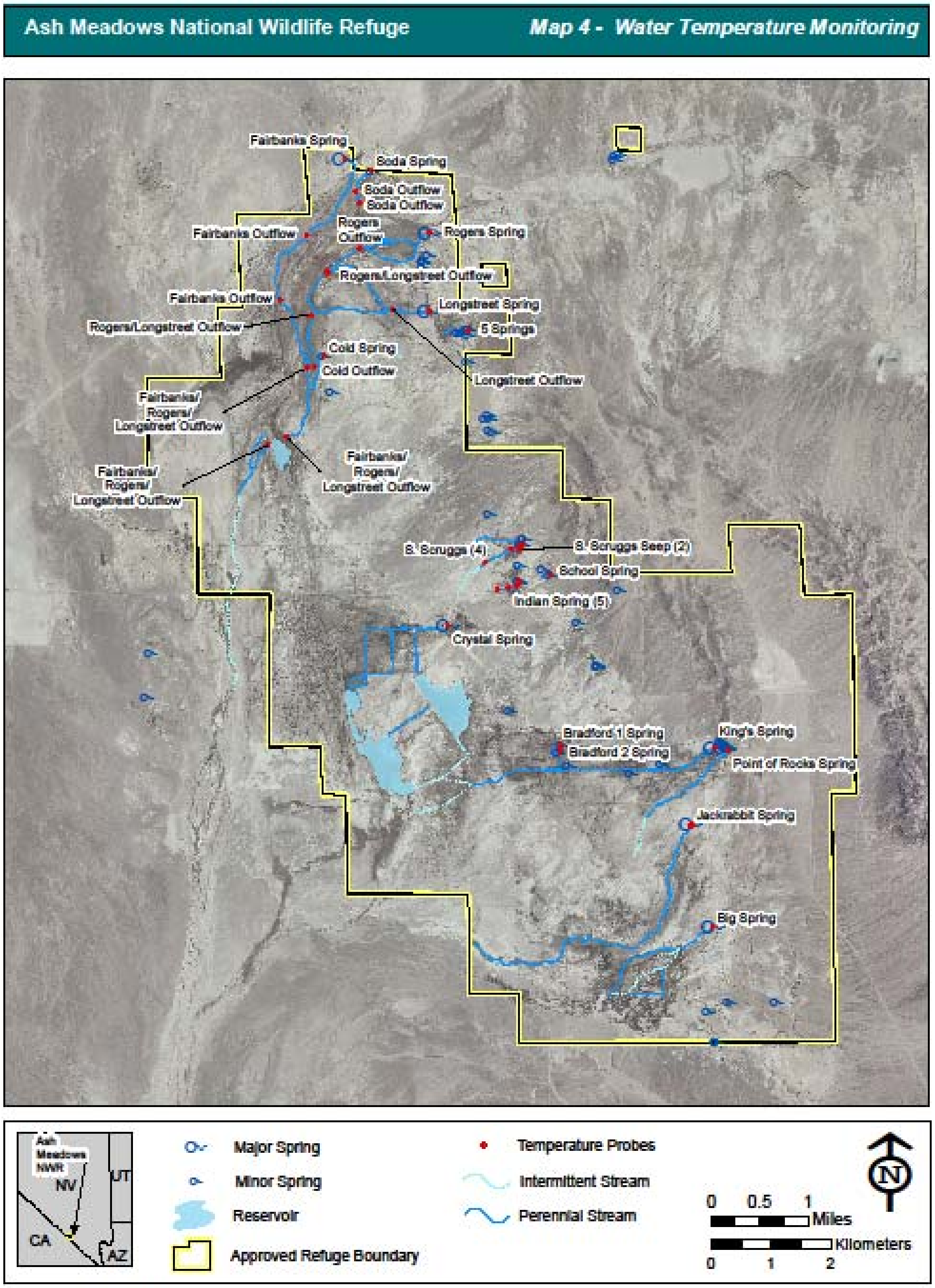
Evapotranspiration (ET) on the Refuge was measured directly in an extensive USGS study (Laczniak et al., 1999) funded by the Department of Energy. The purpose of the study was to accurately quantify the groundwater discharge at Ash Meadows to better model the transport of groundwater contaminants at the National Nevada Security Site (formerly the Nevada Test Site), north of the Refuge. Since the ET at Ash Meadows is primarily supported by groundwater discharge, a measurement of total ET in the area provides an estimate of groundwater discharge.

Measured ET ranged from 0.6 ft per year in sparse, dry saltgrass to 8.6 ft per year for open water. Mean annual ET for the Ash Meadows area was estimated at 21,000 afy. The estimate of groundwater discharge that supports this ET ranges from 18,000 afy to 21,000 afy. The lower estimate assumes a 3,000 afy contribution from location precipitation and the high estimate assumes no contribution. The range of groundwater discharge presented is only slightly higher than previous estimates based on the sum of all springflow measurements in the area (Laczniak and others, 1999).

Table 5 Water Temperatures at Springheads of Selected Springs on the Refuge

Spring Name	Date(s) of Measurements	Average Temperature (C)	Relative Standard Deviation
Fairbanks Spr	Apr 2012 to Jun 2013	27.2	0.7%
Rogers Spr	Apr 2012 to Jun 2013	28.5	0.7%
Longstreet Spr	Apr 2012 to Jun 2013	27.3	0.3%
South Scruggs Spr	May 2012 to Nov 2012	32.9	1.3%
South Scruggs 2 Spr	May 2012 to Nov 2012	33.7	1.2%
Soda Spr	Apr 2012 to Jun 2013	22.8	3.4%
Cold Spr	Apr 2012 to Jun 2013	19.0	2.8%
North Indian Spr	Apr 2012 to Jun 2013	30.7	1.8%
South Indian Spr	Apr 2012 to Jun 2013	30.2	2.2%
Crystal Spr	Nov 2012 to Jun 2013	30.9	0.4%
Kings Pool	Nov 2012 to Jun 2013	31.9	0.4%
Jackrabbit Spr	Nov 2012 to Jun 2013	27.7	1.1%
Big Spr	Nov 2012 to Jun 2013	27.7	1.2%
Point of Rocks	Nov 2012 to Jun 2013	29.8	2.6%
Bradford 1 Spr	Nov 2012 to Jun 2013	16.7	16.0%
Bradford 2 Spr	Nov 2012 to Jun 2013	21.2	2.0%
School Spr	Nov 2012 to Jun 2013	34.1	1.4%
Five Spr Flowing Well	Nov 2012 to Jun 2013	35.0	0.1%

Map 4 – Water Temperature Monitoring Sites at Ash Meadows NWR



Map Projection: NAD 1983 UTM Zone 11N
Map Date: 10/21/2013
Data Source: USFWS cadastral database (boundaries), USFWS field data collection (springs, wells, streams), USDA NAIP 2010 Aerial Imagery (basemap)

The ET study also established several shallow groundwater monitoring wells around the Refuge and monitored these for several years. Continuous and periodic measurements are available for these wells on the USGS NWIS web site (http://waterdata.usgs.gov/nv/nwis/gw). Shallow water levels are at or very near the land surface for much of the winter in many areas of the Refuge.

5.3.5 Sentinel Monitoring Sites

Sentinel Monitoring Sites are a subset of existing water monitoring sites that are identified by the Service for a facility as being most useful for monitoring the status and trends of Service water resources and understanding and protecting these resources. The sites monitor any number of parameters and they can be located on or off the Refuge and include Service and non-Service sites. WRIAs are a good tool for identifying such sites.

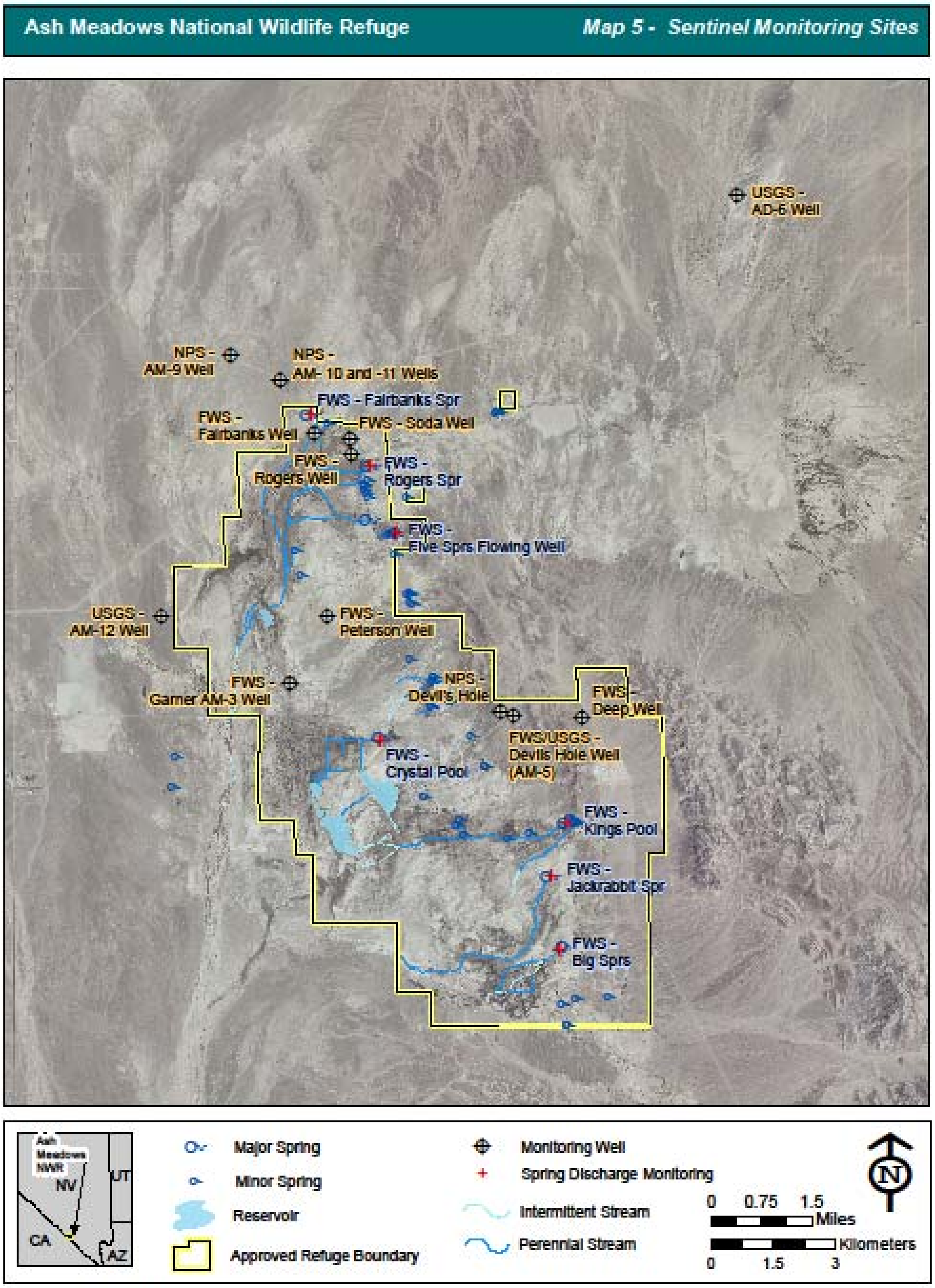
For Ash Meadows, the Sentinel Monitoring Sites include:

1) The seven major springs on the Refuge that are monitored jointly by WRB/Refuge staff. The seven major springs, from north to south, are Fairbanks, Rogers, Longstreet, Crystal, Kings Pool, Jackrabbit, and Big Springs (Table 3, Map 5). The Service assumes that monitoring and protecting the spring discharge at the major springs will protect all springs and groundwater discharge on the Refuge.

2) Devils Hole (USGS Site No 362532116172700) and four other groundwater monitoring wells with water levels that are very closely correlated with Devils Hole (Deep Well, Devils Hole Well, and Five Springs Flowing Well (all located on the Refuge) and Tracer Well 3 (AD-6) to the northeast of the Refuge on Amargosa Flats. The sensitivity of Devils Hole to water level changes was described above, making it an excellent candidate for a Sentinel Monitoring Site. The other sites that closely match water levels in Devils Hole could be used to verify any changes observed in Devils Hole.

3) Given the concern over apparent declines in some of the springs and wells in the northern part of the Refuge, the Sentinel Monitoring Sites should include the Service's groundwater monitoring wells in the northern part of the Refuge as well as the four Gravity Fault Wells to the northwest. The wells on the Refuge include Fairbanks Well, Rogers Well, Soda Well, Peterson Well, and Garner (AM-3) Well (Table 4). The wells off the Refuge include the four Gravity Fault (GF) wells listed in Table 4.

Map 5 – Sentinel Monitoring Sites at Ash Meadows NWR



Map Projection: NAD 1983 UTM Zone 11N
Map Date: 10/21/2013
Data Source: USFWS cadastral database (boundaries), USFWS field data collection (springs, wells, streams), USDA NAIP 2010 Aerial Imagery (basemap)

5.4 Water Rights Overview

5.4.1 Nevada Water Right Law Summary

Nevada water law, like many western states, is based on the doctrine of prior appropriation, or "first in time - first in right." The essential characteristics of a prior appropriation right are:

- Priority is the date of initiation (e.g., the date of permit application or date that construction or diversion began if prior to Water Code).
- Historically, a diversion was required (although many states, including Nevada, now consider in-stream use as "beneficial")
- Appropriative rights are limited by the amount of beneficial use without waste (beneficial use is the basis, limit, and the measure of the right)
- Rights require a permit after 1913 (but prior to 1913 and the enactment of the Water Code, all that was required was a diversion)
- Rights may be lost by forfeiture (statutory period of non-use, usually 5 years) or abandonment (intentional or voluntary non-use)

In 1905, the Nevada Division of Water Resources, headed by the State Engineer, was given the responsibility for administration, management, and appropriation of Nevada's water resources. The law was amended in 1913 to include all groundwater as well as surface waters. The Nevada Water Code explicitly states that all waters of Nevada are public property, and a water right is a usufructuary right. Beneficial use is the measure and limit of a water right in Nevada.

The State Engineer oversees the appropriation and management of both surface water and groundwater in the state. While surface water provides the majority of the total water supply used in the state, surface water sources have been fully appropriated for years. New water development relies almost exclusively on groundwater sources. Any use of water (surface water or groundwater) requires a permit, except for domestic wells for single households. Any person (individual, private organization, corporation, or public agency) can hold a water right. However, a water right does not convey the right to access private property. The state recognizes wildlife as a beneficial use. Furthermore, it recognizes instream flow rights, without diversions, and allows any person to hold an instream flow right (several western states restrict instream water rights to state governmental agencies only).

New water uses or changes to existing uses must be done through a permit application process with the State Engineer. Following public notice of the application, there is a period during which any interested person can file a protest with the State Engineer. If an application is protested, the State Engineer may or may not decide to hold a formal hearing to gather evidence and information. The State Engineer considers the following three criteria when approving or rejecting an application: 1) Is there unappropriated water available from the source? 2) Will the proposed use impair existing water rights? 3) Is the proposed use detrimental to the public interest? Once an application has been approved and a permit granted, it is up to the permittee to complete the necessary work and file proofs to perfect the water right. The water right permit must be perfected to a certificate through beneficial use, generally meaning that water must be applied for the purpose in the permit. The time frame to perfect the right is dependent upon the work involved but is generally 2 to 5 years.

In deciding on the availability of groundwater, the State Engineer has adopted the concept of perennial yield. Perennial yield is defined as the maximum amount of groundwater that can be salvaged each year over the long term without depleting the groundwater reservoir. The perennial yield cannot be more than the natural recharge of the groundwater reservoir and is usually arbitrarily limited to half of the maximum amount of natural discharge. Importantly, limiting the amount of groundwater pumping in a basin to the perennial yield does not necessarily guarantee that there will be no impacts to water rights or water resources.

A water right in Nevada can be lost by abandonment or forfeiture. Abandonment is determined by the intent of the water user to stop using a water right and it does not have a statutory time period. Groundwater rights, but not surface water rights, can be lost by statutory forfeiture if a right is not used for five consecutive years. Water lost through abandonment or forfeiture reverts back to the public and is available for future appropriation. Surface water cannot be lost through forfeiture in Nevada.

5.4.2 Devils Hole and the 1976 Cappaert Decision

Devils Hole, located at the southern end of a limestone hill adjacent to Ash Meadows NWR, is a collapsed opening, lined with travertine, extending at great depth to the carbonate aquifer flow system. It is the only known habitat for the Devils Hole pupfish, an endangered species. 10,000 to 30,000 years of isolation from any predatory or other fish species has allowed the Devils Hole pupfish to evolve into a form utterly different in appearance and behavior from its closest relative. Algae growing on a submerged sunlit ledge in an otherwise darkened pool provides a limited food supply and as a result, the population of Devils Hole pupfish has never been higher than 553.In recent times the population has dropped to as low as 38 individuals (http://www.fws.gov/nevada/protected_species/fish/species/dhp/dhp.html accessed 8/24/12). The most recent count was 104 fish in April 2011. The pupfish gained notoriety not because it is rare, however, but because of a famous Supreme Court decision (Adams et al., 2000).

The 1976 decision of the U.S. Supreme Court in *Cappaert v. United States* is one of the most important and commonly cited water law cases in the country (Fahmy, 2006). The decision predates the establishment of the refuge and pertains to a 40-acre tract of land surrounding Devils Hole that was included as part of Death Valley National Monument by Presidential Proclamation in 1952. The area was protected because of its unique geological features and its endemic pupfish, which were designated endangered in 1967 under the Endangered Species Preservation Act of 1966.

In 1970, the Cappaerts, who owned private farm lands adjacent to Devils Hole, filed 10 applications to appropriate groundwater and began pumping groundwater for irrigation. The water was pumped from the basin-fill aquifer that overlies and is connected to the regional carbonate aquifer. The pumping in the early 1970s, up to 7,000 afy, caused a water level decline in Devils Hole (**Figure 3**) and a decrease or cessation of flow in several major springs in the area. The NPS protested the applications but the Nevada State Engineer granted them on the grounds that “there are no water rights for Devils Hole…” The State

Engineer also lamented that although he thought further hydrogeological studies should be pursued, he had no authority to require them as a condition of a water right permit.

What followed was several years of pumping, accompanied by a steady decline in water levels at Devils Hole. The ensuing legal battles eventually ended up at the U.S. Supreme Court, which agreed unanimously with an earlier Court of Appeals ruling that curtailed groundwater pumping to maintain the water level of the pool. The Supreme Court also held that the 1952 Presidential Proclamation explicitly reserved the amount of water, but no more than that, necessary to protect the scientific interests associated with the pool. In 1978, the District Court issued a final order for the federal reserved water right establishing a minimum pool level of 2.7 feet as necessary for the continued survival of the pupfish. After the groundwater pumping was reduced in the late 1970s, and then halted in 1982, spring flows gradually recovered and the water level in Devils Hole gradually rose, but did not recover to the pre-pumping level. In 1962, the average pool level was 1.1 feet. As of 2011, the average pool level was 1.8 feet and was trending upward.

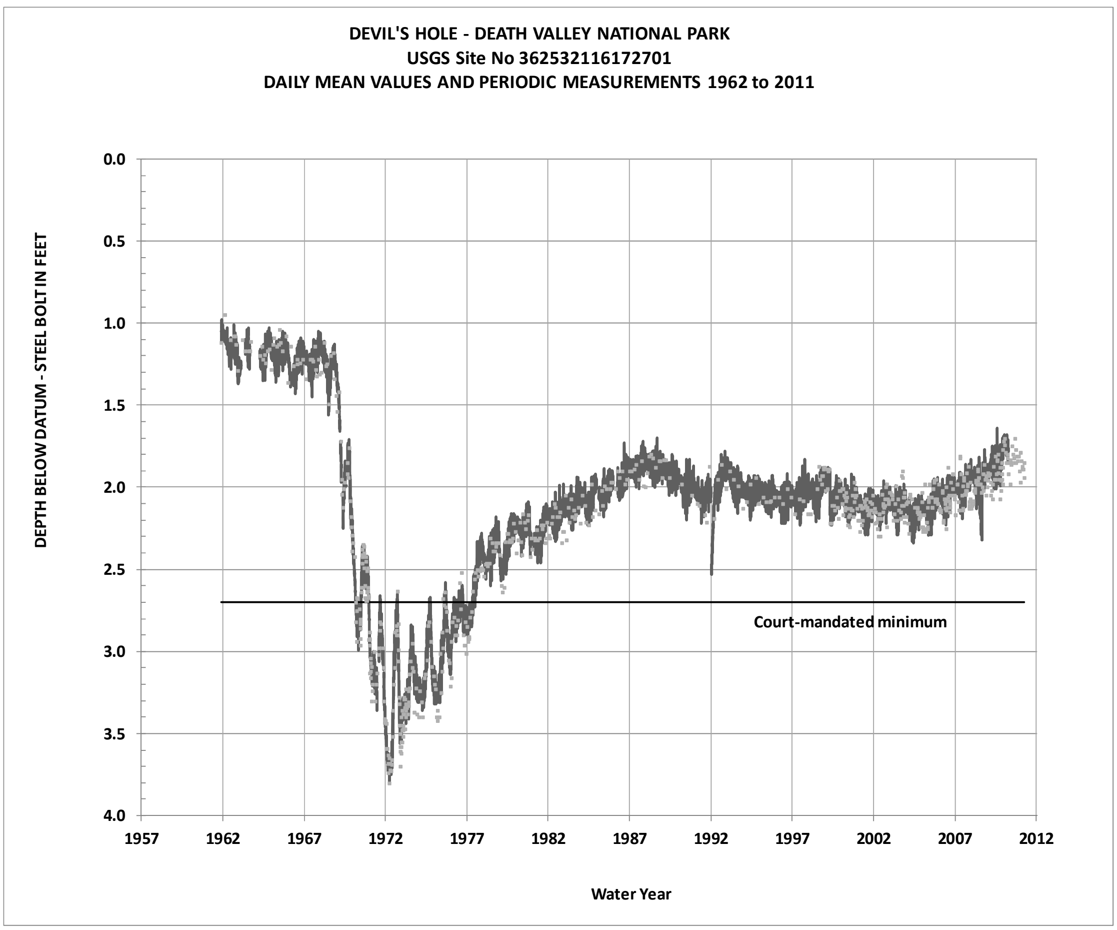


Figure 3. Water levels in Devils Hole for the period 1962 to 2011.

As a result of this decision, the Cappaerts and other private interests sold their lands around Devils Hole to TNC, which eventually sold them to the Service, thus creating the Refuge. The positive developments following this ruling include 1) the fact that the Nevada State Legislature granted the State Engineer the authority to order hydrologic studies and 2) the "public interest" standard in Nevada Water Right law has evolved to include water-related environmental values. The negative developments following the ruling are that 1) the Devils Hole water levels have never fully recovered to their pre-pumping levels, and 2) the demand for groundwater resources in the area, primarily for irrigation, has increased considerably.

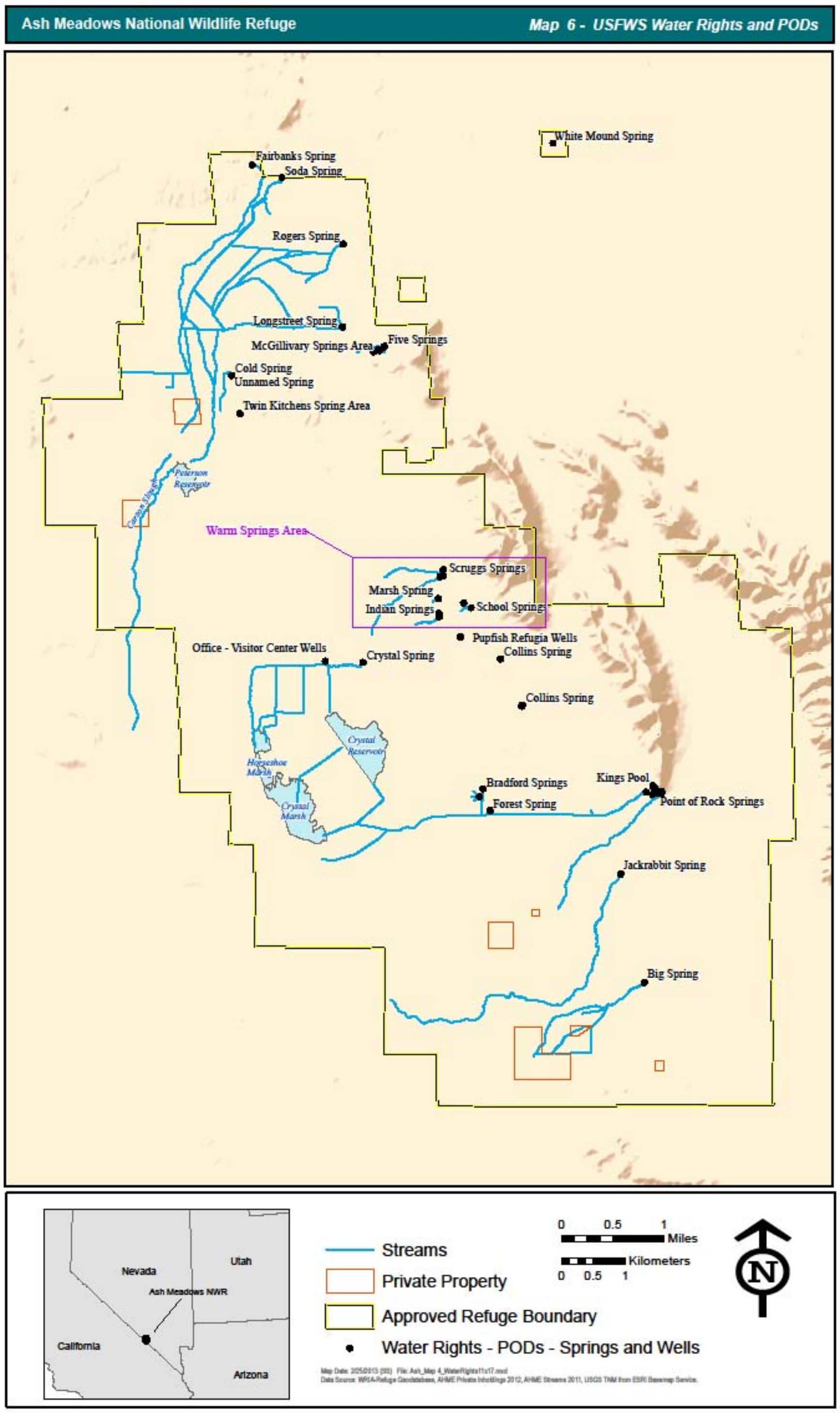
Water levels and spring discharge at Devils Hole and the surrounding Refuge are probably affected by changes in climate, ground-water withdrawals, and seismic events. No conclusive evidence exists, however, to suggest how much influence each of these factors has on the area as a whole, or whether the controlling processes are different for different areas within Ash Meadows.

5.4.3 Ash Meadows Water Rights

The Service currently holds 60 state appropriative water rights for 17,024 afy on the Refuge, 56 certificates for surface water (spring discharge) and four for groundwater. The Point of Diversions (PODs) for all the rights are shown on Map 6 (some PODs have multiple water rights associated with them). The purpose of the surface water rights is wildlife; they are essentially in-stream flow rights for the spring outflows. Most of the surface water rights for spring discharge were acquired from TNC with the property in 1984 or have been appurtenant to more recent property acquisitions. The priority dates of the rights range from 1886 to 1979. The total volume of water appropriated under the Service's surface water rights for springs is 17,014 afy. In the 1990s, the Service filed change applications to change the purpose of all 56 surface water rights from irrigation or stockwater to wildlife. The place of use was changed to the entire refuge and the season of use to all year.

Many of the surface water rights for springs have a combined flowrate and duty (or volume) represented by several individual permits (these are given in the permit conditions). Often, this combined flowrate and duty applies to a spring complex rather than just one spring Table 6 lists the total appropriated flow rate and volume for individual springs or spring complexes on the Refuge. Because the water rights records in the WRB's WREN water rights database are not grouped by spring source and do not give combined flowrates or duties, and the database is not accessible to Refuge staff, WRB developed a separate water rights database, "*Ash Meadows water rights database.mdb*", with this information for the Refuge. This database is maintained by WRB but is accessible to the Refuge as well. The database lists the number of springs and water rights permits associated with each spring complex on the Refuge and the combined flowrate and duty. It does not provide information on the individual permits but that information is readily available from NWDR website (http://water.nv.gov/) or the WRB.

Map 6. Map of USFWS Water Right Point of Diversions on Ash Meadows NWR.



There are currently four rights for groundwater use at the Refuge. Two of the four groundwater rights at the Refuge are for quasi-municipal use for the office and a future visitors center. The other two groundwater rights are for water supply for the pupfish refugia at School Springs. All four groundwater rights are still in the permit phase and have not been certificated, since the visitors center is still being constructed and the pupfish refuge is not fully operational yet. Generally, the groundwater rights appropriate very small volumes, less than 10 afy for all four rights.

The Service holds some of the most senior water rights in the Amargosa Basin, even more senior than the NPS's 1952 federal reserved water right at Devils Hole. However, the potentiometric surface of the carbonate aquifer at Devils Hole is 14 ft to 159 ft higher in elevation than the elevations of the spring orifices on the Refuge (Winnograd and Thordarson, 1975). A small decline in the general potentiometric surface of the carbonate aquifer related to groundwater pumping from other areas may not affect spring flow measurably but may threaten to expose the spawning shelf at Devils Hole. In this sense, the federal reserved water right for Devils Hole is the most sensitive and the most important water right in the area. The message that the Department of Interior has given the Nevada State Engineer in water right protest proceedings in this area is "protect Devils Hole and you will protect Ash Meadows and all the water resources there."

The Service has regularly protested other water applications in the area to protect water rights on the Refuge. Some of these protests have resulted in water right hearings. The most recent water right hearing in which the Service participated was in 2006. The hearing involved water right applications filed by Nye County for groundwater in the Amargosa Desert Hydrographic Basin and protested by the Service and NPS. The applications were denied by the Nevada State Engineer on the basis that all water in the hydrographic basin has already been appropriated and there is no additional water available.

Table 6 Total Appropriated Flowrate and Volume by Spring or Spring Complex*

Spring or Spring Complex	Number of springs associated with rights	Total appropriated flow (cfs)	Total appropriated volume (afy)
Big Springs	1	3.33	1013.1
Bradford Springs Area	3	1.11	717.9
Cold Spring	1	0.02	12
Collins Springs Area	2	0.03	20
Crystal Spring	1	6.53	4727.5
Fairbanks Spring	1	4.01	2903.1
Five Springs Area	2	0.15	100
Jackrabbit Spring	1	2.09	1513.1
Kings Pool/Point of Rocks Springs Area	9	3.56	2574.4
Longstreet Spring	1	2.75	1991
McGillivary Springs Area	2	0.01	9.1
Rogers Spring	1	1.72	1245.2
Forest Spring	1	0.02	13
Soda Spring	1	0.09	65.2
Twin Kitchen Springs Area	2	0.02	5
Unnamed Spring	1	0.01	8.1
Warm Springs Area	7	0.62	94.8
White Mound Springs Area	3	0.002	1.5
	Total	**26.07 cfs**	**17014 afy**

*Table does not include Refuge groundwater rights. This information was extracted from the database file: *"Ash Meadows water rights database.mdb"* maintained by the WRB, last updated 12/5/12.

5.4.4 Amargosa Valley Water Rights, Perennial Yield, and Pumping

The estimated combined perennial yield of the Amargosa Desert Area (which includes Basins 225-230) is estimated at 24,000 afy (Walker and Eakin, 1963). Importantly, this yield includes the 17,000 afy of spring discharge in the Ash Meadows area that is protected through the Refuge's water rights. Walker and Eakin (1963) on pg 29 state that:

"*The tentative perennial yield may be about 24,000 acre-feet a year. Of this, about 17,000 acre-feet can be obtained by full development of the springs in Ash Meadows*"

Of course, "*full development of the springs in Ash Meadows*" is not compatible with refuge purposes. None of this water is available for development. The fact that the perennial yield estimate includes the total spring discharge at the Refuge is often missed or overlooked by other water interests (ex. several planning documents prepared by Nye County), and as a result, these entities cite a perennial yield estimate that is 17,000 afy too high. The estimated groundwater available for other water rights in the Amargosa Desert area is 7,000 afy, based on the difference between the perennial yield and the total regional spring discharge (24,000 afy – 17,000 afy = 7,000 afy). Currently, as discussed below, the volume of allocated water to all users in this area grossly exceeds this amount.

There are 25,630 afy of active groundwater rights in the Amargosa Valley hydrographic basin alone (Basin 230 only) (http://water.nv.gov/data/hydrographic/ accessed August 14, 2012). This number includes groundwater rights only and does not include the Service's water rights for springs, which are considered surface water rights. In practice, not all water rights are pumped to their full allocation. The range of pumping in the Amargosa Valley since about 1993 has been between 12,000 to 15,500 afy (Fenelon and Moreo, 2002; http://water.nv.gov/data/pumpage/ accessed January 7, 2013). The most recent pumping inventory from NDWR indicates that there was 16,536 af of groundwater pumping in 2011. This volume of pumping still exceeds the estimated remaining perennial yield of 7,000 afy available, after accounting for the 17,000 afy of Service water rights at the Refuge.

Groundwater levels in the Amargosa Valley declined between 10 to 30 feet from 1960 to 2000 (Fenelon and Moreo, 2002) as a result of overallocation. In 1979, the Nevada State Engineer issued Order 724, which designated the Amargosa Basin (Basin 230) a critical groundwater management area. Since 1985, the Nevada State Engineer has refused to permit any new water right applications for agricultural purposes in the Amargosa Valley. Groundwater pumping in the California portion of the Amargosa Valley is virtually unregulated, although to date, there has not been much groundwater development on the California side of the valley.

About 90% of the groundwater pumped in the Amargosa Valley is for irrigation. Most of the wells pump from the basin-fill aquifer that overlies the carbonate aquifer. But the two aquifers are connected and so this pumping could be affecting regional groundwater levels and flow as well. Currently, only 1% of the irrigation pumping is from the Ash Meadows groundwater subbasin, with the other 99% from the Alkali Flat-Furnace Creek subbasin. It is likely that the Ash Meadows area has been partially protected from groundwater declines by the fact that the pumping is downgradient of the Refuge and on the west side of the Gravity Fault that separates the Refuge from the rest of the Amargosa Valley. A major question for the Refuge and its water resources concerns if and when these declines will begin to be observed on the east side of the Gravity Fault and within the Refuge. Monitoring of groundwater levels and spring discharge is critical to addressing this question.

5.4.5 Nevada State Engineer Order 1197

In 2008, in response to concern over the continuing declines in water levels at Devils Hole and throughout the Amargosa Basin, the State Engineer issued Order 1197. NRS § 534.120 provides that within an area that has been designated by the State Engineer where, in his judgment, the ground-water basin is being depleted, the State Engineer in his administrative capacity is empowered to make such rules, regulations and orders as are deemed essential for the welfare of the area involved. Order 1197 applies to an area within a 25-mile radius of Devils Hole. The order curtails any new groundwater appropriation in the area as well as restricting any changes in points of diversion of existing rights to locations closer to Devils Hole. Exceptions are made for changes less than ½ mile from the original POD and for small applications seeking 2 afy or less.

The order does not definitively link the groundwater pumping in the basin to declines in the water levels at Devils Hole. In fact, the State Engineer recognized the difficulty in determining whether or not these declines are related to natural or anthropogenic factors.

In 2009, the order was appealed to the 5th District Court by some water users in the Amargosa Valley and the order has been stayed ever since that time. But the State Engineer has essentially followed the order, denying new applications in the area and change applications that would move PODs closer to Devils Hole.

6 Assessment

6.1 Water Resource Issues of Concern

Water levels in some wells and outflows from several of the major springs in the northern part of the Refuge show an apparent decline recently. The three major springs include Fairbanks, Rogers, and Longstreet (Map 3 & 5). All three springs have fairly large discharges and similar water temperatures and chemistry. They are relatively cool (27˚C to 29˚C), considering their large discharges and their proximity to the carbonate ridge, and this fact has led some researchers to suggest that they may be fed by shallower flow paths from the north or northeast (Dudley and Larson, 1976). The early record at Fairbanks Spring shows that it was strongly affected by the local pumping in the 1970s, indicating it was one of the more sensitive springs to groundwater pumping. There were no measurements in the 1970s at Rogers or Longstreet so it is not possible to say whether these springs were affected by the local pumping as well.

The Service currently measures the discharges at all three major springs with Parshall flumes and dataloggers located at the outflow of each spring. Measurements on all three springs began in the 1990s so there is about 20 years of continuous record. In general, discharge measurements with flumes are much less variable than the current meter measurements of discharge collected at the other springs. The measurements at Longstreet Spring varied seasonally but showed no overall trend until about 2005.

Since then, there has been a slow but steady decline in discharge. The decline is still small and is observable partly because of the low variability of the Parshall flume record (Figure 4). Nevertheless, Longstreet Spring is the highest elevation spring of the three northernmost springs and therefore, may be more sensitive to a general decline in the potentiometric surface of the carbonate aquifer. The other two major springs in the northern part of the Refuge, Fairbanks and Rogers, show small declines in discharge over the last several years.

Some of the wells in the northern part of the Refuge may also have declined recently, although the declines are small and not consistent through time or space. Well AM-3 (Garner well), which is the closest well to the Amargosa Farms area, had declined in the mid-2000s but seems to have stabilized recently (Figure 5). Water levels in wells on other parts of the Refuge are fairly stable, suggesting that this is not likely a response to climatic variation. The declines are not large enough or consistent enough yet to rule out natural variation. But if they continue to be observed, the Service should inform the State Engineer that we believe our water rights are being injured.

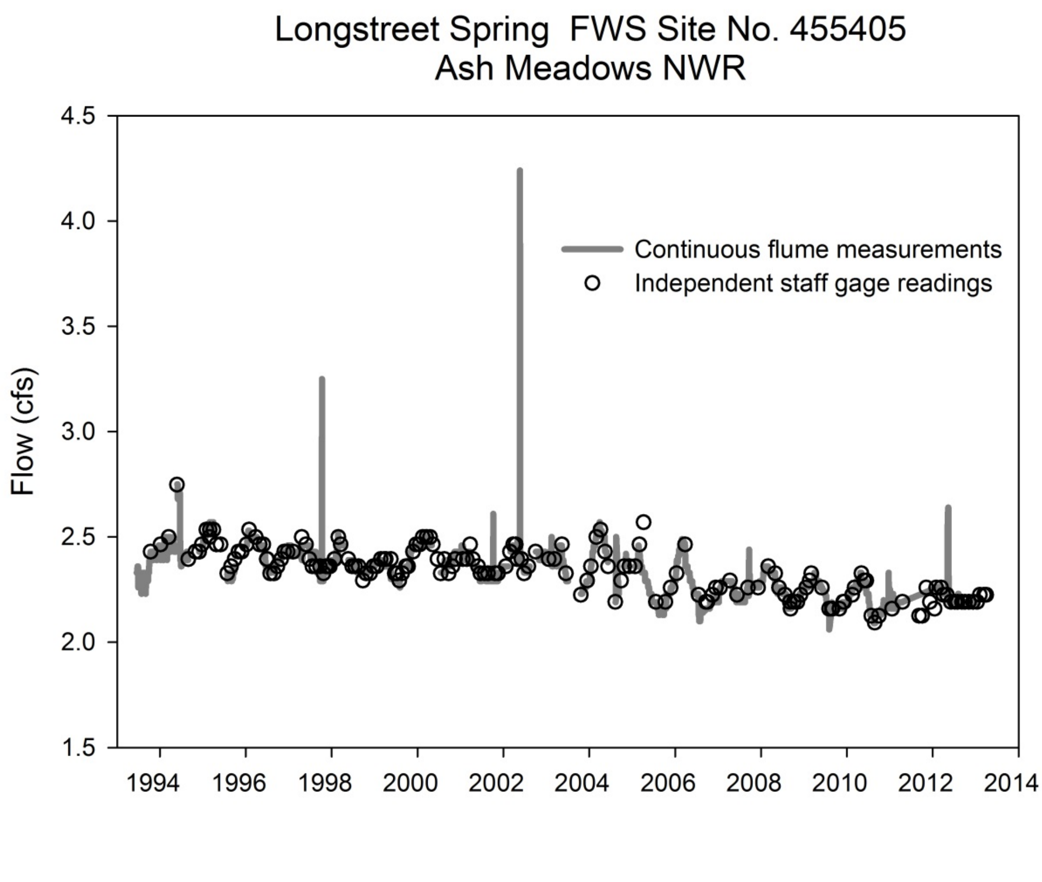


Figure 4. Flow measurements at Longstreet Spring for the period of record.

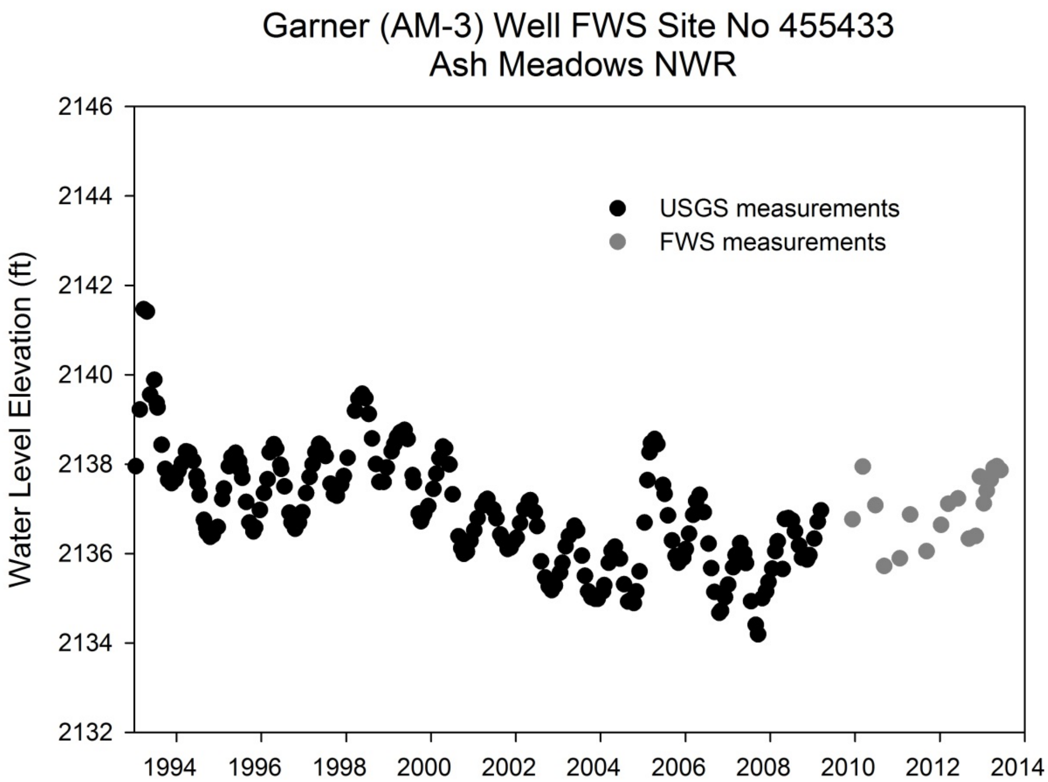


Figure 5. Water level measurements at Garner (AM-3) Well for the period of record.

6.2 Needs/Recommendations

The recommendations for water resources at the Refuge are:

1) Continue the long-term monitoring of springflows and groundwater levels that is jointly conducted by WRB and the Refuge. This monitoring was started about 20 years ago to comply with water right permit conditions and to collect information on the status and trends of springflows and water levels at the Refuge. Of particular interest are these springs and wells in the northern part of the Refuge, because of declines in springflow and water levels that have been observed there recently.

2) Continue to work with the National Parks Service, the Nevada State Engineer, and other agencies and entities to defend the Refuges water rights and water resources from water right applications or changes that may injure those rights or threaten those resources. This may involve filing protests and participating in administrative hearings related to water right protests or seeking a hearing where the Service's water rights are being injured by existing pumping. The most recent water right protest hearing that the Service participated in was in 2006. The Service and the NPS had protested several water right applications filed by Nye County for groundwater in the Amargosa Desert Hydrographic Basin, upgradient of the Refuge and Devils Hole. The protests were ultimately upheld when the Nevada State Engineer ruled that there was no water available for appropriation and that the applications would injure senior water rights held by NPS and the Service.

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