



Chapter 3 Physical Environment

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3.1 Major Landforms

Situated in the wide open spaces of the Harney Basin physiographic area, on the northern edge of the Great Basin, the Refuge centers on three shallow playa lakes, Malheur, Mud, and Harney. These lakes are located in the lowest portion of the Harney Basin and receive life-producing water from the surrounding hills and mountains. Most of the water reaching the lakes arrives in the spring as snow melts and flows southward down the Silvies River, northward in the Donner und Blitzen River (Blitzen River), and through the Silver Creek drainage from the northwest. With an average annual rain/snow fall of only 9 inches, a drought year can result in extremely dry conditions; the lakes can be reduced to a mere fraction of their former size or become alkali-covered playas. The area surrounding the lakes is relatively flat, so a 1-inch rise in the water level will put almost 3 square miles of adjacent land underwater. A year of extremely abundant rain and snow can force water to rise beyond the boundaries of the Refuge to cover surrounding lands, doubling or tripling the size of the marsh. In the mid-1980s three years of above-normal snow forced Malheur Lake beyond the refuge boundary; the lake grew from 67 square miles to more than 160 square miles. The reverse is also possible: in 1992 Malheur Lake was reduced to 500 acres with a depth of 2 inches (USFWS 1992).

Malheur Refuge lies in the Harney Basin in southeastern Oregon. The basin is in a hydrographically closed watershed on the northern reaches of the Great Basin. It lies mainly within the High Lava Plains physiographic province and is characterized as alluvial lowlands and surrounding volcanic rock uplands.

3.2 Climate

3.2.1 Current Climate

Climate Patterns

In winter, air masses moving inland from the Pacific Ocean to the North American continent pick up unlimited moisture from the ocean. The Cascade Range, some 100 miles west of the Refuge, forces this moisture-laden marine air from the Pacific Ocean to rise as it moves eastward. The resultant cooling and condensation produces heavy winter moisture on the western side of the Cascades and a rain shadow effect that extends across eastern Oregon. This produces a semiarid steppe climate for the Harney Basin, with relatively low rainfall in the lowland areas. Higher elevation areas in the basin, including Steens Mountain, are cooler and much wetter than the valley floors. The distribution of vegetation communities, which is strongly controlled by temperature and precipitation gradients, reflects this difference. Vegetation in these higher elevation areas includes western juniper and quaking aspen as well as mountain sagebrush, grasses, and other low-growing shrubs. These areas are very important to refuge water resources because the river systems that supply the Refuge are mainly sourced from higher-elevation areas. In particular, the Blitzen River, which flows through the Blitzen Valley before emptying into Malheur Lake, originates on the western side of Steens Mountain. Because of the importance of the Blitzen River to refuge water resources, the following climate discussion includes the Blitzen watershed, upstream of the Refuge, as well as the valley floor and the Refuge.

Local Temperature and Rainfall Sources 1975-2009

There are several sources of historic climate data for the Refuge. The main data source used here is the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly 2002; Daly et al. 2008). PRISM provides a complete record (i.e., no missing data) of temperature and precipitation data at 4-km resolution for the United States. Monthly minimum and maximum temperature and monthly precipitation PRISM data from 1950 to 2009 was used. A Geographic Information System was used to delineate two areas, the area encompassed by the refuge boundary and the Blitzen watershed upstream of the Refuge and Page Springs. This was then used to intersect the 4-km gridded PRISM data and queried temperature and precipitation for all grid points within the boundaries of these two areas at each monthly time step, so that an average monthly temperature and total monthly precipitation could be calculated for both the Refuge and the Blitzen watershed for every month from 1950 to 2009.

A second source of daily and monthly climate data is the individual weather stations in the area. These include Burns Municipal Airport, four National Weather Service/National Oceanic and Atmospheric Administration (NWS/NOAA) government weather stations on the Refuge (Buena Vista Station, P Ranch Substation, Double-O Station and Refuge Headquarters), and the United States Historical Climatology Network (USHCN) Malheur Refuge Headquarters station (Station No. 355162). Data from the USHCN station data was the main source of data because this station provides a complete record of high-quality climate data (Menne et al. 2009). The PRISM method described above likely used data from all these local stations, as well as snowpack telemetry (SNOTEL) station data described below, to develop the interpolated dataset for the area.

A third source of climate data is two Natural Resources Conservation Service (NRCS) SNOTEL sites, Silvies SNOTEL (Site No. 759) and the Fish Creek SNOTEL (Site No. 477), located on Steens Mountain within the Blitzen watershed (NRCS 2011). The Silvies site is slightly lower (6,990 feet) than the Fish Creek site (7,660 feet) but both sites are at high elevations for SNOTEL sites in Oregon. These sites have April 1 snow water equivalent measurements (SWE) from 1939 to the present, with daily SWE, precipitation, and air temperature measurements beginning in 1984.

Average temperature, precipitation, and April 1 SWE were calculated from the PRISM data or the SNOTEL data using the period 1975 to 2009. Summary statistics (average, maximum, and minimum) for the shorter, more recent period will be more representative of average climate in the area today. Data from the longer period (from 1950 to 2009) were used to evaluate long-term trends in the monthly temperature and precipitation PRISM data and the April 1 SWE data. Temperature or precipitation trends observed in the PRISM dataset were compared to data from the USHCN station. A Mann Kendall test, a nonparametric trend test that is less sensitive to outliers than linear regression, was used for trend testing. Because the trend is less sensitive to outliers, the test results can be thought of as more conservative—meaning it will be more difficult to detect statistically significant trends in the data.

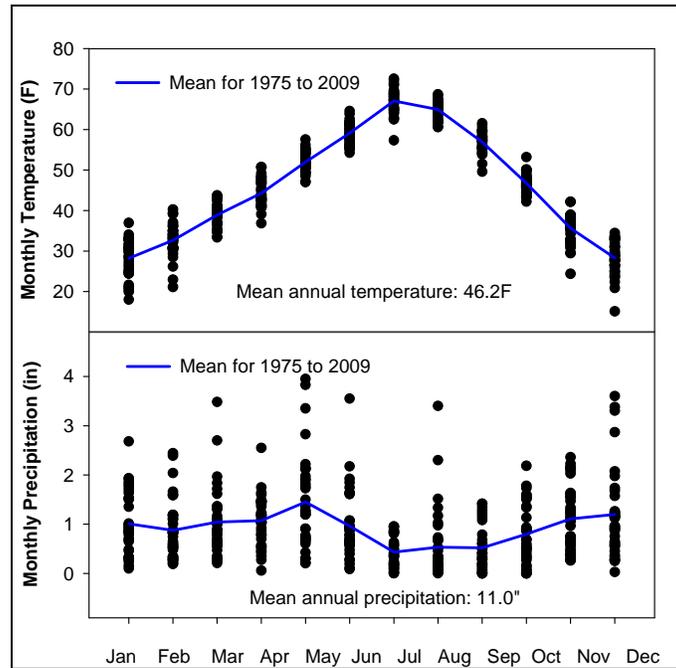
Refuge Temperature and Precipitation Averages 1975-2009

Temperature: The mean annual temperature for the Refuge is 46.3°F for the period 1975 to 2009 (Figure 3-1). July is the warmest month, with an average monthly maximum temperature of 84.9°F. January is the coldest month, with an average monthly minimum temperature

All references to elevations in this document are at the National Geodetic Vertical Datum of 1929 (NGVD29), to the best of our knowledge.

of 18.4°F. Average monthly minimum temperatures are below 32°F from November through April. The USHCN station (elevation 4,118 feet) at Malheur Refuge Headquarters has recorded an average of 18 days a year with temperatures of 90°F or greater, and an average of 182 days a year with temperatures of 32°F or less.

Precipitation: Average annual precipitation for the Refuge is 11.0 inches for the water year (October-September), with most of that total (9.5 inches) falling from October to June (Figure 3-1). The summer months, July through September, are typically very dry, although August has been wet in some years because of thunderstorm activity. Thunderstorms accompanied by lightning are common during the late summer and influence the frequency of wildland fires on and around the Refuge.



Source: PRISM 4-km gridded data.

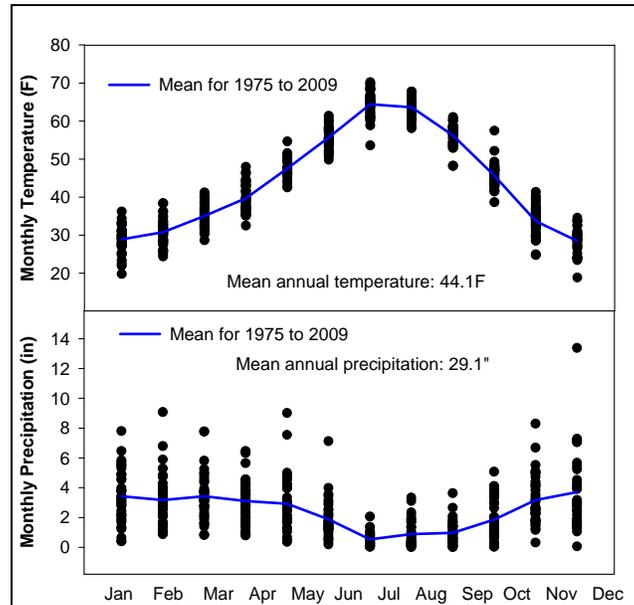
Figure 3-1. Mean and distribution of monthly temperature and precipitation for the area encompassed by Malheur Refuge for the period 1975 to 2009.

Wind: Winds are common in the area with an annual average speed of 6.7 miles per hour (MPH) and gusts over 25 MPH. In general, winds are westerly but switch to the north and east during the winter. Severe wind conditions are usually associated with the onset of late summer thunderstorm activity.

Blitzen Watershed Temperature and Precipitation (Off-refuge)

The Blitzen watershed upstream of the Refuge and Page Springs is higher in elevation than the Refuge (average elevation is 6,200 feet compared with the valley floor elevation of 4,150 feet). Average temperatures are not very different from the valley floor of the Refuge, but precipitation is much greater on the mountain. Over the period from 1975 to 2009, the mean annual temperature for the Blitzen watershed measured 44.1°F (Figure 3-2), with an average monthly maximum temperature of 78.2°F in July and an average monthly minimum temperature of 20.1°F in December, the coldest month.

Average annual precipitation in the watershed is 29.1 inches, almost three times the amount on the Refuge, with most of that (26.7 inches) occurring October through June (Figure 3-2). Much of the winter precipitation in the area falls as snow. April 1 SWE at the two Steens Mountain SNOTEL sites averages 17.6 inches (range 0 to 40.8 inches) at Silvies and 29.0 inches (range 9 to 49.8 inches) at Fish Creek for the period 1975 to 2009. The Fish Creek site receives more snow because of its higher elevation. As in many areas of the West, the spring snowpack represents an accumulated reservoir of water that is released slowly from April through June and sustains streams through the typically dry summers of the region.



Source: PRISM 4-km gridded data.

Figure 3-2. Mean and distribution of monthly temperature and precipitation in the Blitzen River watershed above Page Springs for the period 1975 to 2009.

Climate Variability

Pacific Northwest climate variability is strongly shaped by two large-scale patterns: the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Each ENSO phase (El Niño or La Niña) typically lasts six to 18 months, while, during most of the 20th century, each PDO phase has typically lasted for 20 to 30 years. These climate drivers can act separately or in concert in creating patterns of warm/dry or cool/wet winters. Via their influence over both winter temperature and winter precipitation, these natural climate patterns exert significant influence on snowpack and hydrology.

Although both ENSO and the PDO have been shown to affect climate in the Pacific Northwest (Cayan et al. 1999; Mantua and Hare 2002; McCabe and Dettinger 2002), neither is significantly correlated with precipitation or temperature at the Refuge or in the Blitzen watershed. The lack of any relationship may be due to the fact that the Refuge is located at the intersection of two geographic regions, the Pacific Northwest and the Great Basin, with contrasting responses to ENSO and the PDO.

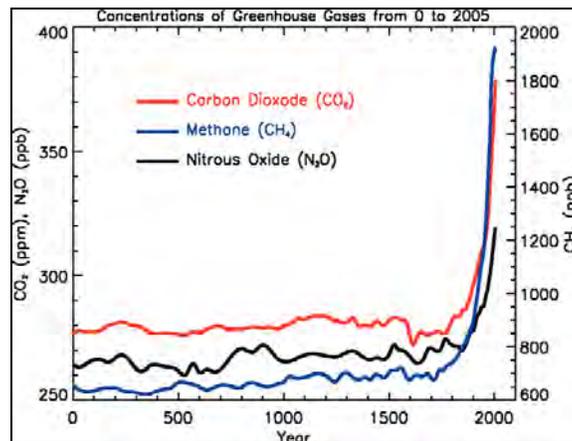
3.2.2 Climate Change

As required by [DOI Secretarial Order 3226](#), issued in 2001, the Service requires consideration and analysis of climate change in long-range planning. Detailed information about climate change is contained in Appendix M. Relevant data that apply to the Refuge have been taken from this appendix and are presented below.

Global Greenhouse Gases

The greenhouse effect is a natural phenomenon that assists in regulating and warming the temperature of our planet. Just as a glass ceiling traps heat inside a greenhouse, certain gases in the atmosphere, called greenhouse gases, absorb heat from sunlight, trapping heat in the atmosphere and warming the planet. The primary greenhouse gases occurring in the atmosphere include carbon dioxide (CO₂), water vapor, methane, and nitrous oxide. CO₂ is produced in the largest quantities, accounting for more than half of the current impact on the earth's climate.

A growing body of scientific evidence from 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; USGCRP 2009). The concentrations of heat-trapping greenhouse gases have increased significantly over the last several hundred years due to human activities such as deforestation and the burning of fossil fuels (Figure 3-3).

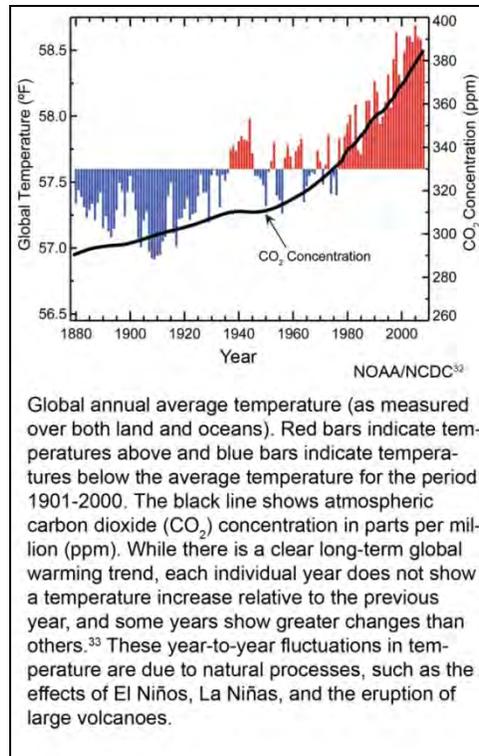


Source: IPCC 2007.

Figure 3-3. Concentrations of important heat-trapping greenhouse gases over the last 2,000 years.

Global Temperature in Relationship to Greenhouse Gases

There is a direct correlation between greenhouse gas concentrations and the temperature of the earth's surface. Global surface temperatures have increased about 1.3°F since the late 19th century (USGCRP 2009), and the rate of temperature increase has risen in more recent years (Figure 3-4). The Intergovernmental Panel on Climate Change (IPCC), a large group of scientists created by the United Nations to evaluate the risk of climate change caused by human activities, reported in 2007 that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC 2007).



Source: USGCRP 2009.

Figure 3-4. Global average temperature and CO₂ concentrations from 1880 to 2008.

In the northern hemisphere, recent decades appear to be the warmest since about A.D. 1000, and warming since the late 19th century is unprecedented over the last 1,000 years. Globally, 2010 and 2005 tie as the warmest years in the instrumental record (1880 to the present), while 2009 was only a fraction of a degree cooler, matching 1998, 2002, 2003, 2006, and 2007 for the second warmest on record, according to independent analyses by NOAA and the National Aeronautics and Space Administration (NASA). The new 2010 record is particularly noteworthy because it occurred in the presence of a La Niña and a period of low solar activity, two factors that have a cooling influence on the planet. However, in general, decadal trends are far more important than any particular year's ranking.

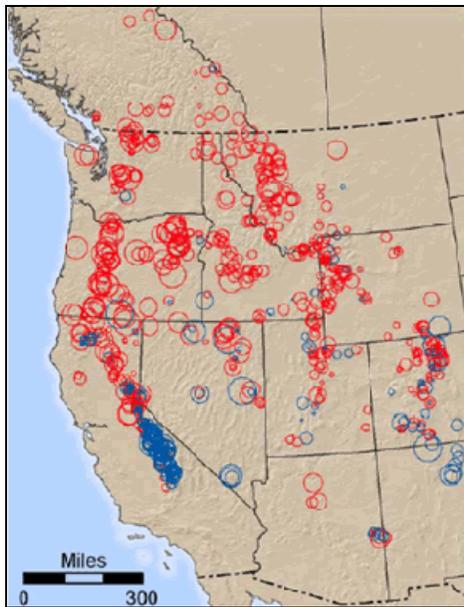
Pacific Northwest Climate Indicators and Trends

From a climate change perspective, the Refuge is more closely aligned with changes that have occurred in the Pacific Northwest than those in the desert regions of the Southwest. In the Pacific Northwest, regionally averaged temperature rose 1.5°F between 1920 and 2000, slightly more than the global average. Warming was largest for the winter months of January through March. Minimum daily temperatures have increased faster than maximum daily temperatures. Longer-term precipitation trends in the Pacific Northwest are more variable and vary with the period of record analyzed (Mote et al. 2005). Looking at the period 1920 to 2000, precipitation has increased almost everywhere in the region. Most of that increase occurred during the first part of the record.

In the Pacific Northwest, increased greenhouse gases and warmer temperatures have resulted in a number of physical and chemical impacts to the region. These include changes in snowpack,

streamflow timing and volume, flooding and landslides, sea levels, ocean temperatures and acidity, and disturbance regimes like wildfires and outbreaks of insects and diseases (USGCRP 2009).

Snowpack Changes: One of the most important responses to warmer winter temperatures in the Pacific Northwest has been the loss of spring snowpack (Mote et al. 2005). As temperatures rise, the likelihood of winter precipitation falling as rain rather than snow increases. This is especially true in the Pacific Northwest where mountainous areas of snow accumulation are at relatively low elevations and winter temperatures are near freezing. Small increases in average winter temperatures can lead to increased rains, reduced snowpack, and earlier snowmelt. The loss of spring snowpack in the Pacific Northwest has been significant, with most of the stations showing, on average, a decrease (Figure 3-5). Data recorded each April 1 show that snowpacks have declined 25 percent over the past 40 to 70 years (Mote et al. 2005). The fact that the declines are greatest at low-elevation sites and that the trend has occurred in the absence of significant decreases in winter precipitation implicates temperatures rather than precipitation as the cause of the trend.



Source: Mote et al. 2005.

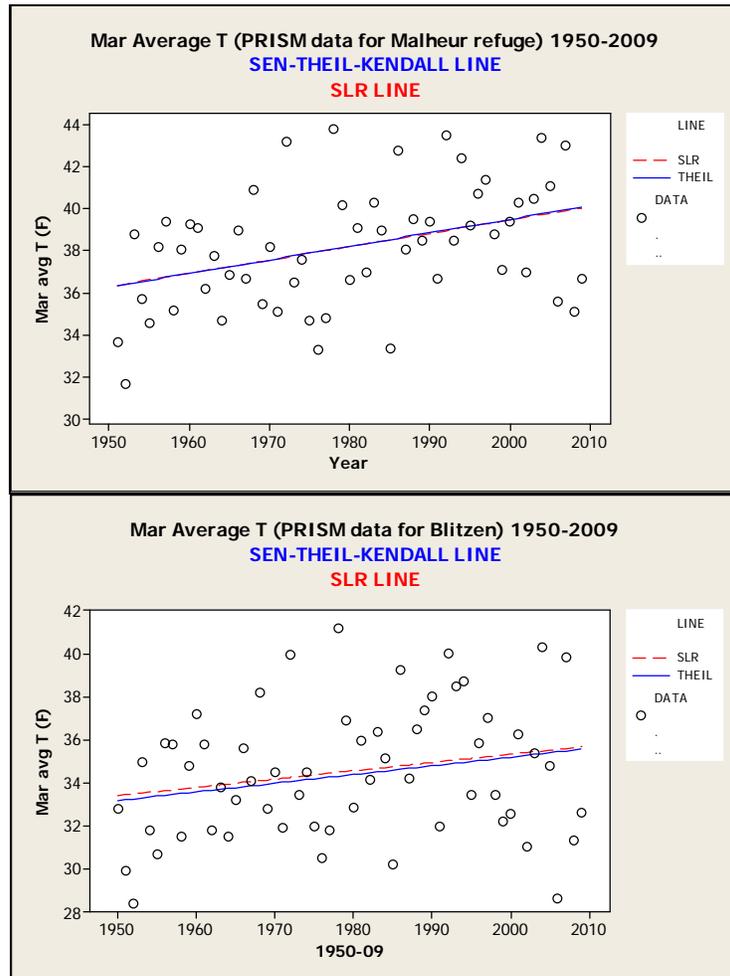
Red (blue) circles indicate decreasing (increasing) snow water equivalent (SWE), with the size of the symbol indicating the magnitude of the trend

Figure 3-5. Trends in April 1 snow water equivalent in the western United States from 1950 to 1997.

Streamflow changes: The decrease in spring snowpack and earlier snowmelt has led to a change in streamflow in many systems, including earlier spring runoff peaks, increased winter streamflow, and reduced summer and fall streamflows. Stewart et al. (2005) examined 302 streamflow gages in the western United States and reported that the timing of winter runoff and annual streamflow had advanced by one to four weeks from 1948 to 2002. The degree of change depends on the location and elevation of the specific river basin. Basins located significantly above freezing levels have been much less affected by warmer temperatures than those located at lower elevations. River basins whose average daily winter temperatures are close to freezing are the most sensitive to climate change, as is apparent from the dramatic shifts in streamflow timing that have resulted from relatively small increases in wintertime temperatures.

Climate Change Indicators and Historical Trends at Malheur Refuge

An analysis of historic PRISM data between 1950 and 2009 for both the refuge area and the Blitzen watershed revealed a statistically significant trend in March monthly temperatures, showing a 3.5°F increase over the period measured (0.6°F per decade; see Figure 3-6). The USHCN data from the Malheur Refuge Headquarters station validate this (data not shown). The USHCN station data also show statistically significant increases in several other months.



Source: PRISM data.

Figure 3-6. Trend in March monthly temperature for the Refuge and the Blitzen from 1950 to 2009.

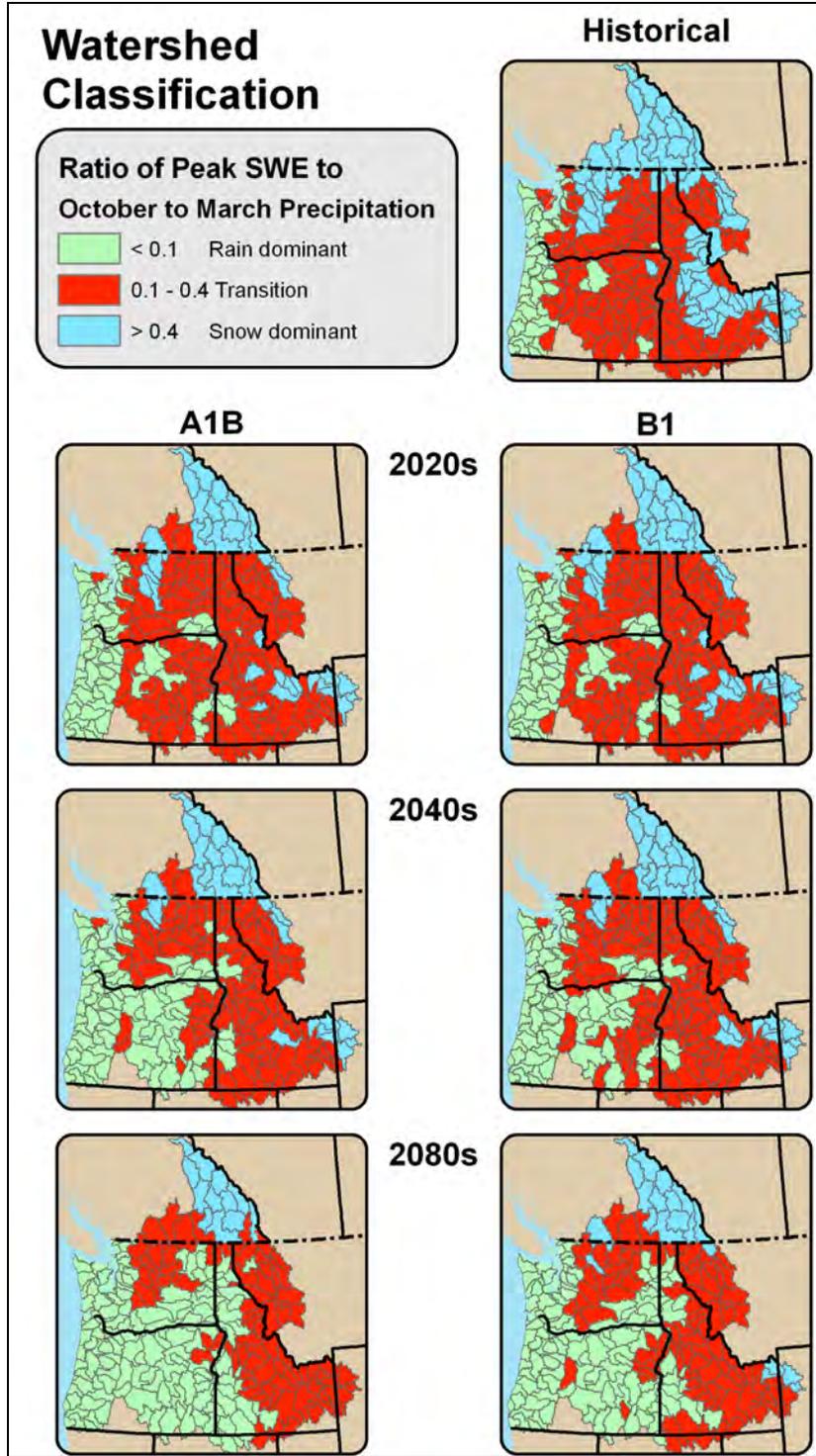
Precipitation data from PRISM and USHCN show opposite trends (one increasing and one decreasing) from 1950 to 2009 but neither trend is statistically significant. As discussed above, winter temperatures, particularly in January and March, have been shown by other studies to be increasing in the West (Hamlet and Lettenmaier 2007; Knowles et al. 2006). The increases can cause more precipitation to fall as rain versus snow, resulting in reduced April 1 SWE, earlier snowmelt, and changes in streamflow.

The SNOTEL data from Steens Mountain suggest that warmer March temperatures may have impacted snowpack at least at lower elevations in the Blitzen watershed. There is a statistically significant decreasing trend (-5 percent per decade or -34 percent) from 1950 to 2009 in the April 1 SWE at the Silvies SNOTEL, the lower-elevation site. April 1 SWE at Fish Creek, the higher-elevation site, shows a very slight decrease from 1950 to 2009, but the trend is not statistically significant. Note that the Blitzen PRISM dataset shows an increase in precipitation over the same period. The fact that precipitation in the Blitzen watershed has increased or at least not changed while SWE at the lower-elevation site has decreased significantly indicates that the decreasing trend at the Silvies SNOTEL site is most likely related to warmer temperatures. Because of the relatively high elevation and cold climate of the Blitzen watershed and the Steens Mountain area, snowpack has not been affected by warming temperatures to the degree it has in other lower-elevation areas around the Pacific Northwest. However, as temperatures continue to warm, snowpack will likely continue to decline.

One of the expected impacts of declining snowpacks and earlier snowmelt is a change in streamflow timing and volume, specifically higher winter flows, an earlier snowmelt runoff peak, and reduced late season baseflows. Because the USGS Blitzen River stream gage has a long period of record (continuous measurements from 1939 on) and is upstream of any significant diversions or regulation, it provides an excellent record of the river's response to climate. To date, few climate change impacts can be observed in the Blitzen River streamflow record, in contrast to other stream systems in the Pacific Northwest. There is no trend in the annual streamflow centroid (the date on which approximately half of the annual volume of streamflow occurs for the water year) or the annual minimum seven-day average flow. There has been no change in the percentage of monthly flows to total annual flow for March through September over the same period (data not shown). There has been a slight decrease in the ratio of June-to-May flows, as might be expected with earlier runoff, and an increase in the annual maximum daily flow, as might be expected with more winter/spring rains, but the statistical significance of both of these trends is weak ($p=0.14$).

In addition to changes in the amount of precipitation, a major concern in the Pacific Northwest is the change in the form of winter precipitation expected due to warmer temperatures. The Climate Information Group at the University of Washington (CIG) has modeled changes in the current and future peak SWE versus October-March precipitation (O-M pcp) for fourth-level hydrologic unit code (HUC) watersheds in the Columbia Basin area, including the Blitzen watershed. CIG has classified watersheds into three categories to reflect projections of the dominant precipitation regime: snow (peak SWE/O-M pcp > 0.4), transition (peak SWE/O-M pcp = 0.1 to 0.4), and rain (peak SWE/O-M pcp < 0.1). Generally, there is a large shift in the Pacific Northwest from snow and transition basins to rain basins. In basins where these changes occur, there will likely be a tendency for higher winter flows and possibly an increased risk of flooding, earlier snowmelt and runoff peaks, and lower summer streamflows (Figure 3-7).

The Blitzen watershed is currently classified as a transition basin and is projected to remain that way until the 2080s under the A1B scenario and through the 2080s under the B1 scenario (see Appendix M), when it will become a rain basin. This shift to a rain basin occurs more slowly than in many of the surrounding basins in the Pacific Northwest and the Blitzen watershed appears to be more resilient to climate change, probably because of the higher elevation and cooler climate in the Steens Mountain area.



Source: CIG 2010. The Blitzen watershed is not identified in this figure; however, it is the small, isolated basin in southeastern Oregon shown in red in the lowest right figure

Figure 3-7. Ratio of April 1 SWE to total October-March precipitation for the historical period (1916-2006), for the A1B scenario (left panel), and for the B1 scenario (right panel) at three future time periods (2020s, 2040s, 2080s).

Observed and Predicted Ecological Response to Climate Change in the Region

An emerging body of literature indicates that over the past three decades, the changes in the climate system, including the human-caused component of warming, have resulted in physical and biological changes in a variety of ecosystems (IPCC 2007; Parmesan 2006; Root et al. 2003) that are discernable at the global scale. Climate change has and will continue to combine with other nonclimate stressors to impact ecosystems and threaten biodiversity. In the Great Basin, climate change, invasive species, habitat fragmentation, and rangeland and riparian degradation have placed numerous species at risk, including sage-grouse and redband trout (Chambers and Pellant 2008).

Disturbances, both natural and human-induced, shape ecosystems by influencing their composition, structure, and function. One observed response to climate change in the Pacific Northwest is the change in disturbance regimes like fire and outbreaks of insects and diseases. Increased spring and summer temperatures, earlier snowmelt, and prolonged drought have contributed to longer fire seasons and an increase in wildfire activity in the Pacific Northwest. Westerling et al. (2006) evaluated the effects of both land-use histories and climate on wildfire and concluded that the increase in fire frequency in the past two to three decades has been driven primarily by recent changes in climate. Areas in southern Oregon, northern California, and the northern Rockies have been especially vulnerable to these changes.

Interactions between climate change and non-native invasive species may combine to increase invasion risk to ecosystems. Bradley (2009) showed that the potential area for cheatgrass invasion, which is sensitive to precipitation and temperature, increased up to 45 percent in the western U.S. with decreasing summer precipitation and warmer winter temperatures. Cheatgrass invasion also interacts with climate change to alter fire regimes. Frequent fires promote invasive grasses like cheatgrass, and large grassland fires are more likely in a warmer, drier climate with exotic grasses present. The cheatgrass-fire cycle has been a major factor in the decline of sagebrush-steppe ecosystems, and climate change is likely to exacerbate this decline (Chambers and Pellant 2008).

Climate change is also expected to cause major changes in grassland and sagebrush distribution across the landscape (Bachelet et al. 2001). Range expansions of woody species are predicted to continue, particularly the expansion of pinyon-juniper into sagebrush steppe and grasslands (Rowland et al. 2008), resulting in a decrease in sagebrush and an increase in woodlands across the West. More frequent wildfires may favor non-native invasive species and exacerbate the loss of big sagebrush, a keystone species that is not very fire tolerant. In the Great Basin, current sagebrush habitat is predicted to decrease 12 percent for each 1.8°F (1°C) increase in temperature, partly because of these factors (Chambers and Pellant 2008). However, more frequent fires might also limit juniper expansion.

Climate change has a large potential to impact aquatic ecosystems in the Pacific Northwest. Although there have been few climate change impacts on Blitzen streamflow to date, aquatic habitats at the Refuge, including rivers, streams, springs, wetlands, and wet meadows, face future threats from climate change. River and stream temperatures may increase with warmer air temperatures and longer growing seasons, threatening redband trout. Water temperatures in the Blitzen River are already quite warm; seven-day average maximum temperatures are frequently near 77°F (25°C) in the summer (Mayer et al. 2007). Even at the upstream end, where the river enters the Refuge from the canyon, water temperatures exceeded the State standard of 68°F (20°C) for an average of 64 days during the summers of 2003 and 2005 (Mayer et al. 2007).

Evaporative and seepage losses in wetlands and wet meadows may increase due to warmer temperatures, longer growing seasons, drier soils, and lower water tables, potentially limiting the available habitat that can be sustained for migratory waterfowl. Changes in transpiration are uncertain. There may be less transpiration because of greater photosynthetic efficiency from higher CO₂ concentrations in the atmosphere, but higher CO₂ concentrations could also mean more plant growth, plant leaf area, and increased transpiration. Earlier runoff and higher evaporation losses could cause a decrease in wetland acreage that can be maintained on the Refuge given the refuge water supply.

Climate Change Adaptation Strategies

The slower response and apparent resilience of the Blitzen watershed to climate change may provide the Refuge with an opportunity to develop and implement climate change adaptation strategies (or adjustments in management). The goal of adaptation is to reduce the risk of adverse environmental outcomes through activities that increase the resilience of ecosystems to climate change and other stressors (USCCSP 2008). *Resilience* is defined as the amount of change or disturbance a system can absorb without undergoing a fundamental shift to a different set of processes and/or structures. One of the most effective means of increasing resilience is to reduce or eliminate nonclimate stressors.

Climate change will combine with other nonclimate stressors to exacerbate existing problems with water supply, aquatic resources, invasive weeds, and ecosystem function on the Refuge. Even now, there are difficulties balancing the needs of water management for wetlands with the needs of in-stream flows for fish. Wetland irrigation and water management on the Refuge decrease river flows, exacerbate high water temperatures, and reduce dissolved oxygen concentrations in the river (Mayer et al. 2007). River temperatures are already at or near the limit of tolerance for redband trout on most of the Refuge. The river was channelized in the 1910s to facilitate drainage and water delivery. Riparian vegetation is limited and the river habitat is degraded, with little complexity. Wetland and wet meadow habitats on the Refuge are threatened by several non-native invasive plant species including perennial pepperweed, Russian olive, and reed canarygrass. Aquatic and riverine habitats are threatened by non-native invasive carp.

Reducing nonclimate stressors means controlling invasive species and could include restoring the river, rehabilitating riparian vegetation, re-establishing where possible the natural sinuosity of the channel, and reconnecting where viable valley wetlands and floodplains with the river channel. Reducing the impacts of current stressors is a “no regrets” adaptation strategy that could be used to enhance ecosystem resilience to climate change. These activities would require time. Fortunately, the fact that climate change impacts are slower to manifest themselves here compared with other areas would allow more time to implement these restoration activities.

Key to the successful implementation of these adaptation and restoration strategies will be the monitoring of results. The NWS weather stations, the USGS Blitzen river gage, and the two NRCS SNOTEL sites on Steens Mountain will continue to provide very valuable climate and streamflow information on the local impacts of climate change. It is in the Refuge’s best interest to see that these sites are maintained and monitored in the future. The Water Resources Branch of the Service monitors streamflows and diversions at several sites on the Refuge; this should be continued as well. The branch also monitored water temperatures in the river during the summers of 2002, 2003, and 2005. This seasonal water temperature monitoring should be continued in the future. Finally, ongoing efforts to monitor and contain invasive species will be important for providing information on the status of nonclimate stressors.

Monitoring may provide information that will require modification of adaptation strategies or point to new restoration needs. One method for integrating new information into resource management decisions given uncertainty is adaptive management. Adaptive management is a process that promotes flexible decision making so that adjustments are made in decisions as outcomes from management actions and other events are better understood. This method supports managers in taking action today using the best available information while also providing the possibility of ongoing future refinements through an iterative learning process.

3.3 Hydrology

This section first describes the hydrologic units within which the Refuge is located. The rivers, streams, and lakes of the Refuge are then explored in detail. Finally, groundwater sources are discussed, followed by water rights.

3.3.1 Hydrologic Units

The USGS maps the river basins and nested sub-basins, watersheds, of the United States using a system of nested hydrologic units. Each region is divided and subdivided into successively smaller hydrologic units. Hydrologic units are identified by a unique code (i.e., an HUC) consisting of two to eight digits. The number of digits indicates the scale: the grossest level of classification receives two digits while the finest based on the four levels of classification in the hydrologic unit system.

The Refuge, together with much of the surrounding area, is contained within USGS Accounting Unit 171200—Oregon closed basins. The area of this accounting unit is 17,300 square miles. Within this area are nine smaller hydrologic units (known as cataloguing units or watersheds). The Refuge includes portions of three of these hydrologic units:

- Unit 17120001—Harney-Malheur Lakes (area=1,420 square miles)
- Unit 17120003—Donner und Blitzen (area=765 square miles)
- Unit 17120004—Silver (area=1,670 square miles)

Although not identified as a USGS-delineated hydrologic unit, many people refer to the Harney Basin as a hydrologic entity. The Harney Basin is a hydrographically closed basin located largely in northern Harney County, bounded on the north by the southern end of the Blue Mountains. The ridge of Steens Mountain separates the basin from the watershed of the Alvord Desert to the southeast. No streams cross the volcanic plains that separate the basin from the watershed of the Klamath River to the southwest. The basin encompasses an area of 5,300 square miles in the watershed of Malheur Lake and Harney Lake. (Wikipedia 2011)

The basin coincides with a large down-warped and faulted structural basin that formed during the late Tertiary (65 to 2.6 million years ago) and Quaternary (2.5 million to 500,000 years ago) periods (McDowell 1992). The shallow playa lakes of the Refuge (Malheur, Mud, and Harney lakes) are located in the center of the basin.

Malheur-Harney Lakes Sub-basin

An assessment of the Harney-Malheur Lakes Sub-basin was prepared in 2001 by the Harney County Watershed Council (HCWC 2001) for future watershed management plans.

The Harney-Malheur Lakes Sub-basin is over 894,000 acres in size; 11.4 percent (101,555 acres) of this sub-basin is managed by Malheur Refuge. The groundwater system encompassed by the sub-basin receives discharge from the adjacent uplands and from stream seepage adjacent to the uplands. Although Silver Creek, the Silvies River, and the Blitzen River do not originate within the sub-basin, all eventually discharge into Malheur Lake or Harney Lake (HCWC 2001).

During the Pleistocene (2.6 million to 11,700 years ago) epoch, the levels of Malheur, Mud, and Harney lakes fluctuated widely with climatic conditions. When levels were high enough, water exited the basin through Virginia Valley via the Malheur River. A Pleistocene basalt flow in the vicinity of Princeton at Malheur Gap, which occurred around 32,000 years ago, prevents outflow from the basin except during very high water events. Lake levels must exceed 4,114 feet in elevation before water can flow over the lava flow at Malheur Gap.

Lake level fluctuations are characteristic of closed basins, and even today the level of Malheur Lake can fluctuate dramatically from year to year. Recent lake level fluctuations attest to the dynamic nature of Malheur Lake levels. Beginning in 1982 Malheur Lake began to rise as greater than normal precipitation occurred in the Harney Basin. By 1985, the lake level exceeded 4,102 feet, a rise of over 7.5 feet in just three years, and Malheur Lake reached 124,440 surface acres. At that time, the combined surface areas of Malheur, Mud, and Harney lakes exceeded 172,000 surface acres, or 279 square miles. The reverse is also common for the lakes: in 1992 Malheur Lake was reduced to 500 surface acres with a depth of 2 inches (USFWS 1992).

Donner und Blitzen Sub-basin

An assessment was prepared for the Donner und Blitzen Sub-Basin in 2003 (HCWC 2003). The Donner und Blitzen Sub-basin originates on the north slope of Steens Mountain and extends northward to the boundary of the Harney-Malheur Lakes Sub-basin. The sub-basin consists of over 505,100 acres, with just 64,652 acres, or 12.8 percent of the land, under refuge management. The Blitzen River is located within this sub-basin and, except during very high precipitation years when flows from the Silvies River reach Malheur Lake, provides the only water supporting Malheur Lake.

Silver Creek Sub-basin

An assessment of the Silver Creek Sub-basin was completed in 2000 (HCWC 2000). The Silver Creek Sub-basin is located in the northwest corner of Harney County with a very small portion extending into Lake County. It is contained in the Malheur Lake Basin. The sub-basin consists of over 1,075,748 acres, with just 20,574 acres, or 1.9 percent of the land, under refuge management in the Double-O Unit. The Silver Creek area in the northwestern part of the Malheur Lake basin comprises all drainage into Harney Lake west of the Narrows, an area of land separating Harney and Malheur lakes.

3.3.2 Rivers and Streams

Three major streams (the Silvies River, the Blitzen River, and Silver Creek) flow from the north, south, and west, respectively, and enter the Harney-Malheur Lakes Sub-basin and ultimately the Refuge. Water originates primarily from snowmelt and runoff from higher elevations; however, springs, especially in the Double-O Unit, also contribute to flows. As these watercourses enter the Harney-Malheur Lakes Sub-basin, flows decrease with irrigation withdrawals before reaching the

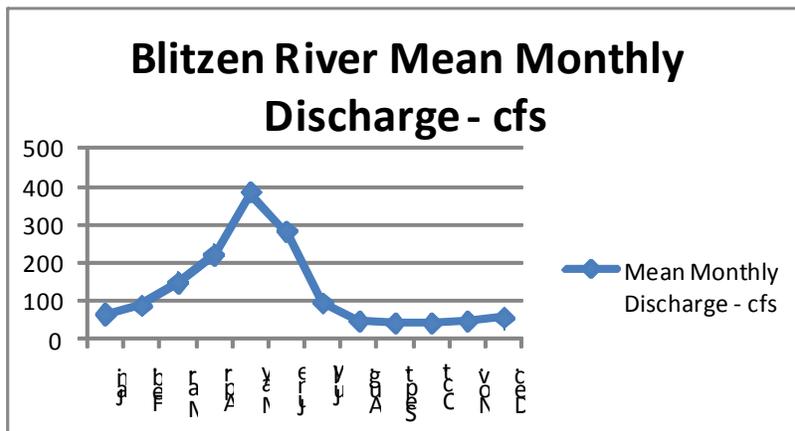
lakes. Two of the three waterways (Blitzen River and its tributary Bridge Creek) have USGS gage stations located just upstream of their entrances into the alluvial valley.

The Blitzen River

The largest watercourse influencing refuge lands is the Blitzen River. The Blitzen River drains the southern portion of the Donner und Blitzen Sub-basin and receives most of its volume from Steens Mountain as snowmelt. By the time the river enters Malheur Lake it has drained an area of 760 square miles (Hubbard 1975). It is joined by a number of tributaries, (Mud, Bridge, Krumbo, and McCoy creeks) as it continues downstream. The discharge of the Blitzen is reduced as it enters the valley because of irrigation withdrawals at four dams.

The maximum annual runoff, recorded at the USGS gaging station upstream of the Refuge from 1939 to 2004, was 198,000 acre-feet in 1984 and the minimum was 36,000 acre-feet in 1992. The mean annual discharge carried by the waterway is 91,000 acre-feet, and Mann-Kendall trend analysis showed no significant change to the mean annual discharge over the 67 year period (Mayer et al. 2007). However, by the time the river reaches the lake the mean annual flow is 60,000 acre-feet. This decrease in flow is the result of a system of dams and irrigation canals that divert water to meadows, marshes, and pools throughout the Blitzen Valley. Figure 3-8 shows the monthly mean discharge for the Blitzen River.

Streamflow on the Blitzen River is driven by snowmelt which contributes increased discharges to the Refuge beginning in early March and reaches a peak in May. The average May volume is 369 cfs, or 22,700 acre-feet for the month, representing 25 percent of the total annual runoff. Flows tend to decline in June with minimum levels attained in August or September averaging a discharge of 42 cfs, or 2,490 acre-feet for the month.



Source: USFWS, Region 1 Water Resources Division.

Figure 3-8. Monthly mean discharge for the Blitzen River.

Water Control and Distribution: A system of dikes, canals, drains, and water control structures were developed along the Blitzen River system beginning in the late 1800s, to facilitate the movement or diversion of portions of the river’s discharge for the benefit of grazing and farming (Burnside 2008). Between 1907 and 1913, 17.5 miles of stream were channelized and straightened. Additional dikes, canals, and water control structures were added between 1935 and 1942 by the Civilian Conservation

Corps. More than 900 water control structures occur in the Blitzen Valley as part of the intensive water management system used by the Refuge to manage ponds, wetlands, and meadows. River water is pooled behind four dams before being diverted via canals and ditches to meadows, ponds, and wetlands. Flows return to the river by surface sheet flow, flow through ditches or pipes, and subsurface seepage (Mayer et al. 2007). Portions of the early water distribution system still exist but have been substantially modified as the Refuge has made changes to manage water in the Blitzen Valley.

Diversion of the Blitzen starts at the Page Springs Dam at the southern end of the Blitzen Valley and continues to be diverted at Grain Camp Dam, Busse Dam, and Sodhouse Dam. The diversion sites from upstream to downstream are as follows: Page Springs Dam, Old Buckaroo Dam, Grain Camp Dam, Busse Dam, Dunn Dam, and Sodhouse Dam. The Refuge maintains a minimum flow of 25 cfs in the river to benefit aquatic resources. Table 3-1 shows the diversion capacity in cfs for canals associated with the main structures used to divert water from the Blitzen River.

Table 3-1. Barrier Diversion Capacity for Structures on the Blitzen River

Structures	Number of Diversion Canals	Cubic Feet per Second
Page Springs	2	200
Old Buckaroo	1	10
Grain Camp	2	303
Busse	2	166
Dunn	2	84
Sodhouse	1	37

The water delivery system of the Refuge is complex and a summary of how this system works is difficult to describe.

Tributaries of the Blitzen River

Five major tributaries contribute water to the Blitzen River after it enters the Refuge (other upstream tributaries on Steens Mountain provide significant flows to the river before it enters the Refuge and are not discussed here). The tributaries are Mud Creek, Bridge Creek, Krumbo Creek, McCoy Creek, and the Diamond Drain, which incorporates water from Cucamonga and Kiger creeks. Mud Creek water flows directly into the East Canal. A portion of Bridge Creek contributes to flows in the East Canal, but most of the water meanders westward until it flows into the Blitzen River. Krumbo Creek flows into Krumbo Reservoir and then enters a series of ditches in the Krumbo Valley before reaching the Blitzen River. McCoy Creek skirts the southern edge of the Diamond Swamp where it becomes channelized in the Diamond Canal before entering the river north of Diamond Lane. The Diamond Drain moves water to the north along the edge of the valley before draining into the river via the Skunk Farm Canal.

The Silvies River

The other main water source for Malheur Lake is the Silvies River, which drains the north side of the Harney Basin. The river receives most of its volume from the Strawberry Mountains and the Aldrich Mountains as snowmelt. It flows through the Bear and Silvies valleys before entering the Harney Basin near the community of Burns. The watercourse drains a larger area than the Blitzen River but provides less inflow to the lake because of upstream diversions and withdrawals. The Silvies River enters the Refuge at two locations on the north side of Malheur Lake when sufficient flows are present. Currently, the Silvies River contributes water to Malheur Lake only when flows exceed upstream water right allocations, usually two to three times per decade.

Silver Creek

The northwestern portion of the Harney Basin and the Refuge is drained by Silver Creek, which flows southward before entering Harney Lake. This waterway drains an area of 544 square miles with most of the volume coming from the Snow Mountain area. The creek travels through the Warm Springs and Silver Creek valleys before entering Moon Reservoir. Shortly below Moon Reservoir, the creek channel turns into a complex series of irrigation ditches on private lands. The creek continues to flow through these ditches until it enters Refuge lands and flows into Harney Lake across a marsh delta and the channel transitions into a playa. Silver Creek contributes standing water over the surface of Harney Lake only during very high water years.

3.3.3 Malheur, Harney, and Mud Lakes

Malheur Lake

Malheur Lake is the highest and freshest of the three lakes. Because the lake depression is broad and shallow, a slight rise in water level results in a large expansion of lake or marsh surface area. Inundated areas typically range from 25,000 to 45,000 acres. During historic times, Malheur Lake surface acres have ranged from completely dry (1934) to 124,000 acres (1986). Water depth ranges from 1 to 6 feet with an extreme depth of 14 feet in 1986. Water quality is variable across the lake, with the freshest water found where the rivers empty into the lake.

Malheur Lake consists of three units that are ecologically and hydrologically distinct (Duebbert 1969). The western unit extends from the Narrows east to Graves Point, a discontinuous ridge, which runs north-south. The central unit extends from Graves Point to the remnants of Cole Island Dike, the dike is created from a discontinuous series of dune islands which trend north-south across the lake. The eastern unit extends from Cole Island Dike to the eastern edge of the lake east of the Pelican Islands. Under normal water levels, Malheur Lake consists of shallow marsh in the western third of the lake, shallow open water in the middle third of the lake, and shallow *Juncus* marsh or mud flats on the eastern third of the lake.

Discharge from the Blitzen and Silvies rivers enters the central portion of the lake, which contains the freshest water on the lake. The central unit also has the lowest point on the lake at 4,088 to 4,089 feet above mean sea level (msl). When water entering the central unit reaches an elevation of 4,091 feet msl, the water spills into the eastern portion of the lake, which contains the most alkaline water in the entire lake. The east side of the lake functions as an overflow reservoir that receives water during wetter periods. The western side of the lake is better connected to the central basin but is hydrographically complex with a series of ponds separated by islands and peninsulas, with a number

of connections that are overtopped at different lake levels. Water starts to flood into the west side when lake elevations reach 4,092 feet msl, and when water elevations drop below 4,093.5 feet msl the surface area of this unit at the Narrows begins to decline (Hamilton et al. 1986).

Malheur Lake last went completely dry in 1934, and it reached its next lowest level in 1961, when the lake was reduced to 500 acres. The highest lake level was recorded in 1986 when the lake reached an elevation of 4,102.6 feet msl and an area of 124,000 surface acres.

Harney Lake

At the lowest elevations in the Harney Basin, Mud and Harney lakes act as a sump for the entire watershed. Harney Lake is a playa and receives water from Silver Creek and the Warm Springs Canal. Usually these flows do not sheet across the lake surface but are lost through infiltration into the permeable layer of the alluvial valley or by evapotranspiration as the water enters the west central portion of the lake. There are a few springs located along the south-central and east-central portions of the playa, but these do not contribute surface water to other portions of the lake.

Harney Lake is described as the most variable and unstable of the three lakes in the Harney Basin watershed and has varied during the historical period from completely dry to nearly 49,000 acres. Harney Lake itself is dry at about 4,079.7 feet msl, but after the dunes on the east side are breached, water quickly sheets over the surface area of the playa from 4,080 to 4,085 feet msl. The lake shoreline becomes relatively steep-sided from elevations of 4,085 to 4,100 feet msl, and under these conditions, the water overtops its defined margin and spreads over the lake plain on its western and northern sides (McDowell 1992). Only during the flood of the mid-1980s did it reach this height. Harney Lake dries up completely during dry periods, with the lake becoming salty as water levels decline and salts accumulate on the playa. When wet, the lake is primarily open water with little aquatic vegetation.

Mud Lake

Mud Lake is broad and shallow like Malheur Lake, and its surface area expands as water levels rise. Malheur Lake must reach a level of 4,093 feet msl before flows enter Mud Lake at the Narrows. Separated by a lunette dune, Harney and Mud lakes first begin to combine as water levels in Mud Lake rise and water begins to seep under the dune ridge between alternating silt and sand layers. A series of shallow ponds develop on Harney Lake parallel to the dune as water seeps under the dune ridge from Mud Lake.

At elevations above 4,097.3 feet msl, the lunette dune separating Mud and Harney lakes may be breached at the Sand Gap, and the three lakes may become connected (Hamilton et al. 1986). This connection is subject to modification by natural and human processes, so the elevation at which water spills from Mud Lake into Harney Lake has varied. For example, in 1972-1973 the water level of Malheur Lake varied between 4,090.8 and 4,094.6 feet msl. During this time period the gap was dammed by private landowners to store water for irrigation before it flowed into Harney Lake and became salty (Hubbard 1975).

3.3.4 Groundwater

Springs

In addition to the streams, a number of springs are located in the lowlands around the margins of Malheur and Harney lakes or make significant contributions to streamflows. Springs with less significant flows or which have outputs farther away generally support a marsh or pond that eventually drains into a channel or vanishes due to evapotranspiration losses.

Springs contributing flows to Malheur Lake from the Blitzen River are Knox (1.3 cfs), Hog Wallow (3.0 cfs), Page (11 cfs), Warm (2.5 cfs), Five Mile (0.5 cfs) and Sodhouse (8.6 cfs) springs. These freshwater springs are used by a variety of wildlife and support a diversity of aquatic species. The other significant springs contributing flow to Harney Lake include the Double-O Spring (14.7 cfs, composed of Ross and Hibbard springs) that joins the Silver Creek channel and empties into Harney Lake, as well as Hughett (12.5 cfs), Barnyard (6.0 cfs), Basque (2.5 cfs), Johnson (2.0 cfs), and Cold springs (0.8 cfs), all of which flow southeasterly before emptying into Harney Lake. Most of the springs in this stream are alkaline (Scharff and Davis 1962).

Aquifers

The groundwater system underlying the basin occurs at two distinct levels. There is a shallow unconfined aquifer that occurs in the upper alluvial fill, commonly within 20 feet of the surface. This is fed by infiltration of precipitation and streamflow on the valley floor. The water table fluctuates seasonally from 3 to 4 feet below the surface in the spring and 8 to 10 feet below the surface in the fall.

The second and deeper aquifer is confined and occurs in the lower part of the Quaternary fill and the underlying Tertiary rocks. Groundwater occurs in porous layers, such as gravel, sand, or porous rock, and is confined by impermeable clay in the upper part of the Quaternary fill. The confined aquifer is fed by infiltration of precipitation, streamflow in the uplands, and infiltration of streamflow where the waterways enter the alluvial basin floor. This is generally within 50 feet or less of the surface. Pressure in the deeper confined aquifer causes water to leak upward to the shallow aquifer. Groundwater withdrawal from wells throughout the basin appears to be lowering the water table in some locations within the Harney Basin (Leonard 1970).

The surfaces of both the confined and unconfined layers slope toward the center of the alluvial basin; interdicting groundwater is discharged through the surface at lower elevations. The piezometric layers under Malheur Lake slope away on the northern, southern, and western margins, indicating that infiltration from the lake is contributing to the groundwater. The relationship between the aquifer layers and Mud and Harney lakes is not documented.

3.3.5 Water Rights and Use

The right to use water on the Refuge is managed through the State of Oregon's Water Resources Department (OWRD). Water rights in Oregon are managed by two basic principles: beneficial use and first in time/first in right. All water use on the Refuge has some form of a State water right. The current exception is springwater in the Double-O Unit of the Refuge. Because these waters originate and terminate on the Refuge, they are exempt from a State-controlled surface water right.

The Service has adjudicated water rights on the Blitzen River and Silver Creek. In addition, the Refuge has 30 wells that have been permitted by the State for domestic, livestock, or irrigation uses. The Refuge has no water rights on the Silvies River and has not applied for any.

Pond/Storage Water Rights

The Refuge has 71 sites where water is stored to meet a variety of wildlife objectives. The majority of these sites are small, holding less than 100 acre-feet, but a limited number do store thousands of acre-feet, such as Derrick Lake and Krumbo Reservoir. Most of the storage sites are seasonally managed.

Blitzen River and Associated Tributaries Water Rights

The adjudicated water right for the Blitzen River and tributaries allows diversion of water between March 15 and October 1 for domestic, livestock, and irrigation purposes. The Service has an application before the State of Oregon to transfer the existing water right from the current use to a Wildlife Refuge Management use. The transfer will also allow the movement of water within the refuge boundaries of the Blitzen valley to meet wildlife management needs. The status of the transfer application is pending based on the outcome of affidavits of cancellation.

The Service has also received a permit for a Wildlife Refuge Management water right for the Blitzen River and tributaries that will allow for water diversion from March 1 through September 30. The ability to use water during this time period enables the Refuge to use runoff events to stimulate plant activity in wetland and meadow habitats. The current permit, which allows the Refuge to use water during this time frame, is conditioned with four primary conditions that the Refuge must address before OWRD will grant an actual water right. These conditions are 1) install water measurements devices with an appropriate reporting plan, 2) complete a water quality plan, 3) complete a bypass flow study, and 4) meet ODFW fish passage and screening requirements. The first two requirements are complete and the second two are near completion.

Through the combination of both existing and permitted water rights, the Refuge is limited to diverting no more than 145,000 acre-feet on an annual basis and no more than 820 ccf at any one point in time.

Silver Creek and Spring Water Rights

The water right to Silver Creek (23,287 acre-feet) is from March 1 to October 1 and is for domestic, livestock, and irrigation use on the Double-O portion of the Refuge. A second important water source for this area is a series of springs that originate and remain on refuge lands. Water from these springs is used in the management of wetland/pond and meadow habitats. Even though these waters are exempt from any type of mandatory water right, the Refuge plans to file for a groundwater right for the springs in the Double-O Unit. Currently the groundwater sources providing water to these springs are potentially threatened by groundwater withdrawals outside of the Refuge. To protect the groundwater that creates unique habitats both within the springs and in associated habitats, a State groundwater right needs to be obtained.

3.4 Topography and Bathymetry

As described above, the Refuge occupies the central and lowest portion of the Harney Basin and contains portions of three delineated sub-basins. Bathymetry is described above in detail in Section 3.3.3. The lowest point of the Refuge is contained in Harney Lake (somewhere below 4,079 feet msl). The Refuge is generally flat with outcroppings of rock that reach 4,800 feet msl.

3.5 Geologic History and Features

The climatic and geologic conditions in this portion of Oregon have changed significantly over time. Nearly 10 million years ago, tectonic faults and regional uplifting began the formation of Steens Mountain on the south side of the Harney Basin. Eventually rising 9,700 feet above the surrounding valleys, Steens Mountain developed a vast ice field covering the upper reaches of the mountain around one million years ago. More recent glaciers carved the spectacular U-shaped gorges on the flanks of the mountain. As the glaciers slowly moved downhill, their weight and movement ground the rock below into a fine powder, or loess. This loess was captured in the numerous streams flowing from beneath the glaciers and carried down the Blitzen River and other creeks on the western flank of the mountain to be deposited on the floodplain of the Blitzen Valley. Turbulent downslope winds pushed these deposits of loess around the valley floor, eventually forming a series of low, vegetation-covered dunes at the south end of the river valley (Burnside 2008).

Corresponding with the cooler and moister conditions of the late Pleistocene epoch, 1.8 million to 11,550 years ago, vast amounts of water flowed into the lowest elevations of the basin; from there it drained down the Malheur River and then to the ocean. This connection to the ocean gave salmon and other fish species access to the basin. However, this continuous access to the ocean ended around 32,000 years ago, when basalt flows erupted in the southeast corner of the basin, blocking the outlet from the lake into the river. As climatic conditions varied over the centuries with shifts in seasonal rain fall and temperature, the right combination of conditions created an enormous lake covering the floor of the basin. At several different times, conditions were wet enough and water levels rose until the lake was over 25 feet deep; when this happened, the water was high enough to spill over the top of the blocked outlet and reconnect the basin to the ocean. Salmon bones discovered in spawning gravels near the connection between Malheur and Mud lakes attest to one of these overflow events around 22,000 years ago (Burnside 2008).

With the end of the cold conditions of the Pleistocene, subtle warming conditions combined with abundant rain fall transformed the lower elevations of the Harney Basin into an expansive pluvial lake. With no outlet to the ocean until the level of the lake crested at over 30 feet, a major portion of the Harney Basin was covered with water by 9,300 years ago. This rise in lake levels would combine Malheur, Mud, and Harney lakes into a deep lake at least four times over the next 9,000 years. A lush, narrow band of wetland vegetation bordered the edges of this lake. As the water expanded southward into the Blitzen Valley, shallower areas developed in to extensive cattail and tule marshes. Remnant shore lines of these pluvial lake occurrences are still evident along the south side of Harney and Mud lakes (see Map 9). Large gravel bars, formed under these large lakes, can be seen at various locations along the south side of the lakes and at the mouth of the Blitzen Valley (Burnside 2008).

These same climatic changes also had a profound influence on the Blitzen Valley. In times of plentiful snow on the upper elevations of Steens Mountain, the Blitzen River burst out of the narrow canyon at the south end of the valley, depositing nutrient-loaded sand and silt on the floodplain.

Water overflowing the banks of the river settled into old channels of the river, creating small, linear ponds and providing water for nearby native grass meadows. Creeks entering the valley from the east side funneled water across these grassy meadows, creating numerous stringers of lush riparian vegetation. As water decreased in the river in the late spring or during periods of lower snowfall, these creeks became increasingly important habitat for wildlife using the area (Burnside 2008).

The geological information presented here is excerpted from McDowell's geomorphic description of the Harney Basin (McDowell 1992). The geology of Harney Basin is characterized by an essentially continuous depositional sequence composed of volcanic and volcanic-derived sedimentary rock. The sequence includes a large number of different lithologies and ages. Faulting, uplifting, and tilting of fault blocks occurred during the Pliocene epoch (5.3 to 2.5 million years ago), creating a closed basin. Today these constructional volcanic features can be seen as faulted and weathered masses within fault-blocked uplands and include Steens Mountain, Wagontire Mountain, and Burns Butte.

The specific origins of the Harney Basin are not known, but the basin may have been partially defined by calderas that formed during the eruption of ash-flow tuffs. Three distinctive and very widespread ash-flow tuffs erupted from the calderas in Harney Basin. They are the Devine Canyon ash-flow tuff, covering three-quarters of the basin up to a maximum depth of 98 feet (30 meters); the Prater Creek ash-flow tuff, covering about a third of the basin to a similar depth; and the Rattlesnake ash-flow tuff, centered over western Harney Basin and covering 19,305 square miles (50,000 square kilometers) up to a maximum depth of 198 feet (60 meters). The fine-grained sedimentary rocks in the Harney Basin suggest a low-relief landscape with closed drainage basins.

A layer of volcanic and sedimentary rock flow was deposited over these ash-flows along the western and northwestern portions of the Harney Basin. This caused the formation of Wright's Point, which is sheltered by a resistant cap of basalt which covered weaker sedimentary rock. As subsequent erosion removed sedimentary rock from the surrounding area, Wright's Point remained. After this eruption, the central basin continued to be deeply eroded but was filled again during the Pleistocene epoch (2.5 million to 12,000 years ago).

Leonard (1970) reported that the Pleistocene fill in the Harney Basin is more than 300 feet thick near Lawen and the east-central portion of the basin. To accomplish this amount of erosion, the basin must have been connected to the Snake River System and externally drained. The external drainage to the basin was probably to the east, into Malheur River and the Snake River system. This is evidenced by the thickest fill occurring in the eastern part of the basin, near the former outlet. Much of the erosion and creation of the incised valleys of the Silvies and Blitzen rivers along with Silver Creek occurred during this period.

External drainage from the basin is controlled by geologic structures in the uplands east of the Harney Basin. The main structural features are north-trending faults. The outlet for Harney Basin and the headwaters for the Malheur River cut through this area at right angles to the fault features. After the early Pleistocene erosion, the basin filled with fluvial sand and gravel along its margins (from streams entering the basin) and lacustrine silt, clay, peat, and ash deposits in the central portion. Minor amounts of eolian deposits also occurred with sand dunes and lunettes on the basin floor and loess in the uplands.

Volcanic activity continued as basalt flows sealed the outlet to Malheur Lake at Malheur Gap, re-establishing a closed basin. Diamond Craters, the youngest geological feature in the Harney Basin, began to develop during this time along the eastern edge of the Blitzen Valley. Following the initial

extrusions of lava, a series of magma intrusions caused doming and cracking of the surface. Explosive eruptions formed craters and distributed tephra and bombs on the surface of the surrounding area, and minor basalt extrusions occurred.

3.6 Soils

The soils of Malheur Refuge have been defined and influenced by the geological actions outlined above. Other influences responsible for soil formation are climate, living organisms, time, and weathering.

Soils on the Refuge include the following orders:

- **Aridisols** are dry desert soils. The lack of moisture greatly restricts the intensity of the weathering process and limits most soil development processes to the upper part of the soil column. Aridisols often accumulate gypsum, salt, calcium carbonate, and other materials. These are commonly located in the sagebrush-steppe habitats on the Refuge.
- **Inceptisols** are soils of semiarid to humid environments which exhibit moderate degrees of soil weathering and development. These are located in the salt desert scrub in the lower Blitzen Valley and Double-O areas.
- **Entisols** are soils that show little or no evidence of pedogenic horizon development. These are areas of recently deposited parent material or areas where erosion or deposition rates are faster than the rate of soil development, such as dunes, steep slopes, and floodplains. An example of these would be the dunes between Harney and Mud lakes.
- **Mollisols** are relatively high in organic content and have a dark-colored surface horizon. These soils are quite rich and are characteristically formed under grass in climates that have moderate to pronounced seasonal moisture deficit.

The NRCS carried out a soil survey for Harney County (Keller and Horn 1997). The following information was compiled using data from that report.

The soils on the Harney, Mud, and Malheur lake beds and the terraces adjacent to them are classified as Lolak, Ausmus, Crowcamp, Poujade, and Lawen series. The very deep, clayey Lolak soils are in the lowest positions on the lake plains (Malheur Lake) and are poorly drained. They formed in lacustrine deposits from volcanic rock. Vegetation is sparse to fairly dense and consists mainly of black greasewood (*Sarcobatus* spp.), seepweed (*Sueda depressa*), saltgrass (*Distichlis spicata*), and rush (*Juncus* spp.). The Ausmus (Harney and Mud lakes area and lower Blitzen Valley) and Crowcamp (Double-O) soils are very deep and on slightly higher positions on the lake plains. They are somewhat poorly drained soils formed in alluvium and lacustrine deposits. Vegetation found in the Ausmus series is mainly of basin wildrye (*Leymus cinereus*), black greasewood, and saltgrass. On the Crowcamp series, native plants are mainly silver sagebrush (*Artemisia cana*), creeping wildrye (*Leymus triticoides*), Nevada bluegrass (*Poa nevadensis*), and mat muhly (*Muhlenbergia richardsonis*). The very deep Poujade soils (Double-O) are on low-lying lake terraces that have a thin mantle of recent alluvium over lacustrine volcanic sediment. They are moderately well drained with vegetation of basin big sagebrush (*Artemisia tridentata*), black greasewood, and basin wildrye. The Lawen (Malheur Lake) soils are slightly higher lake terraces, and are formed in loamy alluvium. They are very deep, well-drained soils formed in wind- and water-deposited sediments. Vegetation is generally basin big sagebrush, western needlegrass (*Achnatherum occidentale* ssp.), Indian ricegrass (*Achnatherum hymenoides*), and basin wildrye.

Near the margins of the basin, perennial streams deposit alluvium over the lacustrine sediment. The sediment eroding from the hills and plateaus is low in alkalinity. The Fury and Widowspring series of soils are very deep and formed in this alluvium. These soils have very dark surface layers, evident by the high content of organic matter and high productivity. The moderately well-drained Widowspring (upper Blitzen Valley) series soils are in areas farther from streams. Vegetation found on Widowspring soils are basin big sagebrush and basin wildrye. The poorly drained Fury soils (dominant throughout the entire Blitzen River Valley) are adjacent to streams. Fury soils are typified by a wide variety of plants including sedges, tufted hairgrass (*Deschampsia caespitosa*), rushes, quackgrass (*Agropyron repens*), alkali bluegrass (*Poa juncifolia*), Sandberg's bluegrass (*Poa secunda*), saltgrass, yarrow (*Achillea millefolium*), lupine (*Lupinus* spp.), three-tip sagebrush (*Artemisia tripartita*), silver sagebrush, willow, shrubby cinquefoil (*Dasiphora fruticosa*), wildrye, and wild rose (*Rosa woodsii*).

Soils on the lake plains that are subject to a fluctuating water table have a high level of salinity and alkalinity. Evaporative recharge is a process that is common to the formation of these soils. During evaporative recharge, water moves upward to the soil surface and carries dissolved salts that concentrate as surface water evaporates and that appear as a white crust. A limited number of plant species are adapted to these saline and sodic conditions. Soils that fit this category are Alvodest, Thenarrows, and Skidoosprings series. The Alvodest series soils (Harney Lake) are very deep, poorly to moderately drained soils formed in lacustrine sediments on basin floors. Vegetation found on these soils is represented by black greasewood, basin wildrye, and saltgrass. The Narrows series (dominant in Mud Lake and Malheur Lake areas) is found on lake terraces. These are very deep, poorly drained soils formed on lacustrine sediments. Alkali bluegrass, saltgrass, and alkali sacaton (*Sporobolus airoides*) symbolize this soil series. Skidoosprings soils (Double-O and the upper Blitzen Valley) consist of a deep, moderately well drained duripan that are formed in lacustrine deposits derived from volcanic rock. These soils are generally found on high lake terraces as remnant mounds in stream dissected areas. Plants associated with these soils are basin wildrye, black greasewood, and inland saltgrass.

The next soils by landscape feature are the series found on plateaus and hills surrounding the basin where a duripan has developed and are represented by the Raz soil series (Double-O and lower Blitzen Valley). These soils are found on lava plateaus and consist of well-drained duripan formed in the alluvium, colluviums, and residuum derived from basalt and tuff. Plants found in association with these soils are Wyoming big sagebrush, bluebunch wheatgrass (*Pseudoroegneria spicata*), Thurber's needlegrass (*Achnatherum thurberianum*), bottlebrush squirreltail (*Elymus elymoides*), and Indian ricegrass.

Soils within refuge boundaries on the steep slopes of the valley basin are Felcher (south and west aspects) and Westbutte (north and east aspects) series. The Felcher series soils (lower Blitzen Valley) dry out in early summer and have lower plant productivity. These are deep, well-drained soils formed in colluvium from volcanic rock. Plants associated with this soil are bluebunch wheatgrass, Wyoming big sagebrush, and Thurber's needlegrass. The Westbutte series stays moist longer in the summer; it has higher organic content and higher plant productivity. This series is a moderately deep, well-drained soil formed in colluvium composed of weathered basalt, tuff, and andesite. Plants found in this series are Sandberg's bluegrass, antelope bitterbrush (*Purshia tridentata*), mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), and scattered western juniper (*Juniperus occidentalis*).

3.7 Fire

Fire has been used as a tool on the Refuge to remove decadent vegetation and improve wildlife habitat for decades and perhaps for as long as a century. There is some documented use of fire prior to 1985; however, most information about the use of fire before this date is based on anecdotal accounts from former refuge biological staff. Fire was used primarily in the winter months to burn cattail stands and overgrown fields to improve wildlife habitat, open up choked marshes, or open a large area to see the condition of water control structures. The majority of prescribed burns from 1985 to the present were implemented during the winter into early spring.

Between 1985 and 1991, the Refuge did not have an established prescribed fire program, and the fire program consisted of a crew leader and three firefighters dedicated to wildland firefighting during the summer. During this period and likely prior to this, biological staff determined where fire was to be used and implementation was performed by refuge staff. From 1985 to 1991, refuge reports show that the primary use of fire was for habitat maintenance and debris removal and that use of fire resulted in the treatment of 17,865 acres, with an average of 2,552 acres per year.

A permanent and professional fire program was established at the Refuge in 1992 with the appointment of a full-time fire management officer and increased staffing. At this time the Refuge began to increasingly use fire as a tool and incorporated the use of mechanical equipment into the program's treatment strategy. From 1992 to 2002, the fire program used prescribed fire and mechanical treatments for habitat maintenance, debris removal, exotic species control, fuel breaks, and hazardous fuels reduction, with the majority of the use for habitat maintenance. Over this period, 32,190 acres were treated with an average of 3,261 acres per year. The refuge fire program was also responsible for fuels management for the southeast Idaho refuges and the northwest Oregon refuges.

Beginning in 2002, the fuels management program reduced the number of annual treatments and acres treated because of staffing shortages, the reoccurrence of perennial pepperweed in areas treated with fire, and a lack of funding for follow-up chemical treatment. The majority of the treatments were for hazardous fuels reduction, but two treatments during this time were for exotic species control. Total acres treated from 2002 to 2006 were 5,098, averaging 1,274 per year, and no treatments were completed in 2006.

In 2007, the Refuge's fuels program was increased with the addition of a new fire management officer, and the Refuge also became a signatory partner in the Burns Interagency Fire Zone, which meant that prescribed fire resources were readily available to implement fuels treatment projects at the Refuge. Between 2007 and 2010, the majority of prescribed fires were conducted for habitat maintenance by burning fields that were out of the haying/grazing rotation and were scheduled to be sprayed in the summer post-treatment, or fire was used to remove decadent vegetation in marsh areas where invasive weeds would not be an issue. There was also an increase in the use of mechanized treatments during this period. During this time a single fall burn was performed with moderate success. From 2007 to 2010, 29,037 acres were treated for an average of 5,807 acres per year.

3.7.1 Objectives of Prescribed Fire in Emergent Marsh

Prescribed fire is used in wetlands at the Refuge to maintain ecological processes, specifically: thinning and opening up emergent vegetation, removing decadent material, stimulating herbaceous production, maintaining herbaceous species diversity, and improving wildlife habitat and foraging. It

is also used to reduce the accumulations of hazardous fuels. Prescribed fires are usually conducted in the winter when marsh vegetation is dormant, migratory nesting birds are not present, and reptiles and amphibians are hibernating. At the Refuge it would be ideal to apply prescribed fire to 25 percent of the marshlands annually. However, budget constraints drive the actual amount that can be accomplished.

1. Remove 50 percent or more of the decadent vegetation
2. Maintain 20 to 40 percent open water among emergent vegetation
3. Release tied-up nutrients
4. Reduce or maintain invasive plant density and cover
5. Maintain habitat for focal plants and animals
6. Provide underwater waterfowl food (both plants and invertebrates)
7. Provide safe nesting and brood-rearing habitat
8. Reduce hazardous fuels
9. Reduce the likelihood of catastrophic wildfire

Complications associated with Prescribed Fire in Wetlands

Noxious weeds: Introduced noxious weeds are a major concern with fire and wetlands. Fire can stimulate the growth of noxious weeds in wet meadows and nearby uplands. Fire equipment can facilitate spreading of seeds. Disturbances such as fire lines often facilitate establishment of noxious weeds.

Access: Access for fire equipment in wetlands is often limited. Operations usually must take place when the ground is frozen. Specialized amphibious equipment like a Marshmaster is usually required on fire lines. Aerial ignition is often required for the main portion of the burn unit to reach areas beyond the range of wheeled or tracked vehicles; however, it is costly.

Adjacent uplands: The uplands surrounding marshes are usually excluded from prescribed burns. Fire in uplands removes woody shrubs and leaves the area vulnerable for colonization of invasive species like cheatgrass and noxious weeds. Intensive follow-up seeding is usually required. The amount of fire line, labor, and equipment needed to keep fire out of uplands can often be insurmountable.

Management Implications for Prescribed Fire in Emergent Marsh and Wet Meadow

- Prescribed fire treatment areas should be rotated to maintain wetlands in various stages of density and recovery. Suitable no-action areas should be allowed for escape cover and alternate habitat. This will provide a wide range of habitat, nesting, and foraging opportunities for wildlife.
- Prescribed burns should be conducted in the late fall and winter when vegetation is dormant and amphibians, reptiles, and invertebrates are hibernating.
- Head fires should be used to minimize fire-residence time. Backing fires and peat fires should only be allowed when addressing specific goals like reducing organic layers or eradicating seed banks.
- Prescribed burn plans should include both pre-burn work and follow-up actions to address invasive species and noxious weeds.

With careful planning and a science- and biological-based understanding, prescribed fire can be a valuable tool in maintaining the productivity and species diversity in wetlands.

3.8 Environmental Contaminants (Point Source)

On-refuge Contaminant Sites: There are no known point sources of environmental contaminants within the approved refuge boundaries.

Off-refuge Contaminant Sites: Three sites have been identified in the Harney Basin as known sources of contaminants. The Burns Air Force Radar Station, located 35 miles northwest of the Refuge, is designated by the Environmental Protection Agency as a Superfund project for the removal of friable asbestos and soils contaminated with polychlorinated biphenyls (PCBs). There is no known pathway for movement of contaminants from the site to refuge lands. The other two locations, in Frenchglen, have been designated by ODEQ as leaking underground storage tank sites. It is unknown whether or not there is a potential conduit to move contaminants from these sites to refuge lands. Additional information on these sites can be obtained at the EPA and ODEQ websites found in the reference section of this chapter (EPA 2011; ODEQ 2011). Municipal wastewater is not an issue in this area, as the only treatment facilities are located in the Burns/Hines communities. These facilities have no outlet to any watercourse that feeds into Malheur, Mud, or Harney lakes. With a rural landscape dominated by ranching and agriculture interests, there is some potential for contamination from fertilizers and other agrochemicals topically applied to flood-irrigated meadows in the Diamond Valley and adjacent to Malheur Lake.

3.9 Air Quality

The action area is not located in a Class I airshed, nonattainment area, or maintenance area (EPA 2009). Air pollution sources include local agricultural activities, wildfires, vehicle traffic on Oregon State Highway 205, and local and refuge traffic.

3.10 Water Quality

States are required to identify waters that do not meet their water quality standards under Section 303(d) of the Clean Water Act (CWA). Such waters are classified as impaired and termed water quality limited. The Blitzen River and its tributaries (Mud, Bridge, and McCoy Creeks) as well as the Silvies River and Silver Creek are 303(d) listed streams for water temperature (<http://www.deq.state.or.us/wq/assessment/rpt2010/search.asp>). In addition, Silvies River is listed for dissolved oxygen and Bridge Creek is listed for iron, beryllium, and manganese. Under the CWA, when a state lists a water body on the 303(d) list as impaired, it must develop a total maximum daily load (TMDL) for the impaired water body to address the sources of the limitation to bring the water body into compliance. Currently, the TMDL for the Blitzen River has not been developed by the ODEQ or approved by the EPA.

A reconnaissance investigation addressing water quality, wetland hydrology, and surface water drainage through the irrigation systems both on and off the Refuge was carried out in 1988-1989 (Rinella and Schuler 1992) following the mid-1980s floods. The study found elevated concentrations of arsenic, boron, mercury, and selenium in some Harney and Malheur lake water and/or biological tissue samples exceeding recommended criteria or guidelines for the protection of the health of

humans, fish, or wildlife, or adversely affecting other identified beneficial uses. In addition, small but detectable concentrations of dichlorodiphenyltrichloroethane (DDT) and its metabolites, and endrin, were reported in lake bottom sediment, while most biota (aquatic plants, invertebrates, fish, bird eggs, and bird tissue) contained small or undetectable levels of organochlorine pesticides and polychlorinated biphenyls (PCBs) were contained in most biota. Although elevated concentrations of some constituents were found in some of the samples, bio-accumulation did not appear to be an issue. None of the elevated concentrations were thought to be associated with agricultural drainage or irrigation systems, but were attributed to water evaporation increasing and accumulating concentrates of harmful ions during periods of drought, and dissolution of these deposits during periods of high water raising the overall loading of these elements. It was concluded that irrigation drainage and agricultural runoff was not causing significant harmful effects to human or resource health.

A later study carried out in 2002-2003 (Mayer et al. 2007) on this same system investigated a variety of standard water-quality measures but did not look at pesticide residues. Mayer et al. (2007) reported the main water-quality parameters of concern in the Blitzen River were conductivity, dissolved oxygen, turbidity, and suspended sediment, total phosphorus, and total nitrogen. With distance downstream, dissolved oxygen decreased, and conductivity, turbidity, suspended sediment, total Phosphorus, and total Nitrogen increased. Low dissolved oxygen concentrations, in particular, were a concern downstream during the summer base flow period. Concentrations were below State standards at downstream sites. Irrigation and wetland return flows contribute to low dissolved oxygen and higher biological oxygen demand in the Blitzen River and may be responsible for some of the low concentrations farther downstream. However, warmer temperatures downstream also contribute to low dissolved oxygen rates.

Late-season increases in river turbidity and total suspended sediments are suspected to be related to dam operations. These two parameters increased at about the time that the dams were opened up in late July and early August.

The timing of conductivity increase downstream on the river seems to implicate return flows as sources of higher conductivity. The return flows were generally much higher than the river conductivities. The increases downstream in the river were observed to occur through the irrigation season and reach maximums in late July, coinciding with the end of the irrigation season on the Refuge.

Return flows were also implicated as a potential source of nutrients to the river. Concentrations of both macronutrients were higher in return flows, and they increased downstream in the river. The wetlands, particularly the wet meadows, appeared to be a source of phosphorus and possibly nitrogen, based on the nutrient budget for the west side of P Ranch area. Despite the fact that nutrient concentrations increase downstream, there did not seem to be a problem with eutrophication and planktonic algae in the river. Concentrations of chlorophyll were very low throughout the river. This may be because of limited phosphorus availability, based on phosphorus concentrations and nitrogen-to-phosphorus ratios in the river.

3.11 Visual Quality

The Refuge and the surrounding area are natural in appearance and undeveloped in nature. Where human signs exist, the feeling is rural, with high integration into the natural world. As a result, the Refuge and the surrounding area are considered to have very high visual quality. Due to the low level

of development, very little light is radiated into the night sky, resulting in excellent star-viewing opportunities.

3.12 Surrounding Land Use

Much of the land surrounding the Refuge or within Harney Basin is in public ownership, and is administered by the BLM, the U.S. Forest Service (USFS), or Oregon Department of State Lands. These public-trust lands are open to public access under the authority of those agencies. Most lands in private ownership are found along the north and east boundary of Malheur Lake, and land use is dominated by rangeland, with some agricultural production (alfalfa).

Harney County has an overall population of 7,700, with small communities in a rural setting. Industrial and commercial development is light, with enterprise based on livestock and agricultural production or recreational and service oriented. The community of Frenchglen is the only consolidated residential area adjacent to the Refuge, and most development near the Refuge consists of individual residences.

3.13 References

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