Hydrology and Water Quality at Malheur National Wildlife Refuge

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INTRODUCTION

Malheur National Wildlife Refuge (NWR) is located in Harney Basin in southeastern Oregon (Figure 1). The refuge encompasses 187,000 acres of open water, wetlands, springs, riparian areas, irrigated meadows and grain fields, and uplands. The original executive order in 1908 protected Harney, Mud, and Malheur Lakes. The refuge was expanded to include the Blitzen Valley in 1935 and the Double-O Unit in 1941. The refuge serves as a major feeding, resting, and nesting area for migratory waterfowl, shorebirds, marsh birds, colonial nesting waterbirds, raptors, and passerine bird species. Water and marsh habitat management on the refuge benefit large numbers of breeding and migrating birds including ducks, geese, swans, colonial nesting species, and other marsh and shorebirds. The refuge also supports large numbers of greater sandhill cranes.

The value of the habitat on the refuge is largely dependent on the availability and management of water resources. Much of the water management on the refuge occurs in the Blitzen Valley, where the infrastructure for water management exists. The Donner and Blitzen (Blitzen) River begins on Steens Mountain and flows north through the Blitzen Valley unit of the refuge and into Malheur Lake (Figure 2). A system of dikes, canals, drains, and water control structures was developed in the early 1900s to facilitate grazing and farming. Twenty miles of the river was channelized and straightened at the same time. The water distribution system still exists and is used by the refuge to manage water in the Blitzen Valley. The area represents the most intensively managed and most productive habitat on the entire refuge, especially because the habitat value of the lakes has declined so greatly with the introduction and proliferation of carp.

Practices to improve and manage habitat on the refuge include vegetation manipulation, through haying, burning, flooding, irrigation, farming and grazing, and water management, through flooding and drainage. Much of the irrigation on the refuge is accomplished by pooling water behind a series of dams along the Blitzen River within the refuge. The water is then diverted via canals into numerous meadows and wetlands and can return to the Blitzen River by surface sheet flow, return flow ditches or pipes, or subsurface seepage. Irrigation occurs from March through mid to late July in most of the Blitzen Valley.

In addition to irrigation, the refuge manages meadow habitat through haying and grazing to provide short-grass feeding habitat or dense nesting cover for greater sandhill cranes and other migratory birds. In August, after the cessation of irrigation, local ranchers (permittees) hay the meadows. The premittees either remove the hay to feed livestock or stack it into small piles or windrows in the hay meadows. Cattle are then grazed in hayed meadows during the fall and winter. Annually, there are up to 40,000 AUMs on Malheur NWR. The method of providing forage for cattle is referred to as rake-bunch grazing. In spring, the young grass shoots and invertebrates associated with the rakebunch grazing meadows are the preferred food for cranes, geese, ducks, and shorebirds migrating through the refuge.

The Blitzen and its tributaries also support a substantial population of the Great Basin redband trout, a native rainbow trout/steelhead that inhabits lakes and streams east of the Cascade Mountains. The Great Basin redbands have been isolated in closed basins for several thousand years (USFWS 2000). The species was petitioned for listing based on habitat degradation that resulted from livestock grazing, irrigation, stream channel manipulations, and reduced riparian vegetation (all practices or conditions that occur on the refuge). The USFWS determined that listing was not warranted at the time (USFWS 2000). However, there is still considerable interest in and concern for the status of this species.

Refuge management practices designed to manage water and migratory bird habitat have the potential to adversely impact redband trout through water quality degradation. Irrigation and water management on the refuge may decrease flows, exacerbate high water temperatures, reduce dissolved oxygen concentration, increase turbidity, increase nutrient loading, and degrade fish habitat. Nutrients, fecal coliforms and other pathogens associated with cattle manure, hayed meadows, and wetlands may enter the Blitzen River via irrigation return flows. These pollutants may decrease water quality (e.g., increased water temperatures, reduced DO, increased algal blooms) and impact native fish species.

The Blitzen River is a 303(d) listed stream for water temperature, dissolved oxygen, and turbidity. Because water quality is impaired with respect to state standards, the entire Blitzen watershed must comply with Total Maximum Daily Loading (TMDL) criteria as specified within the Clean Water Act. The TMDL for the Blitzen River is scheduled to be completed by 2010. A TMDL study may be conducted by the U.S. Environmental Protection Agency and Oregon State Department of Environmental Quality (DEQ) in the future. After TMDL criteria are established, Malheur NWR must monitor and meet regulatory standards for discharges and pollutant loading into the Blitzen River. The refuge will improve water quality by employing best management practices (BMPs), which will eventually be used to establish TMDL water quality standards for the Blitzen Valley watershed.

PREVIOUS STUDIES

There are several previous hydrology and water quality studies for the Malheur NWR area that will be mentioned here briefly. Most of these studies have focused on the area upstream of the refuge or on Malheur Lake itself. Rinella and Schuler (1992) conducted a reconnaissance investigation of water quality, sediment, and biota to determine if irrigation drain water was causing harmful effects of human health or fish and wildlife resources. Although they found high concentrations of As, Bo, and Hg in Malheur Lake samples and in some biological samples, they did not believe there were problems associated with agricultural drainage from the Blitzen River Basin. The authors did report that the concentration of dissolved solids and inorganic constituents, including N and P, increased downstream in the Blitzen River.

In the 1990s, concern became heightened for Great Basin redband trout. In response to a petition for listing, the FWS prepared a status review of the fish (USFWS, 2000). Factors given as contributing to the demise of the fish included warm temperatures, poor water quality, habitat degradation, irrigation diversions, limited fish passage at dams, and the introduction of carp in the Blitzen River and Malheur Lake. The increased concern for the fish and the river produced several studies looking at water quality and water temperature in the Blitzen River and tributaries.

Roy et al. (2001) measured water temperatures, turbidity, pH, and dissolved oxygen at several sites along the Blitzen River and Bridge Creek through the refuge in the summer of 1999. They reported a general increase in water temperatures and conductivity downstream in the refuge, with all Blitzen River sites and the two downstream Bridge Creek sites exceeding the state temperature standard (17.8°C at the time). Turbidity was generally low, but was increased during manipulation of water control structures on the refuge. pH appeared to decrease downstream through the refuge and was always between 7.0 and 9.0. Dissolved oxygen decreased downstream as well, and frequently fell below the state criteria of 6.5 mg/L. Dissolved oxygen was consistently lowest at Sodhouse Lane, the most downstream site on the refuge.

Watershed Sciences (2002) conducted a Forward Looking Infrared (FLIR) survey of water temperatures on Bridge Creek and the Little Blitzen River on August 17, 1999. Although Bridge Creek is a spring-fed stream, the channel flows through a very low-gradient, 2-mile section known as the Bridge Creek Canal, between East Canal and the mouth of Bridge Creek. Water is backed up in this section with a diversion dam and water temperatures increased considerably through this reach. Water temperatures in Bridge Creek were about 12˚C six miles upstream of the confluence with the Blitzen River, 18˚C at the upstream end of Bridge Creek Canal, and 22˚C at the mouth of Bridge Creek.

One more study that we will discuss here is the study of wetland water quality impacts at Lower Klamath NWR (Mayer, 2005). This study examined the effect of wetland water management on water quality at Lower Klamath NWR in south central Oregon. Based on nutrient loads, the study reported that the refuge wetlands increased nutrient concentrations relative to inflows, but decreased nutrient mass loads overall. Nitrogen was removed more effectively than phosphorus. Seasonally flooded wetlands retained less P than permanently flooded wetlands, perhaps because of the annual drying cycle and the decomposition of annual vegetation. Dissolved inorganic nitrogen was removed most effectively in refuge wetlands, possibly through nitrification and denitrification. The study is relevant because of the similarity in habitats and water management between Lower Klamath NWR and Malheur NWR and the possible parallels in water quality impacts.

STUDY GOALS

The goal of this study is to assess the water quality impacts associated with refuge water and habitat management (irrigation of hay and rake-bunch meadows, grazing, surface and subsurface return flows from both wetlands and agricultural fields, dam operations) and to assess BMPs that may be used to address water quality concerns. In addition, as a term and condition to the refuge's new water right permit (P 54164), the refuge must within one year of permit issuance, prepare and submit for approval a Water Quality Monitoring Plan to OWRD and ODEQ. This study quantifies the extent of water degradation associated with current management practices on the refuge. This information will allow the refuge to prepare a water quality monitoring plan for future monitoring and to evaluate and implement BMPs that provide habitat for wildlife (migratory birds and redband trout), improve water quality and aquatic habitat on the refuge, and comply with Oregon law.

The refuge could use several BMPs to potentially water quality concerns. For example, water could be managed more efficiently to reduce return flows from wetland units or surface sheet flows. However, this may increase the proportion of subsurface seepage return flow to the river, which is typically lower in dissolved oxygen and may contain elevated concentrations of nutrients (Mayer, 2005). The effects of return flows may be ameliorated by keeping more flow in the mainstem of the river. Head gates and water control structures could be re-engineered to more efficiently manage water for meadow and wetland management. Water temperature impacts from wetland return flows could be reduced by holding water longer and allowing more water to evaporate rather than drain. Slower drawdowns in wetlands also may reduce turbidity of return flows to the river. Increased efforts to control carp may improve water quality because their feeding and spawning habits increase water turbidity.

River and riparian restoration represents a very important BMP for improving water quality. In 2002, the refuge restored 3.5 miles of instream and riparian habitat, less than one tenth of the entire reach of river on the refuge. Much of the riparian habitat is extremely poor (shallow & wide stream channel, limited willows, steep/bare banks, few deep holes, little habitat complexity). The refuge could conduct much more extensive instream/riparian rehabilitation to increase shading of the river to reduce direct heating from the sun. Riparian rehabilitation could potentially help keep river water cooler, reduce bank sloughing/erosion and improve habitat. Before any of these BMPs could be effectively employed, the refuge requires knowledge of the relative impacts of the various water and habitat management practices used on the refuge.

The study proposes to focus on hydrology and water quality measurements as well as associated impacts to biota. Many of the water quality concerns associated with refuge management practices are closely associated with hydrology. By focusing on both water quantity and water quality, we can most effectively evaluate water quality impacts associated with refuge management practices. Using flow measurements as well as chemical data, we can calculate water budgets and estimate water use on the refuge, calculate mass balances and nutrient loading from refuge habitats, employ simple mixing models, and develop a more sophisticated understanding of water quality on the refuge.

Given the size of the Blitzen Valley, monitoring the entire refuge would be a formidable challenge. The approach we use is to monitor a small section of the refuge and extrapolate the results from this study area to the entire refuge. The area we focus on primarily is the Frenchglen area of the Malheur NWR. It is possible to do a complete water budget of all inflows and outflows for this area. We collected flow measurements and water quality samples from a number of locations along the river, in canals and return flows, and in wetlands, to document overall water quality changes occurring in the system. We monitored temperature continuously at several locations along the river and in the surrounding area as well. We began monitoring with the irrigation season in the spring and continued it until the fall, for two seasons in a row.

STUDY REPORTS AND ORGANIZATION

We present the results from this study in eight reports, organized into four separate sections, all written to be read independently. The first section consists of three reports that examine historical flow information from the Blitzen River, Bridge Creek, and springs on the refuge. The mean and distribution of flow and runoff for various periods are calculated and summarized for both river systems. The accuracy of NRCS runoff forecasts for the Blitzen is evaluated. Long-term trends in flows over the 60+ years of record are examined too. Estimates are developed for inflow from various springs on or near the refuge. This section addresses the question "How much water has the refuge typically received in the past?" The three reports included in this first section are entitled:

Historical Flows, Summary Statistics, and Streamflow Forecasts for the Blitzen River near Frenchglen, Oregon (USGS Site No. 10396000)

Historical Flows and Summary Statistics for Bridge Creek above East Canal, Oregon

Estimated Spring Inflow to the Frenchglen Area of Malheur National Wildlife Refuge

The second section consists of one report that develops water budgets for several different wetlands and areas on the refuge. Consumptive use is estimated and compared for different habitats. The timing of water needs is examined for various areas and habitats. The section addresses the question "How much water does the refuge typically need and when does it need it?" The report included in this second section is entitled:

Water Budgets, Net Inflow, and Consumptive Use Estimates for Malheur National Wildlife Refuge

The third section examines the water quality impacts of water management on the refuge in three reports. Water temperature in the Blitzen River is identified as one of the major water quality issues of concern on the refuge. The first report in this section analyzes the causes of elevated temperatures and discusses modeling results and management alternatives to improve water temperatures. The second report examines water quality conditions and nutrient budgets in the Blitzen River and surrounding areas. The third report focuses water quality and nutrient loading in a permanently-flooded wetland, West Knox Pond. The section addresses the primary question of the study: "What are the water quality impacts of refuge water management?" The reports included in this section are entitled:

Blitzen River Water Temperature Monitoring

Water Quality in the Blitzen River Valley at Malheur National Wildlife Refuge

Water Quality in West Knox Pond at Malheur National Wildlife Refuge

The final section discusses the management implications of the results from the study. The general findings pertaining to water quality are presented and management strategies addressing these issues are discussed. The section addresses the question “What management actions can be implemented to mitigate water quality problems on the refuge?” The report in this section is entitled:

> *Management Strategies for Addressing Water Quality Issues at Malheur National Wildlife Refuge*

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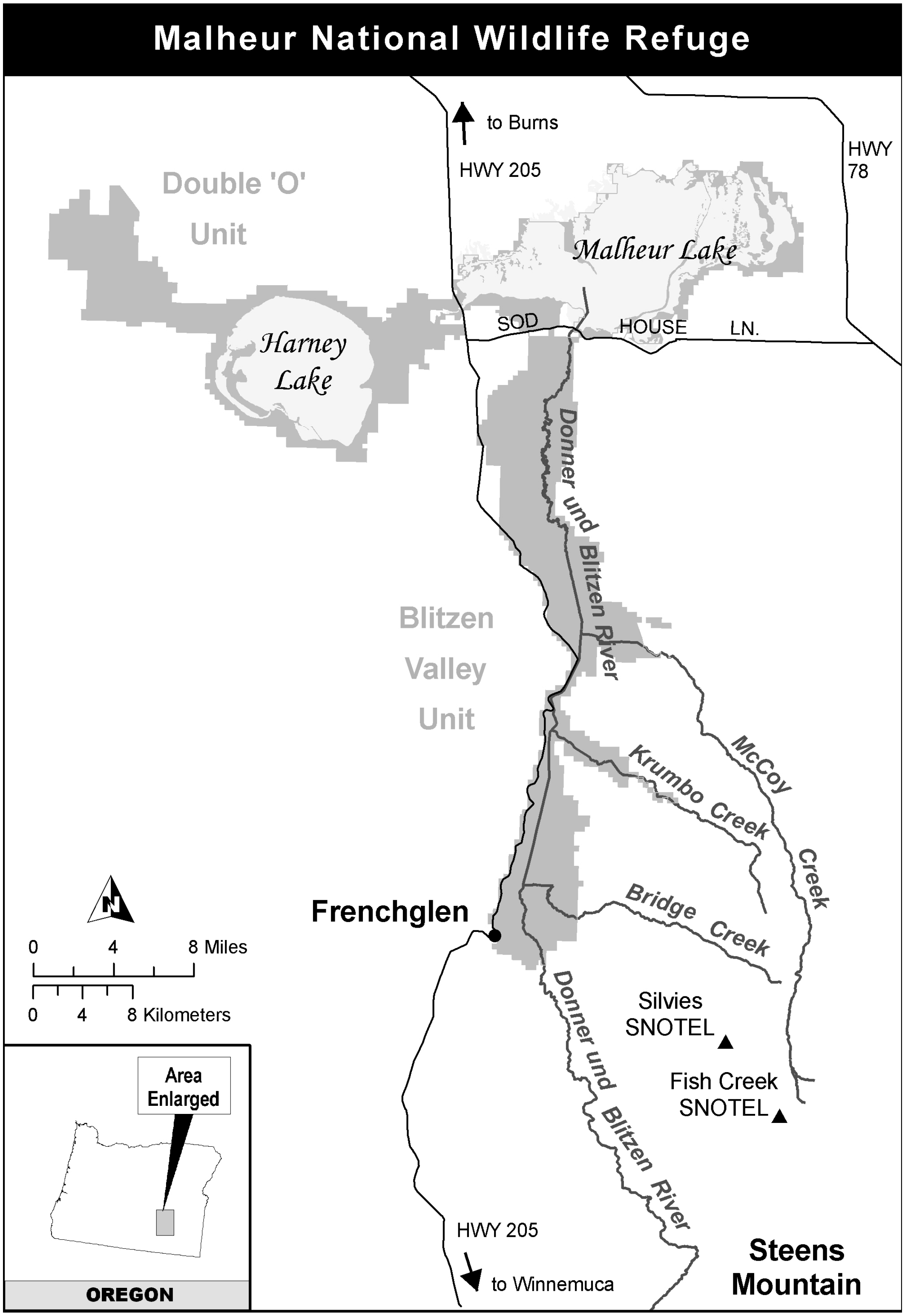

Figure 1. Map showing general location of Malheur NWR with the refuge boundary and units, the SNOTEL sites mentioned in this study, and several major landmarks and geographic features.

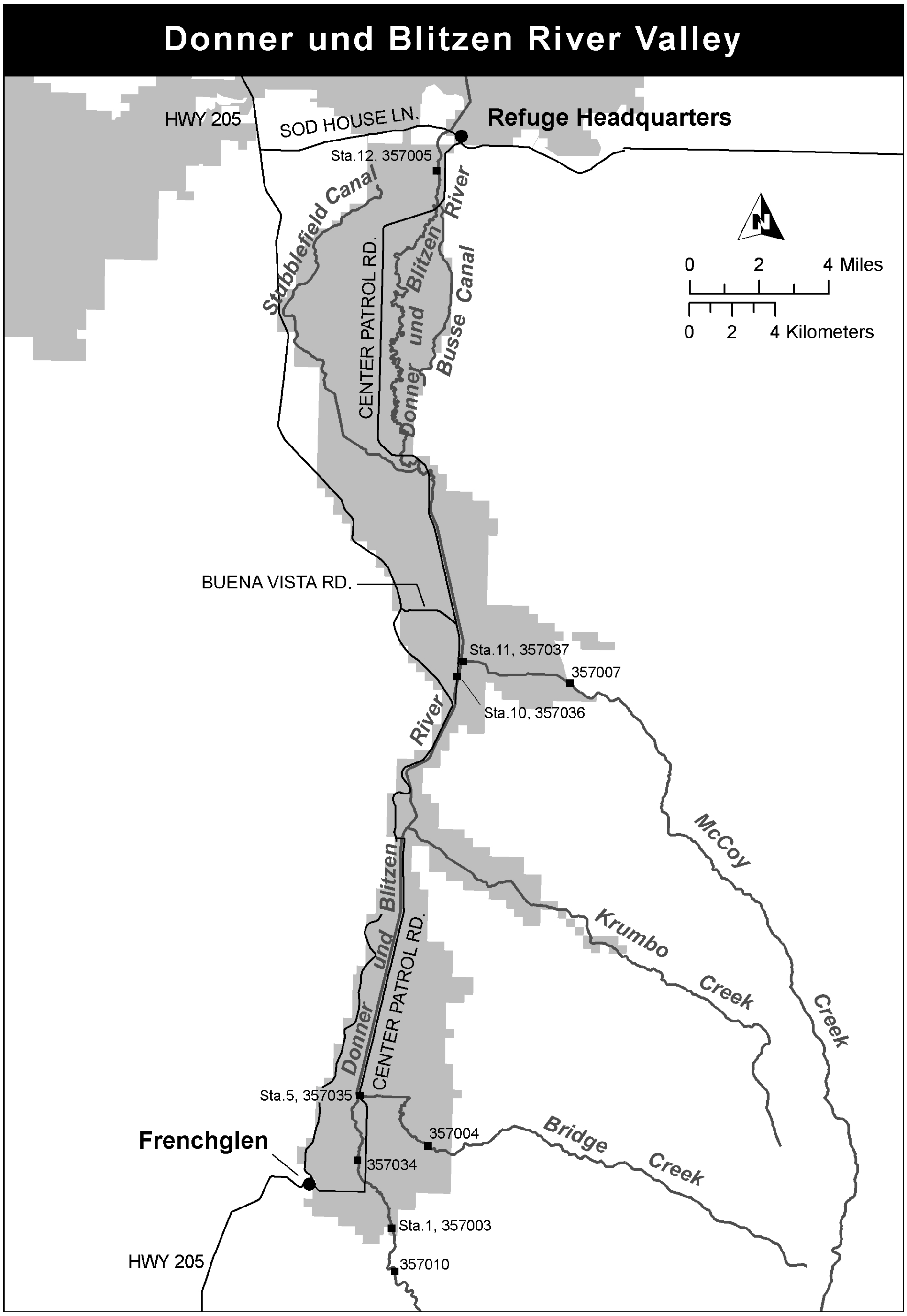

Figure 2. Map of Blitzen River Valley showing rivers and creeks, study monitoring sites, and several major landmarks and geographic features.

Historical Flows, Summary Statistics, and Streamflow Forecasts for the Blitzen River near Frenchglen, Oregon (USGS Site No. 10396000)

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The Donner und Blitzen (Blitzen) River is the main source of water for the Blitzen Valley unit of Malheur NWR (Figure 1). It enters the refuge at the southern boundary near Page Springs Campground, 3.5 miles southeast of Frenchglen, Oregon. The USGS has monitored flows about one mile upstream of Page Springs Campground continuously since 1938. The purpose of this report is to provide information and analysis on the historical flows in the Blitzen River at this site. We will also review streamflow forecasts for this site that are developed annually by the National Resource Conservation Service (NRCS) and examine the relationship between the Fish Creek snotel measurements and flows at this site. Finally, we look at long-term trends in the flow record and compare historical measurements upstream at the USGS gage and downstream at Sodhouse Dam.

Historical Flows

The Blitzen River near Frenchglen, Oregon receives drainage from an area of approximately 200 mi^2 along the midwestern portion of Steens Mountain in southeastern Oregon. The USGS records streamflow continuously in the river at a site located one mile south of the refuge boundary (USGS site no. 10396000, USFWS site no. 357010, Figure 2). The USGS began measurements at this location in the early 1900s and a continuous record of mean daily streamflow exists from 1938 to present. For our analyses, we consider mean daily streamflow for the period from January 1, 1938 to September 30, 2004.

The long period of record is very useful in characterizing summary statistics and variability in the Blitzen flows. There is additional spring inflow to the river in the Page Springs area, between the gage and the refuge boundary (Figure 3). The FWS measures flow downstream of Page Springs Dam at the refuge boundary but this does not capture the water diverted from the Blitzen above Page Springs Dam in the East and West canals. To account for all refuge inflow from the Blitzen, either the diversions must be measured along with the flow below Page Springs Dam, or the additional spring flow must be estimated and added to the flow measured at the USGS gage above the refuge.

Figure 4 shows annual runoff in the Blitzen River along with irrigation season totals for water years 1939 to 2004. Annual runoff in the Blitzen River over the 67-year period of record has averaged 91,000 acre-ft. It has ranged from a minimum of 36,000 acre-ft in 1992 to a maximum of 198,000 acre-ft in 1984. The hydrograph is dominated by a snowmelt signal in the spring and early summer. About 76% of the total annual runoff, or 69,000 acre-ft, occurs during the irrigation season, Mar-15 to Oct-1. 64,000 acre-ft, or 70% of the total annual runoff, occurs within a four and one half month period from Mar-15 through July-31. A Mann-Kendall trend test showed that there was no significant increase or decrease in annual flows over the 67-year period of record (p=0.44).

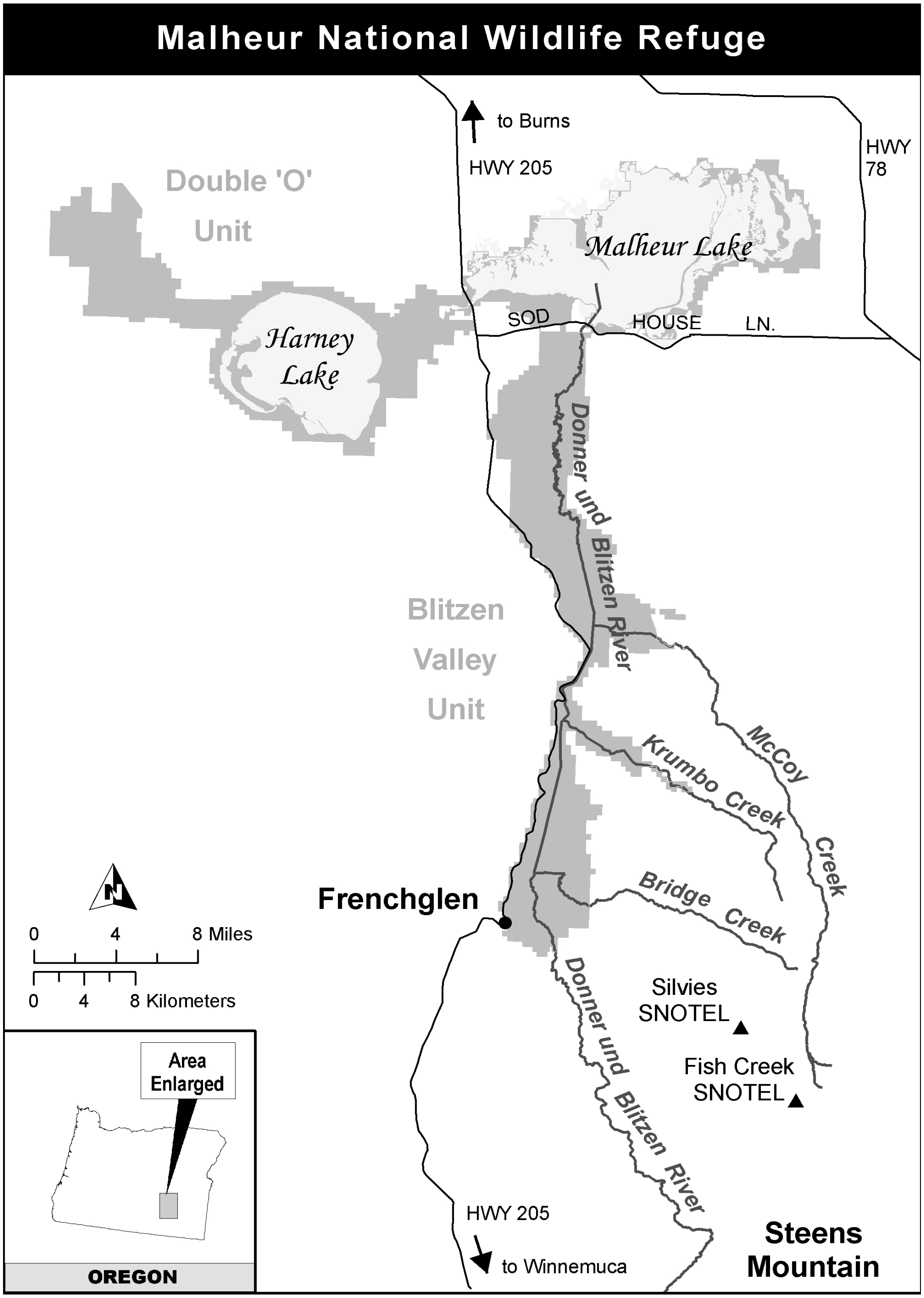

Figure 1. Map showing general location of Malheur NWR with the refuge boundary and units, the SNOTEL sites mentioned in this study, and several major landmarks and geographic features.

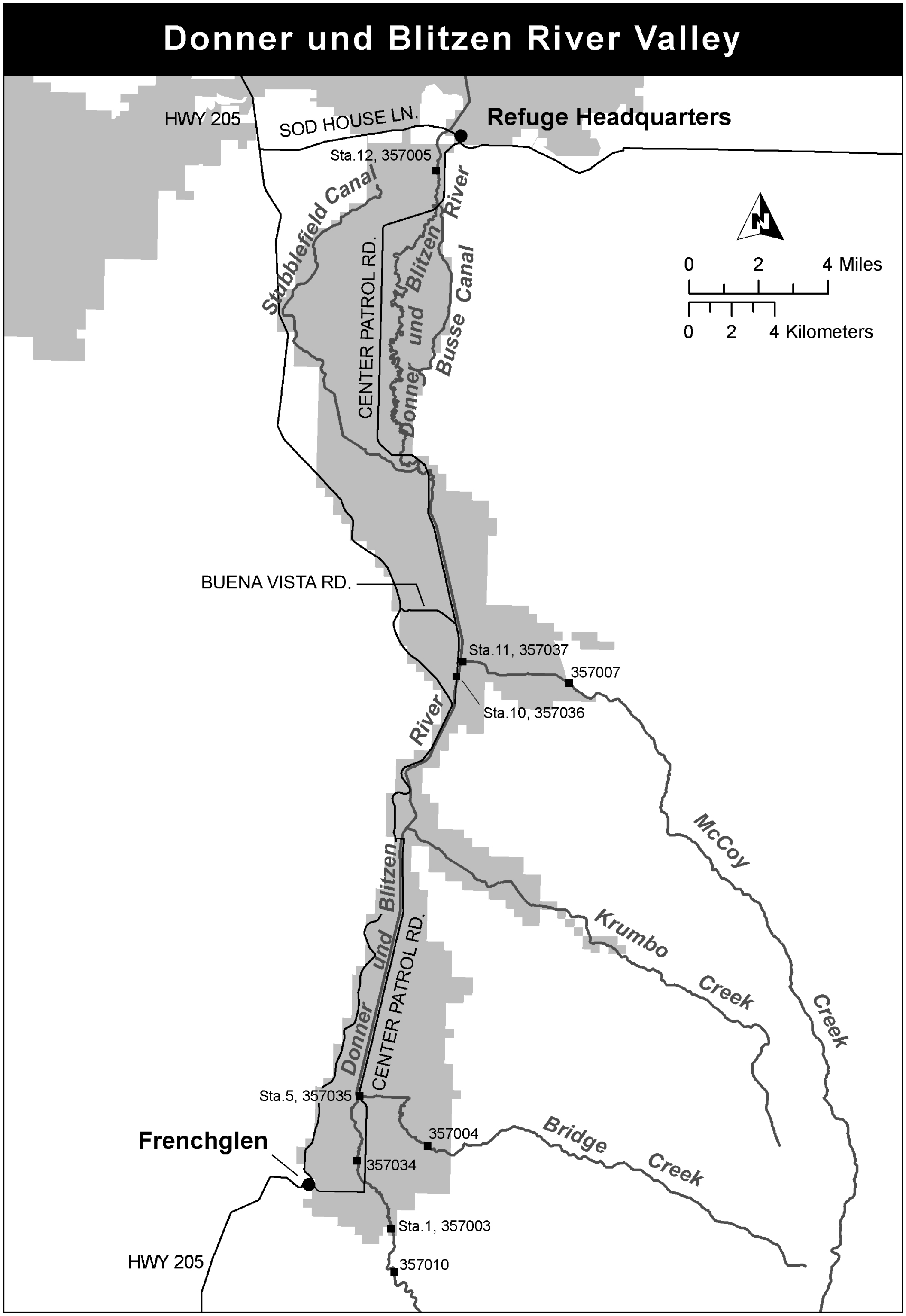

Figure 2. Map of Blitzen River Valley showing rivers and creeks, study monitoring sites, and several major landmarks and geographic features.

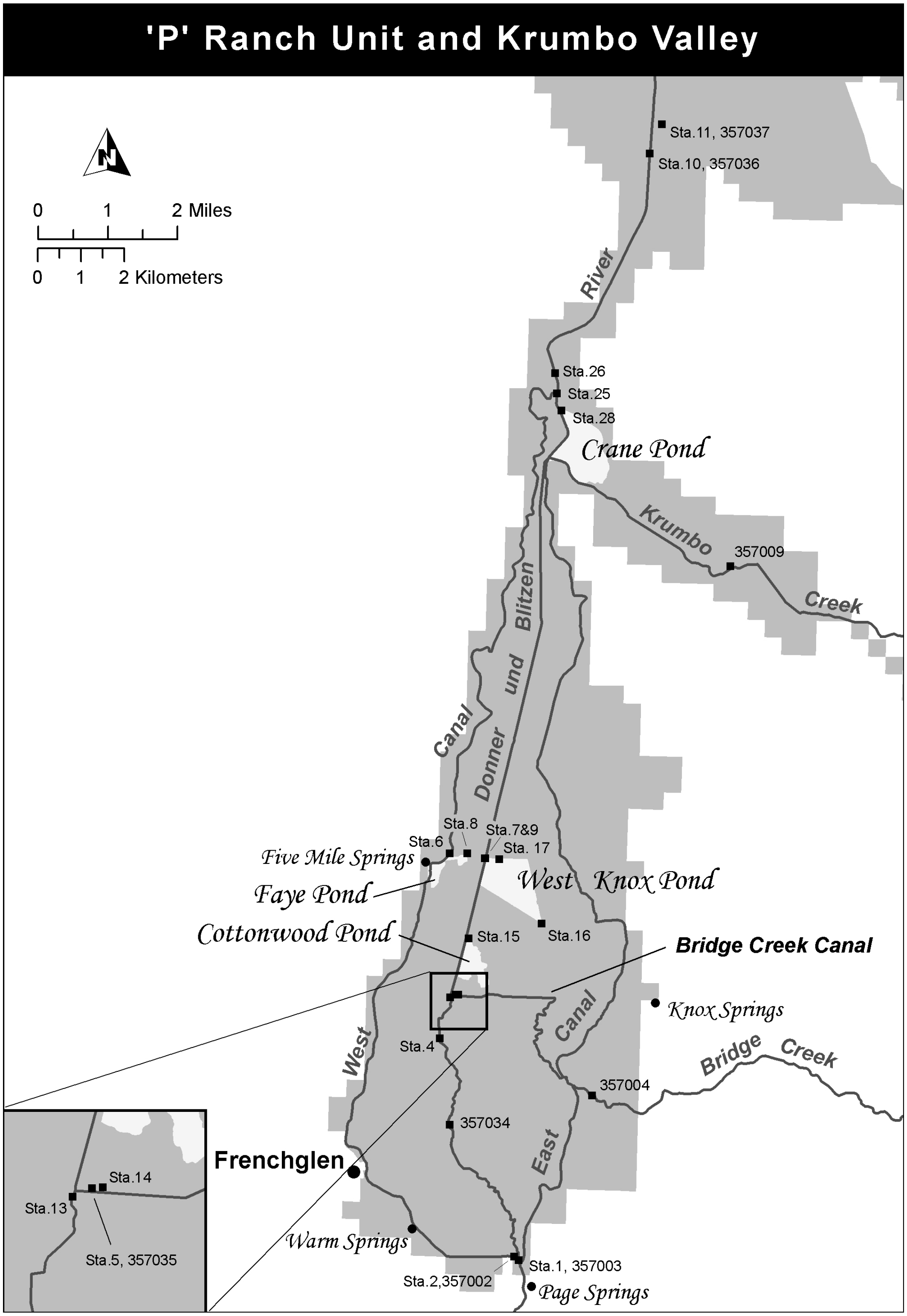

Figure 3. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

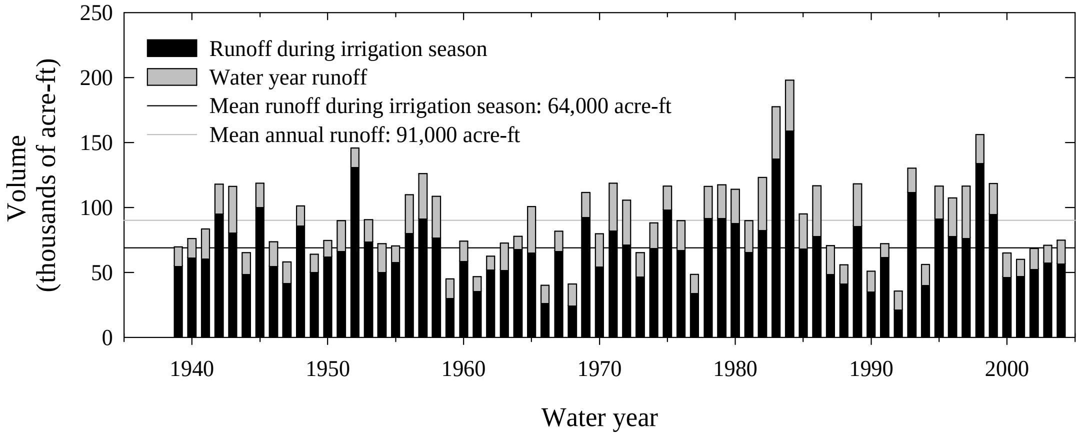

Figure 4. Water year totals and irrigation season totals and means in the Blitzen River, USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1939 to 2004.

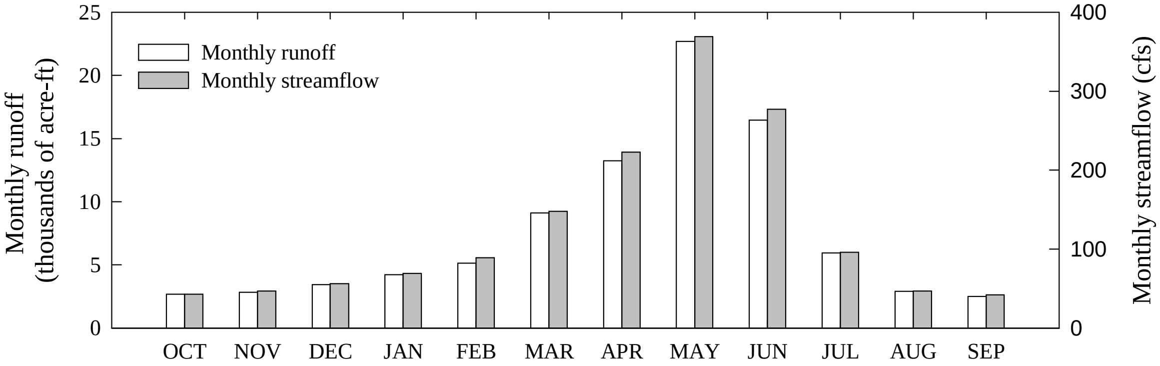

Figure 5. Mean monthly runoff for the Blitzen River, USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1938 to 2004.

Streamflow in the Blitzen River is driven by snowmelt from Steens Mountain. Figure 5 plots the average monthly flows for the period of record and depicts the seasonal distribution of runoff that typically occurs in the Blitzen. Spring snowmelt at lower elevations in the drainage basin contributes to increased streamflows that usually begin in March. Flows generally reach a maximum in May. Flow in May averages 369 cfs (732 acre-ft/day) or 22,700 acre-ft for the month. This monthly volume represents 25% of total annual runoff, indicating that, on average, one-fourth of the total runoff for the year is received in this single month. The minimum monthly flow in May was 105 cfs in 1992 and the maximum was 826 cfs in 1998. Streamflows tend to decline in June and reach baseflow conditions sometime in July.

Minimum flows for the year are usually reached in September. Flows in September average 42 cfs (83 acre-ft/day) or 2,490 acre-ft for the month (2.7% of total annual runoff). September flows represent only about 1/40th of the total runoff for the year. The minimum monthly flow in September was 22 cfs in 1992 and the maximum was 87 cfs in 1984. There is a good relationship between total flow for the water year and Aug-Sept baseflow ($r^2 = 0.87$, Figure 6), with higher water year flows corresponding to higher baseflows in late summer. This implies that runoff forecasts for the Apr to Jul or Apr to Sept periods are useful both as an indication of total water available for irrigation and for predicting baseflows later in summer. As observed with annual flow, a Mann-Kendall trend test showed that there was no significant increase or decrease in baseflows over the 67-year period of record (p=0.35).

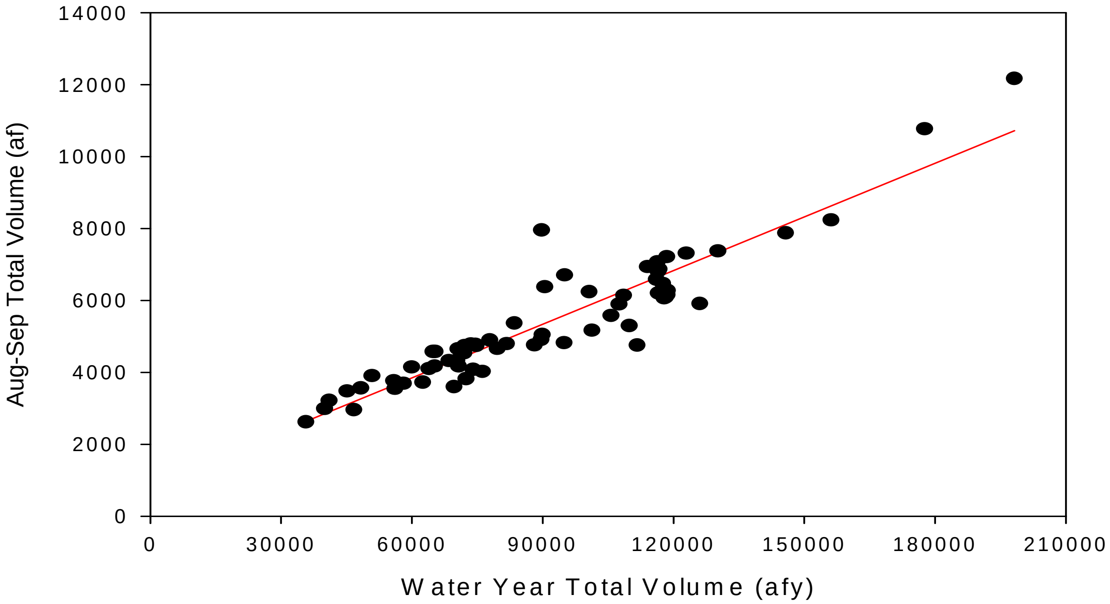

Figure 6. Relationship between total volume for the water year and the volume in Aug-Sep for USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1939 to 2004

While the greatest monthly runoff occurs in May in the Blitzen, mean daily flows for individual days during January and March have exceeded 2,000 cfs several times. These high flow events are attributed to rain-on-snow events. For example, an abnormally high flow event on January 2, 1997 resulted in a mean daily flow of 1,570 cfs (3,114 acre-ft), over 25 times the average flow calculated during two weeks leading up to the event. Snotel weather stations (Figure 1) at Fish Creek (elev. 7900 ft) and Silvies (elev. 6900 ft) recorded precipitation totals of 3.2 and 1.2 inches prior to the event, as well as significant increases in mean daily air temperatures. Streamflow in the Blitzen responds quickly (days) to such events and subsides to near previous levels within days-to-weeks, depending on the magnitude of precipitation, change in air temperature, and volume of water contained in the snowpack. Of the winter months, March has historically had the highest variation in mean daily flows.

NRCS Streamflow Forecasts

Yearly forecasts of runoff in the Blitzen are available from the NRCS on their website at http://www.wcc.nrcs.usda.gov/cgibin/bor.pl. The NRCS forecasts runoff for two periods of the upcoming year: through July and through September. The starting date of the forecast period varies from March through May, depending on the time of the forecast. The flow forecasts through September are only slightly greater than the forecasts through July because so much of the flow in the Blitzen occurs in the spring.

NRCS begins making forecasts in January every year and updates monthly through June. The accuracy of the forecasts increases later in the season since there is less uncertainty remaining in the snowpack information. March and April forecasts are more accurate than January and February. March and April forecasts will probably be most useful for the refuge since they are fairly accurate and still provide early, timely information. Forecasts in May and June are most accurate but these may be too late for the refuge's planning. However, they could provide useful information for adjusting flows and management during the season. The year 1998 provides an example. Forecasted flows in March (140% of normal), April (121% of normal), and May (120% of normal) of that year turned out to be much less than the actual flow. The June forecast (207% of normal) – while still low – was much closer to the actual flow, which was 226% of normal. Such information could be useful for providing feedback and making early-summer adjustments to management on the refuge.

There is a fairly good relationship between the forecasted flows and the actual measured mean flow in September. Forecasts in later months more accurately predict September flows than earlier forecasts. The correlation between the Jun 1st forecast for May – Sept flows and the measured mean September flow for the last 15 years is very good ($r^2 = 0.85$, Figure 7). The regression equation can be used to predict September baseflows with reasonable certainty using the Jun 1st forecast. Note that because this is the mean September flow as measured at the USGS gage, upstream of the refuge, it does not include additional inflow from Page Springs. This inflow would have to be added to the flow at the USGS gage to estimate the flow reaching the refuge at Page Springs during September (see the later report in this section for such estimates).

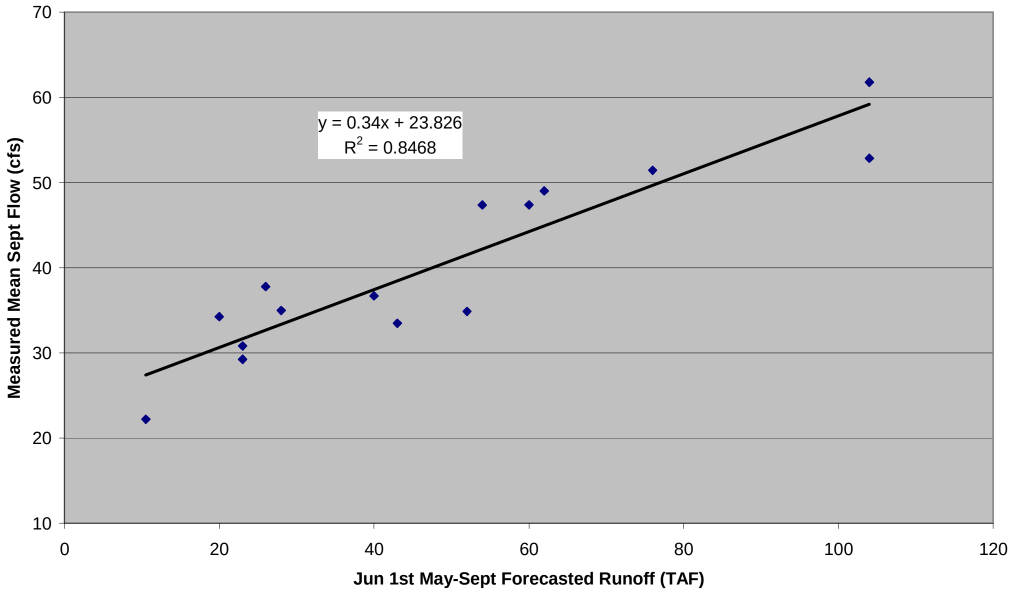

Figure 7. Relationship between NRCS Jun 1st forecasted runoff for the May – September period and measured mean flow in September for USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1990 to 2004.

Figure 8 shows the April 1st April – Sept forecasts and the actual measured April – Sept flows for the most recent 15 years. The graph presents the most probable runoff (the median or 50% exceedance forecast, symbolized with open circles). The other exceedance forecasts (90%, 70%, 30% and 10%) are based on the standard error of the regression equations and describe the range of uncertainty associated with the forecast. The smaller the exceedance percentage associated with a given forecast, the less chance that it will be exceeded. So the 70% exceedance forecast is going to have a higher probability of being exceeded, and will consequently be a lower predicted flow, than the 30% exceedance forecast. As discussed above, the standard errors decrease in later months as the forecasts improve in accuracy. Therefore the range of uncertainty described by the forecasts (and the range of the forecasted flows) decreases around the most probable number in later months. For this reason, the April 1st forecast will have a smaller range of values than the earlier forecasts that precede it.

The NRCS forecast is based, in part on information from the Fish Creek Snotel site on Steens Mountain. There is a good relationship between Apr-Sept flows and the snow water equivalent on April 1st for the entire period of record at this snotel site ($r^2 = 0.60$, Figure 9). The linear regression equation shown in the graph is a crude method of estimating the volume of runoff for the Apr - Sep period.

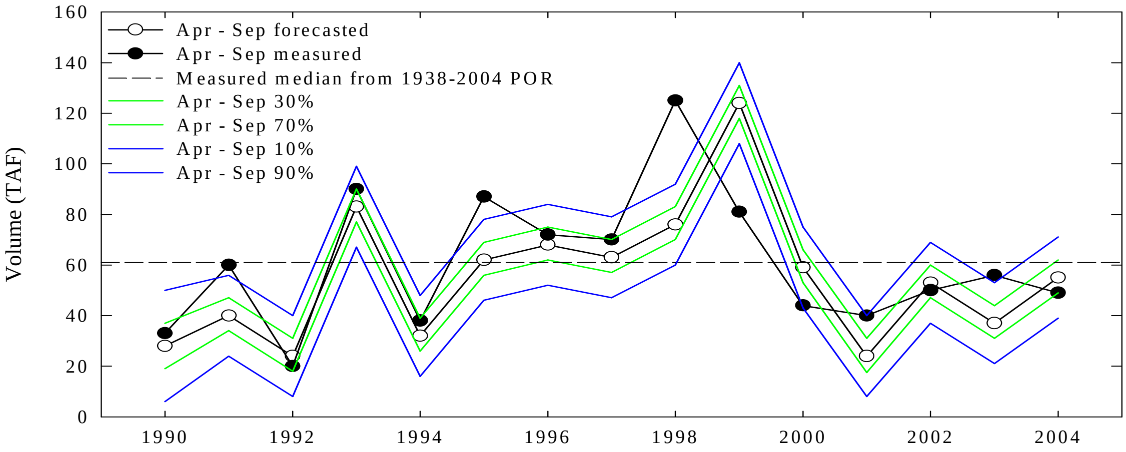

Figure 8. April 1st exceedance forecasts and measured flows for April -September, USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1990 to 2004.

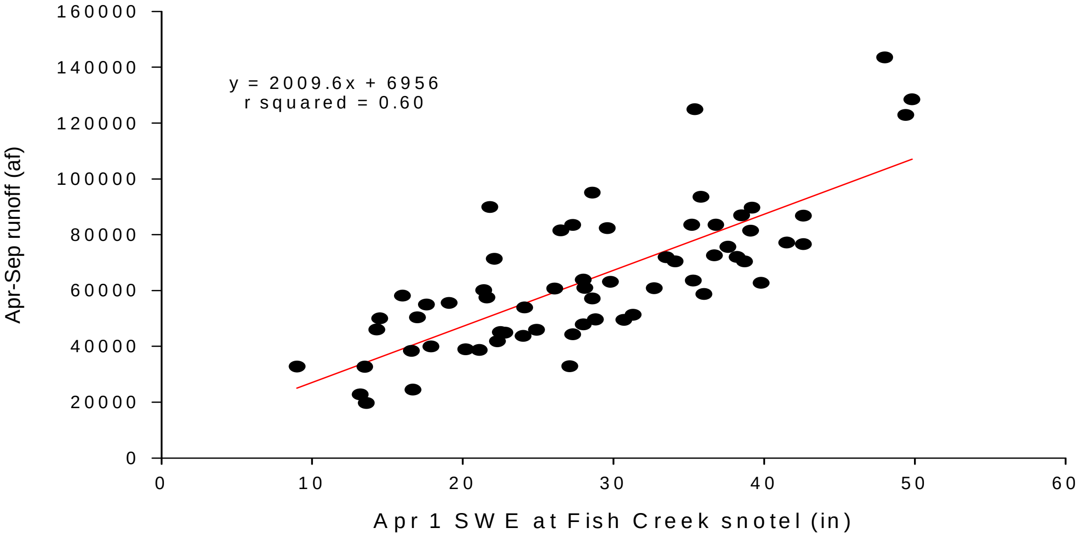

Figure 9. Relationship between April 1st snow water equivalent (SWE) at Fish Creek snotel and measured flows for April -September, USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1939 to 2004.

Ranking of Streamflows

It is useful to have an idea of the relative amount of runoff that is forecast or measured in a given year. We have ranked all years of April to September runoff and classified them according to one of five hydrologic year types, based on the distribution. Figure 10 shows the rank and distribution of April to September runoff for the 67 years in the in the 1938 to 2004 period of record for the Blitzen. The median or 50th percentile of the April – September runoff is 60,650 acre-ft. All values of April – September runoff within the interquartile (between the 25th and 75th percentile of the data) are considered average years (shown in gray). Values less than the 25th percentile (<45,860 acre-ft) are considered dry years and values less than the 10th percentile (<32,788 acre-ft) are considered very dry years. Values greater than the 75th percentile (>78, 860 acre-ft) are considered wet years and values greater than the 90th percentile (>90, 580 acre-ft) are considered very wet years. Using these categories, the amount of runoff forecasted or measured for the April – September period can be assessed relative to all years in the period of record.

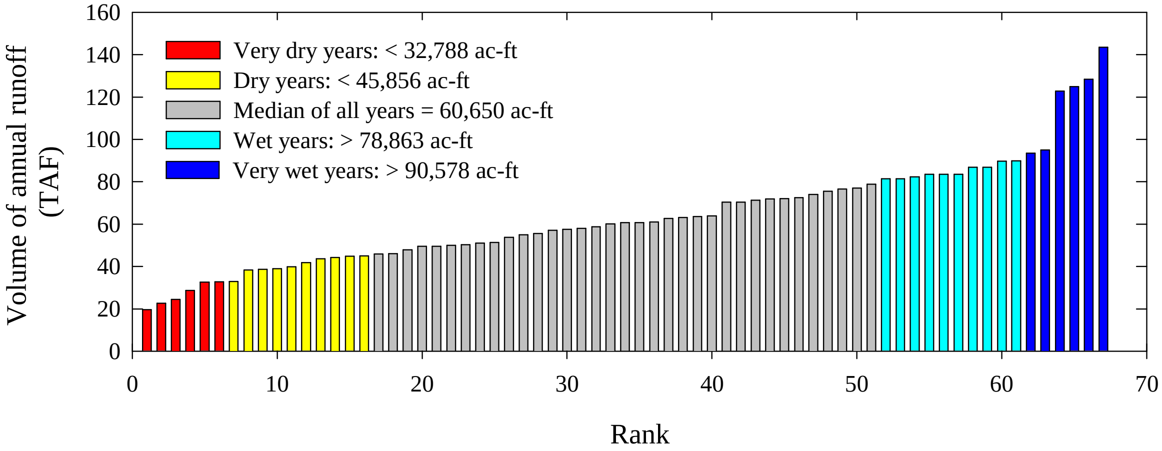

Figure 10. Rank (lowest to highest) and distribution of April-September runoff in the Blitzen River, USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1938 to 2004.

Figure 11 is a histogram showing the distribution of April – September runoff for all years in the period of record. The data show a positive skewness (several observations much higher than the rest of the data) which is common for streamflow data. There is also a suggestion of a bi-modal distribution with one peak around 50,000 to 90,000 acre-ft and a second peak around 110,000 to 130,000 acre-ft. This is not unusual in that wet and dry years are often clustered in cycles and river flows often respond to the cumulative effects of several years of similar climatic conditions rather than individual years.

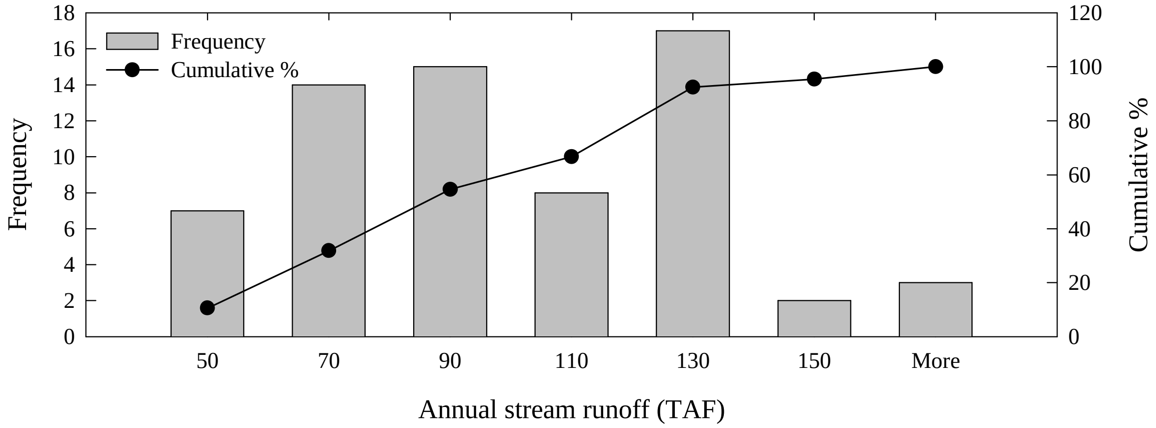

Figure 11. Frequency distribution of April - September runoff for all years in the Blitzen River, USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR, 1938 to 2004.

Comparison of Historical Blitzen Flows at Sodhouse Dam and the USGS Gage

There are historical flow measurements for several groups of years below Sodhouse Dam, the outflow from the refuge. It is interesting to compare these flows with flows measured at the upstream end of the refuge at the USGS Blitzen gage. Not all years at Sodhouse are complete, so we compared the Apr-Sept period for both gages, when available (Figure 12). There is a fairly consistent relationship between inflow at the USGS Blitzen gage and outflow at the Sodhouse gage. The Apr-Sept USGS Blitzen flows explain about 89% and 98% of the variability in the Sodhouse gage flows for the earlier and more recent periods, respectively. There has been slightly more Apr-Sept flow at Sodhouse for a given range of USGS Blitzen flows in recent years. Based on the x-intercept of the two regression lines, there will be very little Apr-Sept outflow at Sodhouse as the Apr-Sept USGS flows approach 35,000 to 40,000 acre-ft (dry years and very dry years). During the wettest years, the Apr-Sept flow at Sodhouse may equal or even exceed the Apr-Sept flow at the USGS Blitzen gage.

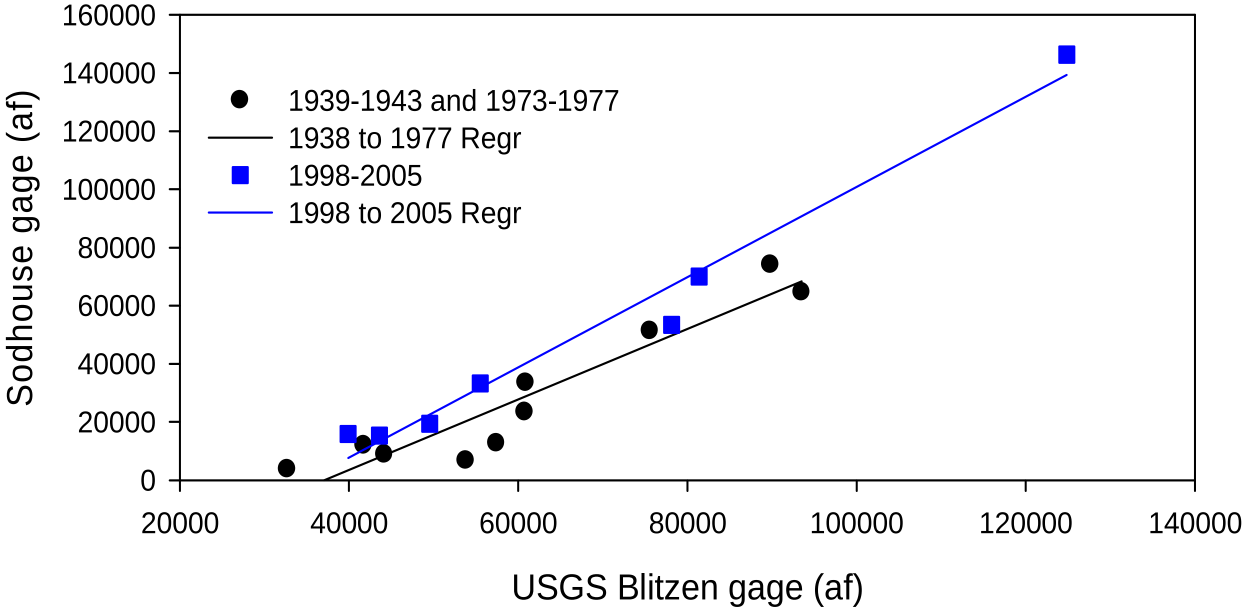

Figure 12. Apr-Sept total flows at the Sodhouse gage and the USGS Blitzen River gage for the years 1939-1943, 1973-1977, and 1998-2005.

Historical Flows and Summary Statistics for Bridge Creek above East Canal, Oregon

Tim Mayer, Rick Roy, Tyler Hallock, and Kenny Janssen
U.S. Fish & Wildlife Service

Bridge Creek originates along the northwestern slopes of Steens Mountain (Figure 1), draining an area only a fraction of the size of the Blitzen River watershed (approximately 30 mi^2). Flow in Bridge Creek moves westerly toward the refuge, where it enters along the eastern boundary roughly 3 miles northeast of Page Springs Dam (Figure 2). After entering the refuge, Bridge Creek joins East Canal for a short distance before separating again and flowing further west and into the Blitzen River. The purpose of this report is to provide information and analysis on the historical flows in Bridge Creek as it enters the refuge and compare those flows with flows in the Blitzen River.

Historical Flows

The USGS recorded streamflow in Bridge Creek above East Canal continuously from 1938 to 1970 (USGS site no. 10397000). The USFWS and the refuge resumed streamflow monitoring and measurements in June of 1994 at the same site (USFWS site no. 357004, Figure 2). Measurements were quite irregular during water years 1994 to 1999, but a continuous record extends from 2000 to 2003. We used the period of record that incorporates measurements from both the USGS and USFWS records, excluding the years 1994 to 1999.

There is little fluctuation in mean annual streamflow for Bridge Creek over the 37-year period of record. Annual runoff has averaged 9,680 acre-ft/yr for the period of record. It has ranged from a maximum of 13,900 acre-ft in 1942 to a minimum of 5,530 acre-ft in 1961. Maximum daily discharge occurred on March 15, 1939 when mean daily flow reached 120 cfs. On two other occasions mean daily flows reached 118 cfs, however, flows of this magnitude are relatively infrequent. Historically, mean daily discharge has been 25 cfs or less 95 percent of the time and 42 cfs or less 99 percent of the time.

Like the Blitzen River, streamflow in Bridge Creek is driven by snowmelt in the spring. However, peak flows are generally of shorter duration and relatively smaller proportion than peak flows in the Blitzen River. Peak flows usually don’t continue past June. By July, flows in Bridge Creek are already near the minimum for the year, much earlier than Blitzen flows recede to baseflow conditions. Minimum flow, or baseflow, generally extends from July through February and averages 11.8 cfs or 716 acre-ft/month (Figure 3), with a minimum and maximum of 693 acre-ft/month (November) and 740 acre-feet/month (July), respectively. Large discharge events have occasionally exceeded 100 cfs during this period. Streamflows during the spring months of April, May and June average 19.1 cfs, 21.5 cfs and 14.6 cfs, respectively with monthly totals amounting to 1,140 acre-ft/month, 1,320 acre-ft/month and 870 acre-ft/month (Figure 3). Average seasonal flows and totals are summarized in Table 1. Total monthly runoff and mean daily streamflow at Bridge Creek are shown in Figure 3.

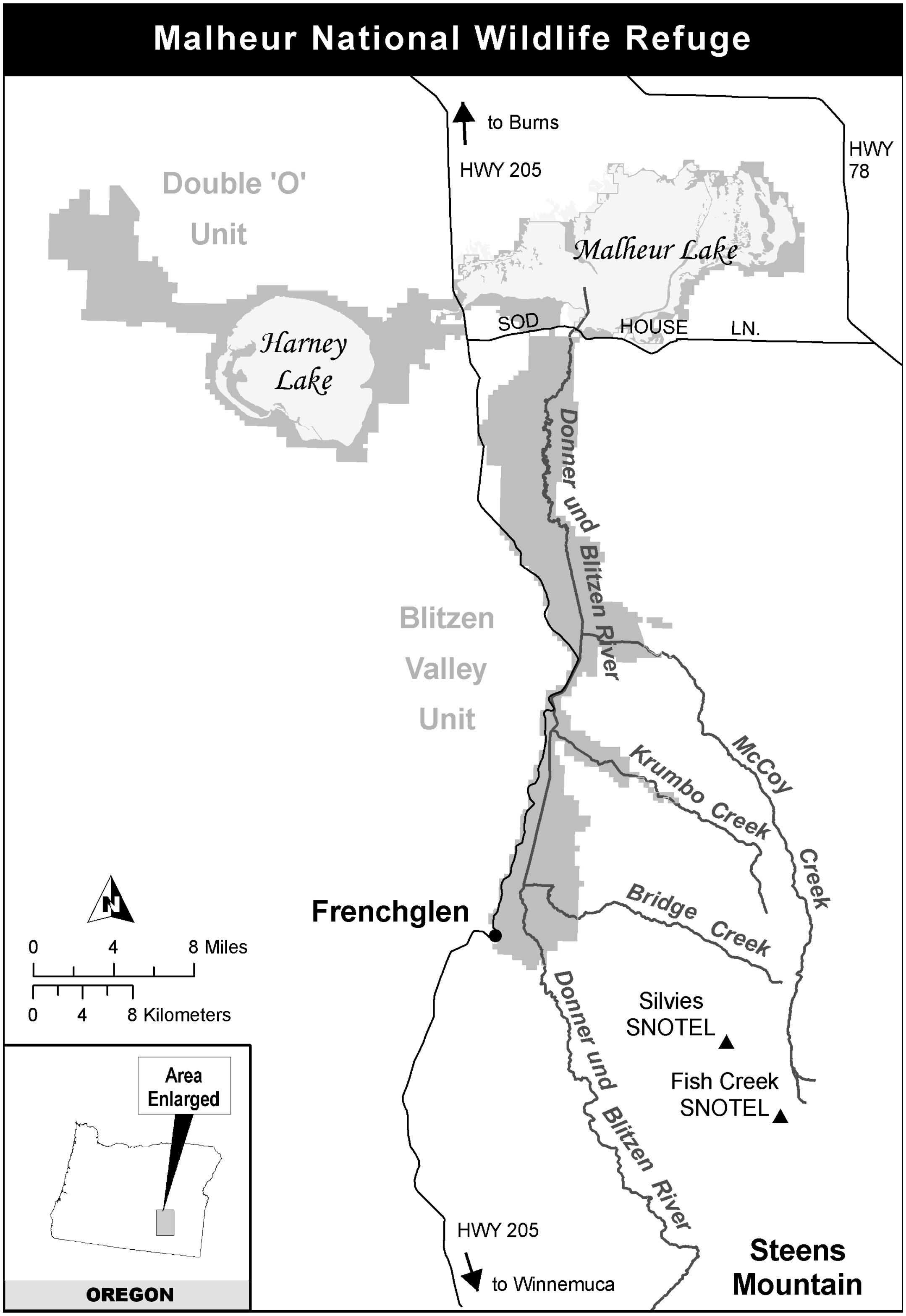

Figure 1. Map showing general location of Malheur NWR with the refuge boundary and units, the SNOTEL sites mentioned in this study, and several major landmarks and geographic features.

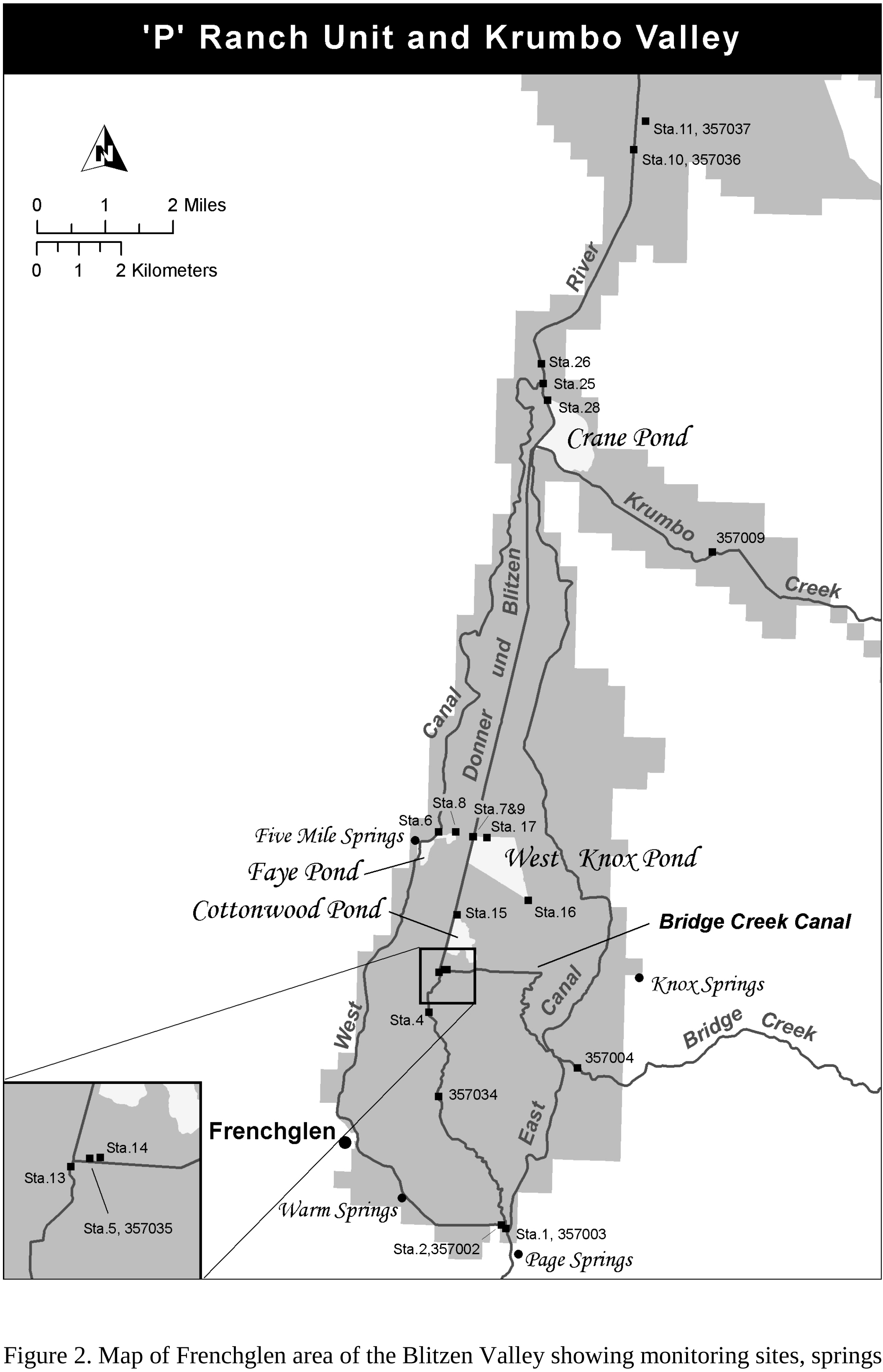

Figure 2. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

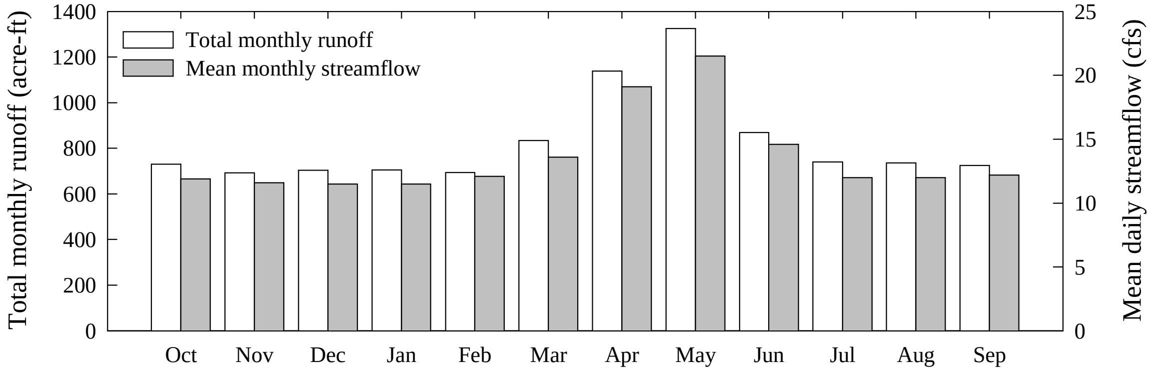

Figure 3: Mean monthly runoff and streamflow at Bridge Creek above East Canal, USGS site no 10397000 (1938 to 1970) and USFWS site no. 357004 (2000 to 2003).

Table 1: Seasonal streamflows and total runoff at Bridge Creek above East Canal

	Fall (Oct – Dec)	Winter (Jan – Mar)	Spring (Apr – Jun)	Summer (Jul – Sep)
Mean daily streamflow (cfs)	11.7	12.4	18.5	12.1
Total monthly runoff (acre-ft)	2,128	2,233	3,368	2,200
Percent of annual total (%)	21	22	34	22
Mean daily streamflow during dry years (cfs)	12.5	11.2	11.8	10.4

Bridge Creek Flows and Blitzen River Flows

Bridge Creek flows are considerably less than Blitzen River flows. Mean annual flow in Bridge Creek is 13.7 cfs and in the Blitzen River is 126.6 cfs. The timing and distribution of flows differ as well. Figure 4 illustrates the monthly percentage of total annual flow over the period of record for both Bridge Creek and the Blitzen River. Generally, Bridge Creek has a higher proportion of baseflow and a lower proportion of peak flows when compared with the Blitzen. Flow in Bridge Creek during peak conditions (Apr – Jun) is 34% of the annual total, compared to 60% in the Blitzen River (Table 1). Approximately 60%, or 5,950 acre-ft, of the total annual flow at Bridge Creek occurs during the irrigation season (Mar-15 to Oct-1). In comparison, irrigation season flows in the Blitzen account for 76% of the total annual flow. September monthly flows account for 7.4% of the total annual flow on Bridge Creek but only 2.7% of the total annual flow in the Blitzen.

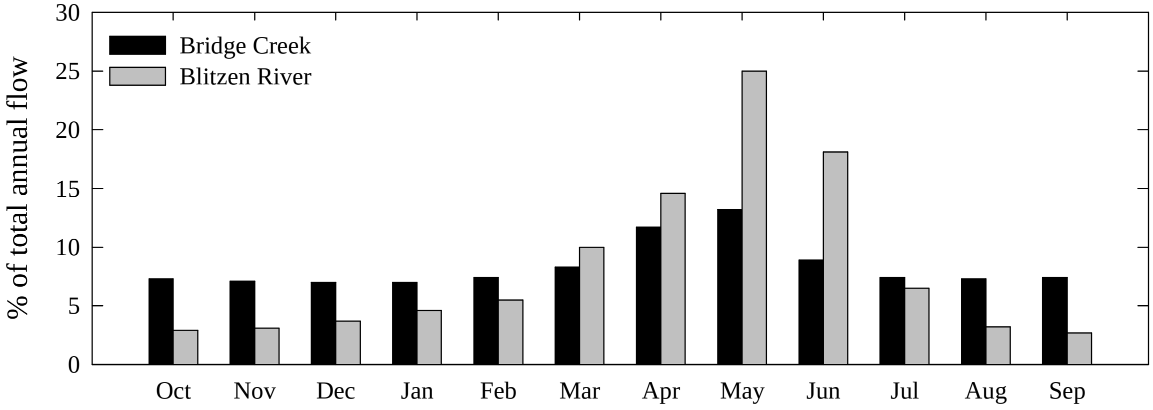

Figure 4: Percentage of total annual flow by month at Bridge Creek above East Canal and Blitzen River near Frenchglen, OR.

During drier than normal years, peak discharge events that are typically observed during spring months are greatly reduced and are only slightly above baseflows. For example, in WY 2002, the maximum daily flow during the runoff period was only 13.5 cfs. What is notable is that baseflows in Bridge Creek during dry years are near normal despite the absence of peak flows in these years (Table 1). Apparently, the spring discharge and subsurface seepage that supports the baseflow in Bridge Creek is not as sensitive to climatic trends as the peak flows.

Discharge in Bridge Creek responds very similarly to changing streamflow conditions measured in the Blitzen River near Frenchglen. Figure 5 is a correlogram illustrating how mean daily streamflows at these sites correspond with one another. The measure is given as a crosscorrelation coefficient, which defines the magnitude of how well the variables, in this case streamflows, are related. The strength of association is described on a scale from -1 to 1, with zero indicating no relation at all, 1 indicating a perfect correlation, and -1 indicating a perfect inverse correlation. The correlogram also provides information on the lag, or offset, of the two variables. The lag describes when or where the two series are most related. Figure 5 illustrates the strength and timing of association between discharge at Bridge Creek and the Blitzen River over a two month span (30 days before and 30 days after). The greatest association is at time zero, where the crosscorrelation coefficient is 0.70. This indicates that in most cases, streamflows at Bridge Creek are changing at the same time as streamflows in the Blitzen River are changing. Figure 5 also shows relatively high coefficients for one day before (0.63) and one day after (0.63) zero lag indicating that streamflow response in Bridge Creek may either discharge slightly before (negative lag) or slightly after (positive lag) Blitzen River. The last noticeable pattern in Figure 5 is that the strength of association is greater for negative lag times than for positive lag times. This suggests that peak flows in the Blitzen River are most likely to occur later or over a longer period than peak flows in Bridge Creek.

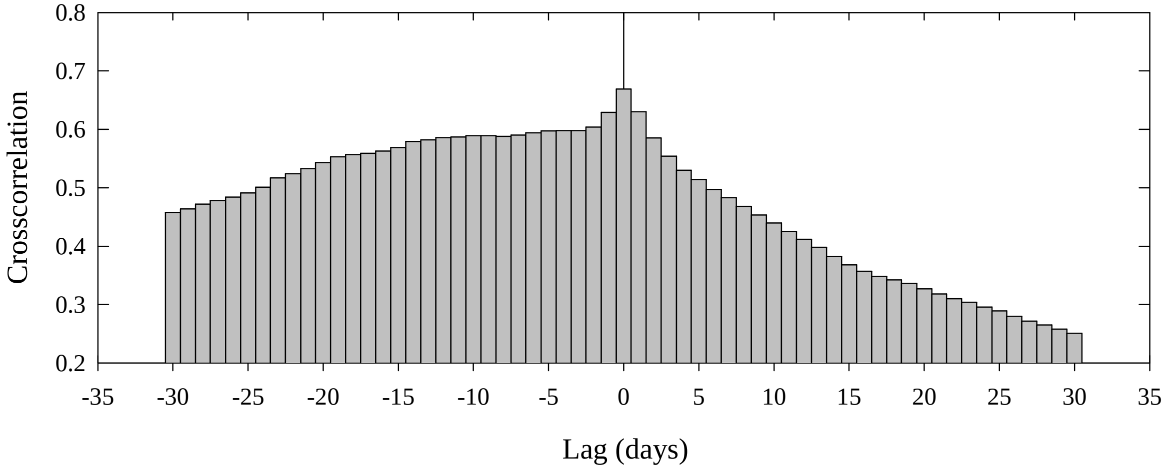

Figure 5: Cross-correlogram of mean daily streamflows at Bridge Creek above East canal and Blitzen River near Frenchglen, OR.

Estimated Spring Inflow to the Frenchglen Area of Malheur National Wildlife Refuge

Tim Mayer, Rick Roy, Tyler Hallock, and Kenny Janssen
U.S. Fish & Wildlife Service

There are four spring systems that contribute flow to the Frenchglen Area of Malheur NWR (Figure 1). One of these spring systems flows into the Blitzen River and the other three flow into East or West Canals. Flow estimates are needed from each of these spring systems to evaluate the total inflow to this area of the refuge. The purpose of this report is to discuss each spring system and provide flow estimates for each.

Page Springs

The main source of water for Malheur NWR is the Blitzen River. The Blitzen River enters the refuge at the southern boundary near Page Springs. Page Springs is the largest spring system in the Frenchglen Area and one of the largest spring systems on the refuge. The spring system contributes a significant but unmeasured volume of flow to the Blitzen River just upstream of the refuge (Figure 1). The total inflow from the Blitzen River to the refuge includes the contribution from Page Springs. Because the spring flow is diffuse and emanates from a number of sources, it can not be measured directly. However, spring flow will be fairly constant and less variable than the flow in the river. The purpose of the analysis is to estimate the discharge from the springs for use in evaluating the total inflow to the refuge from the Blitzen River.

The USGS operates a gaging station on the Blitzen River (USGS site no. 10396000, Donner und Blitzen River nr Frenchglen, OR) about one mile south and upstream of the southern boundary of the refuge. The period of record is from 1911 to 1921 and 1938 to the present. The discharge from Page Springs enters the river downstream of the gage and is not included in the measured flows from this site. Therefore, flow measurements at the gaging station do not provide a measure of the total inflow to the refuge since the station is upstream of Page Springs.

The FWS has a continuous gage below Page Springs Dam that has operated since September 1993. This gage is downstream of Page Springs but is also downstream of the refuge diversions to West Canal and East Canal. Both diversions are unmonitored. Flow measurements at this station do not provide a measure of the total inflow to the refuge unless the diversions to the canals are measured and accounted for.

A number of times in the past few years, the FWS has made instantaneous flow measurements at the East and West Canal diversions to estimate the spring discharge from Page Springs and the total inflow to the refuge from the Blitzen. The sum of the flows in the Blitzen River below Page Springs Dam, the diversion to East Canal, and the diversion to West Canal, minus the Blitzen River flow upstream of Page Springs at the USGS gage gives an estimate of spring flow at Page Springs. We contacted the Portland Office of the USGS for the flow measurements at specific times corresponding to the time of the other measurements.

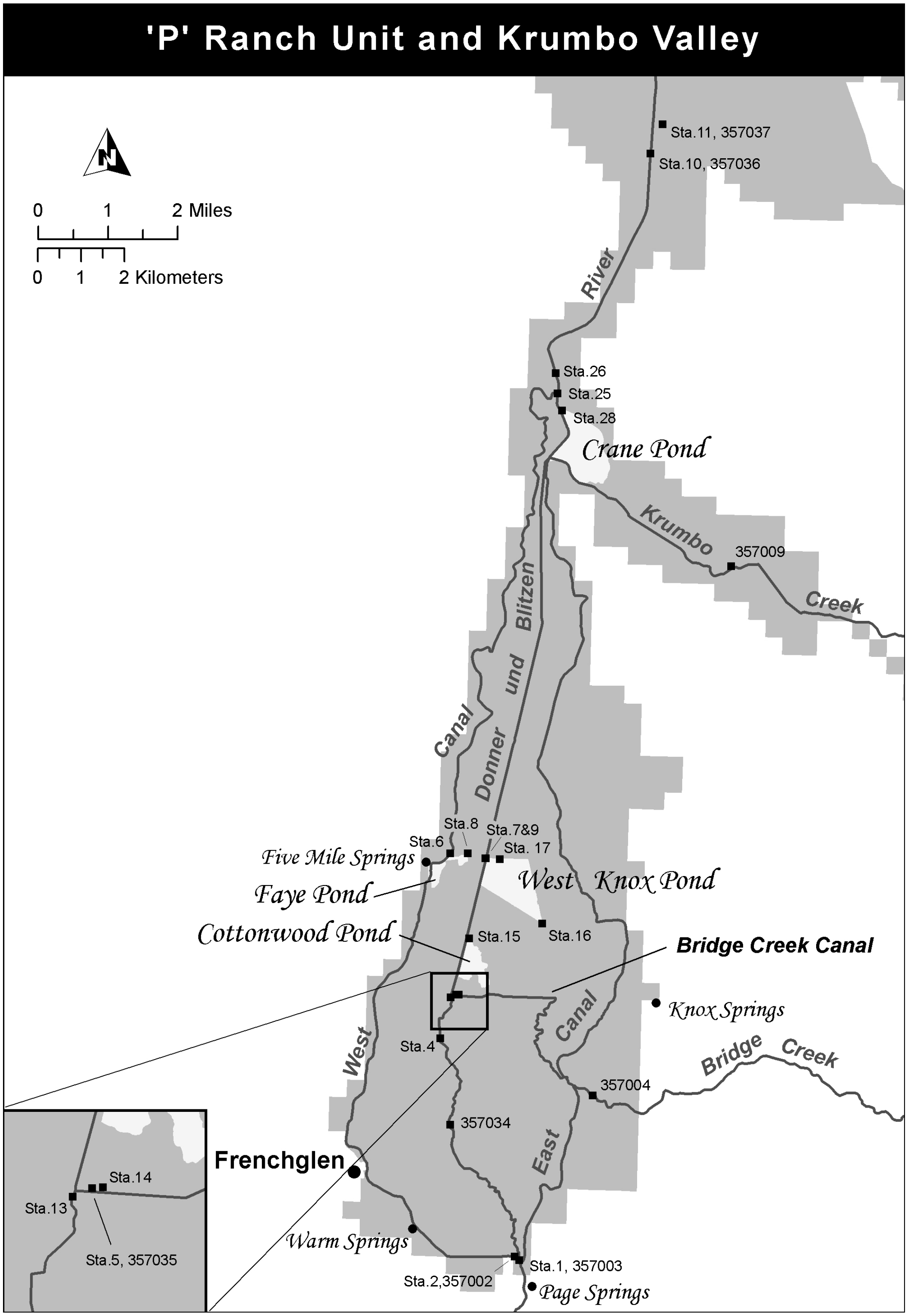

Figure 1. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

One problem with this approach is that the flows in the Blitzen River vary diurnally, especially during the runoff period in spring and early summer. It can require a couple of hours to measure the diversions in the East and West Canals and the river flows below Page Springs Dam and at the USGS gage can change during that time. The estimates of Page Springs flows during the runoff period may be problematic because of the diurnal variability in flows at this time of year. In addition, water is lost to flooding and bank storage during these periods and rating curves are typically less accurate at higher flows, creating other problems with the spring flow estimates during high water.

The resulting spring inflow estimates are shown in Figure 2 and Table 1. We have made measurements in 1997, 1998, 2002, 2003, and 2005. The measurements span wet years (1997 and 1998) and dry years (2002 and 2003) and the spring discharge estimates reflect this. 1997 and 1998 estimates are higher than 2002 and 2003. Although the winter of 2005 was very dry, the spring was very wet and the estimated spring flow was relatively high as well. The flow from Page Springs is estimated to range from 6 cfs in 2002 and 2003 to 12 to 16 cfs in 1997, 1998, and 2005. The average of all five years is 11 cfs. Adding 11 cfs to the USGS flows measured on the Blitzen River will provide a reasonable estimate of the total inflow from the Blitzen River to the refuge. Subtracting the flow below Page Springs Dam (FWS 357003) from the total refuge inflow as estimated above will provide an estimate of the combined volume of water diverted to the East Canal and West Canal.

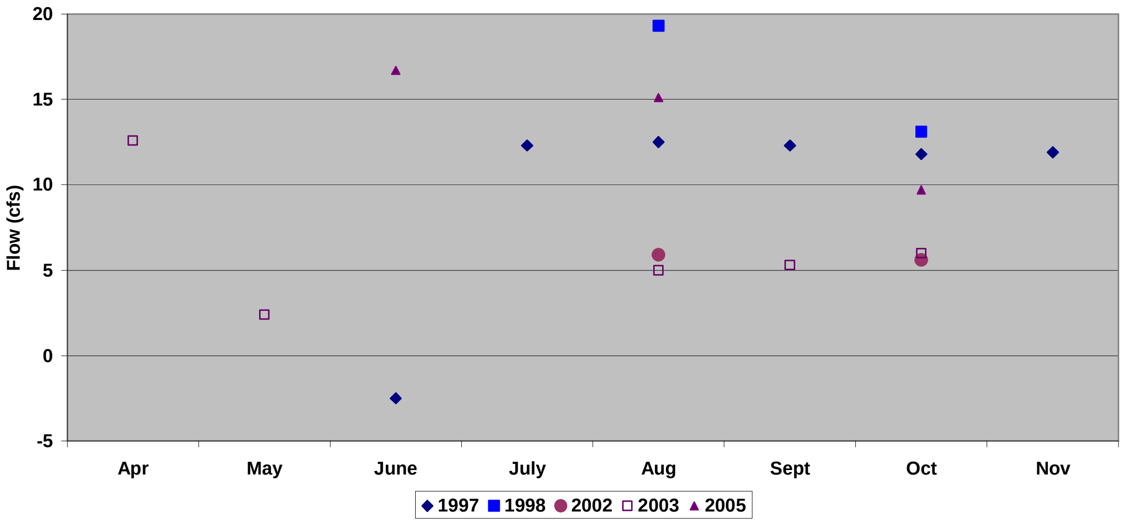

Figure 2. Estimated Spring Discharge at Page Springs near Frenchglen, OR, for the years 1997, 1998, 2002, 2003, and 2005.

Warm Springs

Warm Springs is located just south of the refuge between Page Springs and the town of Frenchglen (Figure 1). It is a smaller spring system than Page Springs and contributes flow into the West Canal. As with Page Springs, the flow emanates from several sources and can not be measured directly. Estimates of the contribution from Warm Springs were made by measuring the West Canal upstream of the springs at the Blitzen River and downstream of the springs at the Page Springs/Frenchglen Road. This approach measures the net contribution of the springs since there is some loss from evapotranspiration in the marshy areas along West Canal in the vicinity of the springs. Measurements were made when there were no diversions from West Canal along this reach. Paired measurements were made on the following four dates in 2003: Mar-12, Aug-4, Aug-27, and Oct-1.

The net contribution of flow from Warm Springs was 2.5 cfs in March, 0.2 to 0.3 cfs in August, and 0.6 cfs in October (Table 2). A seasonal pattern is apparent with a maximum contribution in the spring and a minimum in summer. This variation may reflect the greater evapotransipiration loss in the summer from the adjacent wetland and meadow as well as variability in spring flow. The specific conductance of the water in West Canal increased 1.4 to 1.5 times between the two measurement sites. The increase probably resulted from the evapotranpiration losses as well as the inflow of higher conductivity water from the springs. These are warm water springs and the water temperature in West Canal increased between the two measurement sites significantly (about 5ºC based on two measurements in August). For purposes of estimating total inflow to the refuge, an average inflow of 2.5 cfs can be assumed in spring, 0.25 in summer, and 0.5 cfs in fall.

Five Mile Springs

These springs are located along West Canal just south of Five Mile Road (Figure 1). Estimates of the contribution of flow from these springs were very small (<0.5 cfs), based on three sets of paired measurements on West Canal upstream and downstream of the springs.

Knox Springs

These springs are located on East Canal just east of Knox Swamp and Knox Ponds (Figure 1). Flow from these springs is collected in a channel and can be diverted directly into East Canal or across East Canal into Knox Swamp. The channel is too small for flow measurements with a current meter but inflow was estimated visibly at about 1 cfs. The spring flow appears fairly constant throughout the season. These are cold water springs.

Table 1: Synoptic flow measurements for estimates of Page Springs inflow.

Water Year 1997	time	6/17/97	time	7/8/97	time	8/20/97	time	9/18/97			Average
East Canal	1405	49.5	1520	38.4	1500	20.2	1140	33.1			
West Canal	1300	45.0	1530	34.4	1700	21.4	1330	5.7			
Blitzen River	1135	183.0	1550	54.5	1105	19.9	1230	20.5			
Total Refuge Inflow at Page Springs		**277.5**		**127.3**		**61.5**		**59.3**			
USGS Blitzen abv Page Sprs	1300	280.0	1530	115.0	1300	49.0	1200	47.0			
Estimated Spring Inflow		***-2.5***		***12.3***		***12.5***		***12.3***			***12.1***
Water Year 1998	time	10/23/97	time	11/18/97			time	8/10/98	time	10/29/98	
East Canal	1417	3.3	1335	2.9			1435	12.3		5.0	
West Canal	930	2.6	1515	7.5			1300	6.8	915	2.0	
Blitzen River	1040	53.9	1420	45.5			?	76.2	1015	65.2	
Total Refuge Inflow at Page Springs		**59.8**		**55.9**				**95.3**		**72.1**	
USGS Blitzen abv Page Sprs	1200	48.0	1400	44.0			1400	76.0	1200	59.0	
Estimated Spring Inflow		***11.8***		***11.9***				***19.3***		***13.1***	***16.2***

Table 1: Synoptic flow measurements for estimates of Page Springs inflow (continued).

Water Year 2002	time	8/8/02	time	9/9/02							Average
East Canal	1325	9.9	1515	8.2							
West Canal	1400	5.4	1640	3.9							
Blitzen River	1315	27.6	1620	28.6							
Total Refuge Inflow at Page Springs		**42.9**		**40.6**							
USGS Blitzen abv Page Sprs	1400	37.0	1530	35.0							
Estimated Spring Inflow		***5.9***		***5.6***							***5.8***
Water Year 2003	time	4/3/03	time	5/1/03	time	8/3/03	time	8/27/03	time	10/1/03	
East Canal	1040	20.8	1150	15.9	1020	4.6	840	8.2	1520	8.55	
West Canal	900	37.2	1030	33.2	1100	6.4	930	4.7	1600	2.97	
Blitzen River	1000	60.6	1100	65.3	1100	38.0	900	26.5	1545	26.5	
Total Refuge Inflow at Page Springs		**118.6**		**114.4**		**49.0**		**39.3**		**38.0**	
USGS Blitzen abv Page Sprs	1000	106.0	1100	112.0	1300	44.0	1000	34.0	1600	32	
Estimated Spring Inflow		***12.6***		***2.4***		***5.0***		***5.3***		***6.02***	***6.3***
										Average:	***10.1***

All USGS flows are instantaneous values at the time of the other flow measurements, obtained from the Portland office (Jo Miller, 503 251-3201)

Table 1: Synoptic flow measurements for estimates of Page Springs inflow (continued).

Water Year 2005	time	6/21/05	time	8/2/05	time	10/4/05	Average
East Canal	1725	45.7	2000	10.7	1500	9.7	
West Canal	1830	25.1	1900	*1.0*	1500	*1.0*	
Blitzen River	1630	137.9	1930	51.4	1400	41.8	
Total Refuge Inflow at Page Springs		**208.7**		**63.1**		**52.4**	
USGS Blitzen abv Page Sprs	1630-1830	192.0	1930-2030	48.0	1400-1500	42.7	
Estimated Spring Inflow		***16.7***		***15.1***		***9.7***	***13.8***

Table 2: Synoptic flow measurements for estimates of Warm Springs inflow.

Date	West Canal Flow at Page Springs	West Canal Flow at Frenchglen/Page Springs Rd	Estimated Net Spring Inflow	Temperature (C) at Page Springs	Temperature (C) at Frenchglen/Page Springs Rd	Conductivity (uS/cm) at Page Springs	Conductivity (uS/cm) at Frenchglen/Page Springs Rd
3/13/03	1.33	3.83	2.50				
8/4/03	6.20	6.39	0.19	14.2	19.1	90	129
8/27/03	4.67	4.93	0.26	17.5	21.2	101	151
10/1/03	2.97	3.53	0.56				

Water Budgets, Net Inflow, and Consumptive Use Estimates for Malheur National Wildlife Refuge

Tim Mayer, Dar Crammond, Rick Roy, Kenny Janssen
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The purpose of this report is to develop water budgets for six areas of the refuge with different scales and mixes of water use. The data for the water budgets comes from several sources: flow and survey data collected during this study; flow data collected routinely by the Water Resources Branch (WRB) for the maintenance of water rights and instream flows; and water rights information on irrigated acreage and areas of open water ponds/wetlands. The development of water budgets will allow us to estimate consumptive use and water requirements for different habitats and during different times of the year. We can also use water budgets to calculate nutrient loads and evaluate downstream water quality impacts. All of this information will be very useful in managing habitat and water at Malheur NWR.

BLITZEN VALLEY

The first water budget we developed is for the entire Blitzen Valley area of the refuge (Figure 1). This area includes all irrigated lands south of Sodhouse Lane and north of Page Springs, including the Krumbo Valley and the refuge lands in the Diamond Valley.

Methods

Total inflow and outflow for the Blitzen Valley area is based on the information submitted in the 2002 through 2005 annual Oregon Water Use Reports for Malheur NWR. We calculate total inflow to the Blitzen Valley as the sum of four gages: USGS Blitzen gage plus estimated Page Springs inflow upstream of Page Springs Dam; Bridge Creek above East Canal; total outflow from Krumbo reservoir; and McCoy Creek above Diamond Swamp. We estimate total outflow as the flow at the Blitzen below Sodhouse Dam. We are not accounting for inflow to this area from direct precipitation, other streams and springs (ex. Mud Creek, Web Creek, Boca Lake, Warm Springs, 5-Mile Springs), and subsurface inflow. There is unaccounted outflow to this area as well (several outflow channels under Sodhouse Lane to Malheur Lake, subsurface outflow).

We define net inflow as the difference between inflow and outflow for the two periods considered: April-Sept and the Oct-Sept water year. Net inflow provides an estimate of consumptive use, or water loss to evapotranspiration (ET) and seepage, from various habitats on the refuge. This assumes that changes in storage over the period are negligible. Net inflow and consumptive use do not equate to the entire water need on the refuge. There is water use on the refuge that is non-consumptive too, such as water that flows through a wetland or field and then returns to the river or water that is held for a time in a wetland or field and then released later in the season. Such non-consumptive uses are not included in the calculation of net inflow.

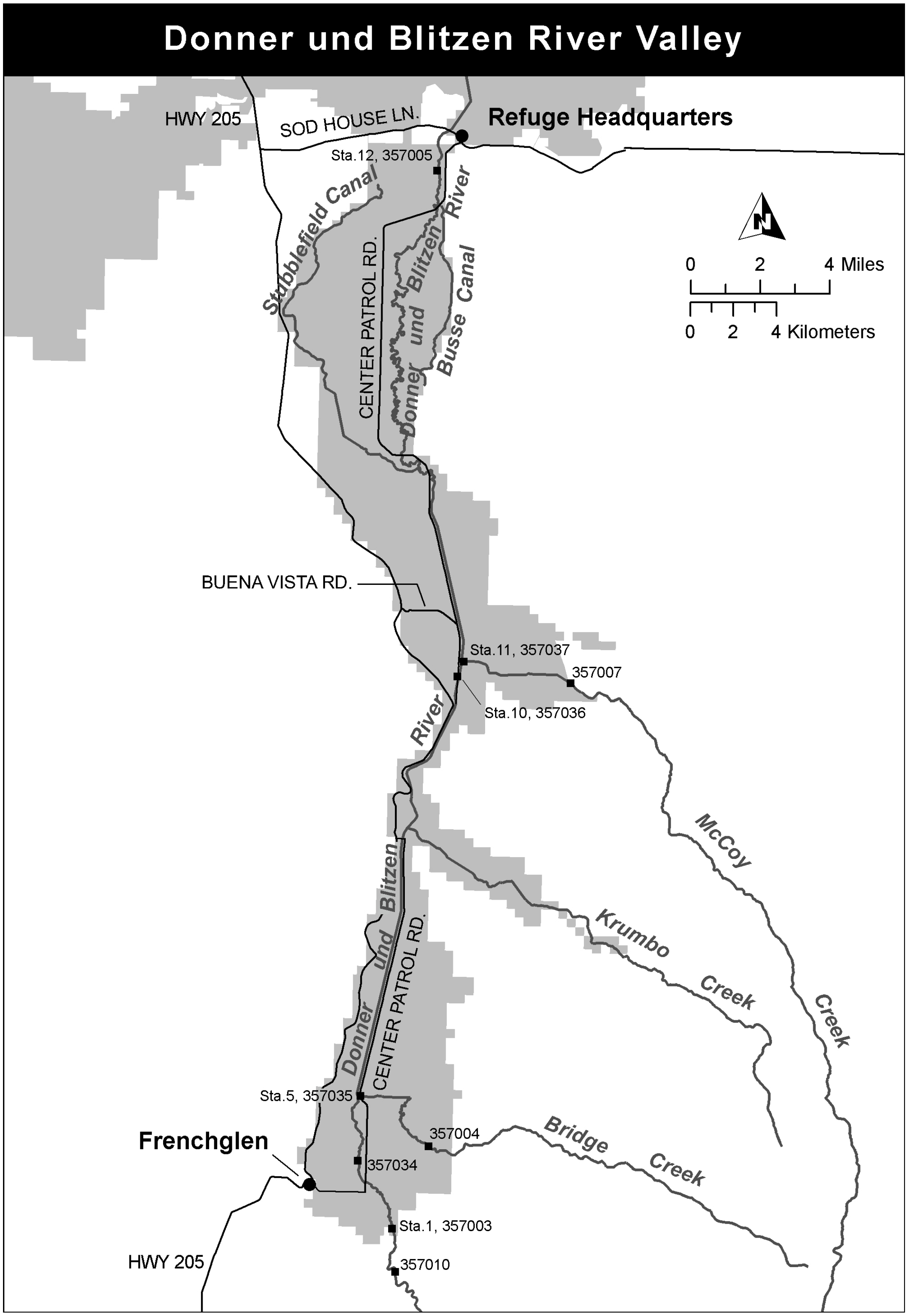


Figure 1. Map of Blitzen River Valley showing rivers and creeks, study monitoring sites, and several major landmarks and geographic features.

We express the net inflow for the Blitzen Valley as a consumptive use rate in the tables. It is calculated here as the difference between inflow and outflow divided by the total irrigated acreage for the area of consideration. Minister and Glaser Surveying, acting as Oregon Certified Water Rights Examiners (CWREs), mapped irrigated areas and areas of open water for the WRB in 1994. We checked the delineated acreage using 2005 aerial photography. We also compiled surface area information on open water ponds/wetlands, generated by our CWRE for the Ponds Bill water right certificates. The estimates of irrigated areas are approximate and may slightly overestimate the amount of irrigated land in any one year as not all lands are irrigated and not all ponds are full every year.

We present the percentile rank of the runoff for the period (Apr-Sept or water year) relative to all runoff totals for the same period in the 68-year record at the USGS Blitzen River gage. The percentile rank is a general indication of how wet or dry the year was, in terms of runoff. High percentile ranks mean wet years and low percentile ranks mean dry years. We also present Apr-Sept and Oct-Sept total precipitation at Burns, Oregon as a general indication of how wet or dry the year was in terms of direct precipitation input.

Results

The total irrigated area, including open water ponds, in the entire Blitzen Valley section of the refuge is about 36,000 acres. A maximum of 6,500 acres, or 18 % of this irrigated area is open water ponds and wetlands. However, most ponds are not filled to the maximum level every year or even throughout the season, and some may be dry all year, so this acreage number is likely high. The remaining 29,500 acres of irrigated area consist of wet meadows and fields. Some of these areas are hayed or grow grain for wildlife purposes.

The period from 2002 to 2005 includes one wetter year, 2005, and three dry years, 2002, 2003, and 2004 (Table 1). The estimated rates of consumptive use range from 1.3 to 1.7 acre-ft/acre for the Apr-Sept season and 1.3 to 1.9 acre-ft/acre for the water year. These are gross consumptive use estimates for all the lands in the Blitzen Valley. Individual areas within the refuge will use more or less than this general rate. In particular, individual open water or seasonal wetlands appear to use two to three times this average rate, as described further below. Most of the habitat in the Blitzen Valley consists of wet meadows and fields. Cuenca (1992) gives irrigation requirements for alfalfa, spring grains, and winter grains in Harney Valley as about 1.6 to 1.7 acre-ft/acre. Consumptive use estimates developed here are close to these numbers.

Most of the diversions in the Blitzen Valley occur in spring and summer, during the irrigation season. The volume of water diverted outside of the irrigation season is small. Diversions are highest in May, followed by April and June (Figure 2). The refuge diverts water into flooded fields and wetlands during the spring runoff period, when water is available, and then uses it consumptively, typically in place, throughout the summer. The refuge stops diverting water for the most part by the 3rd week of July and only a small volume of water is diverted in August and September.

The volume and timing of water used consumptively on the refuge is a function of water availability, water management, climate factors, and habitat management in a given year. The different habitats on the refuge require different amounts of water, as described further below. The average rates estimated here for the entire Blitzen Valley are collective averages of the individual rates for each habitat type, weighted by the size of that habitat throughout the area. Furthermore, climate factors such as precipitation, temperature, and wind can affect ET rates for all habitats. A hot, dry summer may result in more irrigation water being used consumptively in all habitats because of higher ET rates.

Habitat management also affects the consumptive use rates on the refuge. For example, in 2002, Boca Lake and Darnell Pond were left dry for construction projects and carp control. This resulted in about 1,000 acres of the total maximum 6,500 acres of open water ponds/wetlands being dry that year. In 2003, much of the area served by the East Canal was fallowed. Several of the ponds in that area were dry as well. These factors could be partially responsible for the lower consumptive use rates in 2002 and 2003.

Water availability in dry years like 2002 and 2003 may affect consumptive use on the refuge too. The refuge may limit overall irrigated acreage overall in any year due to reduced water availability and the need to maintain Blitzen River flows. Water availability also affects the timing of diversions seasonally. Water is diverted most heavily in the spring runoff period, because this is when it is available and efficiently diverted. Finally, the refuge curtails irrigation around the 3rd week of July to dry some fields and meadows for haying, which reduces the amount of consumptive use and ET from much of the irrigated area on the refuge.

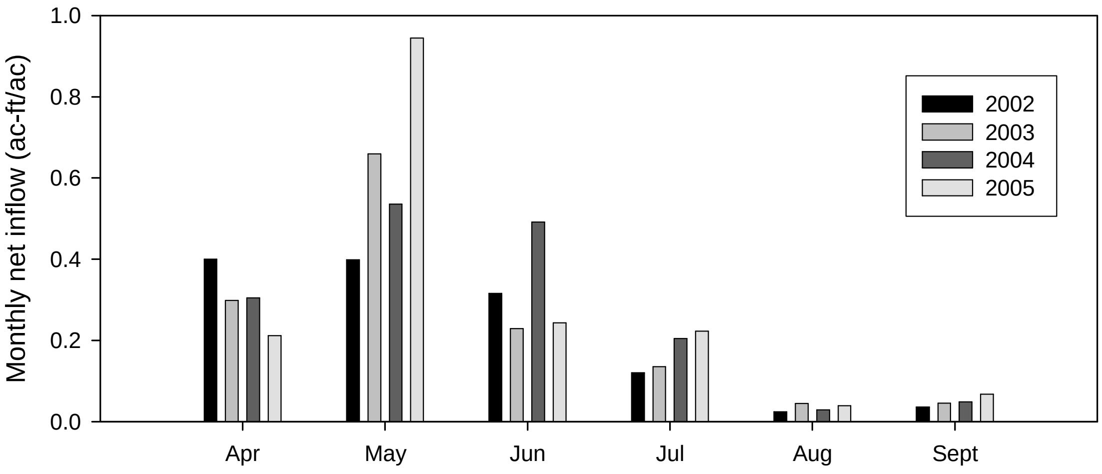


Figure 2. Monthly net inflow for Blitzen Valley, 2002 to 2005.

Table 1. Runoff, precipitation, inflow, outflow and consumptive use rates for the entire Blitzen Valley area of the refuge, 2002 to 2005
Units are acre-feet unless otherwise indicated.

Year	*2002*	*2003*	*2004*	*2005*
Apr-Sept runoff percentile	30%	40%	29%	75%
Apr-Sept pcp (in)	2.1	4.2	3.6	6.5
Apr-Sept inflow	66754	84167	75196	117709
Apr-Sept outflow	19837	32999	16758	55082
Apr-Sept net inflow	46917	51168	58437	62628
Apr-Sept CU rate (ac-ft/ac)	1.3	1.5	1.7	1.8
Oct-Sept runoff percentile	24%	30%	41%	58%
Oct-Sept pcp (in)	6.8	7.8	9.4	12.6
Oct-Sept inflow	96312	108921	113980	142994
Oct-Sept outflow	50499	55114	46412	78069
Oct-Sept net inflow	45863	53807	67569	64926
Oct-Sept CU rate (ac-ft/ac)	1.3	1.5	1.9	1.9

FRENCHGLEN AND BUENA VISTA AREA

The next water budget we developed is for the Frenchglen and Buena Vista area, a smaller subset of the lands described above (Figure 1). It includes all irrigated lands north of Page Springs and south of Stubblefield Canal, excluding the Diamond Valley refuge lands east of the Blitzen River.

Methods

Total inflow for this area is based on the information submitted in the 2002 through 2005 annual Oregon Water Use Reports for Malheur NWR. We calculate the total inflow to this area as the sum of three sites noted above: USGS Blitzen gage plus estimated Page Springs inflow upstream of Page Springs Dam; Bridge Creek above East Canal; and the total outflow from Krumbo reservoir. WRB measures the total outflow from the area as Blitzen River flow below Grain Camp Dam. This site is not reported to the state under the current Malheur measurement plan. The winter record is not complete for this site, so only the Apr-Sept period is considered here.

We present Apr-Sept percentile rank and Apr-Sept total precipitation at Burns, Oregon, as a general indication of how wet or dry the year was. As above, the acreage estimates are based on CWRE mapping of irrigated acreage and the Ponds Bill certificates. The difference between total inflow and outflow is the estimated net inflow for this area. Inflow and outflow for this area are not completely captured by these measurements. Additional inflow to the area occurs through direct precipitation, through the Stubblefield Canal, which irrigates a small portion of the lands (500 to 1000 ac) within the Buena Vista area, and through other unmeasured sources. Additional outflow occurs through a return flow pipe at the corner of Center Patrol Road and Buena Vista Road downstream of the gage below Grain Camp Dam, through East Grain Camp Canal, and other unmeasured losses. We express net inflow as a consumptive use rate, defined as discussed above.

Results

The total irrigated area in the Frenchglen and Buena Vista Area is about 22,000 acres. This includes as much as 5,300 acres (24%) of open water ponds and wetlands. The estimated open water pond/wetland area is likely high for the same reasons as discussed above. The estimated consumptive use for this area ranges from 0.9 to 1.4 acre-ft/acre for the Apr-Sept period (Table 2). Consumptive use estimates for this area appear to be fairly consistent and similar to those for the entire Blitzen Valley, with the exception of 2005. The lower rate in 2005 may have been due to the cool, wet spring that occurred that year. There was likely a considerable precipitation and runoff input to the area during that year that was not accounted for with the inflow measurements. As with the consumptive use estimates above for the entire Blitzen Valley, these are gross estimates that may not apply to all individual lands and habitats.

Table 2. Runoff, precipitation, inflow, outflow and consumptive use rates for the entire Frenchglen and Buena Vista area of the refuge, 2002 to 2005.
Units are acre-feet unless otherwise indicated.

Year	*2002*	*2003*	*2004*	*2005*
Apr-Sept runoff percentile	30%	40%	29%	75%
Apr-Sept pcp (in)	2.1	4.2	3.6	6.5
Apr-Sept inflow	60334	70429	61816	85526
Apr-Sept outflow	32142	42846	33217	68154
Apr-Sept net inflow	28192	27583	28599	17372
Apr-Sept CU rate (ac-ft/ac)	1.4	1.4	1.4	0.9

WESTSIDE P RANCH AREA

This water budget is based on flow measurements we collected in 2002 as part of this study. The area is defined as all irrigated lands on the refuge south of 5-Mile Road, bounded to the south and west by West Canal and to the north and east by the Blitzen River (Figure 3).

Methods

We calculate the total inflow into the area as the sum of flows at West Canal at Page Springs; Highline Flume where it crosses the Blitzen River; and diversions at New Buckaroo and Old Buckaroo Dams. We calculate the total outflow from this area as the sum of flows at West Canal at 5-Mile Road; the diversion from Faye Pond into Jones Field at 5-Mile Road; and the return flow channel from Faye Pond that empties into the Blitzen River just upstream of 5-Mile Bridge. We monitored all of these sites from March through August of 2002, either continuously with Sigma flow meters or periodically with current meters. Sites that were monitored continuously were checked with independent measurements. For periodic flow measurements, we interpolated flows to get a daily record. We summed all daily inflows and outflows by month and only the monthly flows are presented here.

As above, the acreage estimates are based on the irrigated acreage and Ponds Bill certificates provided by our CWREs. There are three open water ponds in this area, Darnell Pond, Baker Pond, and Faye/5-Mile Pond. Faye/5-Mile Pond is south of and adjacent to 5-Mile Road. We monitored water levels in this pond by collecting readings of the staff gage.

Results

The total irrigated acreage in this area, including open water ponds/wetlands, is about 4,000 acres, based on the 1994 and 2005 aerial photography. There is as much as 220 acres, or 5%, of the total area in open water ponds and wetlands. This is a smaller proportion of open water area than for the entire Blitzen Valley. Moreover, the largest pond, Darnell Pond (109 acres), was dry in 2002. The consumptive use rate for the area was 1.5 acre-ft/acre, similar to the range for the entire Blitzen Valley. Most diversions occurred in April through June, during the spring runoff when flows are high and water is available to divert (Table 3 and Figure 4). Very little water was diverted after July and net inflow was actually slightly negative in August. A negative net inflow means that outflow was slightly greater than inflow for the period.

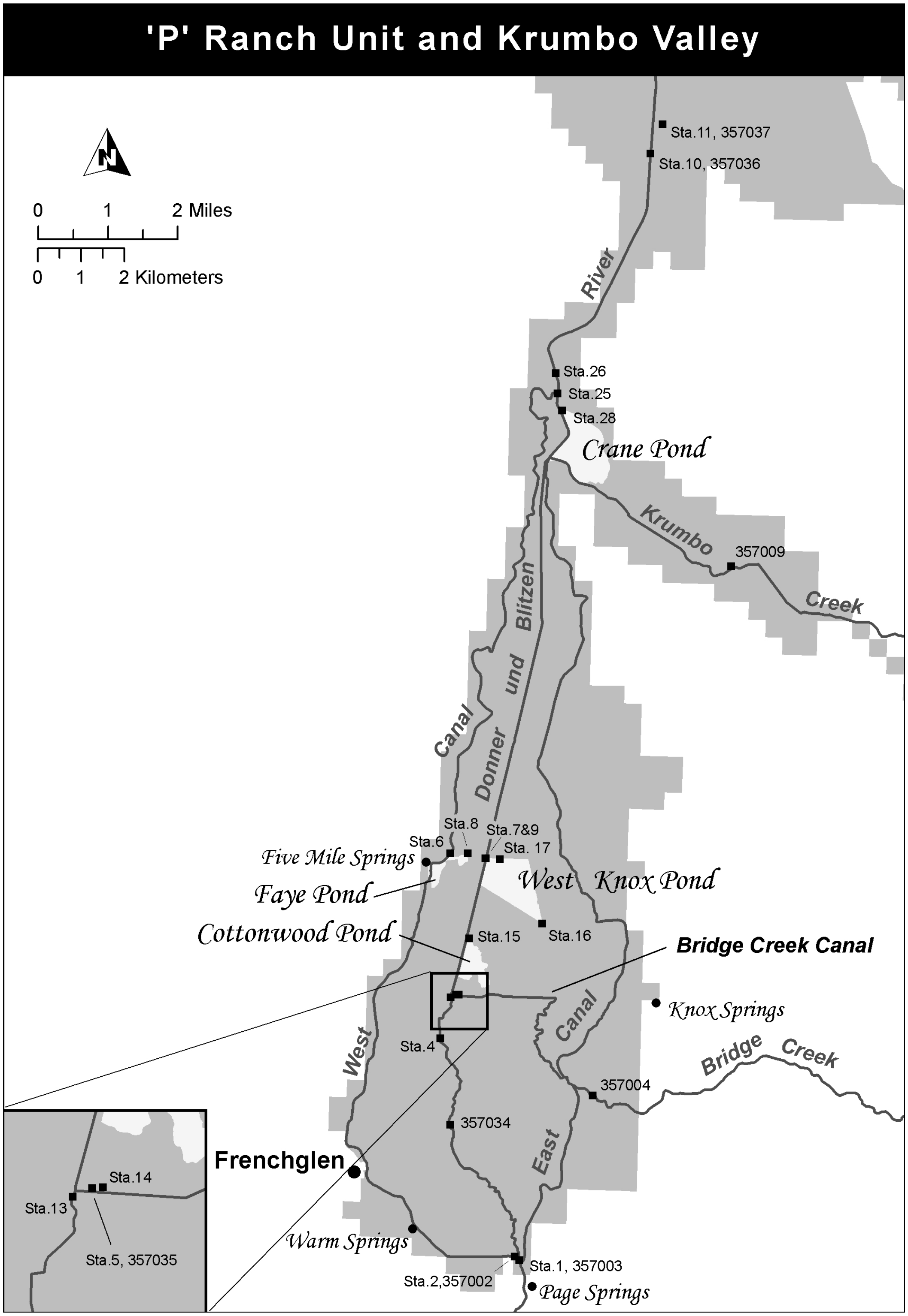


Figure 3. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

Table 3. Inflows and outflows for Westside P Ranch Area, 2002.
Units are acre-feet unless otherwise indicated.

	Mar	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Total*
W Canal at Page Sprs	462	2178	1698	1614	872	323	7147
Highline Flume	0	536	592	439	0	0	1568
New Buckaroo	208	1605	2050	1612	748	110	6334
Total Inflow	**670**	**4320**	**4340**	**3666**	**1620**	**433**	**15049**
Faye P return flow	0	71	682	351	135	135	1372
Jones Field diversion	33	842	1790	1494	802	19	4981
W Canal at 5-Mile Rd	286	585	512	354	432	564	2733
Total Outflow	**319**	**1497**	**2984**	**2199**	**1369**	**718**	**9087**
Net Inflow	**351**	**2822**	**1356**	**1466**	**251**	**-285**	**5962**
CU Rate (ac-ft/ac)	**0.09**	**0.71**	**0.34**	**0.37**	**0.06**	**-0.07**	**1.5**

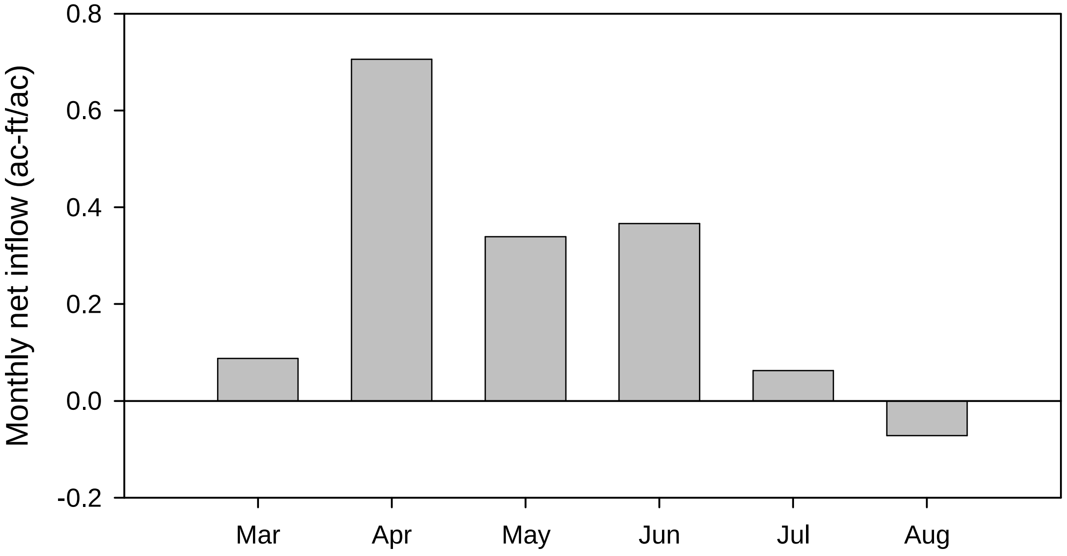


Figure 4. Monthly net inflow for Westside P Ranch, 2002 to 2005.

KRUMBO VALLEY

This water budget is for the area that includes all irrigated lands within the Krumbo Valley, downstream of the Krumbo reservoir and east of the Blitzen River (Figure 3). The refuge stores water in the reservoir and uses it as needed downstream to irrigate lands in the Krumbo Valley.

Methods

Total inflow for this area is based on the information submitted in the 2002 through 2005 annual Oregon Water Use Reports for Malheur NWR. WRB measures total inflow to the area using the flow at the Krumbo flume, located in the outlet channel downstream of the Krumbo reservoir. Total outflow from the area is not measured but is reasonably assumed to be zero. According to the refuge staff, flows are managed so that in most years, there is little or no outflow from the irrigated area. The exception is during years of really high spring runoff. The consequence of us underestimating outflow from the area would be an overestimate of consumptive use. We consider two periods: Mar-Sept and the Oct-Sept water year. We measured pond levels in Crane Pond in 2003 as part of this study, but they are not regularly monitored.

Results

The total irrigated area in Krumbo Valley is about 920 acres, based on the CWRE mapping and the 2005 aerial photography. There is a maximum of 400 acres, or 43%, open water ponds and wetlands (Crane Pond, at 335 acres, is the main pond in the area). This is a higher proportion of open water to irrigated land than in other areas. The consumptive use rate ranges from 1.3 to 1.7 acre-ft/acre for Mar-Sept and 1.6 to 2.8 acre-ft/acre for the water year (Table 4). The Mar-Sept rates are about equal to the average rates estimated for the entire Blitzen Valley, but the rates during the water year are higher. If outflow is underestimated, as discussed above, the rates may be overestimated.

Considering the greater proportion of open water/emergent wetland areas in Krumbo Valley, it is surprising that the Mar-Sept water use is not higher than rates for the entire Blitzen Valley. The reason for this may be that part of the water used to meet ET during the Mar-Sept season probably comes from water stored in the valley wetlands, both during and outside of the irrigation season. In 2003, pond levels in Crane Pond decreased by more than 2.25 feet from mid-April to early July. A decrease of this magnitude represents a considerable volume of water, given a surface area of 335 acres, and means much of the summer ET demand at Crane Pond was met through water stored in the pond. This suggests that the 1.6 acre-ft/acre of net inflow for the valley in 2003 was not adequate to sustain the pond levels and meet the total ET demand of the area.

The greater extent of open water/emergent vegetation wetlands in this area as compared to the entire Blitzen Valley is a function of the storage capacity upstream in Krumbo reservoir. Water is available longer in the summer to maintain wetlands and open water areas. Because of this ability to store water, the timing of monthly flows is later than in other areas (Figure 5). Peak monthly net inflow is in June and July, which coincides more with actual ET demand.

Table 4. Inflow and consumptive use rates for Krumbo Valley, 2002 to 2005
Units in acre-feet unless otherwise indicated.

Year	*2002*	*2003*	*2004*	*2005*
Mar-Sept inflow	1567	1484	1165	1220
Mar-Sept CU rate (ac-ft/ac)	1.7	1.6	1.3	1.3
Oct-Sept inflow	2571	2030	1498	1535
Oct-Sept CU rate (ac-ft/ac)	2.8	2.2	1.6	1.7

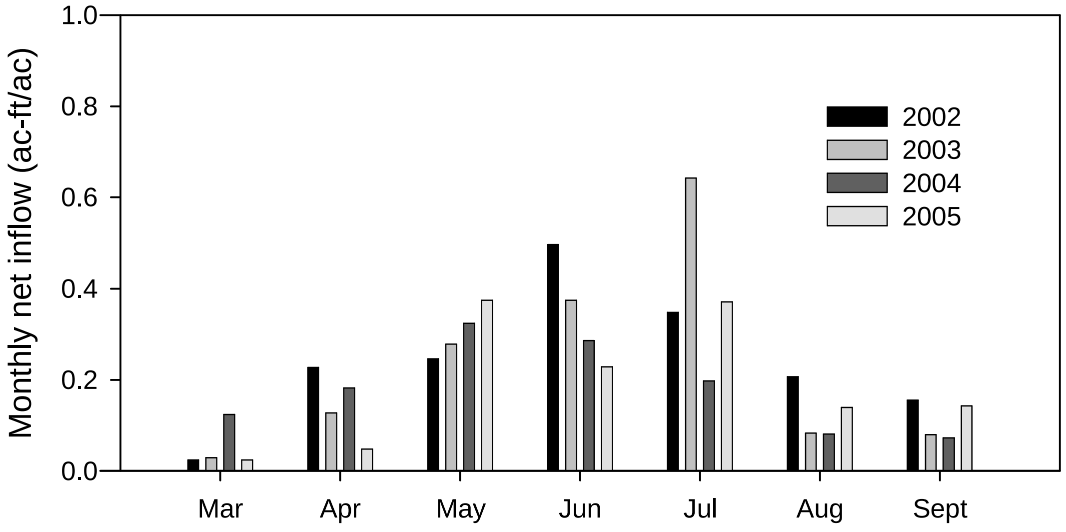


Figure 5. Monthly net inflow for Krumbo Valley, 2002 to 2005.

COTTONWOOD POND (SEASONAL WETLAND)

In contrast to the previous four water budgets, this water budget is for one individual wetland rather than an area combining wetlands, wet meadows and fields. Cottonwood Pond is located on the east side of the Frenchglen area, adjacent to the Blitzen River (Figure 3). It was managed as a spring seasonal wetland in 2002 and 2003. The refuge flooded the wetland in spring and allowed it to drain or evaporate by summer.

Methods

We measured pond levels, inflow, and outflow as part of this study in both 2002 and 2003. We measured inflow using a Marsh McBirney Flo-Tote that recorded depth and velocity continuously at 15-min intervals. We recorded pond levels periodically using a staff gage in the pond. For this study, we outfitted the top board in the flash board outflow structure with a thin metal plate to function as a sharp-crested weir. We collected measurements of head at the outlet structure with a Water Stik and applied a weir equation to estimate surface outflows. In 2002, there was surface outflow over the flash board structure from Apr 26 to May 20, 2002. Because the pond level was fairly constant in that interval, there was little variation in outflow. We interpolated between periodic measurements to estimate the total outflow. In 2003, the pond level was lower than in 2002 and the water level never reached the top of the flash boards at the outflow. There was zero surface outflow that year. We mapped the perimeter of the water surface contour with a GPS on May 1, 2002 at a staff gage level of 1.94. The perimeters of two small islands within the pond were also mapped. We calculated the surface area of the wetland using this GPS information.

Results

We determined that about 100 acres of the 160-acre unit is inundated at flood-up. This is equivalent to the estimated area of the pond, 102 acres, based on the Ponds Bill certificate.

When a seasonal wetland is flooded, water is used to inundate the wetland, saturate the underlying soil, and meet ET demand (Mayer, 2004). We consider all of this water in the consumptive use estimate here although, in actuality, not all of this water is necessarily used "consumptively." Additionally, the proportion of water used for these different components varies with the time of year that the wetland is filled. In this wetland, ground water depths at the time of flood-up were about the same in both years so it is likely that the volume of water needed to saturate the underlying soils did not vary between the two years. However, ET losses in this pond were likely much different because the timing of flood-up varied in the two years.

Figure 6 and Table 1 present the results of the monitoring. In 2002, the unit was flooded from the middle of April to the beginning of July. In 2003, the unit was flooded from the end of May through the end of August. The average rate of inflow to the wetland was 7.0 acre-ft/day in 2002 and 3.8 acre-ft/day in 2003. There was total net inflow of 204 acre-ft in 2002 and 342 acre-ft in 2003. The consumptive use rate was 2.0 acre-ft/acre in 2002 and 3.4 acre-ft/acre in 2003. More water was required to fill and maintain the unit in 2003 and the pond levels were actually lower than in 2002. This is probably because the unit was flooded later, during the summer rather than in the spring, and at a slower inflow rate than in 2002. The evaporative loss is much higher in summer than in spring and it appears that the slower inflow rate in 2003 could not keep up with the greater ET demand in the summer. This can be seen in the 2003 water levels, which were dropping throughout the summer even while there was inflow. In 2002, by contrast, the pond remained inundated for at least a month after inflow ceased in May.

The 2003 consumptive use rate for this pond is much higher than the average rates described above for the entire Blitzen Valley or the other smaller areas examined. Those average rates reflect the consumptive use requirements of all habitats on the refuge and, in general, there are few seasonal wetlands that are flooded in late spring and maintained through the summer. Most of the habitat in the Blitzen Valley is wet meadows and fields. The 2003 rate for Cottonwood Pond is similar to the rates reported for fall seasonal wetlands at Lower Klamath NWR (Mayer, 2004). In general, flooding seasonal wetlands in the late spring and summer will likely require more water than other habitats. Levels in seasonal or permanent wetlands in the summer will decrease rather quickly should the inflow be reduced or stopped at any time.

Table 5. Water Budget for Cottonwood Pond for 2002 and 2003. Units are acre-feet unless otherwise indicated.

Water Budget Component	**2002**	**2003**
Dates of flooding	4/15 to 7/1	5/27 to 8/25
Total inflow	225	342
Total outflow	31	0
Total net inflow	**194**	**342**
Estimated CU rate (ac-ft/ac)	**1.9**	**3.4**

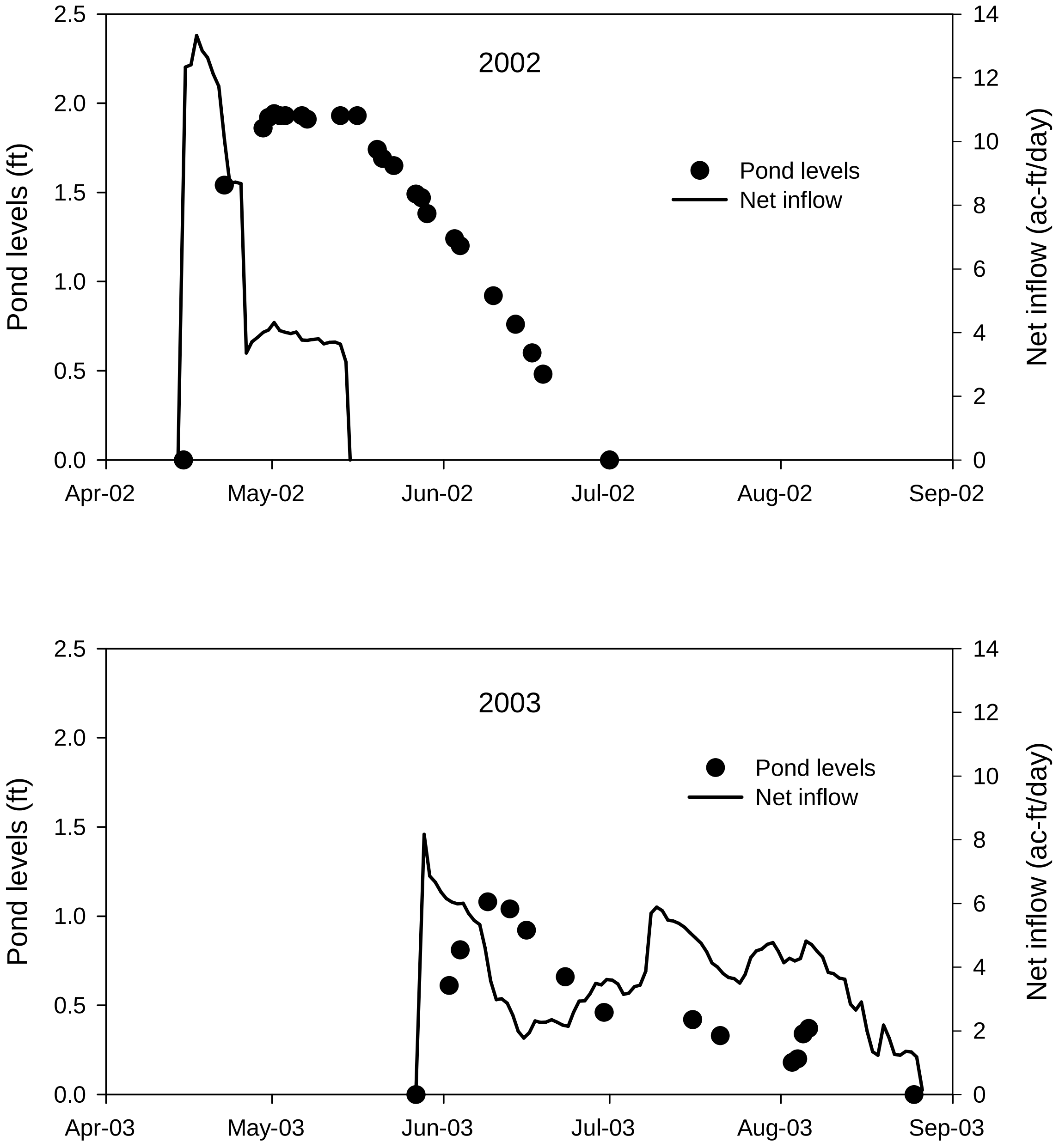


Figure 6. Pond levels and net inflow for Cottonwood Pond in 2002 and 2003.

WEST KNOX POND (PERMANENT WETLAND)

This water budget is also for an individual wetland, West Knox Pond, located on the east side of the Frenchglen area, adjacent to the Blitzen River and north of Cottonwood Pond (Figure 3). The refuge managed the area as a permanently flooded wetland in 2002 and 2003. The water budget for this area is more detailed than in the other areas because we tracked precipitation and changes in storage in the wetland in addition to measuring surface inflows and outflows. We used a water budget equation to estimate ET at the wetland. The water budget equation, formulated in simplified terms, describes the change in water stored in a water body over some period (ΔV) as the total inflow minus the total outflow (ΔV = total inflow – total outflow). For West Knox Pond, assuming no significant ground water inputs or losses, the total inflow includes surface water inflows and precipitation and the total outflow includes surface water outflows and ET. The water level in West Knox Pond indicates the change in storage. By measuring total inflows, total outflows, and changes in storage, one can solve the water balance to estimate ET losses from the pond.

Methods

We measured pond levels, inflows, and outflows for the period May 1 to September 30 in 2002 and 2003 as part of this study. We measured pond levels with a staff gage that was installed in the pond in May 2002. We recorded staff gage heights approximately every week in 2002 and then estimated daily pond levels by interpolating between observations. In 2003, we installed a Global Water pressure transducer and datalogger to record pond levels hourly. We averaged these hourly readings for daily means.

We developed a capacity curve for the pond to determine changes in storage in the pond. We mapped the perimeter of the pond's edge with a GPS at two water surface elevations spanning the range of pond levels. We determined the surface area of the pond at each mapped water level and developed a stage-area relationship, which allowed us to determine the wetted area of the pond for any given water level in the pond. We also developed a stage-volume relationship as well, by interpolating the underlying slope related to the area change (Mayer, 2004), which allowed us to determine changes in volume with elevation.

Total inflow to West Knox Pond includes diversions and precipitation; we assumed both ground water flow and overland flow were negligible. The source of surface water for West Knox Pond, Bridge Creek, is diverted through the K-2 Canal. In 2002, we monitored depth and velocity continuously at the inflow at hourly intervals from Jun-21 to Sept-6, using a Sigma flow meter. We collected independent flow measurements periodically as a check on the automated equipment. We calculated average daily inflow using the hourly data. Prior to Jun-21, daily inflows were estimated by interpolating between periodic flow measurements. In 2003, we made independent inflow measurements almost weekly from 21-Apr to 30-September. We estimated total surface inflow by interpolating between the twenty independent flow measurements.

We determined the precipitation input to West Knox Pond by multiplying daily precipitation totals recorded at P-Ranch (station ID: 6853) by the area of the pond. Missing days were estimated, based on observations at nearby weather stations using the normal-ratio method (Dingman, 2002). The nearby stations included OO-Ranch (station ID: 6302), Malheur refuge headquarters (station ID: 5162), Fields (station ID: 2876), and Burns Municipal Airport (station ID: 1175).

The refuge regulates the pond level and surface water outflow by manipulating boards in a flash board structure at the north end of the pond. For this study, we outfitted the top board in the structure with a thin metal plate to function as a sharp-crested weir. We applied a weir equation to estimate surface outflows using the continuous record of pond level that we developed. We collected periodic measurements of head at the weir with a Water Stik, as an independent check on outflow estimates.

The remaining terms not accounted for in the water balance equation are seepage and ET losses. Groundwater seepage out of the pond would be expected if the hydraulic gradient between the pond and the groundwater was downward toward groundwater. However, a standpipe piezometer installed in the west end of West Knox Pond, adjacent to the river, indicated a small hydraulic gradient (<0.07 ft/ft) into the pond. This was unexpected since the water surface elevation of the pond is higher than the water surface elevation of the adjacent river. However, several periodic flow measurements we collected concurrently in the river upstream and downstream of the pond (Station 13 and Station 9) indicated little or no seepage gain from the pond as well. Therefore, seepage loss from the pond was assumed to be negligible and all losses were assumed to be from ET. By designating total outflow as surface outflow from the pond plus ET, and accounting for changes in storage, the water-balance equation can be rearranged to solve for ET (ET = total inflow – surface water outflow – ΔV). To the extent that there is groundwater seepage into or out of the pond, we would underestimate or overestimate ET.

ET estimates at West Knox Pond based on measurements were compared with theoretical calculations of potential ET rates. The purpose was to identify a theoretical ET method that could be used to examine the variability of ET over a longer period and to compare the 2002 and 2003 estimates with the range of estimates. A number of methods are available for estimating ET (Rosenberry et al., 2004) differing in terms of their input data requirements and time periods over which they are calculated (e.g. daily, weekly, monthly, etc.). Some methods require only air temperature, while others require measurement of numerous hydrological and/or meteorological conditions. The choice of any particular method is often limited by the availability of input data at a specific site. Rosenberry et al. (2004) reported that even some of the less rigorous methods give reasonable estimates of ET

Of the thirteen techniques compared by Rosenberry et al. (2004), the only methods applicable for estimates at West Knox Pond are those that use air temperature or both air temperature and incoming solar radiation as inputs, because these are the only data available West Knox Pond. A preliminary investigation of those methods at West Knox Pond revealed that the Jensen-Haise method compared best with the water-balance ET estimates in 2002 and 2003. Rosenberry et al. (2004) reported that this method is among the more favorable techniques when compared to energy-budget measurements of ET.

The Jensen-Haise method requires air temperature and incoming solar radiation as input data. We used mean daily air temperatures recorded at P-Ranch (station ID: 6853). We found air temperatures at Burns Municipal Airport (station ID: 1175) to be very similar to those measured at P-Ranch between the months of May and October and we used these to replace missing values at P-Ranch (70% missing in 2002 and 20% in 2003). Total daily incoming solar radiation is recorded at the Eastern Oregon Agricultural Research Center in Burns, Oregon. We computed a daily average by dividing the total incoming solar radiation for the day by the number of sunlight hours. We calculated total hours of sunlight for each day using methods outlined in Dingman (2002) with information specific to the latitude of West Knox Pond. We estimated the total May through September ET at West Knox Pond for a 25-year period of record (1979 to 2003) using the Jensen-Haise equation.

Results

Figure 7 is a map of the surface area of the pond at two water levels: 1.84 ft and 2.41 ft on the staff gage. These two water levels span the range of normal operating water levels at the pond. Surface areas are 207 acres and 226 acres at the two water levels, respectively. There is little increase in surface area at the higher water level; relatively steep levees on three sides retain water. The total area of the wetland unit is about 300 acres.

Figure 8 shows the pond levels and net inflow over time for both years. Pond levels were highest in the spring and lower in the summer and fall. The range of pond levels was about 0.7 feet in both years. Pond levels were about 0.2 feet lower in 2002 compared with 2003. The pond level is regulated through flash boards at the outlet and the difference between years resulted from setting the crest of the boards at a lower elevation in 2002. The lower board height in 2002 also resulted in continuous surface outflow for the entire period. In contrast, there was only a limited period with surface outflow over the flash boards in 2003.

We estimated the decrease in storage over the season at 119 acre-ft in 2002 and 123 acre-ft in 2003 (Table 6). Pond surface area was slightly smaller in 2002 as well, due to the lower levels. The range of surface area was 206 to 230 acres in 2002 and 212 to 235 acres in 2003. The surface area is not very sensitive to changes in water level at the range of pond levels observed during these two years.

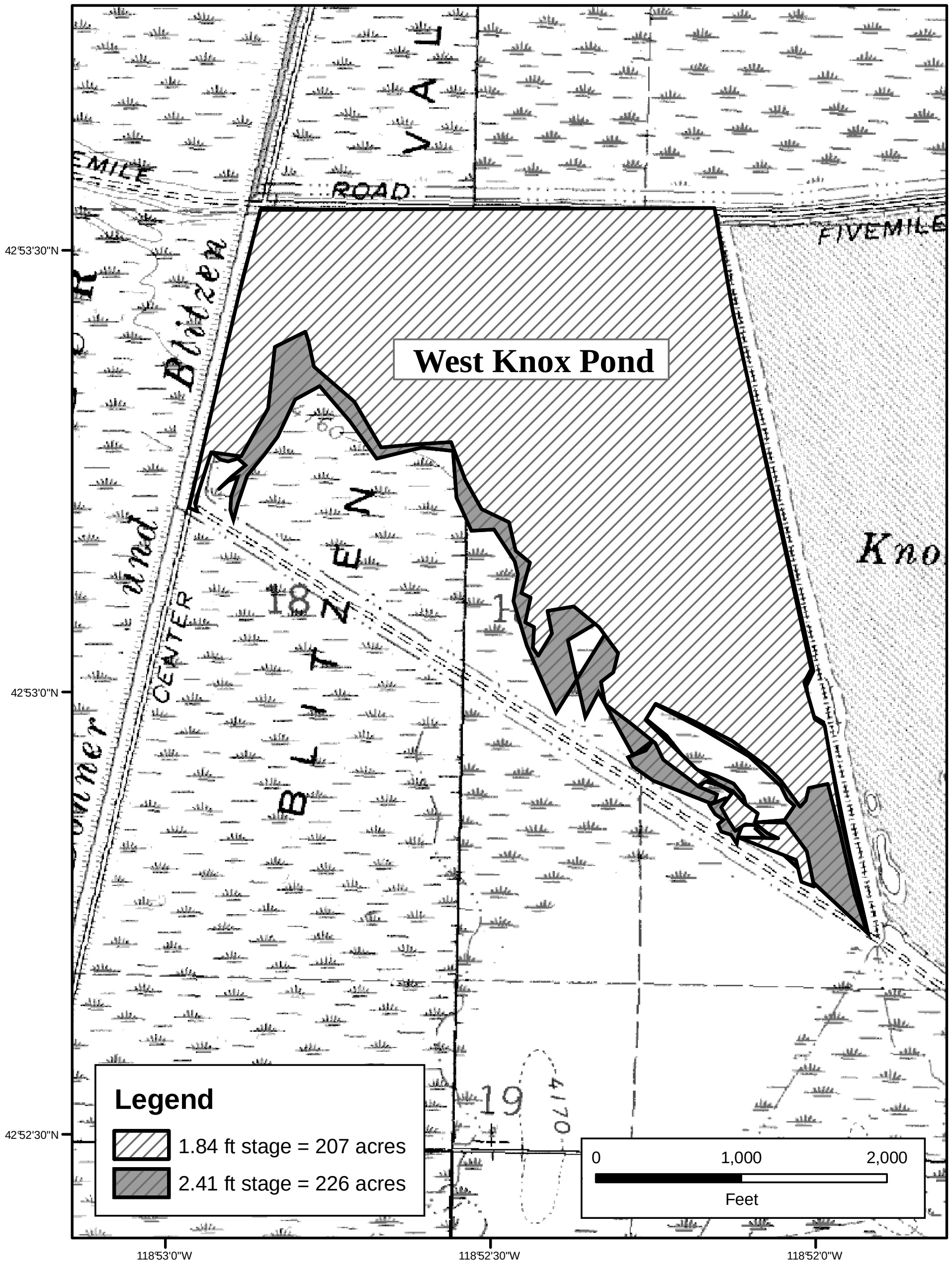


Figure 7. Surface area of West Knox Pond at staff gage levels of 1.84 ft (207 acres) and 2.41 ft (226 acres).

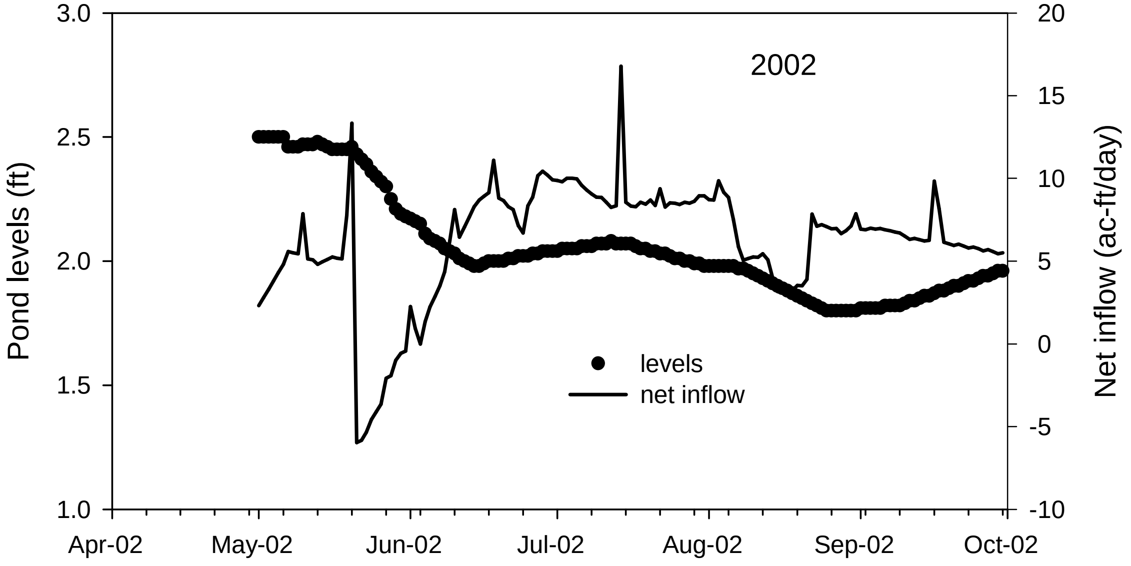
Daily surface inflows averaged 9.9 acre-ft/day in 2002 and 5.4 acre-ft/day in 2003. The volume of total inflow (surface inflow and precipitation) for the May through September period was 1556 acre-ft in 2002 and 888 acre-ft in 2003 (Table 6). The smaller rate and volume of inflow in 2003 probably resulted from adjustments in the diversion structure at Bridge Creek. Total precipitation in 2002 was 43 acre-ft (Table 1) or < 3% of the total inflow for the period. In 2003, precipitation totaled 62 acre-ft, or 7% of the total inflow for the period.

As discussed above, we assume that outflow from the pond is primarily through surface water flows and ET. Water levels remained above the height of the weir crest at the outflow structure for the entire period in 2002, in part because the flash boards were set at a lower elevation in 2002. In 2003, the water level of the pond receded below the height of the weir crest for several months, resulting in zero outflow from July through the September, primarily because the flash boards were set higher. Total volume of surface outflow was 614 acre-ft in 2002 and 128 acre-ft in 2003 (Table 6). Net inflow (total inflow minus outflow) was 942 acre-ft in 2002 and 760 acre-ft in 2003. We summed net inflow plus changes in storage to provide estimated consumptive use or ET in West Knox Pond for both years.

Figure 9 presents monthly ET at West Knox Pond (ET_{wb}) for the May through September period in 2002 and 2003. For both periods, ET shows the expected seasonal trend; lower in the spring and fall with a maximum in July. The estimated total ET requirement for the season was 1061 acre-ft, or 5.0 acre-ft/acre, in 2002 and 883 acre-ft, or 4.0 acre-ft/acre, in 2003 (Table 6). However, we believe that improved information on pond levels, pond volume, and surface outflows in 2003 allowed for a more accurate estimate of ET in our results and we have more confidence in the 2003 ET value of 4.0 acre-ft/acre. The estimated ET losses are considerably greater than surface outflows, especially in 2003. This implies that most of the water requirement for the pond is used to meet ET demand.

Table 6: Water Budget for West Knox Pond for 2002 and 2003. Units are acre-feet unless otherwise indicated.

Water Budget Component	**May-Sept 2002**	**May-Sept 2003**
Total surface inflow	1513	826
Precipitation input	43	62
Total Inflow	**1556**	**888**
Total Surface Outflow	**614**	**128**
Change in Storage	**119**	**123**
Residual	1061	883
Estimated ET Rate (ac-ft/ac)	**5.0**	**4.0**



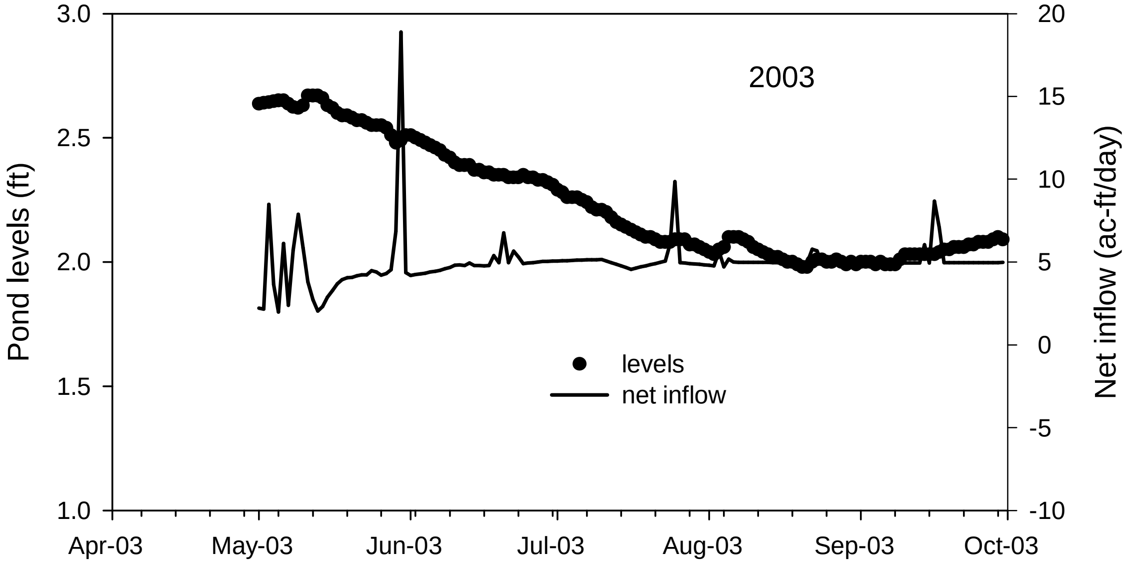


Figure 8: West Knox Pond levels and net inflow in 2002 (top) and 2003 (bottom).

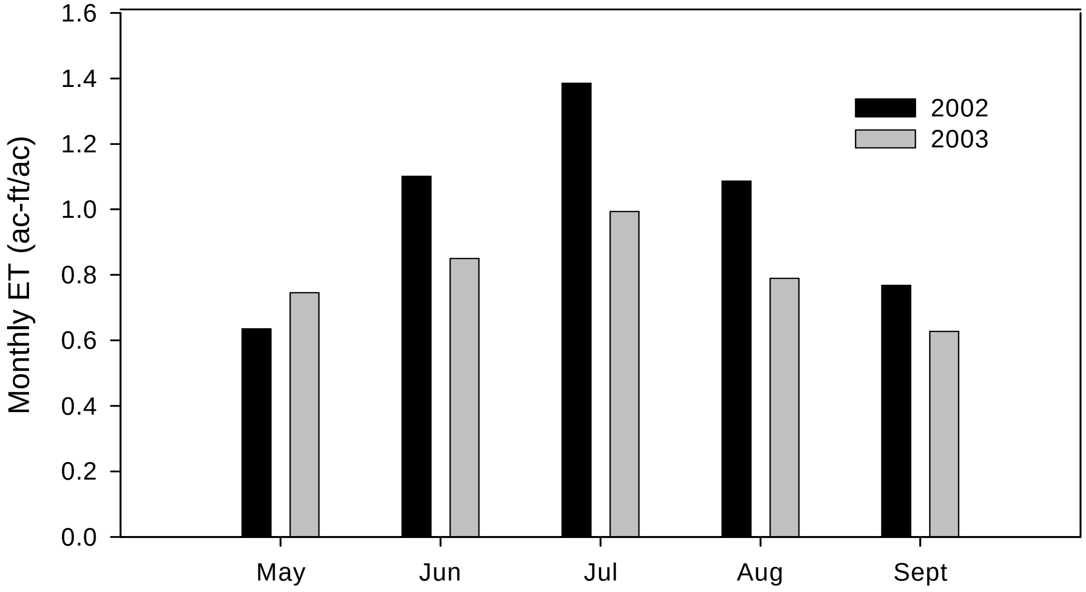


Figure 9: West Knox Pond monthly ET requirement in 2002 and 2003.

Measurements of ET from open water and bulrush marsh at Ruby Lake NWR in northeastern Nevada totaled 3.4 acre-ft/acre and 3.1 acre-ft/acre, respectively, for the May through September period in 2000 (Berger et al., 2001). The elevation of the valley floor at Ruby Lake NWR is about 6,000 ft, two thousand feet higher than Malheur NWR and this may be one reason for the higher ET rates at Malheur NWR. Dunne and Leopold (1996) report annual Class A pan evaporation rates of 4.5 to 5 feet in the area of Malheur NWR. Evaporation in natural water bodies is usually only 70 to 75% of Class A pan evaporation but the authors state that it can be as high as 90% or more in a shallow water body. The estimated evaporation rate derived using pan evaporation and pan coefficients in the 80-90% range is comparable to the 2003 ET rate estimated in the water budget. Higher pan coefficients may apply at West Knox Pond and other shallow, open water bodies at Malheur NWR.

Using the Jensen-Haise method, we estimated an ET rate for the May through September period of 4.1 acre-ft/acre in 2002 and 4.5 acre-ft/acre in 2003. The theoretical potential ET is less than our 2002 estimate and greater than our 2003 estimate. Over the 25-year period, the total May – Sept Jensen-Haise ET requirement ranged from a minimum of 3.3 ft in 1979 to a maximum of 4.5 ft in 2003 with a mean and median value of 3.8 ft. The interquartile range (25th to 75th percentile) for the 25-year record of Jensen-Haise ET is 3.6 to 3.9 ft.

For the 25-year period, the May-Sept Jensen-Haise predicted ET loss was the fourth highest in 2002 and the maximum in 2003. This is because of the high air temperature and solar radiation during those two years. The average July air temperature for 2002 and 2003 were warmer than 25-year average July air temperatures. Average May-Sept air temperatures were normal in 2002 and were the highest on record in 2003. A similar pattern exists for average monthly incoming solar radiation, which is expected because air temperatures are a thermal response to solar heating. Average May–Sept incoming solar radiation in 2003 and 2002 were the second and third highest on record.

SUMMARY

The Blitzen Valley has about 36,000 acres of irrigated area, including as much as 6,500 acres of open water ponds and wetlands. Aggregate consumptive use rates for the entire Blitzen Valley are between 1.3 and 1.7 acre-ft/acre for the irrigation season. Smaller areas within the Blitzen Valley generally have similar consumptive use rates. Actual irrigation diversion requirements might be somewhat higher than this because not all of the water diverted is used consumptively. The consumptive use rates are based on historical diversion, which are limited by water availability, refuge management, infrastructure constraints, and instream flow requirements. Diversions are greatest during the spring runoff period and are much reduced after July, when some fields are dried for haying and grazing. Seasonal and permanent wetlands that are maintained throughout the summer can have much higher consumptive use rates (as high as 4.0 acre-ft/acre or more) but the proportion of land in this kind of habitat in the Blitzen Valley is fairly small – less than 20%. One exception is in Krumbo Valley, where the ability to store and later divert water allows for a higher proportion of summer wetlands and ponds.

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Blitzen River Water Temperature Monitoring

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INTRODUCTION

Water temperature is one of the most important factors influencing the health of fish and other aquatic organisms (Coutant, 1976). The body temperature of fish fluctuates in response to the temperature of the aquatic medium in which they live. As a result, almost every response of fish, from spawning, feeding activity, and digestive and metabolic processes to distribution and survival is dictated by the thermal range of their immediate environment. Temperature can act as a lethal or stressing factor that ultimately kills fish; as a controlling factor that regulates growth and metabolism of fish; or as a limiting factor restricting activity and distribution of fish.

Great Basin redband trout appear to have adapted to function at warmer water temperatures than other trout (USFWS, 2000). Sustained temperatures greater than 21˚C are thought to be harmful, although redband trout are able to survive temperatures as high as 28˚C and fluctuations of as much as 20˚C over a 24-hour period (USFWS, 2000). The State of Oregon water quality standards states that the “seven-day-average maximum water temperature for streams identified as having redband trout use must not exceed 20.0º C ” (ODEQ, 2007).

Water temperature in a given river reach is a function of the interaction of river conditions (channel width and degree of incision, riparian shading), hydrologic factors (stream discharge, tributary inflow, subsurface inflow), and meteorological variables (air temperature, relative humidity, solar radiation) (Bartholow, 1989). Refuge management practices can potentially affect many of these factors. Grazing practices, chemical treatment of invasive/noxious weeds, dredging, diking, channel straightening and other management actions can reduce riparian vegetation and shading. These actions may also affect the physical conditions of the stream channel by increasing width-to-depth ratios and channel incision. An incised stream channel may lower the groundwater table, reducing available water for riparian vegetation and changing subsurface hydrology. Irrigation diversions can reduce stream discharge. Irrigation and wetland return flows may be warmer than ambient river temperatures and can cause warming.

One purpose of this monitoring was to better understand the relationship between stream temperatures and water management on the refuge. A second purpose was to monitor compliance with state temperature standards established for waters in the Malheur Lake Basin. A third purpose of this work was to develop a temperature model of the system that could be used to examine the impact of various refuge management practices on river temperatures, including reduced river flows due to irrigation diversions; impounded river waters from diversion dams; irrigation return flows from wetlands and hayfields; and changes in riparian vegetation. The objective was to investigate the effectiveness of different management alternatives to improve river temperatures.

Stream Morphology and Restoration

The Blitzen River crosses the southern boundary of the refuge near Frenchglen, Oregon, where it exits from a narrow, confining canyon to a wide, flat valley (Figure 1). The river elevation gradient decreases from about 30 ft/mile in the canyon to about 12 ft/mile in the valley. Several decades of cattle grazing, removal of willows and other riparian vegetation, irrigation diversions, and channelization, have resulted in a severely degraded river and riparian system within the refuge (Landston, 2003). For the first five miles on the refuge, until the confluence with Bridge Creek, the river maintains a pool and riffle system with natural sinuosity. The river flows in what is probably a historic channel. According to an analysis by Sampson (2002), prior to 2002, this river reach was limited by a lack of bed formations, diverse depositional environments, cross-section variability, and woody vegetation abundance. The river was severely entrenched through this section and did not spill onto the floodplain, even at the flow of record (Sampson, 2002). Several irrigation diversion dams back up the river to supply water for adjacent meadows and wetlands: Page Springs Dam at the refuge boundary, New Buckaroo dam 2.5 mi downstream and Old Buckaroo Dam 2.9 mi downstream.

In the fall of 2002, restoration work was completed in the reach between Page Springs Dam and Bridge Creek (Sampson, 2002). This work included riparian vegetation planting, establishment of root wad revetments, and construction of rock weirs across the river. The FWS constructed seventeen rock weirs over roughly 3 miles between New Buckaroo Dam and the mouth of Bridge Creek. Construction of the weirs began in the fall of 2002 and was completed by March of 2003. The goal of this work was to increase in-stream habitat complexity, diversify hydraulics and sediment transport processes, increase friction to allow more sediment deposition, reactivate a portion of the floodplain and raise the water table below the surrounding meadows by aggrading the stream channel with the use of rock weirs. This water quality study attempted to monitor water temperature before and after this work, but unfortunately, the temperature recorder upstream of this restoration project malfunctioned in 2002 and the data could not be used.

Downstream of Bridge Creek, the Blitzen is straight and channelized for about 18 miles until Stubblefield Canal above Busse Dam (Figure 1). The river is entrenched along this reach and disconnected from its floodplain, resulting in a degraded riparian zone. There are two major diversion dams within this reach: Grain Camp Dam, 17.4 mi downstream of the boundary, and Busse Dam, 25.5 mi downstream of the boundary. Downstream of Busse Dam and Rocky Ford, the river returns to a slightly more meandering channel, although it remains deeply entrenched and lacks adequate riparian vegetation in this reach. Sodhouse Dam, at the end of this reach, is 44 mi from Page Springs and the southern boundary of the refuge. The river enters Malheur Lake, four miles downstream of Sodhouse Dam.

Water is diverted from the river mainly March through July at each of the diversion dams along the river, for irrigation of meadows and wetlands adjacent to the river. Some of this irrigation water makes its way back to the river as return flow, either in surface channels or as subsurface seepage.

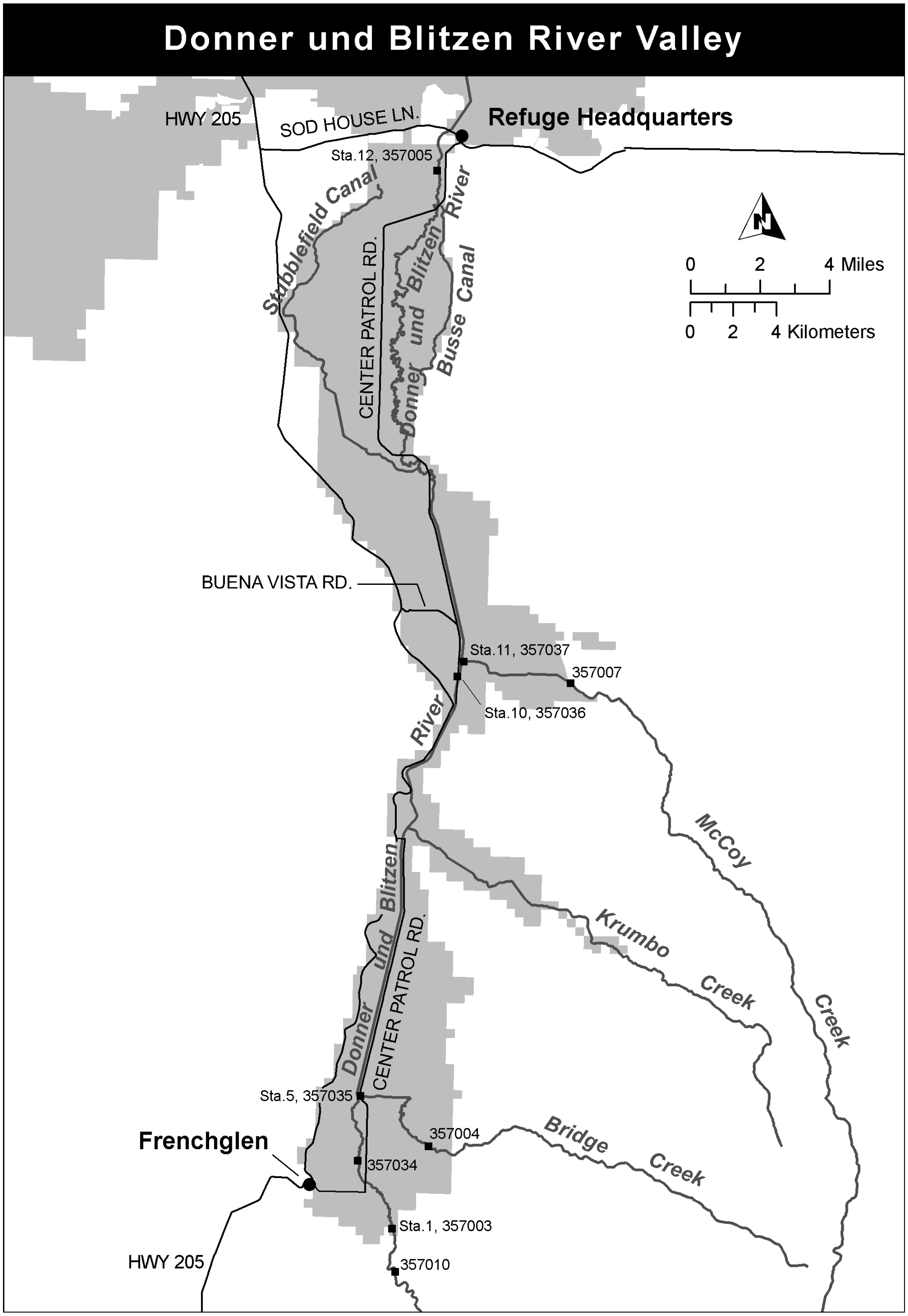


Figure 1. Map of Blitzen River Valley showing rivers and creeks, study monitoring sites, and several major landmarks and geographic features.

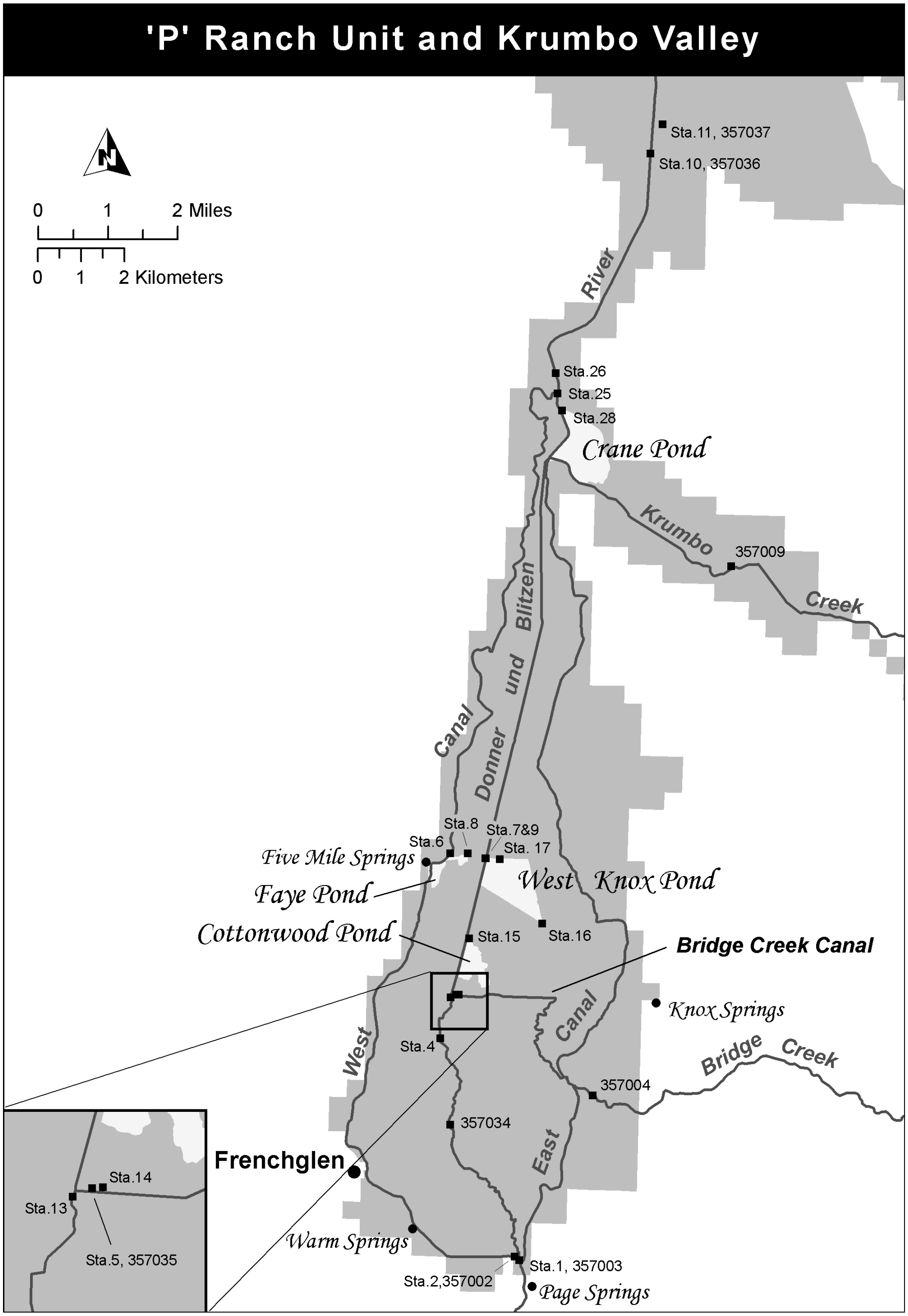


Figure 2. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

METHODS

We monitored water temperature at a number of stations along the Blitzen River in 2002, 2003, and 2005 and one site on Bridge Creek in 2003 (Figures 1 and 2). Table 1 lists the name, station number, and location of the river monitoring sites. Station 3 (Old Buckaroo, USFWS site no. 357034) was discontinued after 2002. Station 10, located just downstream of Grain Camp Dam and monitored in 2002, was moved 3 miles upstream of the dam to Station 26 in 2003 and 2005. In 2002 and 2003, we monitored temperature in the spring and summer periods. In 2005, we did not begin monitoring until late June.

Table 1. River Temperature Monitoring Sites

Station Number	Station Name	Distance downstream of Station 1 (mi)
1	Blitzen River blw Page Springs	0
3	Blitzen River at Old Buckaroo	2.9
13	Blitzen River at Bridge Creek	5.2
5	Bridge Creek at Blitzen	5.2
9	Blitzen River at 5-Mile Bridge	7.2
10/26	Blitzen River at Grain Camp	17.4 (Sta 10) / 14.5 (Sta 26)
12	Blitzen River blw Sodlhouse	44.0

Table 2. Irrigation Return Flow and Wetland Temperature Monitoring Sites

Station Number	Station Name	General location of Station
7	Faye Pond return flow channel	West side of Blitzen River just upstream of 5-Mi Bridge
17	West Knox Pond (permanent wetland)	East side of Blitzen River, south of Knox Drain Rd
28	Crane Pond (permanent wetland)	Adjacent to Blitzen River at downstream end of Krumbo Valley

We recorded water temperatures hourly using Optic StowAway temperature loggers, Optic Tidbits, and/or Hydrolab multi-probes. In addition, we made independent temperature measurements with a traceable thermometer at one or two week intervals during the monitoring period. If there were discrepancies between the independent and continuously recorded temperatures, we considered the continuous temperature data suspect and we removed them from the record for that period. We calculated daily averages, maximums and minimums from the hourly data. We also used air temperatures and flow records in the analyses. We examined air temperatures from weather stations at P-Ranch (station ID: 726853) and Burns Municipal Airport (station ID: 726830) but ultimately, only air temperature data from Burns Municipal Airport were used because of significant gaps in the temperature record for P Ranch. Daily air temperatures at Burns are highly correlated with air temperatures at P Ranch. We used flow records from the following sites: the USGS Blitzen River at Frenchglen, OR; the FWS Blitzen River below Page Springs; the FWS Blitzen River below Grain Camp; and the FWS Blitzen River below Sodhouse.

Figure 3 shows the edited period of record by year for each temperature monitoring station on the Blitzen River. Gaps in the records represent loggers that malfunctioned or were lost, or poor quality data that were removed from the record. The first year of temperature monitoring, 2002, was especially problematic. This is part of the reason that we collected another season of data in 2005. Most of the 2002 summer period is missing for Station 1 (Blitzen River blw Page Springs) and Station 12 (Blitzen River blw Sodhouse). The temperature logger at Station 1 appeared to read too high for much of the summer of 2002, based on independent measurements, and the data were removed for the period. The logger at Station 12 was lost in 2002. Unfortunately, these two sites represent the entry and exit points of the river on the refuge, which are critical to the analysis of temperature impacts. Another major data gap in the temperature record occurs in the first half of the 2005 summer for Station 12. For reasons unknown, the temperature logger did not record any data for this period.

In addition to the river monitoring sites, we monitored water temperatures from several wetlands in the Frenchglen area in 2002 and 2003 (Table 2). These included Faye Pond and West Knox Pond in 2002 and 2003 and Crane Pond in 2003. Temperatures were collected near the wetland outlets from April to the end of summer, or until the return flow from the wetlands ceased or the wetland became too shallow. Water temperatures at the outlets were assumed to represent temperatures of return flows reaching the river, although at some sites, return flow channels between the outlets and the river are several hundred yards in length, which may allow some additional heating.

We calculated seven-day average maximum temperatures from the daily maximums for all sites and periods with continuous hourly data between June 1 and Sept 30. We determined the number and percentage of days exceeding the state standard within this period. We assessed the magnitude of exceedences by calculating cooling degree days, using 20˚C as a base, at all sites with a complete record for the June to Sept period. Cooling degree days are defined as the cumulative sum of the difference between the 7-day average maximum temperature and the base (20˚C) for all days exceeding 20˚C.

Water temperatures in rivers vary diurnally, seasonally, and annually in response to stream channel conditions, hydrology, and meteorology. Channel conditions on the refuge are progressively impacted downstream by the combined effects of diversions dams, irrigation return flows, channel incision, and channelization. Hydrology and meteorology were significantly different during the three years of monitoring. Therefore, we were able to examine the effect of each of these factors looking at variations in temperatures among years and longitudinally along the river.

We used several statistical methods to analyze the data. Linear regression was used to relate water temperatures to air temperatures. A 3-day running mean air temperature was used in the correlations to smooth some of the daily fluctuations from the air temperature record. Analysis of covariance (ANCOVA) was used to analyze for differences in slopes and/or intercepts of regressions between seasons (spring runoff/summer baseflow) and between years (2002, 2003, 2005). In ANCOVA, the data are assigned to groups and multiple regressions were performed with all the data using a binary variable to represent the groups. In this case, the groups represent either seasons or years. For seasonal comparisons, data from May 1 to June 15 were used for the spring season and July 15 to Sept 30 for the summer season, to avoid the transition period from runoff to baseflow. Two multiple regression models are used in ANCOVA, one to test for a difference in intercepts between the groups and the second to test for a difference in slopes and intercepts between groups.

We used a t-test (or a Mann-Whitney test) to test for significant differences in means (or medians) between groups. We used a paired t-test (or Wilcoxon signed rank test) to test for significant differences in means (or medians) between paired groups of data. Where two sources of water were mixed, we used the mixing equation to estimate the combined temperature:

$$T_j = \frac{Q_1 * T_1 + Q_2 * T_2}{Q_1 + Q_2}$$

where

T_j = temperature at junction
Q_n = discharge at source n
T_n = temperature at source n

Finally, we used SSTEMP Version 2.0 (Bartholow, 2002), a simple one-dimensional, steady-state, stream segment model, to further investigate temperature relationships along this reach and examine refuge management alternatives to improve water temperatures. SSTEMP handles only single stream segments for a single time step (day, month, etc.) for a given run. Batch model runs can be executed through a comma-delimited input file. Based on input describing stream geometry, location, elevation, shading and steady-state hydrology and meteorology, the model predicts the daily mean and maximum stream temperatures at specified distances downstream. In general terms, it calculates the heat gained or lost from a parcel of water as it passes through a stream segment. The theoretical basis for the model is strongest for mean daily stream temperature, as opposed to daily maximum or minimum daily stream temperatures.

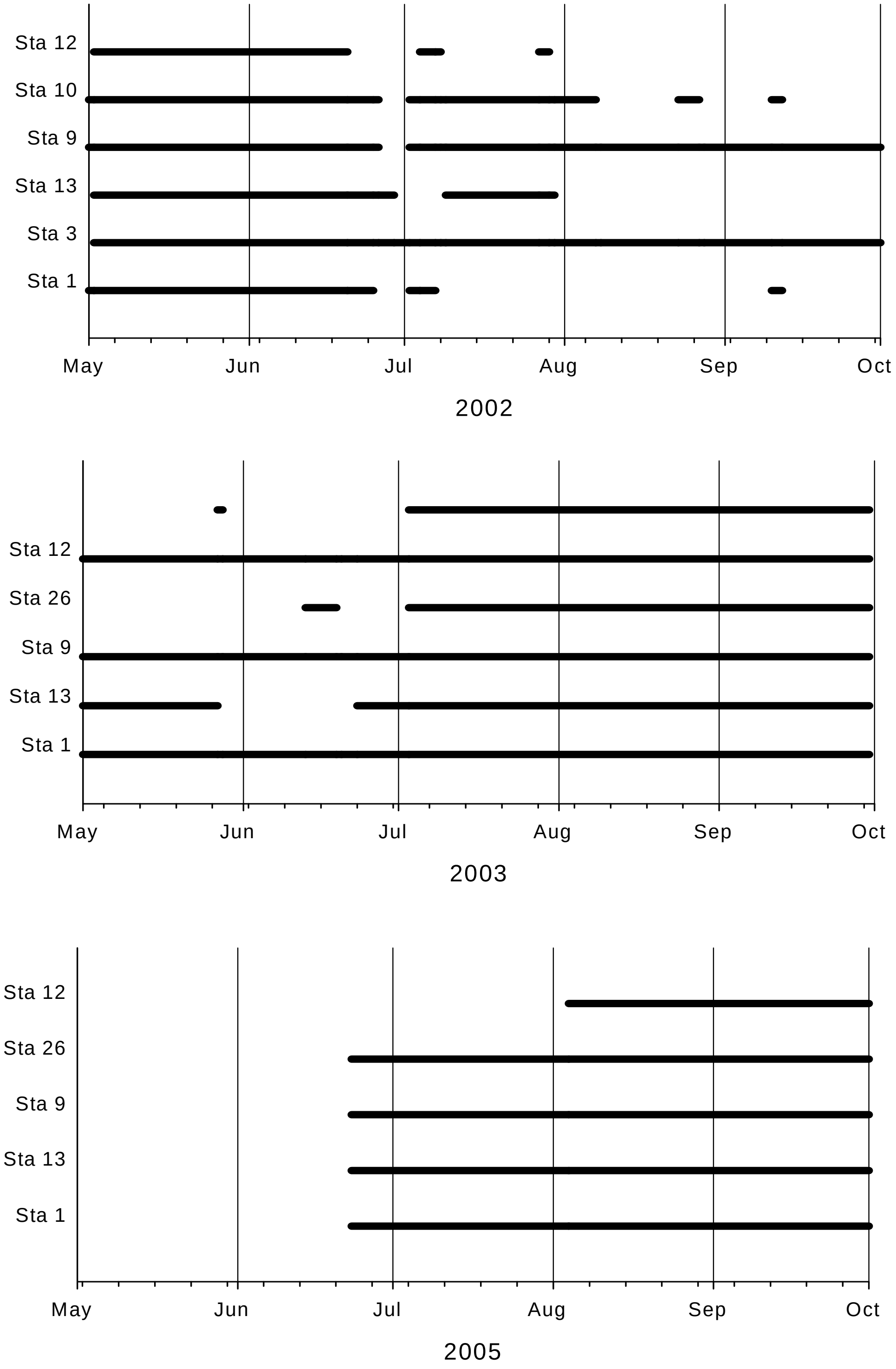


Figure 3. Period of record for all Blitzen River temperature monitoring stations during the three years of study.

We modeled river temperatures for the river reach from Page Springs Dam to 5-Mile Bridge for a 35-day period from July 1 to August 4, 2003. We selected this period because temperature and flow data were available from a number of river and wetland sites and because it was particularly warm during the period. We calibrated the model using daily average and maximum temperatures for Station 13 (Blitzen River above Bridge Creek) and Station 9 (Blitzen River at 5-Mile Bridge). Since SSTEMP only models a single reach at a time, data were input for three individual segments of the river for the reach from Page Springs to 5-Mile Bridge, with output from one segment used as input for the next downstream segment.

We delineated segments based on the presence of irrigation diversions, tributary inflows, or the availability of flow and temperature data at sites. The first segment was from Page Springs to New Buckaroo Dam, because irrigation diversions reduce the flow past this site for part of the period. The second segment was from New Buckaroo dam to Station 13, because we had temperature and flow data at this site and Bridge Creek flows into the Blitzen just downstream of this site. The third segment was from Station 13 to Station 9 at 5-Mile Bridge, where we also had temperature and flow data.

The model predicted water temperatures for the first segment above New Buckaroo Dam, which was then used as input, along with the estimated diversions and return flows in the second segment from New Buckaroo Dam to Station 13, to predict daily water temperatures at Station 13. These model temperatures for the second segment at Station 13 were “mixed” with Bridge Creek tributary inflow, using the mixing equation above, and used these as model input along with estimated return flows, to predict daily water temperatures for the third segment at Station 9, the Blitzen River at 5-Mile Bridge. We used the measured daily average temperatures at Station 13 and Station 9 to independently check the model output and calibrate the model.

RESULTS AND DISCUSSION

Hydrological and Meteorological Conditions in 2002, 2003, and 2005

Figure 4 shows the Apr-Sept Blitzen River flows at several flow monitoring sites for the three years of temperature monitoring. The four sites, from upstream to downstream are 1) the USGS Blitzen gage upstream of the refuge, 2) the Blitzen below Page Springs, 3) the Blitzen below Grain Camp, and 4) the Blitzen below Sodhouse. In most years, the runoff period on the Blitzen typically extends from April through May or June and the baseflow period begins sometime in July. Peaks in flow at the downstream sites are attenuated and delayed relative to the upstream sites. Flow generally decreases in the downstream direction due to diversions and losses on the refuge. About the 3rd week of July, the FWS stops most diversions on the refuge and flows at the downstream sites usually increase and become approximately equal to the upstream sites.

The three years of temperature monitoring spanned a range of flow conditions. According to the stream ranks presented in the previous section of this report, the April to September runoff measured at the USGS Blitzen River gage was below normal in 2002 and 2003 and above normal in 2005. Total April-September runoff was 49,565 af in 2002 (31st percentile of all years), 55,509 af in 2003 (41st percentile of all years), and 78,140 af in 2005 (75th percentile of all years). Average baseflow for July 1 to September 30 was 43 cfs in 2002, 40 cfs in 2003, and 55 cfs in 2005. 2003 had greater April to September runoff but smaller average baseflow as compared to 2002. Of the three years, 2005 has the highest April-September runoff and average baseflow. In general, higher river flows should mean cooler water temperatures.

Air temperature is the single most important influence on stream temperature, particularly when stream flow is low and width-to-depth ratios are high (Bartholow, 1989). Crisp and Howson (1982) found that they could explain 86% to 96% of the variance in water temperatures from several streams with linear regressions containing only mean air temperatures. The addition of rainfall or stream discharge did not improve the regressions. Smith and Lavis (1975) reported a similar relationship between air temperature and water temperatures in several other streams.

The average Jun-Sept air temperature at Burns Municipal Airport was 17.7˚C in 2002, 18.9˚C in 2003, and 17.1˚C in 2005. Two-sample t-tests of all pairs of means indicated that the Jun-Sept period in 2003 was significantly warmer than 2005 ($p=0.005$) but not significantly different from 2002 ($p=0.054$). There were 116 cooling degree days in 2002, 152 in 2003, and 106 in 2005. 2003 was much warmer than 2002 or 2005, with a higher mean summer temperature and a greater number of cooling degree days. As discussed in the previous *General Water Budgets for Malheur NWR* report, the average May-Sept air temperatures in 2003 are the highest on record for the period from 1979 to 2005. In addition, 2003 had the lowest average baseflow of any of the three years. As well as having the highest runoff and baseflow of the three years with temperature monitoring, 2005 was the coolest summer.

Water Temperatures in 2002, 2003, and 2005

Daily mean air and water temperatures for 2002, 2003, and 2005 are presented in Figure 5 for river and wetland monitoring sites. Daily air temperatures generally reached their annual maximums around mid-July/beginning of August. River temperatures follow the trend in air temperatures closely, increasing rapidly as runoff recedes in late June, peaking in mid-July/beginning of August, and then decreasing. River temperatures become warmer earlier in the season with distance downstream, suggesting that river conditions on the refuge are conducive to warming. The warmest site on the river is Station 12 (Biltzen below Sodhouse Dam), which is the furthest downstream monitoring site.

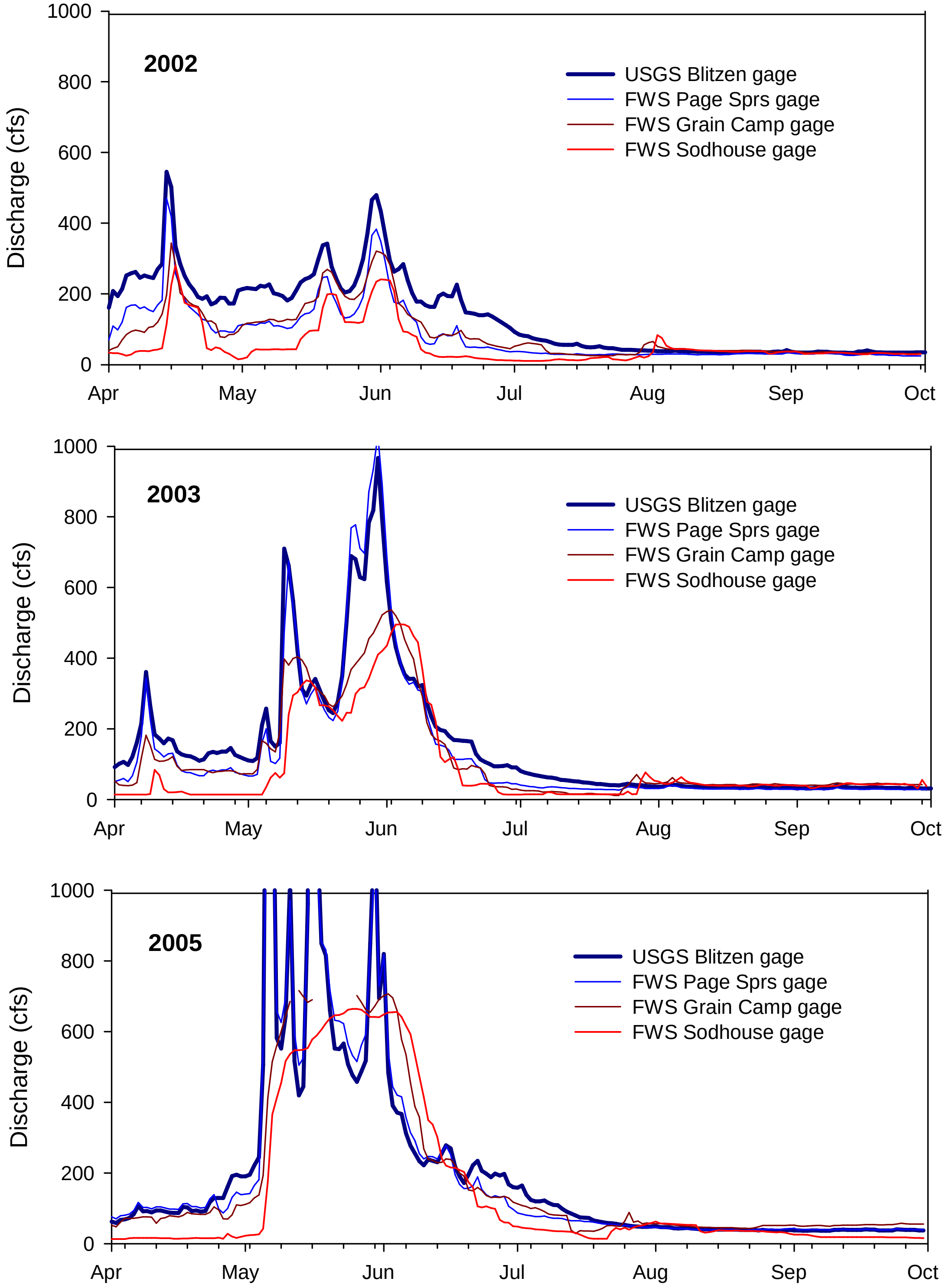


Figure 4. Blitzen River daily flows at USGS gage, Page Springs Dam, Grain Camp Dam, and Sodhouse Dam for Apr-Sept, all three years.

Water temperature is strongly correlated with air temperature at all river monitoring sites, especially in the summer baseflow period (Figure 6). Air temperature explains from 82 to 85% of the variance in Jul-Sept water temperatures for all three years. One can observe the effect of higher river flows in the different response of river temperatures to air temperatures during spring runoff and summer baseflow. Figures 6a and 6b present linear regressions of daily water temperature with 3-day average air temperatures at several sites during spring runoff (May 1-Jun 15) and summer baseflow (Jul 15-Sept 30) for 2002 and 2003. In general, river temperatures are higher for a given range of air temperatures under baseflow conditions than runoff conditions. The difference between the two periods is smaller at sites further downstream. ANCOVA indicated the slopes and intercepts of the regressions are statistically greater during the baseflow period ($p<0.05$), with the exception of Station 12 in 2003. These results suggest that water temperatures are warmer and increase more rapidly for a given range of air temperatures during the baseflow period as compared to the runoff period.

The median Jul-Sep discharge below Page Springs Dam was 30 cfs in 2003 and 41 cfs in 2005. Despite the higher baseflow in 2005 compared to 2003, we found no statistically significant differences in the slopes or intercepts of the regressions when summer baseflow (Jul-Sept) temperatures were grouped by years. However, looking at July alone, when the difference in median flows was greater for the two years (median July flows of 32 cfs and 61 cfs, respectively), there was a significant difference in the intercepts of the regressions, suggesting that the higher baseflow in July 2005 had an effect on the air/water temperature relationship. Mean daily river temperatures at Station 9 were about 0.75 to 1.5˚C cooler for a given range of air temperatures in July 2005 versus July 2003. Daily maximum temperatures were about 2 to 4˚C cooler in 2005. The temperature modeling results discussed below examine the effect of increased flows further.

Figure 5 also shows wetland water temperatures for 2002 and 2003. Wetland water temperatures behave very similarly as a group and generally warm more rapidly than river temperatures from mid-May to early July. The water in the wetlands has a long residence time in shallow, unshaded water bodies, giving it ample opportunity to equilibrate with air temperatures. Water temperatures in 2003 at Station 5 (the downstream end of Bridge Creek) were also warmer than the Blitzen River and similar to wetland water temperatures (Figure 5). Although this is a spring-fed stream, the channel flows through a very low-gradient, 2-mile section with numerous wetlands known as the Bridge Creek Canal, between East Canal and the mouth of Bridge Creek. Water temperatures increase considerably through this reach. In August 1999, water temperatures in Bridge Creek were about 12˚C six miles upstream of the confluence with the Blitzen River, 18˚C at the upstream end of Bridge Creek Canal, and 22˚C at the mouth of Bridge Creek (Watershed Sciences, 2000). Overall, water temperatures in the wetlands and canals adjacent to the river appear to reach equilibrium with air temperatures much earlier than the river, especially upstream Blitzen River sites. The

Blitzen below Page Springs and other upstream sites on the river are much slower to increase until the beginning of July, when runoff flows have receded.

Figure 7 shows the increase in median Jul-Sept water temperature with distance downstream in 2003 and 2005. Jul-Sept water temperatures warm about 4.2˚C in 2003 and 3.2˚C in 2005 through the entire extent of the refuge and this difference is statistically significant ($p<0.002$). The most rapid rate of increase appears to occur between Stations 1 and 13, in the first 5 miles of the refuge. Temperatures increased 0.36 and 0.16˚C/mile for 2003 and 2005, respectively, in this reach. Temperature increases are less, ranging between 0.05 and 0.10 ˚C/mile, over the remaining length of the refuge. This is somewhat surprising since the channel conditions in the first five miles appear to be much better than further downstream, especially following the restoration in 2002. There may be several reasons for this.

First, the river transitions to lower gradient conditions as it enters the refuge from the canyon. Riparian and topographic shading is greatly reduced in the valley as compared to the canyon upstream. The abrupt changes in channel and topographic conditions may mean that river temperatures are far from equilibrium with air temperatures as the river enters the refuge. One would expect a rapid response under such conditions, as water temperatures attempt to equilibrate with air temperatures. Further downstream, as water temperatures near equilibrium, the response will be slower and warming will not be as rapid.

Another contributing factor for the rapid warming in this reach of the river and elsewhere could be warmer tributary flow from Bridge Creek Canal and return flow from adjacent wetlands (Faye Pond, West Knox Pond, and Crane Pond). However, Station 13, located on the Blitzen River upstream of Bridge Creek and upstream of most wetland return flow, appears to be warming more than would be expected based solely on the mixing of river waters and estimated wetland return flows upstream of this site. At least at the present time, it appears that in the first five miles of the refuge, reduced topographic and riparian shading is responsible for the warming observed in the Blitzen River, rather than wetland return flows and tributary inflow from Bridge Creek. The modeling results described below confirm that tributary inflow and return flows are not significantly warming the river under the current conditions in this reach.

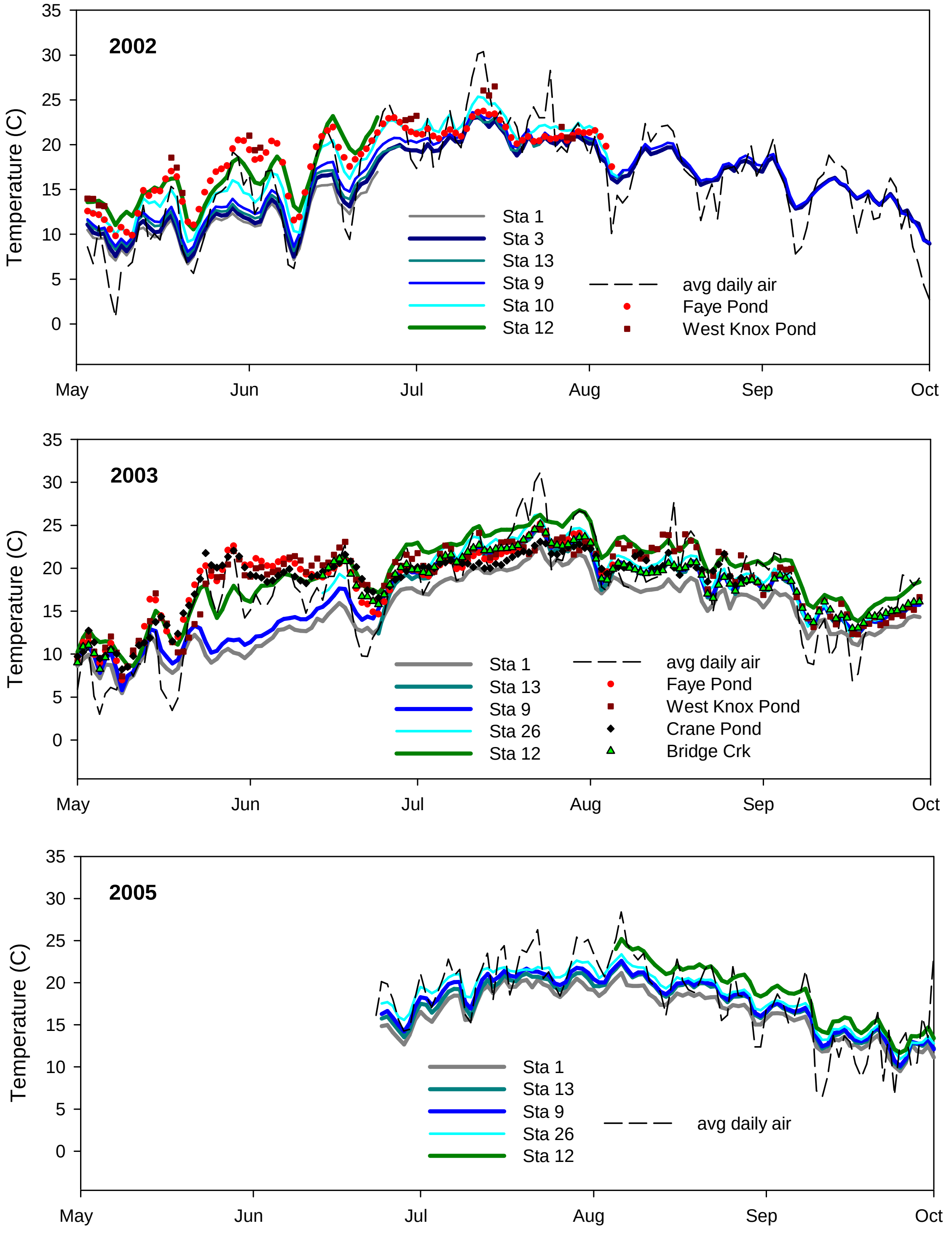


Figure 5. Average daily air temperature and water temperatures for the river monitoring stations for all three years and the wetland sites for 2002 and 2003.

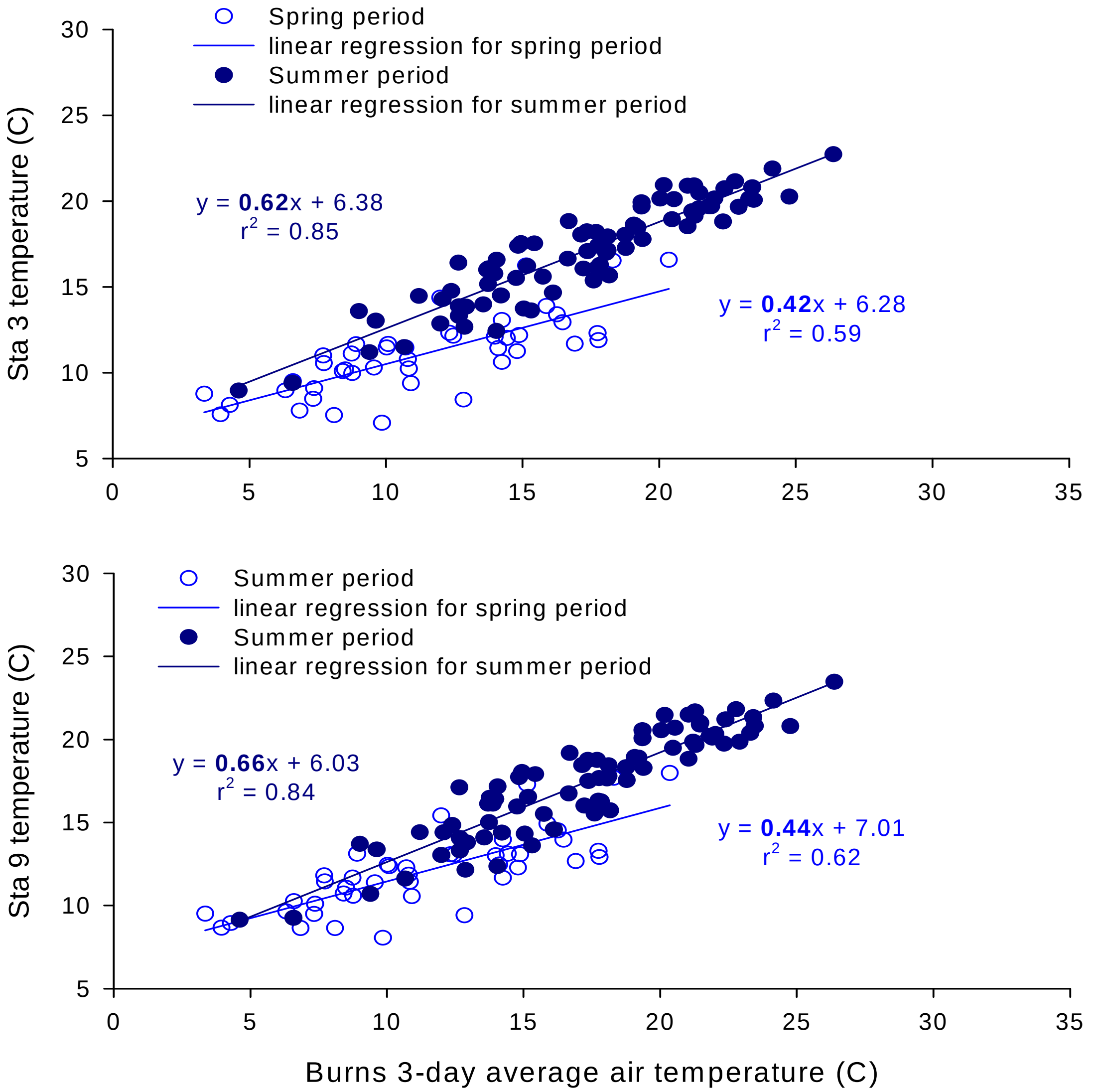


Figure 6a. Regressions of 3-day average air temperature and river water temperatures for spring runoff (May 1-Jun 15) and summer baseflow (Jul 15-Sept 30) periods in 2002.

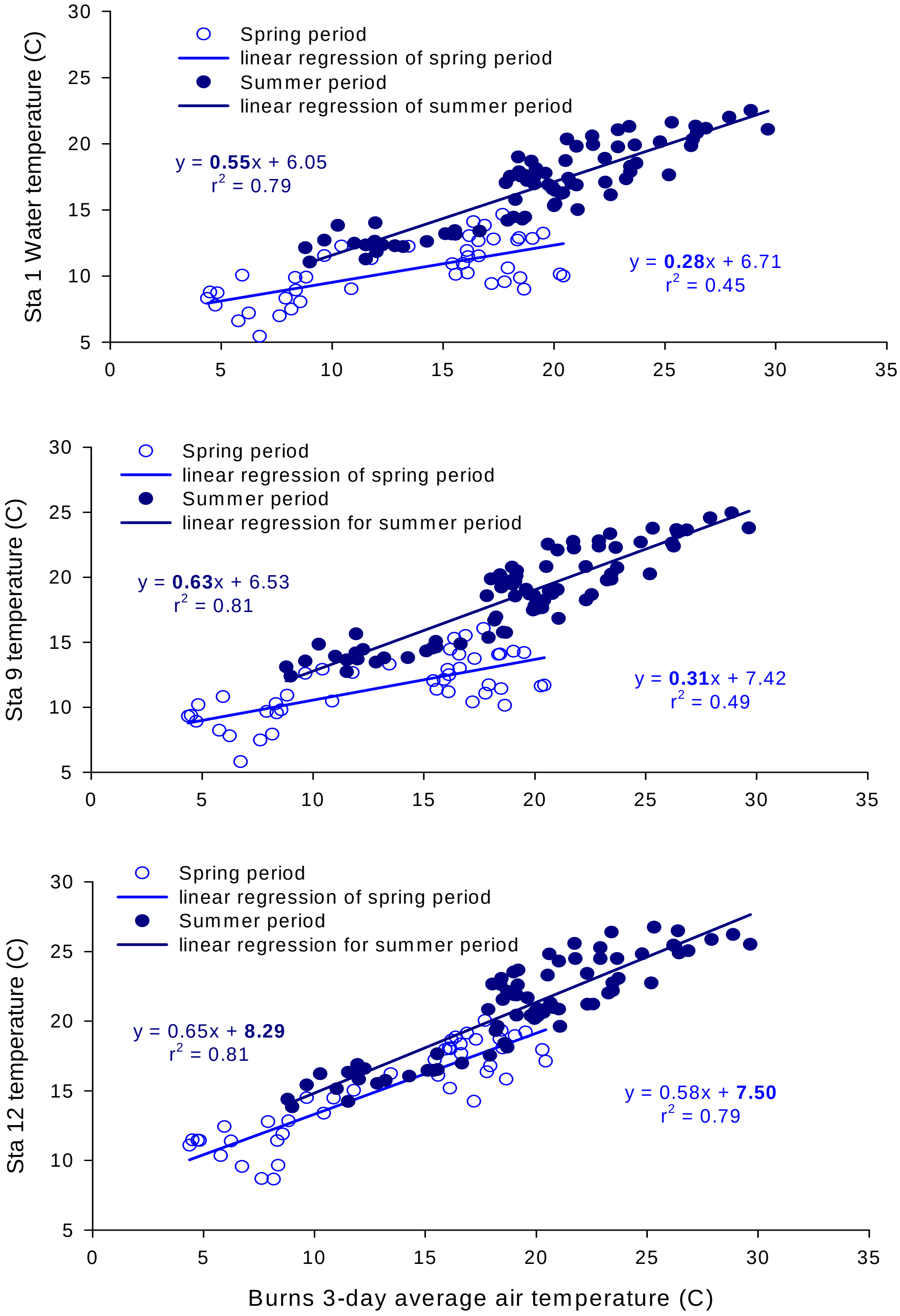


Figure 6b. Regressions of 3-day average air temperature and river water temperatures for spring runoff (May 1-Jun 15) and summer baseflow (Jul 15-Sept 30) periods in 2003.

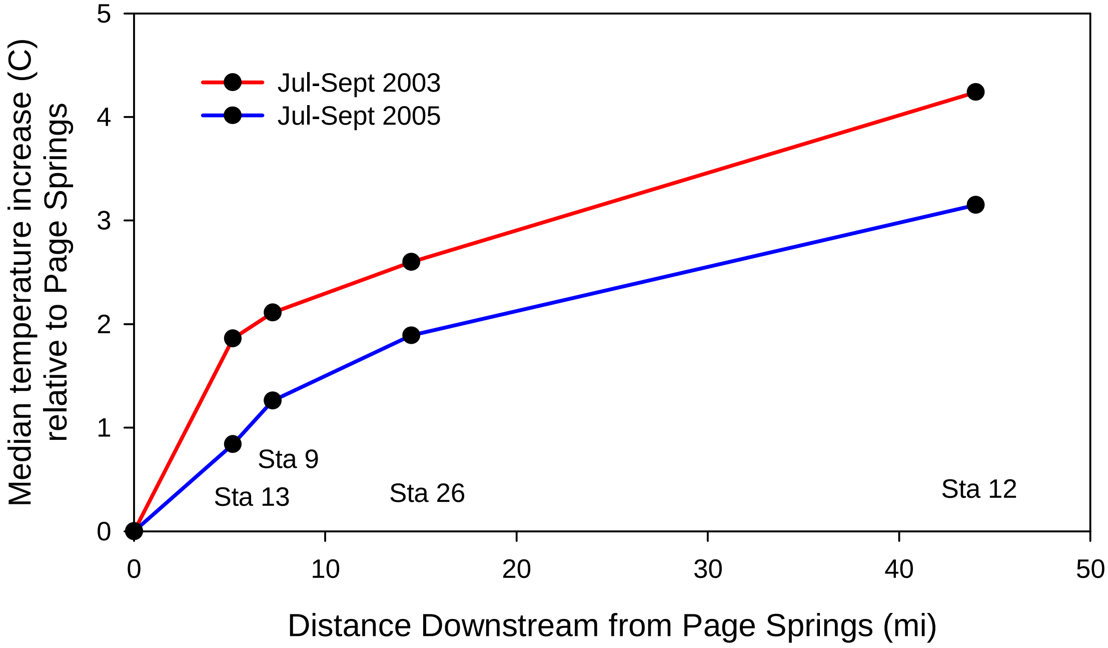


Figure 7. Increase in Jul-Sept median temperature with distance downstream from Page Springs for 2003 and 2005.

Water temperatures at Station 12 (Blitzen River below Sodhouse Dam), the furthest downstream site on the refuge, reflect the combined influence of warmer tributary and return flows sources, decreased flows due to diversions, low-gradient channel conditions, and reduced riparian shading. Several low-gradient tributaries and return flows from numerous wetlands and hayfields in the Blitzen Valley enter the Blitzen River along the entire reach through the refuge upstream of Sodhouse Dam. Station 12 water temperatures increase more quickly in the spring in comparison to upstream sites. Water temperatures become equal to wetland and tributary temperatures in early June and they begin to exceed these temperatures in early July. Return flows decrease considerably through the summer as diversions for irrigation cease, so the effect of these sources on river temperatures later in the summer should be negligible. The rapid warming in the river observed at downstream sites during late spring and early summer is likely due to the combined effect of return flows, irrigation diversions, channel conditions, and reduced shading.

The 7-day average maximum exceeded the Oregon state standard of 20˚C at all sites for a considerable period of each summer of temperature monitoring. Table 3 presents the number of days of exceedences by year for each station that had a complete record over the summer period. The number of days with exceedences increased in a downstream direction, but even the water entering the refuge exceeded the state standard for a significant period each year. The Blitzen River below Page Springs Dam had 68 and 58 days with exceedences for 2003 and 2005, respectively. Downstream sites had progressively more days with exceedences. The maximum number of days with exceedences was 83 in 2003 at the Blitzen below Sodhouse Dam.

Table 3. Number of Days Exceeding the State Temperature Standard (20˚C) at each Station for 2002, 2003, and 2005 (NA indicates an incomplete record for that station during that year)

Station Number	Station Name	2002	2003	2005
1	Blitzen River blw Page Springs	NA	68	58
3	Blitzen River at Old Buckaroo	53	Station discontinued	
9	Blitzen River at 5-Mile Bridge	76	73	66
10/26	Blitzen River at Grain Camp	NA	NA	58
12	Blitzen River blw Sodlhouse	NA	83	NA

The number of days with exceedences is a measure of the frequency of high temperatures. The magnitude of high temperature exceedences during a given period is also important to fish and other aquatic organisms. Cooling degree days generally increased downstream, although there were problems with computing this cumulative measure because of the gaps in the record for some sites. The conclusion is that both the frequency and magnitude of exceedences increase downstream.

Spring inflow from Page Springs has a small but significant cooling effect on river temperatures. Measurements collected with a temperature sensors upstream and downstream of Page Springs during August 2005 indicated that, on average, the river was 0.2˚C cooler downstream of the springs (p=0.000). Blitzen flows upstream of Page Springs averaged 41 cfs in Aug 2005 and estimated Page Spring inflows averaged 14 cfs in Aug 2005. To cool the water the observed amount (0.2˚C), the estimated water temperature of the spring inflow would have to be about 0.8˚C cooler than the river upstream, which appears reasonable when compared to instantaneous observations of spring water temperatures in Aug 2005.

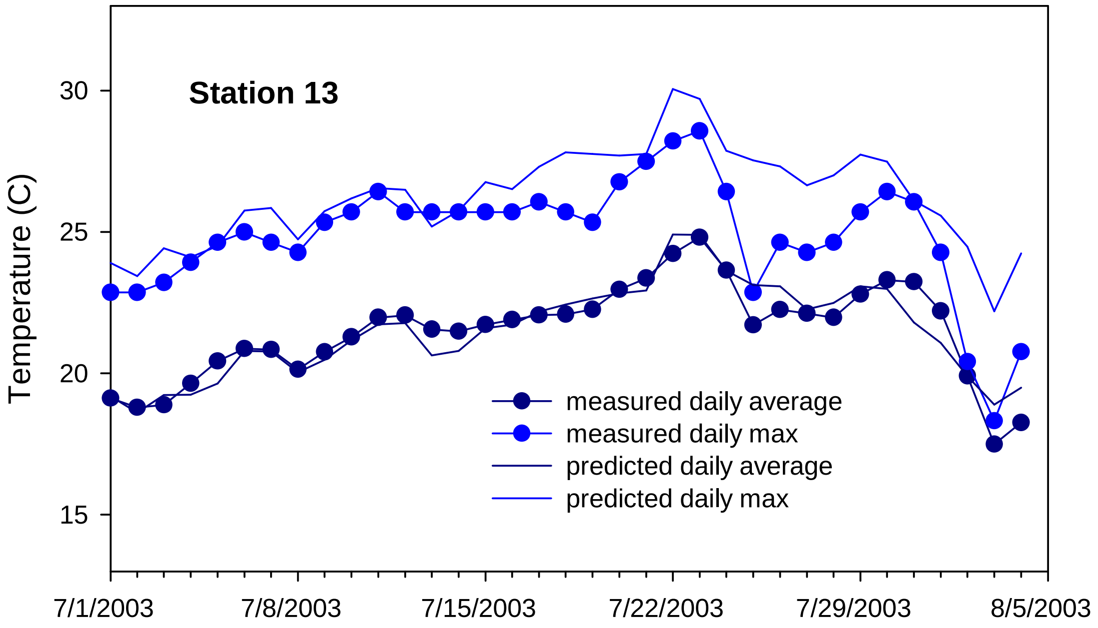
Modeling Results

We used the topographic and riparian shade components as the primary calibration variables for the SSTEMP model, since most other input variables for the model are known. We assumed a shade-producing strata of trees 10 ft high and 10 ft in crown diameter with trunks positioned 10 feet back from the water, and having a density of 21%. The density term refers to both the continuity of the vegetation along the channel and the light-filtering ability of the vegetation. Assuming that about 25% of the stream bank is vegetated with willows and other local riparian vegetation and this vegetation screens about 85% of the sunlight, the computed density is 21% (0.25*0.85=0.21). The resulting model-calculated total shading value, or the percent of the water surface that is shaded through the day, is 9%. This is low but may be realistic for the refuge, given the sparse riparian vegetation that exists presently and the channelization and grazing practices that have occurred historically (Langston, 2003). The predicted and measured daily average temperatures at 5.25 miles at Station 13 and 7.25 miles downstream at Station 9 for the period Jul 1 to Aug 4, 2003 are shown in Figure 8. Predicted and measured average temperatures agree fairly well for the period (r^2=0.97 and 0.86, respectively). The agreement between predicted and measured maximums at Stations 13 and 9 is weaker (r^2=0.64 and r^2=0.74, respectively) and appears slightly biased. As discussed in the Methods section, the theoretical basis for the model is strongest for mean daily stream temperature. The poorer estimates and weaker correlations for maximum temperatures are not unexpected for this reason.

For our purposes, this calibration is adequate. The point of this modeling exercise was to create an input dataset that reasonably simulated observed temperatures downstream and then to examine the effect of various management alternatives on water temperatures. Alternatives examined included the effect of additional flow, the effect of additional riparian shading, and the effect of reduced tributary and return flow.

Table 4 presents the medians of predicted temperatures for the Jul 1 to Aug 4, 2003 period at Station 13 and Station 9 for current conditions and for each management alternative. Figure 9 presents the predicted daily average and maximum temperatures at Station 9 graphically for the current conditions and for each management alternative.

The first and second management alternatives we modeled (Alt 1 and 2) increased flows below Page Springs Dam by 15 cfs and by 30 cfs, respectively, which are 50% and 100% greater than the measured median flow below Page Springs Dam for the Jul 1 to Aug 4, 2003 period of 32 cfs. The increases could possibly be accomplished through reduced diversions, assuming the water is available at the refuge boundary. The model carried the additional flow through all segments and predicted the resulting mean and maximum temperatures at Station 13 and 9. With additional flow in the river, the water temperatures are significantly cooler for the Jul 1 to Aug 4, 2003 period (Table 4). Predicted daily means and maximums at Station 9 are 0.5˚C and 0.9˚C cooler with 15 cfs of increased flow (Alt 1) and 0.7˚C and 1.5˚C cooler with 30 cfs of increased flow (Alt 2) for the period. The modeled reductions in mean and maximum temperatures at Station 9 under Alt 2 are nearly equal to the observed reductions at Station 9 between July 2003 and July 2005, two periods which had flow differences equivalent to those modeled here.



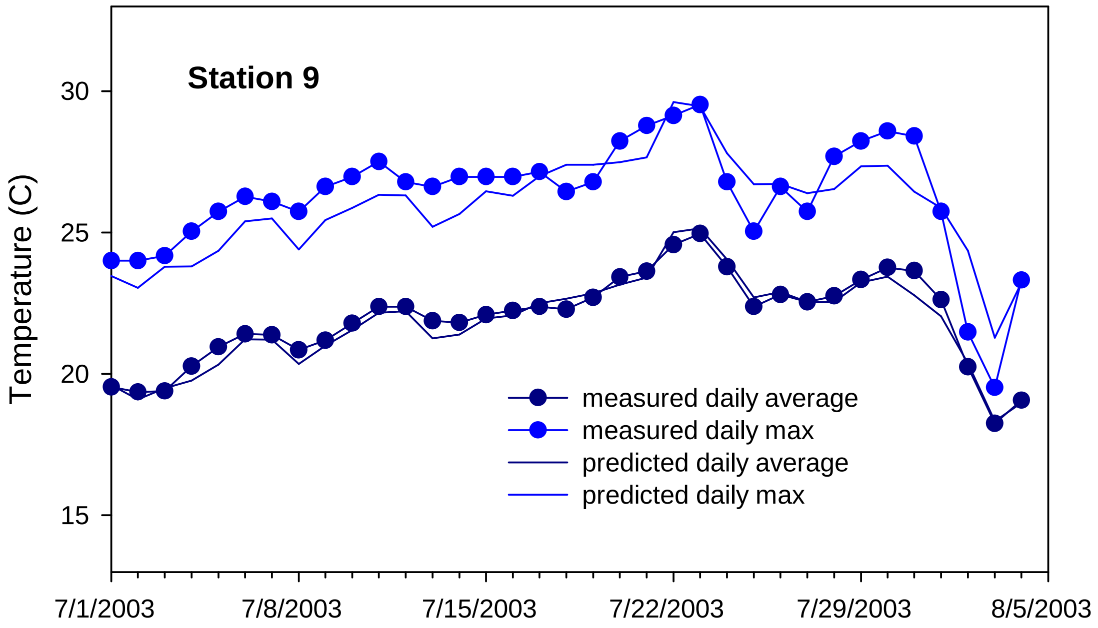


Figure 8. Measured and predicted water temperatures at Station 13 and Station 9 for the period Jul 1-Aug 4, 2003.

Riparian shading is another important factor that could be affected through refuge management. Under current conditions, the model calculated a total shading of 9% with the initial input parameters we assumed for riparian vegetation. To test the effect of shading, we modeled Alt 3 which increased the total shading by assuming that 80% rather than 25% of the stream bank is occupied with vegetation. We also increased the height of the vegetation from 10 feet to 15 feet and moved the trunks of the trees from 10 feet to 5 feet from the water. Assuming that the vegetation still screens about 85% of the sunlight, Alt 3 resulted in a vegetation density of 68% (0.80*0.85=0.68) and a model-calculated total shading of 27%. With this change in riparian vegetation, the predicted daily mean and maximum river temperatures at Station 9 are 1.0˚C and 1.8˚C cooler than measured temperatures for the period (Table 4).

Next, we modeled the combined effect of the increased shading described above and flow increases of 15 and 30 cfs (Alt 4 and 5). With the increased riparian vegetation and 15 cfs of additional flow (Alt 4), the predicted mean and maximum river temperatures at Station 9 are 1.3˚C and 2.5˚C cooler for the period. With the increased riparian vegetation and 30 cfs of additional flow (Alt 5), the predicted mean and maximum river temperatures at Station 9 are 1.4˚C and 2.9˚C cooler than measured temperatures for the period (Table 4, Figure 9).

Another management alternative would be to reduce the tributary inflow and return flows reaching the river (Alt 6), since these waters appear to warm up more quickly than the river in early summer. Practically, it would be difficult to reduce or eliminate all tributary and return flow but we wanted to investigate the effect of tributary and return flow contributions using the model. When we modeled daily water temperatures with no tributary and return flow within the entire reach, there was almost no change in daily means or maximums compared to measured water temperatures for the period. The differences between Alt 6 and the current conditions were quite small and at Station 9, not significantly different from zero (p=0.238). The model results from Alt 6 suggest that the observed water temperature increase in the first 7.2 miles of river occurs because the river is equilibrating to air temperatures and new channel conditions on the refuge, not because of warmer tributary and return flows.

Reducing tributary and irrigation return flows in this reach would produce marginal benefits in terms of river temperatures and would come at a cost in terms of management flexibility and biologic productivity. Practically, it would be difficult to reduce or eliminate all tributary and return flow. These sources do not seem to be that important to river temperatures, at least under the current conditions considered in this reach. However, they may be more important at downstream sites, particularly Station 12, the Blitzen below Sodhouse Dam.

For the first five management alternatives examined, the daily maximum water temperatures are affected more significantly than the daily average temperatures (Figure 9). While the accuracy of the SSTEMP model is less for maximum water temperature predictions, it seems reasonable to assume that the relative affect of any management change would be greater for maximum water temperatures than for average water temperatures. This is important to consider because the maximum water temperatures are probably of most concern for fish and the water quality standard is based on maximums.

Table 4. Medians of Modeled Temperatures under Management Alternatives
at Station 13 and 9 for the Period Jul 1 to Aug 4, 2003*

	Sta 13 daily mean	Sta 9 daily mean	Sta 9 daily max
Current conditions	21.7	22.1	26.3
Alt 1 – increase flow 15 cfs	21.3	21.6	25.4
Alt 2 – increase flow 30 cfs	21.0	21.3	24.8
Alt 3 – increase riparian veg	20.8	21.1	24.5
Alt 4 – increased riparian veg with 15 cfs	20.6	20.8	23.8
Alt 5 increased riparian veg with 30 cfs	20.5	20.7	23.4
Alt 6 – eliminate all tributary and return flows	21.6	21.8	26.3

*The median differences between all paired observations under current conditions and each alternative were all found to be statistically significant with p values = 0.000, except for Station 9 daily means under Alternative 6. Maximum temperatures are presented for Station 9 but not Station 13.

The benefit of higher flows alone on water temperatures is small under the range of flows and conditions considered here. Furthermore, any such increase would mean reduced diversions to the wetlands on the refuge. The costs associated with reduced diversions would need to be carefully weighed against the degree of cooling expected to be realized in the river. One advantage of increased flows is that they can be implemented relatively quickly.

Improved riparian shading, as modeled under alternative 3, appears to be very effective at cooling river temperatures, even more so than increasing flows by as much as 30 cfs. The assumed changes in riparian vegetation seem feasible, although they would take time to implement. Riparian shading offers multiple terrestrial shading and it is likely that there would be additional benefits to aquatic habitat and channel conditions. Some combination of increased flows and improved riparian shading is the most effective alternative for reducing Blitzen River temperatures. Flows increases could be greater in the first few years until conditions in riparian shading improved. Even with better shading and more flow, the water temperature standard would still probably be exceeded, but the frequency, and likely the magnitude, of exceedance would be less. Blitzen River temperatures downstream of Station 9 will likely be quite warm, verging on or exceeding the standard of 20˚C, unless channel conditions and riparian vegetation are improved throughout the entire refuge. The important point with these results is that any management attempts to improve Blitzen River temperatures should begin at the furthest upstream reach on the refuge, where temperatures warm most rapidly.

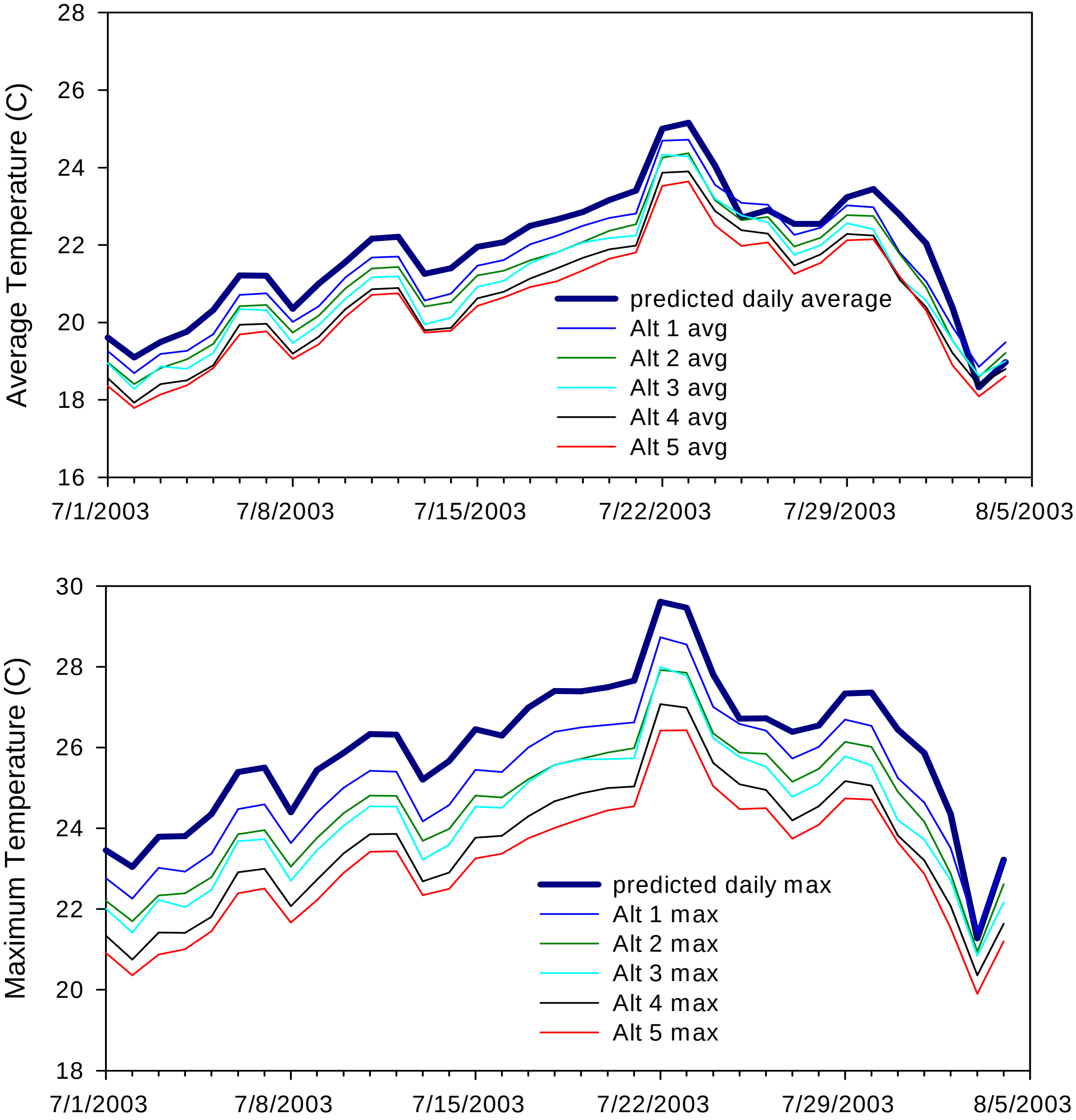


Figure 9. Predicted daily average and maximum temperatures under current conditions (bold line) and for five different management alternatives (described in Table 4 and in the text) for the period Jul 1-Aug 4, 2003.

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Water Quality in the Blitzen River Valley at Malheur NWR

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INTRODUCTION

The purpose of this report is to describe and evaluate the existing water quality conditions in the Blitzen Valley at Malheur NWR. We examine water quality in the river, in canals and return flow channels, and in adjacent wetlands and other habitats. We present summary statistics for various water quality parameters, estimate nutrient loads, and evaluate water quality impacts from refuge management activities. We develop nutrient budgets for two different areas on the refuge. Water temperature has been examined in a separate report and will not be discussed in detail here. Water management and water use in the Blitzen Valley has also been discussed in previous reports. Water quality and nutrient budgets for West Knox Pond, a permanently-flooded wetland, are covered in a separate report as well.

METHODS

We collected instantaneous measurements of field water quality parameters at a number of sites within the Blitzen Valley in 2002 and 2003. Measurements were collected from the beginning of April through the end of September in both years. The monitoring sites were located along the Blitzen River and in tributaries, adjacent wetlands, and return flow channels. Figures 1 and 2 along with Tables 1 and 2 present the name, station number, and location of each site. The measurements were collected about every two weeks, with more frequent measurements during the summer. The parameters we measured included water temperature, conductivity, pH, dissolved oxygen, and turbidity. Water temperature and conductivity were measured with an Orion Conductivity Meter, model 115. pH was measured with a Orion pH meter, model 210, and a glass electrode. Turbidity was measured with a Hach turbidimeter. We calibrated all meters prior to use each day. Dissolved oxygen was measured colorimetrically with a Hach Digital Titrator and DO kit.

We also collected hourly continuous measurements of water temperature, conductivity, pH, and dissolved oxygen with Hydrolabs at several of the sites. In 2002, the Hydrolabs were deployed at Stations 1, 9, 10, and 12. In 2003, they were deployed at Stations 1 and 26. We calibrated the Hydrolabs before deployment and the calibration was checked after deployment. The Hydrolabs were deployed concurrently for 96 hour periods approximately every two weeks from May through September.

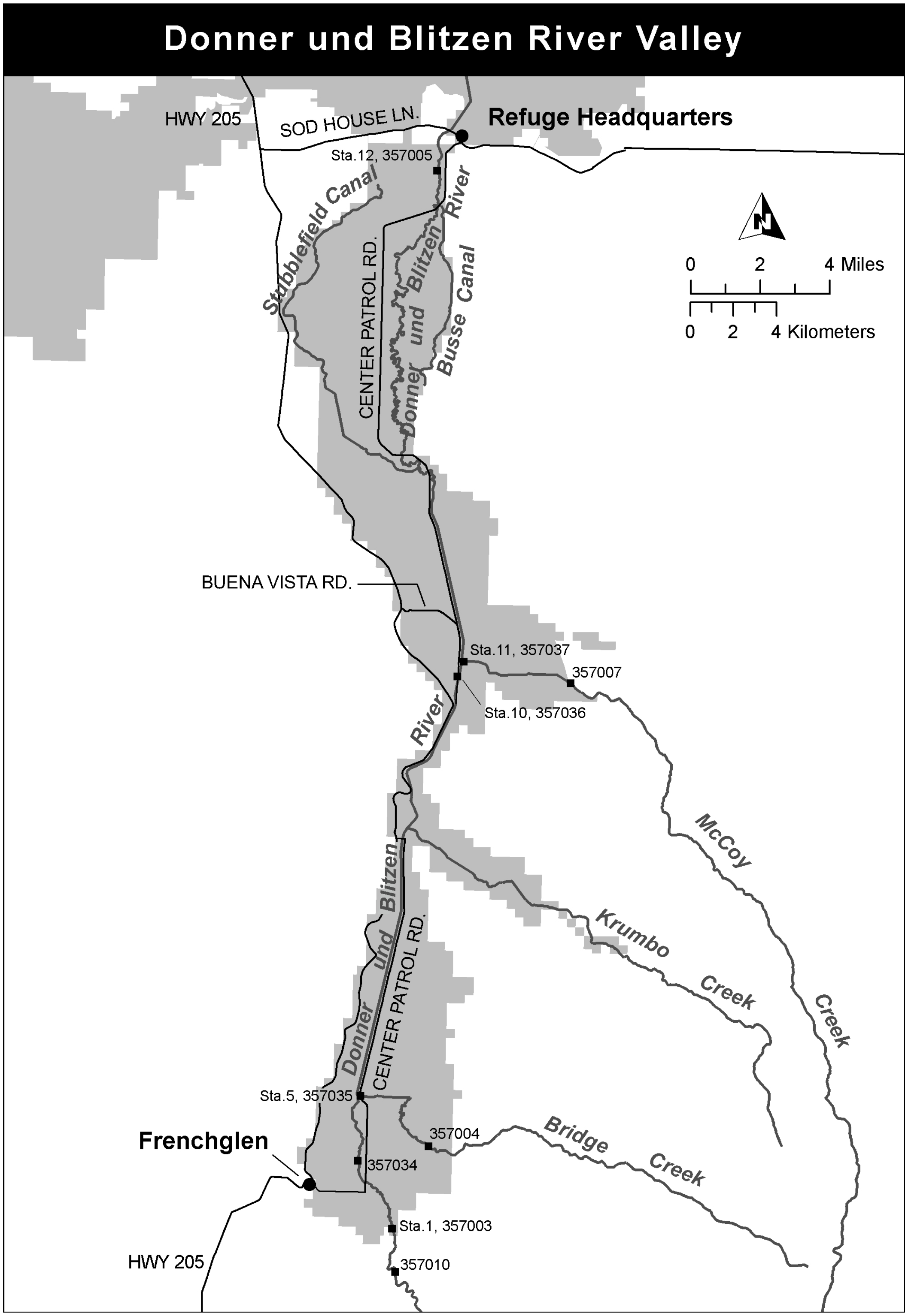


Figure 1. Map of Blitzen River Valley showing rivers and creeks, study monitoring sites, and several major landmarks and geographic features.

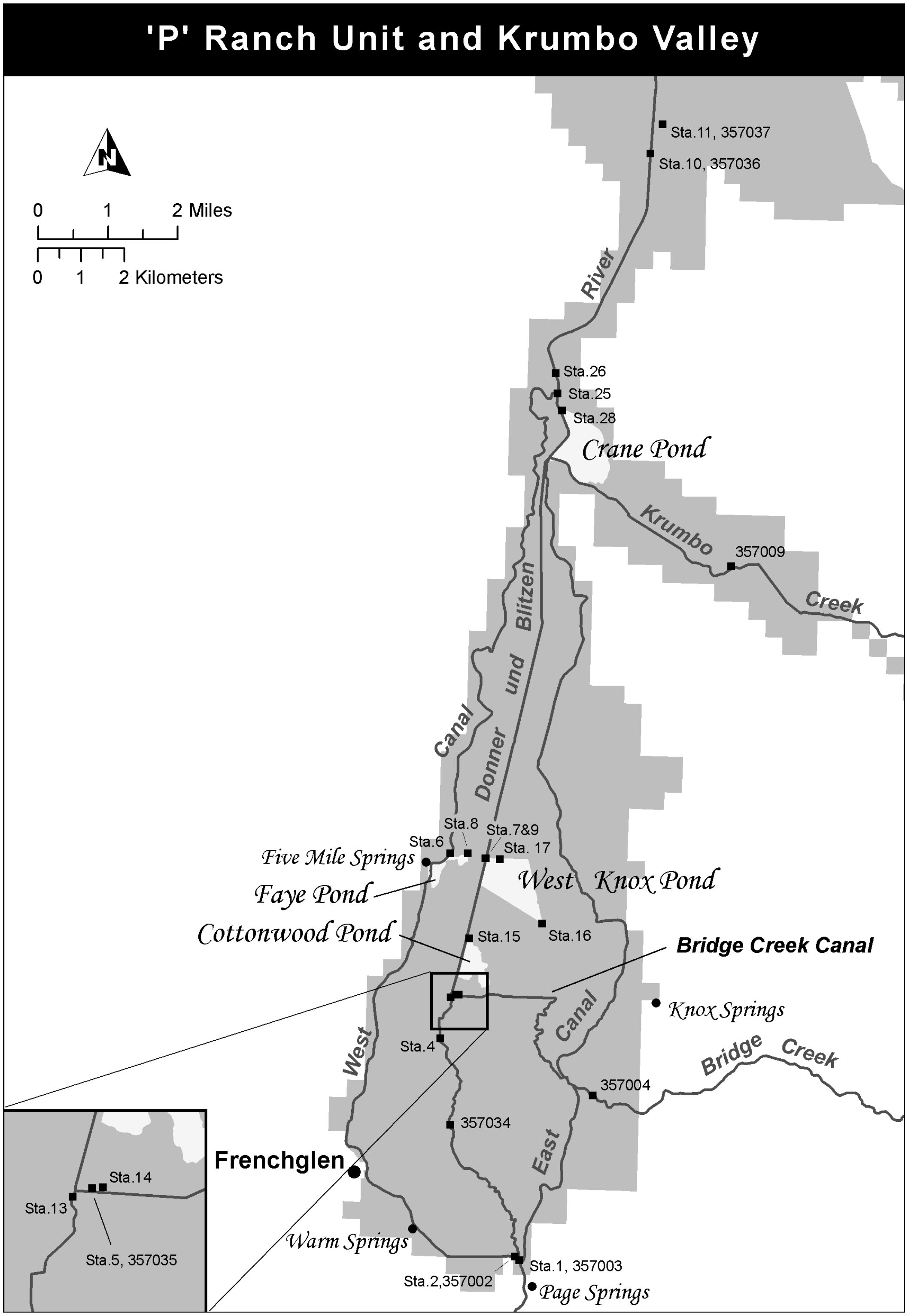


Figure 2. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

We collected grab samples from the sites for laboratory analyses of soluble reactive P (SRP), total P, ammonia-N, nitrate- and nitrite-N, total N, chlorophyll a, biological oxygen demand (BOD), and total suspended solids (TSS). For this study, the analytical sum of nitrate and nitrite is assumed to be nitrate and will be referred to as such. We analyzed chlorophyll a and BOD at almost all sites in 2002 but a reduced number of sites in 2003, based on the low concentrations we reported for many sites in the 2002 samples. Several samples were analyzed for E. coli and total coliform in the spring of 2002 but we discontinued these analyses, based on the low results for all samples. All laboratory analyses used standard analytical methods.

Table 1. River Water Quality Monitoring Sites

Station Number	Station Name	Distance downstream of Station 1 (mi)
1	Blitzen River blw Page Springs	0
13	Blitzen River at Bridge Creek	5.2
5	Bridge Creek at Blitzen	5.2
9	Blitzen River at 5-Mile Bridge	7.2
10/26	Blitzen River at Grain Camp	17.4 (Sta 10) / 14.5 (Sta 26)
11	McCoy Creek at Blitzen	17.9
12	Blitzen River blw Sodlhouse	44.0

Table 2. Irrigation Return Flow and Wetland Water Quality Monitoring Sites

Station Number	Station Name	General location of Station
7	Faye Pond return flow channel	West side of Blitzen River just upstream of 5-Mi Bridge
25	Rock Crusher Pond return flow channel	West side of Blitzen River, outlet channel for West Canal
17	West Knox Pond (permanent wetland)	East side of Blitzen River, south of Knox Drain Rd
15	Cottonwood Pond (seasonal wetland)	East Side of Blitzen River, north of Bridge Creek
28	Crane Pond (permanent wetland)	Adjacent to Blitzen River at downstream end of Krumbo Valley

We describe summary statistics and use box plots to show the distributions of the various water quality parameters as a function of distance downstream on the refuge. In a box plot, the box defines the interquartile range (25th to 75th percentile), the line inside the box defines the median, and the whiskers extending above and below the box define the 90th and 10th percentiles, respectively. Any data values outside of this percentile range are plotted as separated points. Censored data (nondetectable concentrations) were analyzed and plotted using the censored data techniques of Helsel (2005). We used a Kruskal-Wallis test to test for statistically significant differences among a group of sites for a given year and period (runoff or baseflow). We used a t-test (or a Mann-Whitney test) to test for significant differences in means (or medians) between periods (runoff and baseflow) at an individual site.

We developed mass balances and nutrient budgets for both total N and total P for different areas and habitats using the concentration data and the water budget information that was developed in an earlier report. For the nutrient budgets, we divided the irrigation season into two periods, runoff and baseflow, and calculated separate mass balances for each period. The transition from runoff to baseflow was arbitrarily considered by us to occur on Jul 1, which is consistent with the other reports in this study. We averaged total N and total P concentrations for each period and then multiplied that average by the total volume of water for each period to determine the mass of nutrient moving past a given site.

RESULTS

Flows

Figure 3 shows the Apr-Sept Blitzen River flows at several flow monitoring sites for the two years of water quality monitoring. The four sites, from upstream to downstream are 1) the USGS Blitzen gage upstream of the refuge, 2) the Blitzen below Page Springs, 3) the Blitzen below Grain Camp, and 4) the Blitzen below Sodhouse (see Figure 1). The April to September runoff measured at the USGS Blitzen River gage was below normal in 2002 and 2003. Total April-September runoff was 49,565 af in 2002 (31st percentile of all years) and 55,509 af in 2003 (41st percentile of all years). Peak flows were much higher in 2003 than 2002 but baseflows were lower. Average baseflow for July 1 to September 30 was 43 cfs in 2002 and 40 cfs in 2003. In both years, the runoff period on the Blitzen extends from April through May or June and the baseflow period begins sometime in July. We arbitrarily separated the runoff and baseflow periods on Jul 1 in both years. Peaks in flow at the downstream sites are attenuated and delayed relative to the upstream sites and flow generally decreases in the downstream direction due to diversions and losses on the refuge. About the 3rd week of July, the FWS stops most diversions on the refuge and flows at the downstream sites increase and become approximately equal to the upstream sites, as seen in Figure 3.

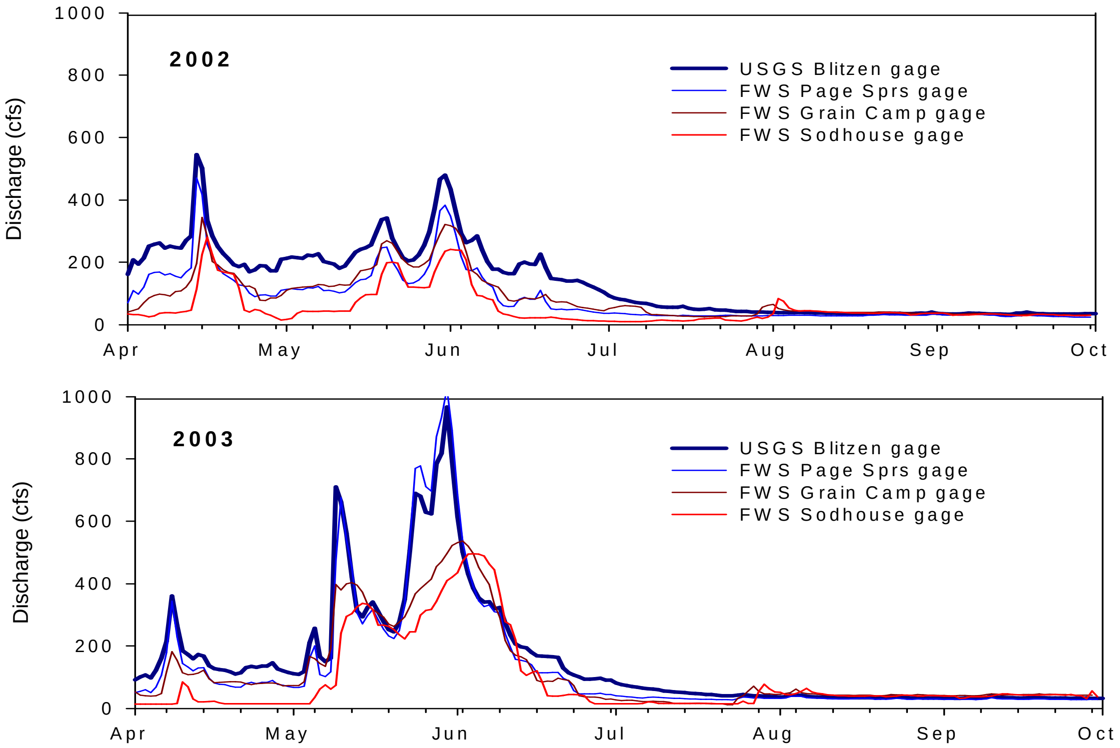


Figure 3. Blitzen River daily flows at USGS gage, Blitzen below Page Springs, Blitzen below Grain Camp, and Blitzen below Sodhouse Dam for Apr-Sept, for 2002 (top) and 2003 (bottom).

Electrical conductivity

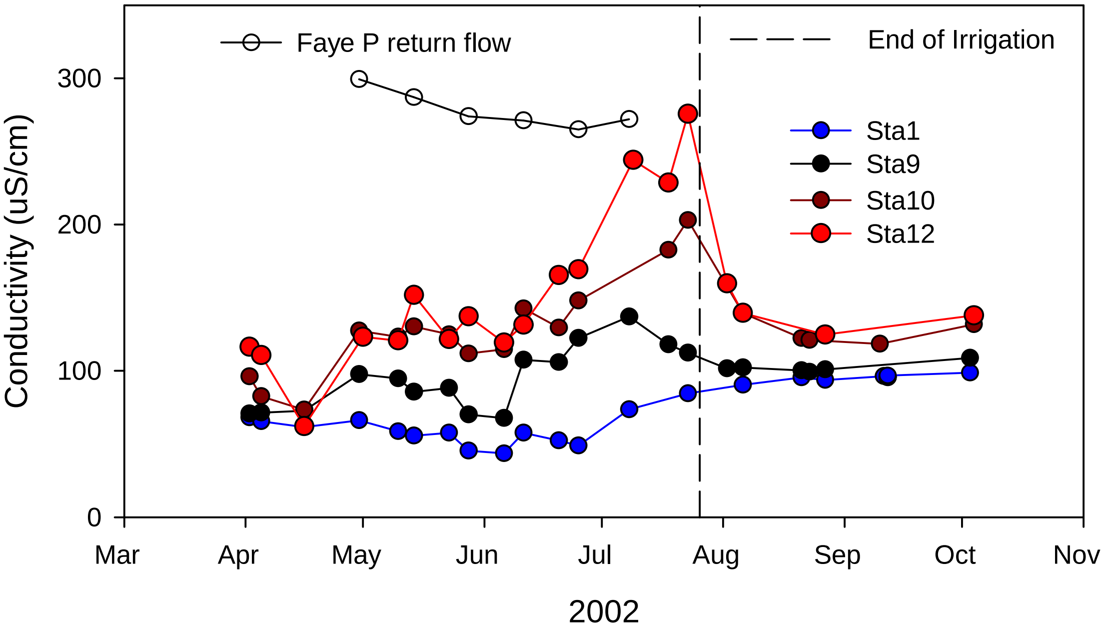
Electrical conductivity is a measure of the dissolved ions in the water and a surrogate measure of water quality. High conductivity is not necessarily harmful to fish and other aquatic organisms in and of itself, but it can be associated with other harmful constituents. There is no state water quality standard for conductivity.

Conductivity in the Blitzen River ranges from about 50 µS/cm at the upstream end of the refuge to about 275 µS/cm at Sodhouse (Figure 4 and Table 3). Roy et al. (2001) reported a similar range and a similar increase with distance downstream in their monitoring results from Jul-Sept, 1999. A Kruskal-Wallis test indicated that, for both periods and both years, the median from at least one site was significantly different from the group at the 0.05 level. The highest river conductivities occur downstream at Station 10/26, Blitzen River near Grain Camp, and Station 12, Blitzen River below Sodhouse. Conductivity also increases seasonally, from the runoff period to the baseflow period. For most of the upstream sites (Stations 1, 13, and 9), this increase was statistically significant. There was no significant increase between the two periods at the downstream sites (Stations 10/26 and 12), except at Station 12 in 2002. Conductivities are more uniform all season at downstream sites when grouped by period. However, there were changes in conductivity throughout the summer that point to the contribution of irrigation return flows as a source of higher conductivity.

Table 3. Median values of conductivity (µS/cm) for runoff and baseflow periods in 2002 and 2003 at Blitzen River sites from upstream to downstream. Paired values in bold are significantly different ($p<0.05$) for runoff and baseflow periods.

Station Number	Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
1	Blitzen River blw Page Springs	**57.7**	**94.6**	**72.4**	**89.8**
13	Blitzen River abv Bridge Creek	na	102.5	**77.5**	**97.2**
9	Blitzen River at 5-Mile Bridge	**87.0**	**102.2**	**82.3**	**109.2**
10/26	Blitzen River nr Grain Camp	124.0	131.8	112.1	133.6
12	Blitzen River blw Sodlhouse	**122.4**	**159.6**	119.4	130.8

Time series plots of conductivity for several river and return flow sites in 2002 and 2003 are presented in Figure 4. For all sites, except the Blitzen below Page Springs, conductivity peaks in July, just prior to the cessation of irrigation and declines in August. Roy et al. (2001) reported a similar trend in conductivity in their monitoring results from Jul-Sept, 1999. This could be indicative of the contribution from irrigation return flows to the river, especially given that the trend is less evident at upstream sites where there is less return flow. Our monitoring of return flows indicates that they are typically higher in conductivity than the river (150 to 300 µS/cm). They represent a greater proportion of the total flow in the river once runoff recedes in July and therefore, they would affect river water quality most at this time. Return flows are greatly reduced or eliminated altogether after irrigation is stopped about the 3rd week in July, so they would affect river water quality much less after this time. This is probably why conductivity declines in the river sites after the end of the irrigation season.



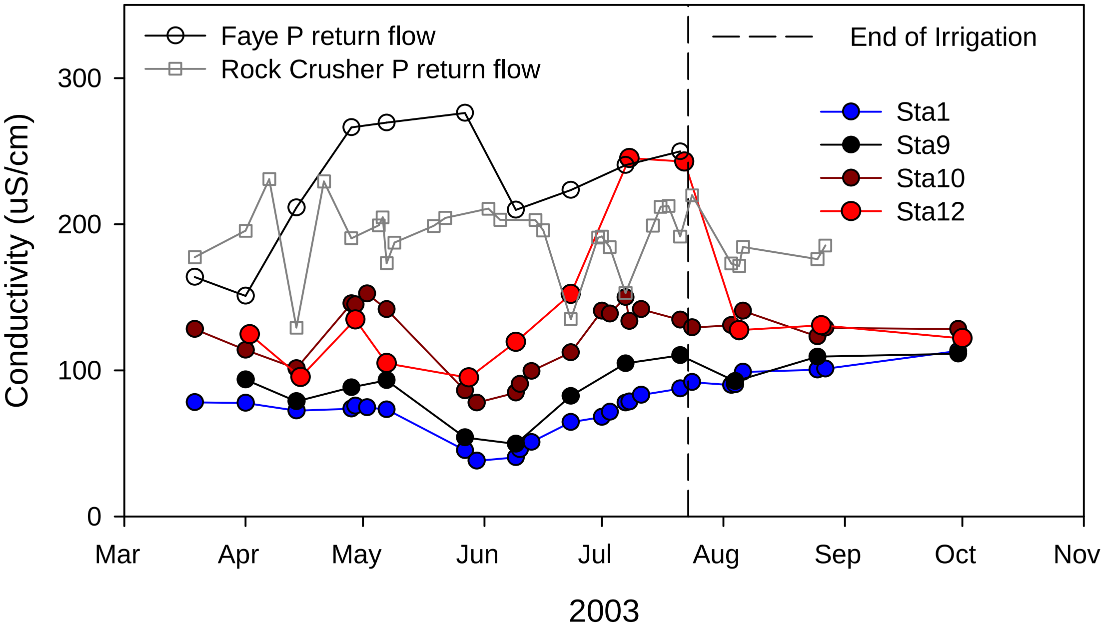


Figure 4. Electrical conductivity at Blitzen River and return flow water quality monitoring stations in 2002 (top) and 2003 (bottom).

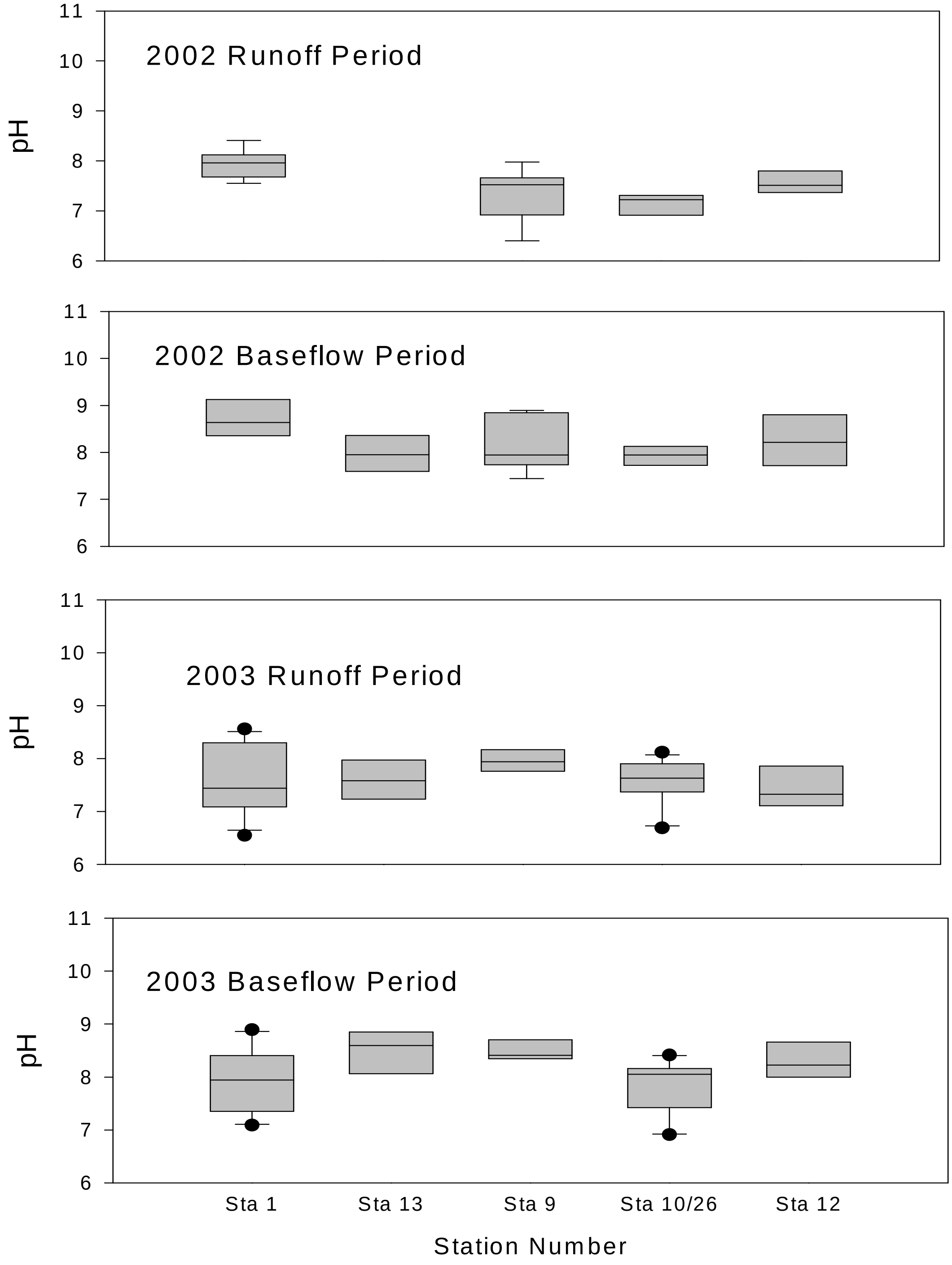


Figure 5. pH at Blitzen River water quality monitoring stations during the runoff and baseflow periods in 2002 (top) and 2003 (bottom).

pH

pH is a measure of the negative log of the hydrogen ion activity, or concentration, in water. The higher the pH, the lower the concentration. The state water quality standard for pH in the Malheur Lake Basin is 7.0 to 9.0.

pH in the Blitzen River generally ranges from 7.0 to 8.5 (Figure 5). At times, pH in the Blitzen River has exceeded the state standard of 9.0, but only at Station 1 at the upstream boundary of the refuge. pH varies diurnally and seasonally. The consumption of CO_2 during the day through photosynthesis can increase pH. pH decreases at night due to increase of CO_2 from re-equilibration with atmospheric CO_2 and decomposition of organic matter. Seasonally, pH is higher during the baseflow period. Warmer temperatures and lower flows increase primary productivity and respiration. And lower flows mean the water column is slower to equilibrate with atmospheric CO_2.

pH tended to decrease downstream in 2002 but not in 2003. A Kruskal-Wallis test indicated that the median from at least one site was significantly different from the group at the 0.05 level for both periods in 2002 but neither period in 2003. The pH at all sites was more uniform in 2003 during runoff and baseflow. Roy et al. (2001) reported a decrease in pH with distance downstream in their monitoring results from Jul-Sept, 1999. A Mann-Whitney test was used to test for significant differences between runoff and baseflow periods at individual sites. The sites with statistically significant differences between the two periods are shown in bold in Table 4. For most sites, the difference between the two periods is significant, with pH higher during the baseflow period. pH in irrigation return flow channels was very similar to river pH and ranged between 7.0 and 8.0. Wetlands that remained flooded through the summer had higher pH, ranging from 8.0 to 9.0 or even greater at times. Overall, return flows do not seem to be affecting river water quality in terms of pH.

Table 4. Median values of pH for runoff and baseflow periods in 2002 and 2003 at Blitzen River sites from upstream to downstream. Paired values in bold are significantly different ($p<0.05$) for runoff and baseflow periods.

Station Number	Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
1	Blitzen River blw Page Springs	**8.0**	**8.6**	7.4	7.9
13	Blitzen River abv Bridge Creek	na	8.0	**7.6**	**8.6**
9	Blitzen River at 5-Mile Bridge	**7.5**	**7.9**	**7.9**	**8.4**
10/26	Blitzen River nr Grain Camp	**7.2**	**7.9**	7.6	8.1
12	Blitzen River blw Sodlhouse	**7.5**	**8.2**	**7.3**	**8.2**

Dissolved oxygen

Dissolved oxygen (DO) is one of the most important water quality parameters for the health of fish and other aquatic organisms (Wetzel, 2001). DO varies diurnally in response to photosynthesis and decomposition. Oxygen is produced during the day through photosynthesis and consumed at night through decomposition. DO will also vary seasonally in response to changes in the vegetation and organic matter concentrations. The solubility of DO is also inversely related to water temperature. As water temperatures warm seasonally, the solubility of DO decreases and concentrations will decrease.

The state water quality standard for DO in the Blitzen River has not been formally defined (Dick Nichols, DEQ Manager in Bend, OR, personnel communication). The statewide water quality criteria for dissolved oxygen in waters identified as providing cold-water aquatic life is a concentration not less than 8.0 mg/L or 90% saturation. Cold-water aquatic life means “aquatic organisms that are physiologically restricted to cold water, including but not limited to native salmon, steelhead, mountain whitefish, char (including bull trout), and trout.” Water bodies in the Malheur Lake Basin may be designated as providing “cold-water aquatic life” but they have not been formally designated yet.

DO concentrations at several sites in the Blitzen River and tributaries dropped below this criteria during the runoff and baseflow periods of both years. Two trends are evident in the data. First, there is a decrease in DO concentrations downstream from Page Springs to Sodhouse (Figure 6). The lowest dissolved oxygen concentrations occur downstream at Station 10/26, Blitzen River near Grain Camp, and Station 12, Blitzen River below Sodhouse. Roy et al. (2001) reported a similar trend in their monitoring results from Jul-Sept 1999. The decrease in concentrations with distance downstream occurs during runoff and baseflow periods. A Kruskal-Wallis test indicated that, for both periods and both years, the median from at least one site was significantly different from the group at the 0.05 level. A Mann-Whitney test was used to test for significant differences between runoff and baseflow periods at individual sites. The sites with statistically significant differences between the two periods are shown in bold in Table 5.

The second trend is a decline in DO concentrations and % saturation from runoff to baseflow period in both years at some sites (Table 5). Time series plots of % saturation in 2002 and 2003 for several river and return flow sites are presented in Figure 7. The measure, % saturation, takes into account any decline in DO concentration related to increasing water temperatures. All river sites begin at about the same DO % saturation in spring and decline throughout the season. Downstream sites decline more than upstream sites. In 2002, DO % saturation recovers in late summer at most sites but in 2003, this does not occur.

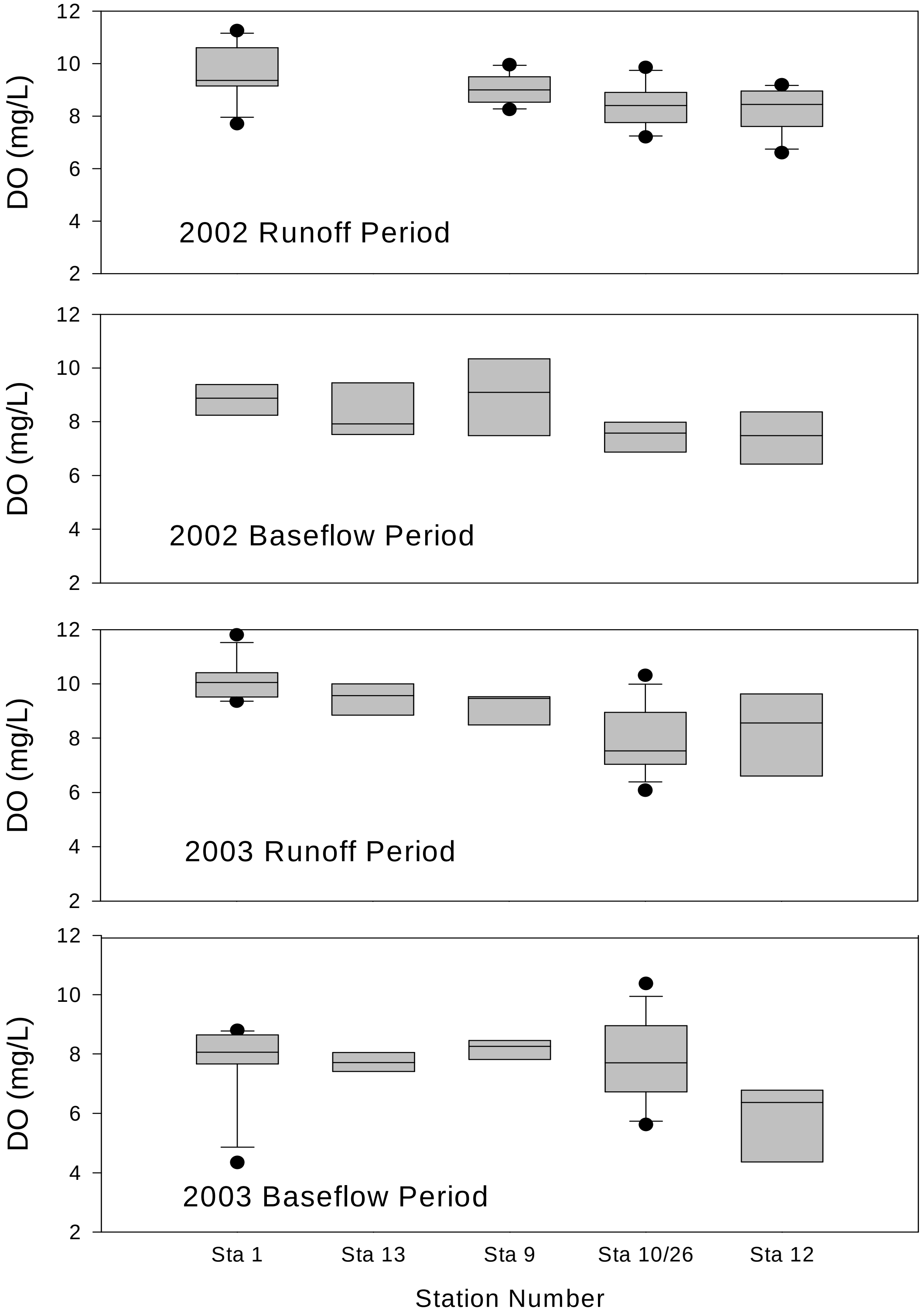


Figure 6. Dissolved oxygen concentrations at Blitzen River water quality monitoring stations during the runoff and baseflow periods in 2002 (top) and 2003 (bottom).

Table 5. Median values of dissolved oxygen concentrations (mg/L) and % saturations for runoff and baseflow periods in 2002 and 2003 at Blitzen River (upstream to downstream) and tributary sites. Paired values in bold are significantly different ($p<0.05$) for runoff and baseflow periods. Years without data mean no monitoring occurred.

Station Number	Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
1	Blitzen River blw Page Springs	9.4 (94%)	8.9 (88%)	**10.1** (102%)	**8.1** (79%)
13	Blitzen River abv Bridge Creek	Na	7.9 (77%)	**9.6** (92%)	**7.7** (73%)
9	Blitzen River at 5-Mile Bridge	9.1 (90%)	9.1 (91%)	9.5 (95%)	8.3 (81%)
10/26	Blitzen River nr Grain Camp	**8.4** (83%)	**7.6** (74%)	7.5 (73%)	7.7 (75%)
12	Blitzen River blw Sodlhouse	8.4 (83%)	7.5 (72%)	8.6 (77%)	6.4 (60%)
5	Bridge Crk at Blitzen	**8.8** (87%)	**6.5** (61%)	**8.9** (87%)	**7.4** (71%)
11	McCoy Crk at Blitzen	9.2 (92%)	8.5 (84%)		

Table 6. Median values of dissolved oxygen (mg/) at irrigation return flow and wetland sites in 2002 and 2003. Years without data mean no monitoring occurred.

Station Number	Station Name	2002	2003
7	Faye Pond return flow channel	4.9 (n=6)	6.4 (n=10)
25	Rock Crusher return flow channel		4.7 (n=33)
17	West Knox Pond	6.6 (n=22)	6.4 (n=25)
15	Cottonwood Pond	6.9 (n=2)	7.1 (n=7)
28	Crane Pond		8.2 (n=11)

Return flow sites are consistently lower in DO than river sites (Table 6). It is likely that return flows and tributaries are contributing to low DO in the river. Unlike conductivity, river DO remains low after irrigation is stopped the 3rd week of July, especially in 2003. As will be discussed under BOD, irrigation and wetland return flows are contributing biodegradable organic material to the river, in addition to low DO waters. This material may be subsequently decomposing, causing DO levels to remain low even after return flows have ceased.

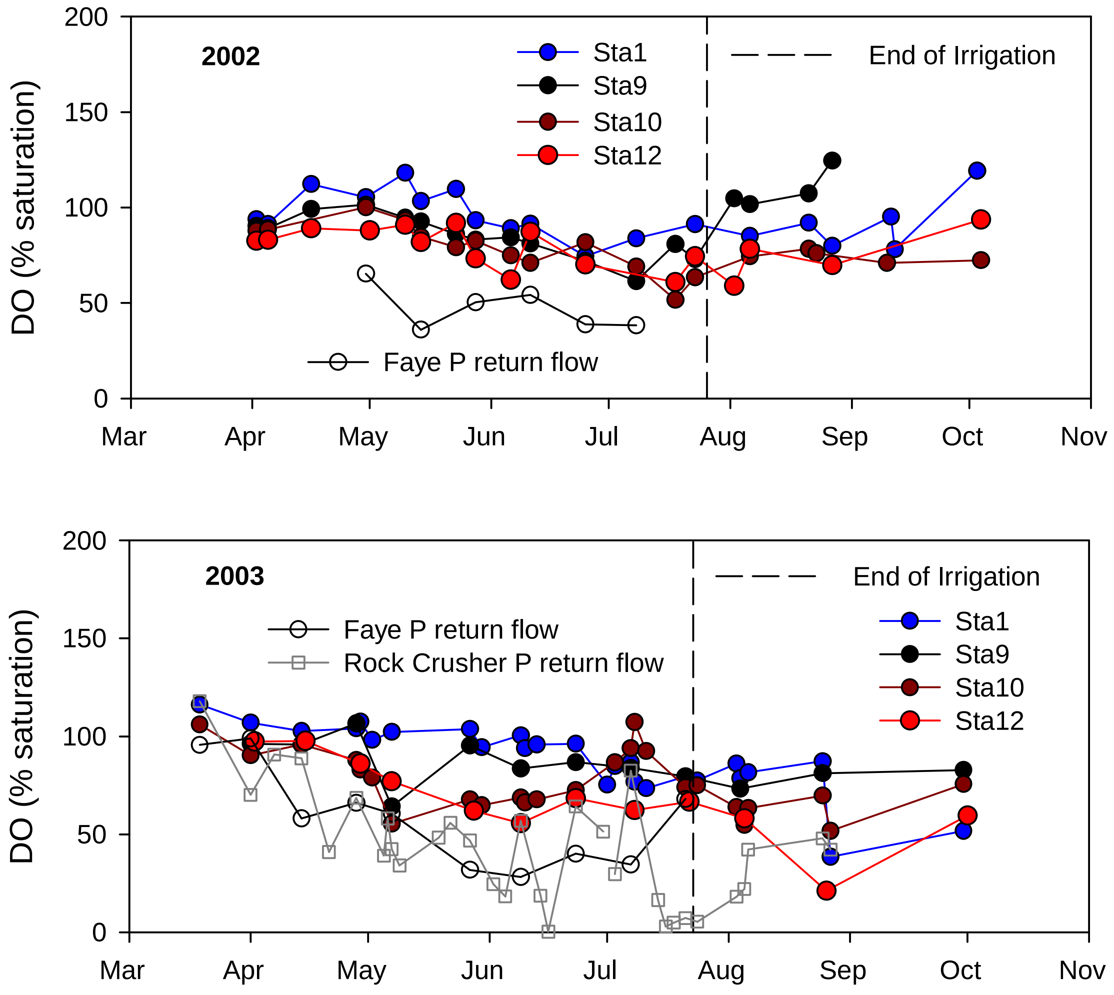


Figure 7. Dissolved oxygen percent saturation at Blitzen River and return flow water quality monitoring stations in 2002 (top) and 2003 (bottom).

Hydrolab monitoring results for pH and DO

Both pH and DO are affected by biological processes (photosynthesis and decomposition) and both parameters, particularly DO concentrations, are partly a function of water temperatures as well. This results in variations diurnally as well as seasonally. We characterized this diurnal and seasonal fluctuation with the 3-day continuous deployments of Hydrolabs at various times during the season. Figures 8 and 9 present box plots of the hourly data collected from early, mid, and late season deployments at two sites along the Blitzen. The sites are Station 1, Blitzen below Page Springs, where the river enters the refuge, and Station 10/26, Blitzen near Grain Camp, about one-third of the way downstream through the Blitzen Valley (Figure 1). Generally, there is much less diurnal fluctuation at the downstream site, especially with pH. Interquartile ranges of pH (represented by the size of the box in the boxplots) are smaller at the downstream sites, as can be seen in Figures 8 and 9. This may indicate less biological activity in this part of the river, at least in terms of primary productivity. There is less fluctuation in pH under high flows, as can be observed in the late May measurements from both sites in both years.

DO concentrations are lower at the downstream site than the upstream site but the seasonal trends are similar at both sites. Under high flows in late May, DO concentrations are high and do not fluctuate much diurnally. Seasonal minimums of DO occur in July at both sites, especially in 2002, and this was evident in the instantaneous values collected at all river sites. One reason for this may be that water temperatures reach their seasonal maximums in July. The solubility of DO is a function of water temperature and increasing temperatures result in lower DO concentrations. Moreover, warmer water temperatures increase the rate of organic decomposition, which consumes DO. Another factor could be the contribution of low DO irrigation return flows through the end of July. DO concentrations recover somewhat in late summer as water temperatures decrease and return flows diminish. DO concentrations rebound in August and September at both sites.

Biological oxygen demand (BOD)

BOD is an empirical test of the oxygen requirements for biodegradation of organic material in a water sample. It can be used to indicate the relative concentration of biodegradable organic material in waters and the general water quality of a water body. Higher BOD will correspond with lower DO. Pristine waters have a BOD of < 1.0 mg/L and moderately polluted water have BOD ranging from 2.0 to 8.0 mg/L. There is no state standard for BOD in the Malheur Lake Basin.

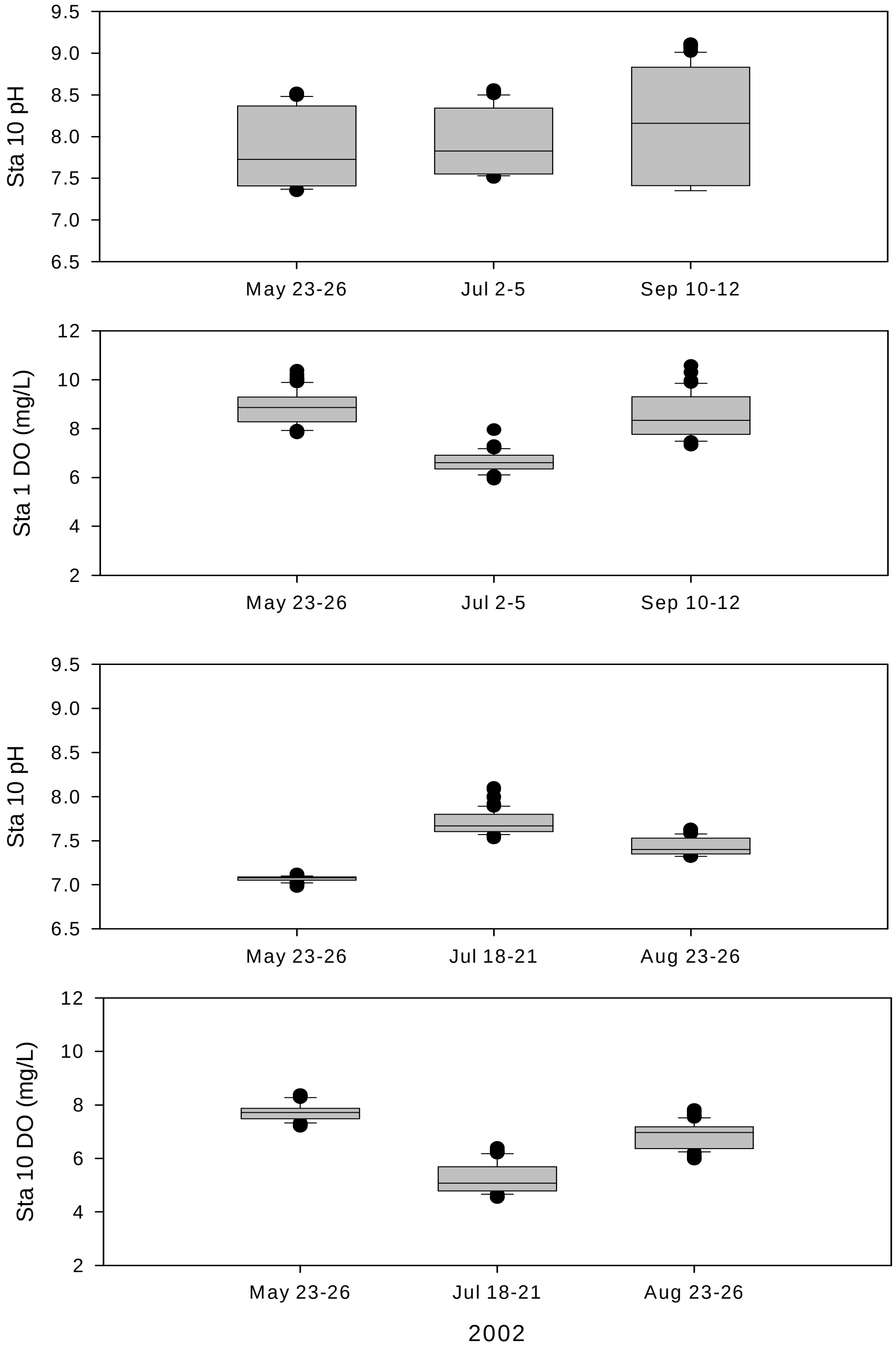


Figure 8. Distribution of hourly pH and dissolved oxygen concentrations at two Blitzen River water quality monitoring stations (Stations 1 and 10) for three deployments in 2002.

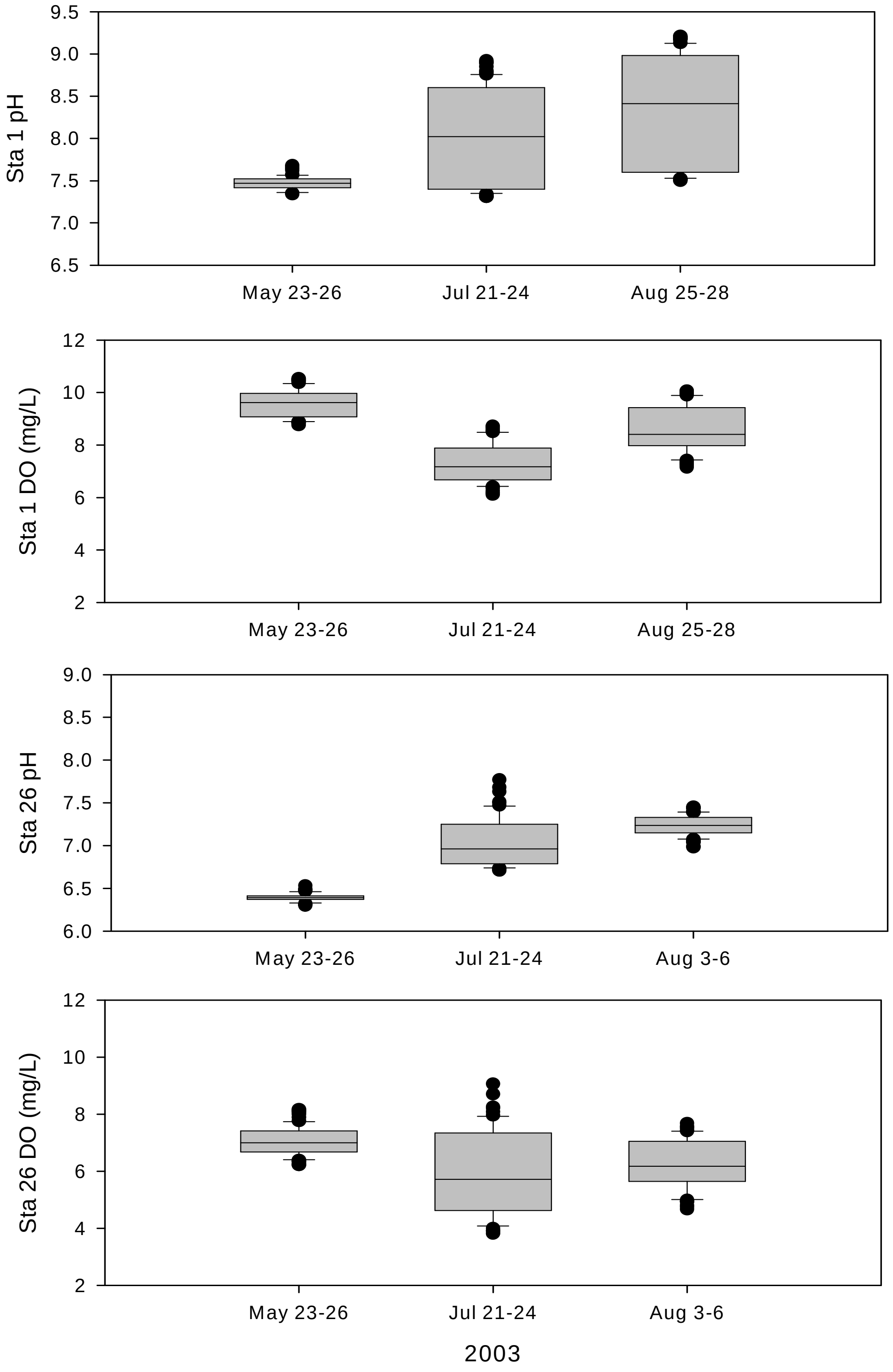


Figure 9. Distribution of hourly pH and dissolved oxygen concentrations at two Blitzen River water quality monitoring stations (Stations 1 and 10) for three deployments in 2003.

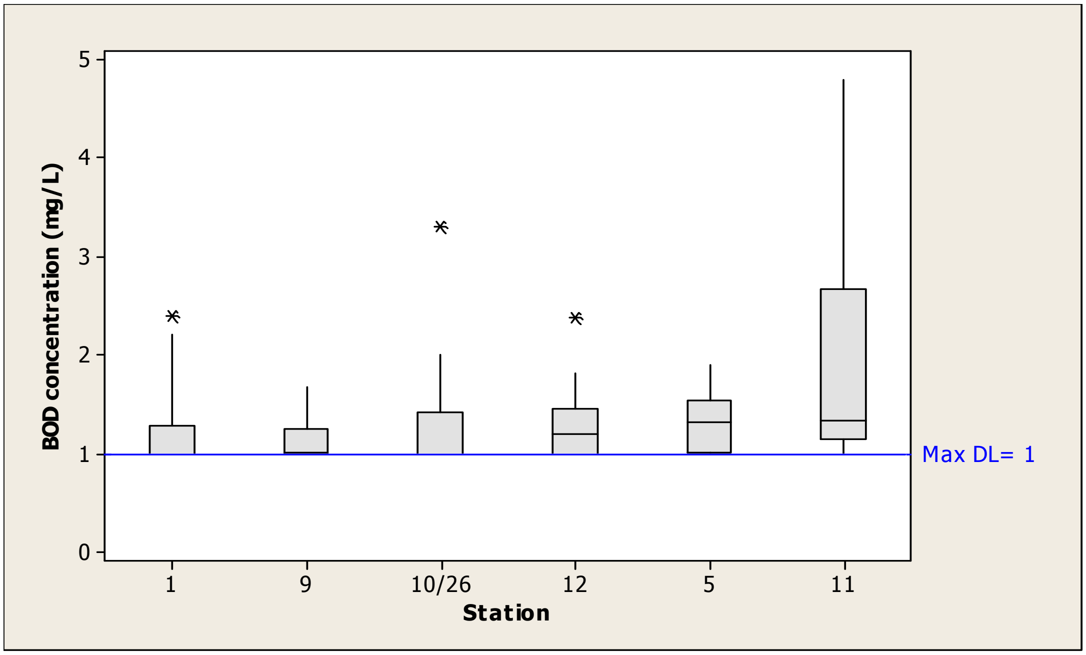


Figure 10. Censored boxplots of BOD for Blitzen River water quality monitoring stations for both 2002 and 2003.

BOD data for both seasons and both years are grouped by site and presented in Figure 10. Between 40 and 60% of the river samples and 60 to 80% of the tributary samples were non-detects (< 1.0 mg/L). Station 12, Blitzen below Sodhouse, and the two tributary samples have higher concentrations than the other river sites. A smaller percentage of the return flow and wetland sites, between 0 and 30%, were below the detection limit. In general, these sites had higher BOD concentrations than the river and tributary sites. It is likely that irrigation and wetland return flows are contributing biodegradable organic material to the river, resulting in lower DO concentrations in the river.

Turbidity and total suspended solids (TSS)

Turbidity and TSS are two independent instantaneous measures of the amount of suspended solid material in the water. The suspended solids can be organic (possibly organic matter or algae) or inorganic (clay and silt particles that carried in suspension); the two measures do not distinguish between forms of suspended matter. The state water quality standard for turbidity is that there can be no more that a 10% cumulative increase in natural stream turbidities, measured relative to a control point immediately upstream of the turbidity-causing activity. The standard is directed more at point sources and it’s not clear how it would apply to refuge activities.

The two field water quality parameters follow similar trends at all sites, which is not surprising since the two parameters are different measures of suspended solids in the water column. In the upstream Blitzen River sites (Stations 1, 13, and 9), turbidity and TSS were closely correlated with flows, increasing with high flows and decreasing with low flows (Figure 11). Values at Station 5 (Bridge Creek at Blitzen) showed a similar seasonal trend. Turbidity at all these sites is much lower during the baseflow period compared to the runoff period. At the downstream Blitzen River sites, turbidity increased during runoff, decreased in mid-summer briefly, and then increased again in late summer and early fall. This occurred most obviously at Station 12 (Blitzen below Sodhouse) in 2002 and 2003 and Station 10 (Blitzen near Grain Camp) in 2002. A Kruskal-Wallis test indicated that, for the baseflow period in both years, the median from Station 10 in 2002 and Station 12 in 2002 and 2003 was significantly different from the other sites at the 0.05 level. A Mann-Whitney test was used to test for significant differences between runoff and baseflow periods at individual sites. The sites with statistically significant differences between the two periods are shown in bold in Table 7**.** All of the upstream sites show significant differences between runoff and baseflow periods but Station 10 in 2002 and Station 12 in 2002 and 2003 do not, because of the late season increase at these two sites.

Irrigation return flows could partly be responsible for the late season increase at the downstream sites. Wetlands likely settle solids, especially inorganic material, reducing turbidity and TSS, but there is much more photosynthetic activity and biotic production of suspended material in some of these wetlands (like West Knox Pond). The volume of return flows reaching the river in August and September is small but they could be contributing to suspended solid loads in the river.

Table 7. Median values of turbidity (NTU) for runoff and baseflow periods in 2002 and 2003 at Blitzen River sites from upstream to downstream. Paired values in bold are significantly different ($p<0.05$) for runoff and baseflow periods.

Station Number	Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
1	Blitzen River blw Page Springs	**13.6**	**4.0**	**10.2**	**2.3**
13	Blitzen River abv Bridge Creek	na	3.1	**12.5**	**2.3**
9	Blitzen River at 5-Mile Bridge	**17.3**	**3.8**	**21.0**	**4.4**
10/26	Blitzen River nr Grain Camp	6.4	11.0	**20.0**	**5.3**
12	Blitzen River blw Sodlhouse	12.2	12.6	31.1	17.9

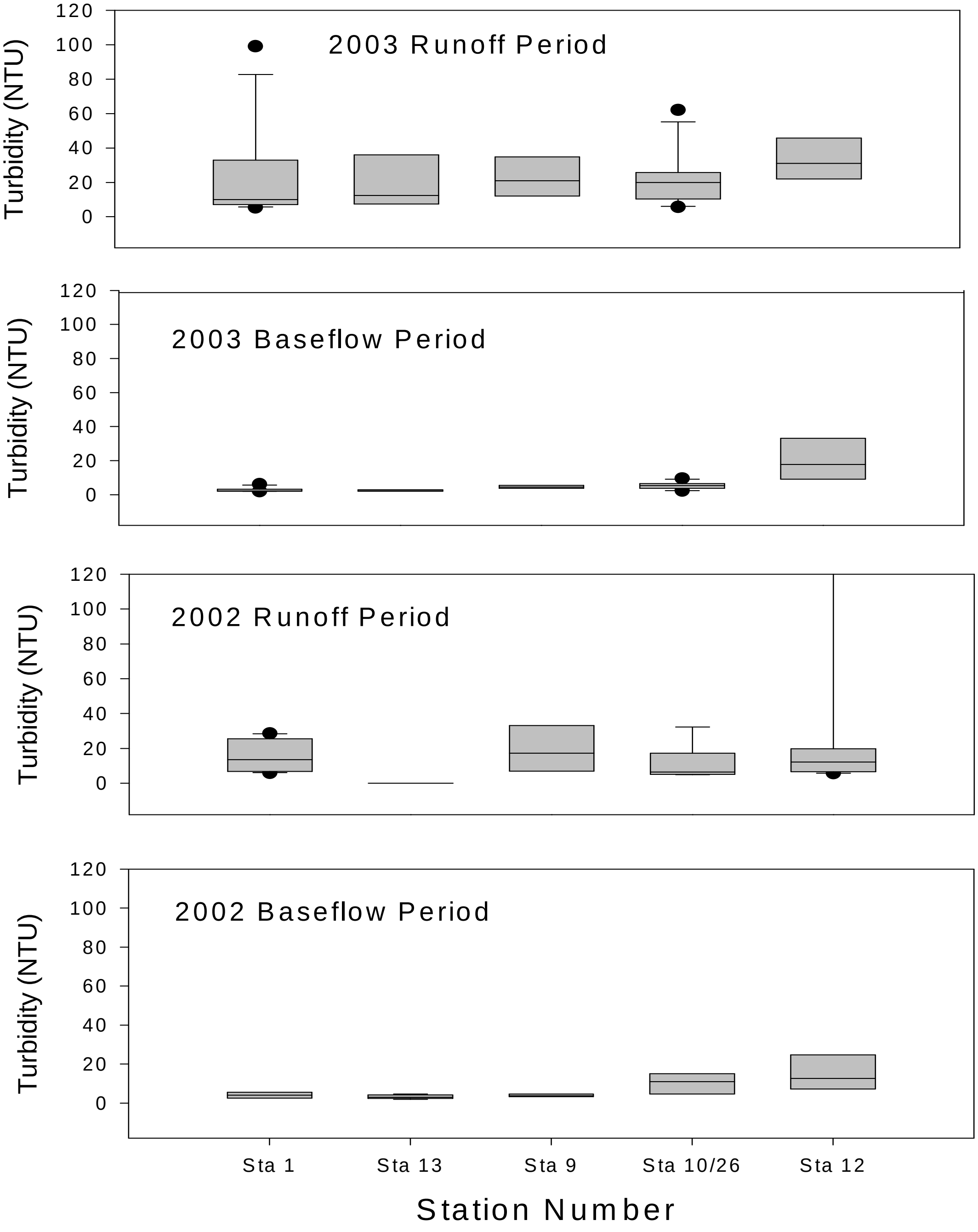


Figure 11. Turbidity at Blitzen River water quality monitoring stations during the runoff and baseflow periods in 2002 (top) and 2003 (bottom).

More likely, downstream increases in turbidity later in the season are related to dam operations. The dams back up water for diversion during the irrigation season, and likely trap sediment in the process. When diversions are ceased about the 3rd week of July, the dam gates are opened and this trapped sediment may be mobilized. The timing of the late season increases seems to implicate dam operations since turbidity increases coincide with the opening of the dams in late July and early August. Carp activity may also contribute to sediment mobilization.

Phosphorus

Phosphorus is most often the nutrient limiting primary productivity in freshwater ecosystems (Wetzel, 2001). There is no state water quality standard for P in Malheur Lake Basin. Total P concentrations in nonpolluted natural waters extend over a very wide range but are generally between 0.01 and 0.05 mg/L (Wetzel, 2001).

There are two basic forms of forms of phosphorus that were distinguished analytically in this study: total P and SRP. Total P is a measure of all P in the sample and includes solid organic and inorganic forms and dissolved forms. SRP is a measure of dissolved P, which is primarily orthophosphate. It is primarily SRP that is immediately bioavailable to organisms.

Total P concentrations in the river increase downstream through the refuge from Page Springs to Sodhouse Dam (Figure 12 and Table 8). Median total P concentrations from Page Springs to Sodhouse increase two to threefold or more. The most obvious increases occur downstream at Station 10/26 and Station 12. A Kruskal-Wallis test indicated that, for both periods in both years, the median from at least one site was significantly different from the group at the 0.05 level. Differences between runoff and baseflow periods were not as strong. Generally, total P concentrations were higher during the runoff period but this was not always the case and the differences were not always statistically significant (Table 8).

High concentrations of total P are episodic and may be related to suspended sediment and higher flows. The largest range of total P concentrations occurred during the 2003 runoff period. This may be related to the large range of flows during this period. Total P is associated with suspended sediment, especially at the upstream sites, and both of these parameters increase with higher flows. Downstream concentrations were not as closely related to suspended sediment and may reflect a combination of sources of P, including irrigation and wetland return flows and internal loading from resuspended sediments coinciding with dam operations. Concentrations of total P in return flows and adjacent wetlands were typically much higher than the river concentrations (Table 9). This source could be partly responsible for increasing total P concentrations downstream.

The percentage of P as SRP ranges from about 30 to 50% in the river samples, with no apparent trends downstream or seasonally. The percentage of SRP in wetland and return flow samples ranges higher, from 30 to 75%. It's likely that organic P is getting converted to SRP in wetlands and flooded fields. Mayer (2005) described a similar trend in wetlands at Klamath Basin NWR. This means that return flows from wetlands and wet meadows in the Blitzen Valley could be a source of bioavailable P at times.

Table 8. Median values of total phosphorus (mg/L) for runoff and baseflow periods in 2002 and 2003 at Blitzen River sites from upstream to downstream. Paired values in bold are significantly different ($p<0.05$) for runoff and baseflow periods.

Station Number	Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
1	Blitzen River blw Page Springs	0.04	0.03	0.05	0.01
13	Blitzen River abv Bridge Creek	na	0.03	**0.03**	**0.02**
9	Blitzen River at 5-Mile Bridge	**0.07**	**0.04**	**0.09**	**0.04**
10/26	Blitzen River nr Grain Camp	0.10	0.09	**0.13**	**0.05**
12	Blitzen River blw Sodlhouse	0.08	0.11	0.13	0.12

Table 9. Median values of total phosphorus (mg/L) at irrigation return flow and wetland sites in 2002 and 2003. Years without data mean no monitoring occurred.

Station Number	Station Name	2002	2003
7	Faye Pond return flow channel	0.29 (n=9)	0.25 (n=10)
25	Rock Crusher return flow channel		0.13 (n=20)
17	West Knox Pond	0.53 (n=14)	0.51 (n=12)
15	Cottonwood Pond	0.13 (n=4)	0.16 (n=8)
28	Crane Pond		0.45 (n=11)

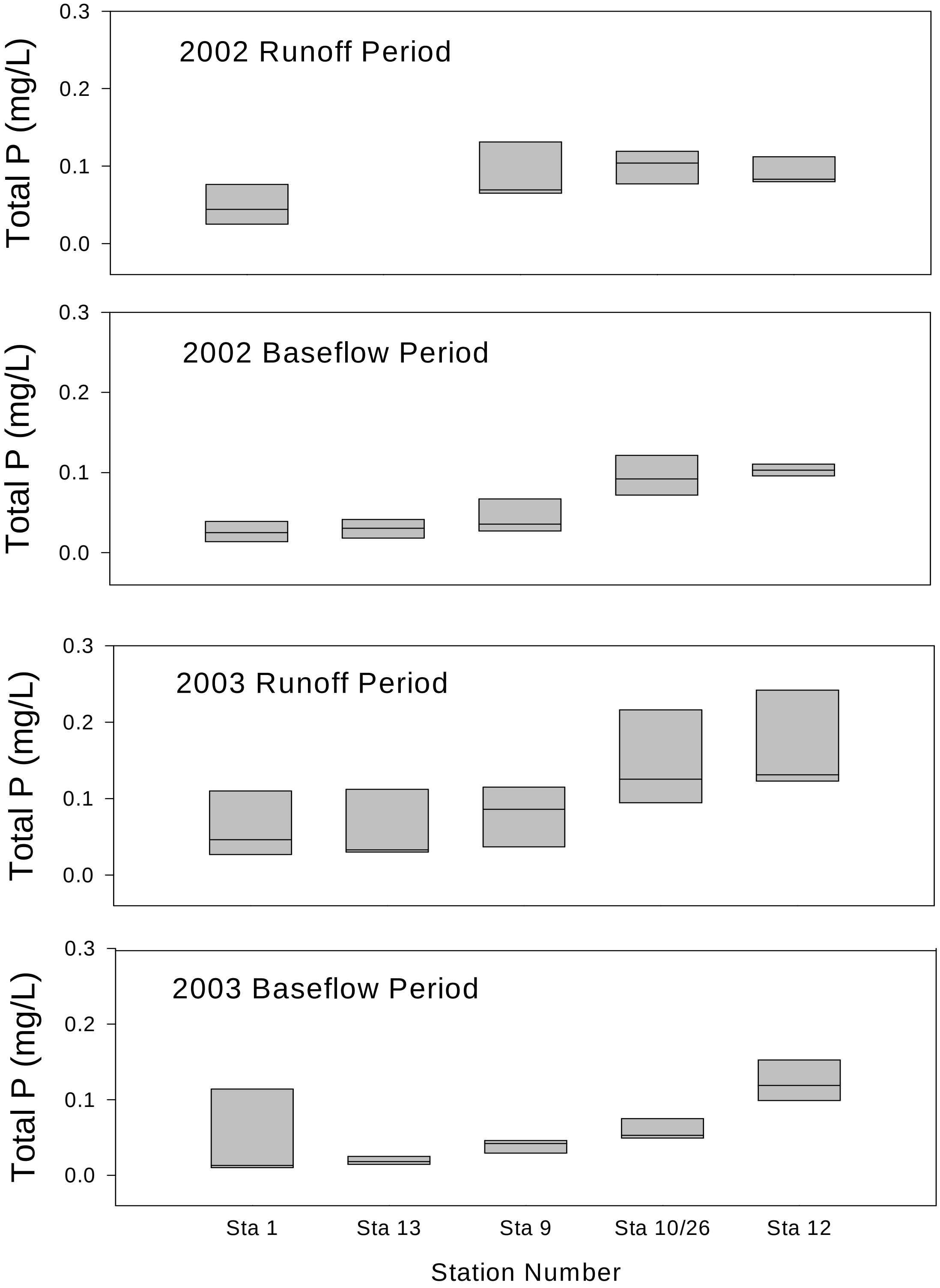


Figure 12. Total P at Blitzen River water quality monitoring stations during the runoff and baseflow periods in 2002 (top) and 2003 (bottom).

Nitrogen

Nitrogen is another macronutrient essential for primary productivity. It occurs in freshwater in numerous forms: dissolved molecular N_2, organic forms, nitrate, nitrite, and ammonia. Sources include precipitation, nitrogen fixation, and inputs from surface and ground water drainage (Wetzel, 2001).

There are three basic forms of forms of nitrogen that can be distinguished analytically: total N, nitrate-N, and ammonia-N. Total N is a measure of all N in the sample and includes solid organic and inorganic forms and dissolved forms. Most of the solid N is going to be in organic form. Nitrate is the oxidized form of dissolved N. Ammonia is the reduced form of dissolved N. Both of these dissolved forms are immediately bioavailable to organisms.

Median total N concentrations from the river sites were not significantly different from each other during the runoff period but during the baseflow period of both years, there was at least one site that was statistically different from the other sites. For individual sties, there were no significant differences between periods at any of the sites in 2002 (Table 10). In 2003, several sites had significantly higher concentrations of total N during the runoff period. These were the same sites that had significant differences in total P concentrations (see Table 8). As with total P, this may be related to the higher flows that occurred during runoff in 2003. The higher total N is likely associated with suspended organic material.

The most obvious trend in N concentrations is an increase in total N at the two most downstream sites, Station 10/26, Blitzen near Grain Camp, and Station 12, Blitzen below Sodhouse (Figure 13). During the baseflow period of both years, total N concentrations decreased along the upstream end of the refuge and then increased further downstream. This could reflect the effect of irrigation return flows. As with total P, the concentrations of total N in irrigation return flows and wetlands are much higher than in the river (Table 11). Return flows represent a greater proportion of the total flow in the river once runoff recedes in July and therefore, they would affect river water quality most at this time.

The percentage of N as nitrate and/or ammonia, also referred to as bioavailable N, ranges from 12 to 30% in the river samples. The highest fraction, 30%, occurred at Sta 1, Blitzen below Page Springs, in both years. The fraction of N as nitrate or ammonia decreased with distance downstream even as total N increased. The fraction was even lower in most of the irrigation return flows and wetlands and ranged from 2 to 14%. Mayer (2005) reported similar findings for wetlands in the Klamath Basin NWRC. The wetlands in the Klamath Basin and Malheur may be sink for bioavailable N through mineralization, nitrification, and denitrification.

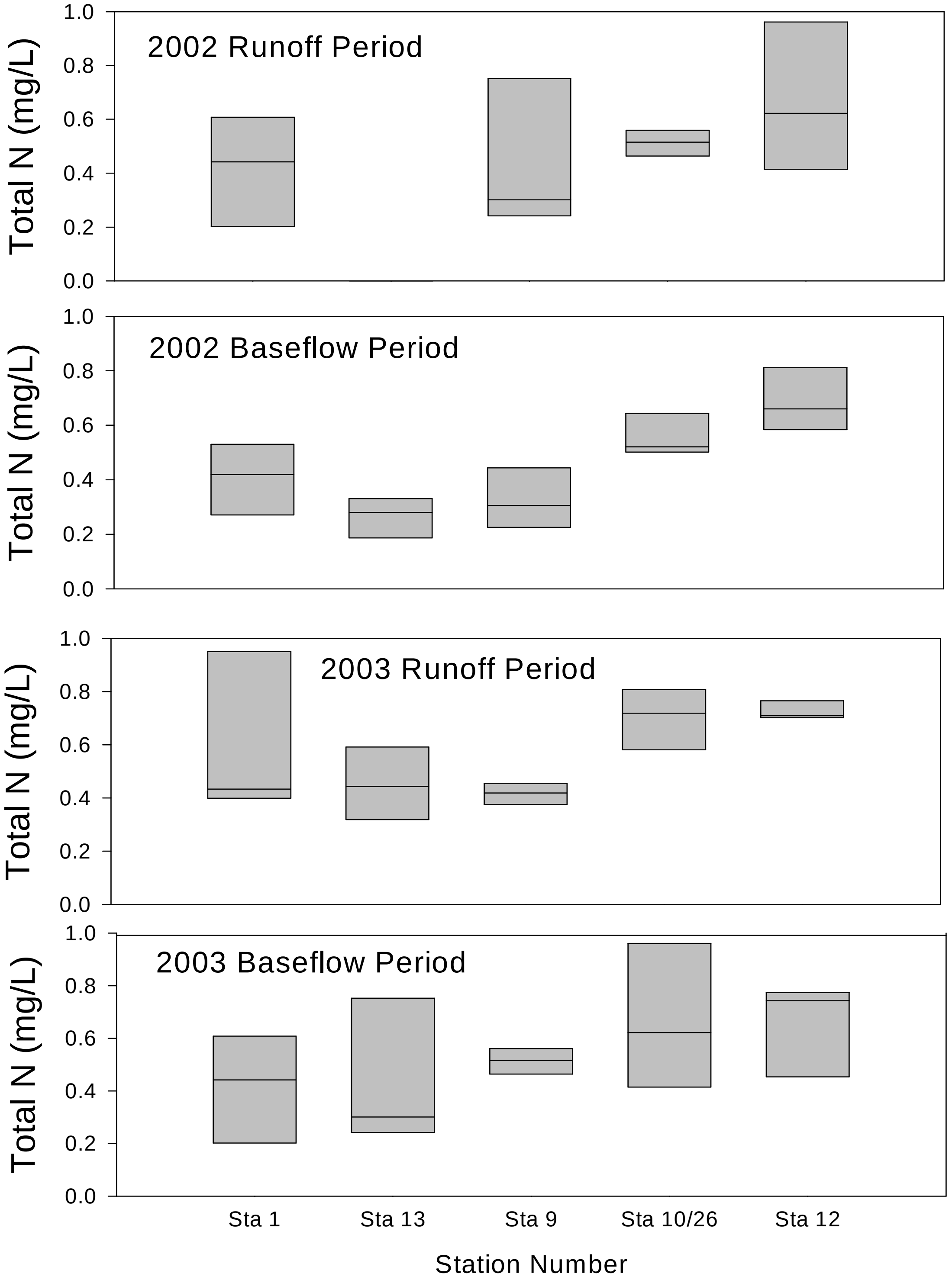


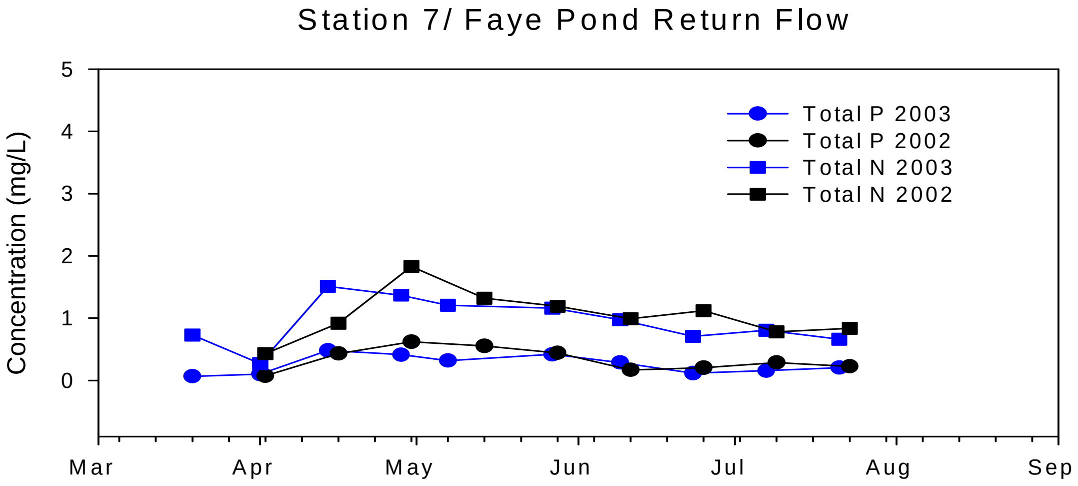
Figure 13. Total N at Blitzen River water quality monitoring stations during the runoff and baseflow periods in 2002 (top) and 2003 (bottom).

Table 10. Median values of total nitrogen (mg/L) for runoff and baseflow periods in 2002 and 2003 at Blitzen River sites from upstream to downstream. Paired values in bold are significantly different ($p<0.05$) for runoff and baseflow periods.

Station Number	Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
1	Blitzen River blw Page Springs	0.44	0.42	0.44	0.27
13	Blitzen River abv Bridge Creek	Na	0.29	**0.44**	**0.15**
9	Blitzen River at 5-Mile Bridge	0.30	0.31	**0.42**	**0.30**
10/26	Blitzen River nr Grain Camp	0.52	0.52	**0.72**	**0.38**
12	Blitzen River blw Sodlhouse	0.62	0.66	0.71	0.74

Table 11. Median values of total nitrogen (mg/L) at irrigation return flow and wetland sites in 2002 and 2003. Years without data mean no monitoring occurred.

Station Number	Station Name	2002	2003
	Faye Pond return flow channel	0.99 (n=9)	0.89 (n=10)
25	Rock Crusher return flow channel		1.08 (n=20)
17	West Knox Pond	1.50 (n=14)	2.28 (n=12)
15	Cottonwood Pond	0.78 (n=4)	1.37 (n=8)
28	Crane Pond		2.56 (n=11)



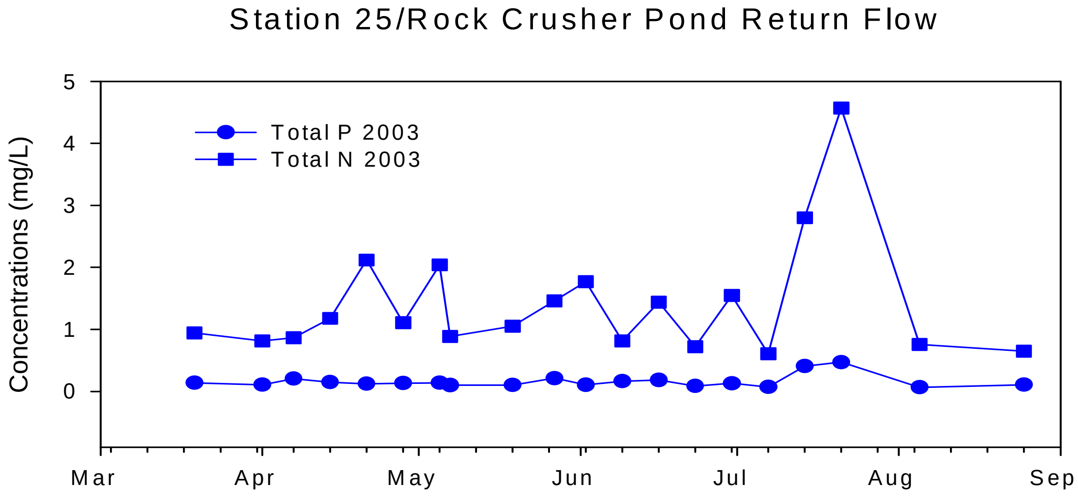


Figure 14. Total P and Total N at two return flow sites along the Blitzen River, Station 7 sampled in 2002 and 2003, and Station 25, sampled in 2003 only.

N and P in irrigation and wetland return flows

In general, concentrations of total P and total N in the wetlands and irrigation return flows are higher than the river concentrations (Figure 14). At Station 7, Faye Pond return flow, and Station 25, West Canal return flow, concentrations of TP and TN increased through spring and peaked in May, then declined in both years. At Station 25, they increased considerably in July 2003 again, especially total N, for reasons unknown. The higher concentrations early in the season could be a result of decomposition of vegetation and other organic material, including cow manure, from the previous season. This makes physical sense, however, we don't really have enough monitoring information to verify sources.

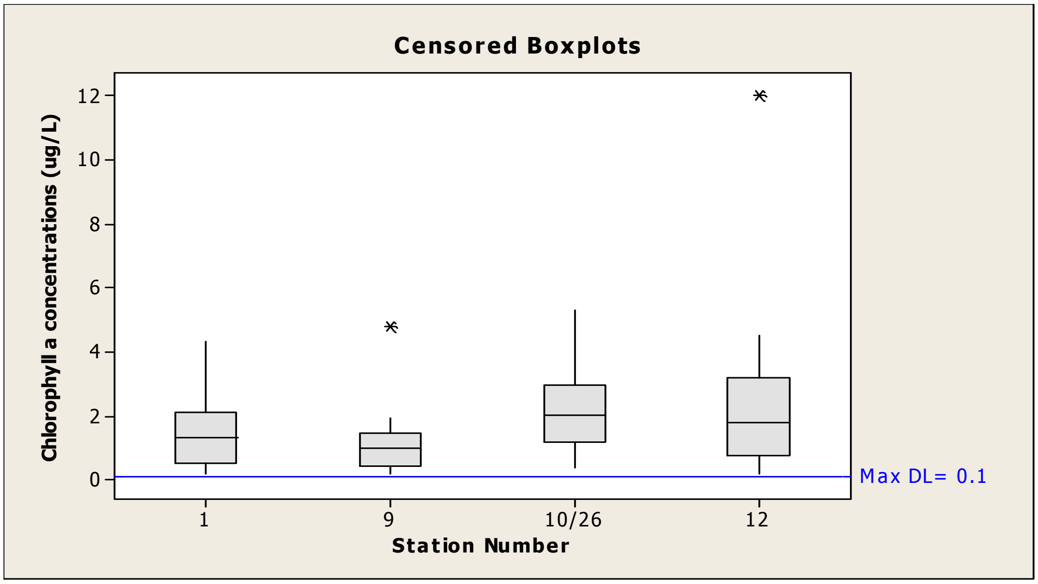


Figure 15. Censored boxplots of chlorophyll a for Blitzen River water quality monitoring stations for both 2002 and 2003.

Chorophyll a

Nutrient-rich waters can facilitate excessive algae growth and poor water quality. Chlorophyll a concentrations are an indicator of algal biomass and general water quality conditions. All plants, including algae, contain chlorophyll a. For planktonic algae, chlorophyll a constitutes about 1 to 2 % of the dry weight. The state water quality standard for chlorophyll a is 15 µg/L for rivers, but this standard does not apply to marshes.

Chlorophyll a concentrations were low overall (< 4 µg/L) and showed little variability in time or space (Figure 15). For the river sites, roughly 5% to 25% of the samples were below the detection limit of 0.1 µg/L. A Kruskal-Wallis test indicated that there were no significant differences in the medians between sites at the 0.05 level. There was a slight tendency for higher concentrations with distance downstream. Despite the availability of macronutrients, there appears to be little problem with excessive algae and euthophication in the river. The chlorophyll a concentrations represent grab samples from the water column. We did not attempt to sample for periphytic algae, only planktonic algae.

Based on TN:TP ratios, the upper reaches of the Blitzen River appear to be P-limited, with TN:TP molar ratios of >23 much of the time (Wetzel, 2001). This may be one reason for the low algal biomass in the river. P concentrations do increase downstream and the system appears to be less limited in terms of P further downstream. However, algal biomass appears low even in this reach, based on chlorophyll a concentrations in the water column.

E. coli and total coliform

E. coli and total coliform are bacteria groups that are commonly used as indicators for fecal contamination. *E. coli* is an indicator for fecal material from mammals. The state standard for *E. coli* is that the geometric mean of 5 samples collected over a one month period can not exceed 126 organisms per 100 milliliters and no single sample can exceed 406 organisms per 100 milliliters.

E. coli samples from Station 1, Blitzen below Page Springs, were very low (geometric mean of 1 organism/100 ml). Numbers increased slightly downstream at Station 10, Blitzen near Grain Camp, and Station 12, Blitzen blw Sodhouse Dam, but they were still quite low (geometric means of 10 organisms/100 ml or less). Station 7, Faye Pond return flow, and Station 17, West Knox Pond, also had low numbers (geometric means < 5 organisms/100 ml). The highest numbers of E. coli were found in samples from Station 11, McCoy Creek at Blitzen, but the numbers were still well below the standard (< 50 organisms/100 ml).

Total coliform is a broader indicator of fecal material from all warm-blooded animals. Geometric means for total coliform ranged in the low hundreds for all sites. There did not appear to be any trends downstream. There is no state standard for total coliform.

Nutrient Budgets and Mass Loadings

In the previous section of this report, we have examined how concentrations of water quality constituents change through the refuge. Now we will examine how mass loads change. A mass load is defined as concentration*discharge. We develop nutrient budgets, based on mass loads, for several river reaches, areas, and habitats on the refuge for the Apr-Sept period. These are based, in part, on water budget information developed and discussed in the previous report entitled "*Water Budgets, Net Inflow, and Consumptive Use Estimates for Malheur National Wildlife Refuge.*"

Buena Vista/Frenchglen Area

We consider the river reach between Page Springs and Grain Camp for the first nutrient budget (Figure 1 and 2). This reach of the Blitzen River flows through the Buena Vista/Frenchglen area of the refuge and nutrient concentrations will be affected by management practices in this area. The total irrigated area in the Frenchglen and Buena Vista Area is about 22,000 acres. This includes as much as 5,300 acres (24%) of open water ponds and wetlands. We developed a water budget for this area in a previous report.

Methods

We consider total mass load into this reach as the sum of mass load at Station 1, Blitzen below Page Springs, and Station 5, Bridge Creek at Blitzen. We consider total mass load out of this reach to consist of the mass load at Station 10/26, Blitzen near Grain Camp. The difference between mass in and mass out of this reach will give us an estimate of the other potential sources and sinks of nutrient mass that are not measured, including irrigation and wetland return flows, groundwater seepage, and internal loading from sediments. Negative balances (when mass out is greater than mass in) indicate sources of nutrients and positive balances indicate sinks. There are some diversions that are not accounted for in this mass budget. Diversions at Grain Camp through the Buena Vista Canal and the Grain Camp Canal are diverted upstream of Grain Camp Dam, along this reach, but return flows, to the extent that they exist, enter the river below this reach. This means that mass may be returned to the system in return flows that are not accounted for in our budget. However, it is likely that the quantity of return flow and mass is small.

Results

Table 12 presents the mass loads for total P and total N by year and period. Generally, loads were much higher during the runoff period than the baseflow period, primarily because of the higher flows. This makes sense; more mass moves in and out of the river reach under higher flows. The higher flows in the 2003 runoff period compared with the 2002 runoff period resulted in higher mass loads as well. There was a tendency for total N to be reduced (positive differences) and total P to be increased (negative differences) through the reach, but the only statistically significant difference between inflow loads and outflow loads occurred for total P in the baseflow period in 2002. Other than that period, the variability was too large to identify significant differences.

Analyses of the concentration data above suggested that wetland and/or irrigation return flows were a potential source of total P in the river. The load differences, although statistically weak, support this as well.

Table 12. Mean Total P and Total N mass loads and standard errors (kg/period) for the Blitzen River between Page Springs and Grain Camp for runoff and baseflow periods in 2002 and 2003. Paired values of inflow loads and outflow loads in bold are significantly different (p<0.05).

Station Name	2002 runoff	2002 baseflow	2003 runoff	2003 baseflow
TP inflow loads	3155 ± 514	**363 ± 48**	4731 ± 1160	619 ± 342
TP outflow loads	3100 ± 226	**812 ± 108**	7389 ± 1617	515 ± 52
Difference	55	-449	-2568	104
TN inflow loads	23961 ± 4334	4884 ± 708	40070 ± 7514	4548 ± 1141
TN outflow loads	17590 ± 1957	4479 ± 325	30580 ± 2671	3424 ± 744
Difference	6371	365	9490	1124

Westside P Ranch Area

Next, we consider an area of lands rather than a specific river reach. The area is the Westside P Ranch Area, defined as the 4,000 acres of irrigated lands south of 5-Mile Road, bounded to the south and west by West Canal and to the north and east by the Blitzen River (Figure 2). In 2002, this area included only about 120 acres (3%) of open water ponds and wetlands. Most of the area is irrigated wet meadow. We developed a water budget for this area for 2002 in a previous report. Here, we develop a nutrient budget for 2002 for the same area, based in part on that water budget information.

Methods

We consider total mass load into this area as the sum of the mass load at Station 2, West Canal at Blitzen, and Station 4, Highline Flume, and diversions at New Buckaroo and Old Buckaroo. We consider total mass load out of this reach to consist of return flows at Station 8, Jones diversion, and Station 7, Faye Pond return flow, and Station 6, West Canal at 5-Mi Road. The difference between mass in and mass out will give us an idea whether water and habitat management practices in this area serve as a source or sink for nutrients. We measured flows continuously at both sites on West Canal and upstream and downstream of the New Buckaroo and Old Buckaroo diversions. We measured flows periodically at Faye Pond return flow, Jones diversion, and Highline Flume. Concentrations at Station 1, Blitzen below Page Springs, were assumed to be representative of concentrations at West Canal, Highline Flume, and New and Old Buckaroo diversion. Concentrations at Faye Pond return flow were assumed to be representative of Jones diversion as well. Concentrations at West Canal at 5-Mi Road were collected and measured as part of the study.

Results

Table 13 presents the mass loads for total P and total N for the runoff and baseflow period in 2002. As with the Blitzen River reach, much more mass moved during the runoff period compared with the baseflow period. The Westside P Ranch area is a source of total P and total N (negative differences for both nutrients during both periods), with statistically more nutrients exported from the area than moving into the area, with the exception of total N during the runoff period. In terms of mass percentage, there was more total P exported than total N. The area appears to be more of a source of P than N. This could be due to the wetting/drying cycle that occurs in these wet meadow areas since these areas are only irrigated until about the 3rd week of July. The annual drying cycle allows oxidation of newly-formed organic matter and release of nutrients, especially P, which then move into the water column upon flooding (Reddy et al., 1999; Mayer, 2005). Furthermore, wet meadows are dominated by annual vegetation, as opposed to perennial vegetation. The predominance of annual vegetation may result in less P being translocated back into the below-ground biomass at the end of the growing season and more being released into the water column upon flooding (Mayer, 2005). Mayer (2005) reported export of P from seasonally flooded wetlands in the Klamath Basin, for similar reasons.

Table 13. Mean Total P and Total N mass loads and standard errors (kg/period) for the Westside P Ranch area for runoff and baseflow periods in 2002. Paired values of inflow loads and outflow loads in bold are significantly different ($p<0.05$).

Station Name	2002 runoff	2002 baseflow
TP inflow loads	**782 ± 155**	**69 ± 14**
TP outflow loads	**2433 ± 513**	**458 ± 43**
Difference	-1651	-389
TN inflow loads	6254 ± 1316	**1036 ± 213**
TN outflow loads	8170 ± 1054	**1741 ± 55**
Difference	-1646	-705

The total P outflow load from this area is considerable when compared to the total P mass load in the river for the same period. This is less true for total N. Based on these results, we can assume that return flows from seasonally-flooded wet meadow habitat are contributing to P concentrations in the river. This source is likely responsible for part of the increase in P concentrations downstream. However, based on the low chlorophyll a concentrations in the river, concerns with increased P concentrations and eutrophication do not seem to be warranted at this time.

CONCLUSIONS

Based on the water quality results from this study, the main water quality parameters of concern in the Blitzen Valley are conductivity, dissolved oxygen, turbidity and suspended sediment, total P, and total N. Dissolved oxygen decreases and conductivity, turbidity, suspended sediment, total P, and total N increase with distance downstream. Low dissolved oxygen concentrations, in particular, are a big concern downstream during the summer baseflow period. Concentrations are below state standards at downstream sites. Irrigation and wetland return flows are contributing low DO- and higher BOD-waters to the river and may be responsible for some of the low concentrations further downstream. But warmer temperatures downstream also undoubtedly contribute to the DO decreases.

Late season increases in river turbidity and TSS may be related to dam operations. These two parameters increase at about the time that the dams are opened up, in late July and early August.

The timing of conductivity increases downstream on the river seems to implicate return flows as sources of higher conductivity water. The return flows are generally much higher than the river conductivities. The increases downstream in the river are 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 are also implicated as a potential source of nutrients to the river. Concentrations of both macronutrients are higher in the return flows and they increase downstream in the river. The wetlands, particularly the wet meadows, appear to be a source of P and possibly N, based on the nutrient budget for the Westside P Ranch Area.

Despite the fact that nutrient concentrations increase downstream, there does not seem to be much of a problem with eutrophication and planktonic algae in the river. Concentrations of chlorophyll a are very low throughout the river. This may be because of limited P availability, based on P concentrations and N:P ratios in the river.

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West Knox Pond Water Budget and Water Quality

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INTRODUCTION

The purpose of this report is to describe and evaluate the existing water quality conditions in West Knox Pond, a permanently flooded wetland, at Malheur NWR, for the May through September period of 2002 and 2003 (Figure 1). We present summary statistics for various water quality parameters, estimate nutrient loads, and evaluate water quality impacts from management activities at this wetland. A water budget was determined for this area in a previous section of this report.

METHODS

Instantaneous measurements of field water quality parameters were collected from the inflow and outflow of West Knox Pond from the beginning of April through the end of September in 2002 and 2003. The measurements were collected every two to three weeks, with more frequent measurements during the summer. Parameters measured included water temperature, conductivity, pH, dissolved oxygen, and turbidity. Water temperature and conductivity were measured with an Orion Conductivity Meter, model 115. pH was measured with a Orion pH meter, model 210, and a glass electrode. Turbidity was measured with a Hach turbidimeter. All meters were calibrated prior to use each day. Dissolved oxygen was measured colorimetrically with a Hach Digital Titrator and DO kit.

Hourly continuous measurements of water temperature, conductivity, pH, and dissolved oxygen were also collected with Hydrolabs. The Hydrolabs were calibrated before deployment and the calibration was checked after deployment. The Hydrolabs were deployed concurrently for 96 hour periods approximately every two to three weeks. In 2002, Hydrolabs were deployed concurrently at both the inflow and the outflow. We compared the paired hourly measurements from the Hydrolabs at the inflow and outflow using a Wilcoxon signed rank test. In 2003, Hydrolabs were deployed at the outflow only.

Hourly measurements of water temperature were also collected continuously for the entire season at the inflow and outflow of the pond, using Optic Stowaway temperature sensors. In 2002, the Stowaway at the outflow was lost at the beginning of the summer so there are not continuous data at this site for the entire season. There is a complete record of temperature at both sites for 2003. Seven-day-average maximum temperatures were calculated using the continuous hourly measurements. The state water quality standard for temperature is based on a seven-day-average maximum. The value is computed on a given day by averaging the daily maximum temperature from the current day and the three days preceding or following the current day. In 2002, such calculations could not be done for the outflow since continuous data were not available at this site for the entire season.

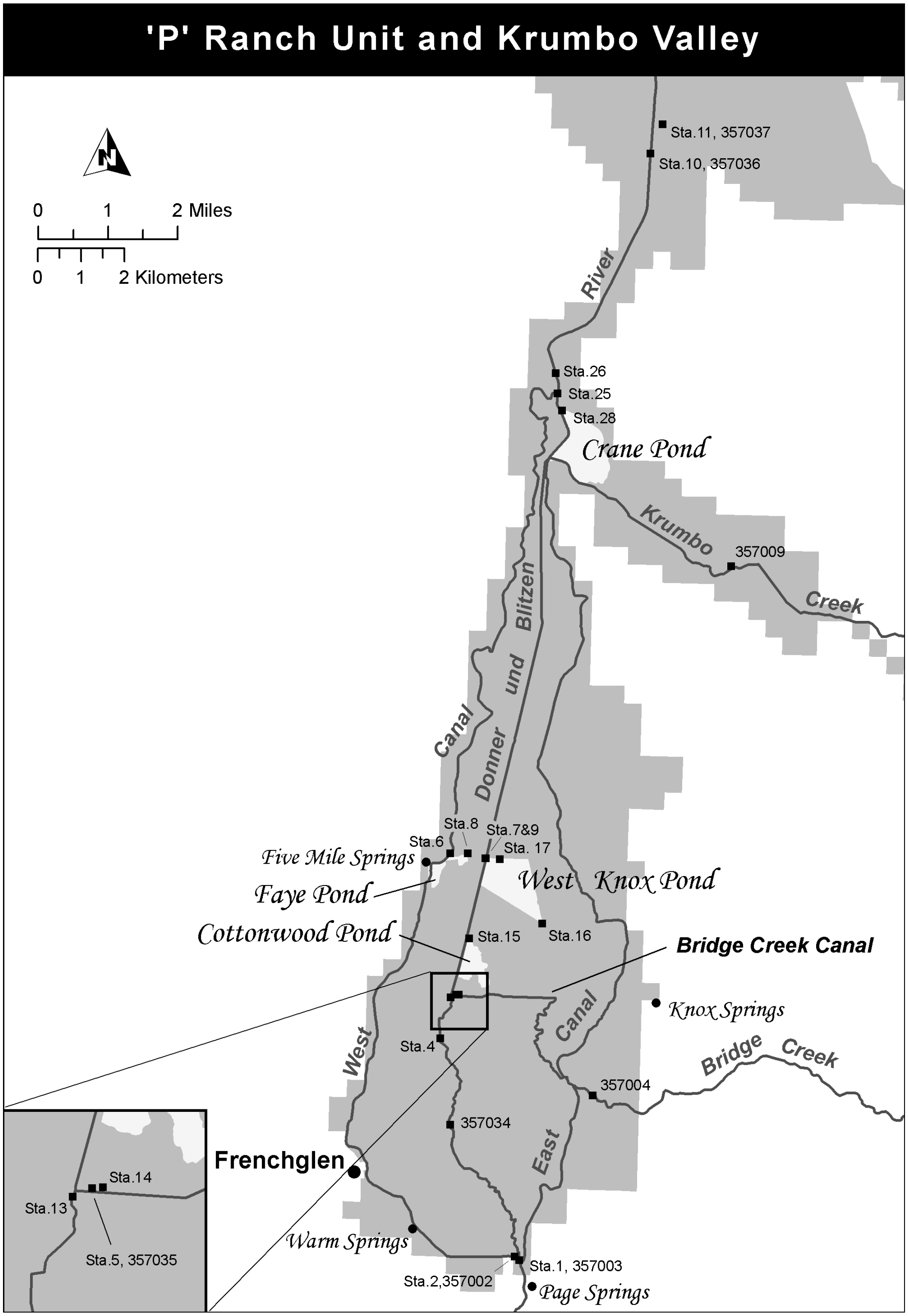


Figure 1. Map of Frenchglen area of the Blitzen Valley showing monitoring sites, springs, wetlands, and geographic features referred to in this study.

Water quality samples were collected for laboratory analyses of soluble reactive P, total P, ammonia-N, nitrate- and nitrite-N, total N, biological oxygen demand, and total suspended solids. For this study, the analytical sum of nitrate and nitrite is assumed to be nitrate and will be referred to as such. Several samples were analyzed for E. coli and total coliform as well in 2002. Chlorophyll a was analyzed semi-regularly in 2002 and in every sample in 2003. All laboratory analyses used standard analytical methods.

Measurements at the outflow were collected in the wetland near the outflow structure, regardless of the volume of outflow occurring at the time of sample collection. These are referred to as outflow samples and measurements, even if there was no outflow at the time they were collected.

Water Quality Monitoring Results and Discussion

Water Temperature

The State of Oregon water quality standards state that the “seven-day-average maximum water temperature for streams identified as having redband trout use must not exceed 20.0º C (68.0º F).” While West Knox Pond does not have redband trout use, the surface outflow is tributary to the Blitzen River which is redband habitat. Water temperatures in the West Knox Pond outflow exceeded the state standard from the end of May to the beginning of September in 2003 (the only year for which there is a complete record at the outflow) (Figure 2). There was some thermal stratification in West Knox Pond and the Optic Stowaway sensor at the outflow was positioned near the bottom of the water column in 2003. It is possible that water temperatures near the surface were even greater than what is reported here. This is significant since the outflow structure is designed to take water from the top of the water column. The Hydrolabs were positioned closer to the surface of the water column and we believe the data from the Hydrolabs better represent surface water temperatures.

Outflow temperatures equaled or exceeded inflow temperatures during most of the 2003 season (Figure 2). On average, outflow temperatures were 0 to 4 degrees greater than inflow temperatures for both years. There difference between the two sites is close to zero in early spring but increases to a maximum in July and August. This is expected since the quiescent water in the shallow wetland is warmed to a greater degree than the inflow from Bridge Creek, as air temperatures increase throughout the summer. However, the water in the inflow also warms throughout the season. Both Bridge Creek and the Knox Pond diversion canal are channelized above the West Knox inflow structure and water slows and warms in these sections of the stream (ODEQ, 1999). Inflow water temperatures at West Knox Pond exceeded the Oregon standard from the end of May through the beginning of August, with the exception of a few days in June, in both 2002 and 2003. Bridge Creek is redband trout habitat. An examination of the 2003 temperature data from Bridge Creek at the Blitzen (Station 5), downstream of the Knox Pond diversion canal, showed that the temperature standard was exceeded for most of July and August in 2003.

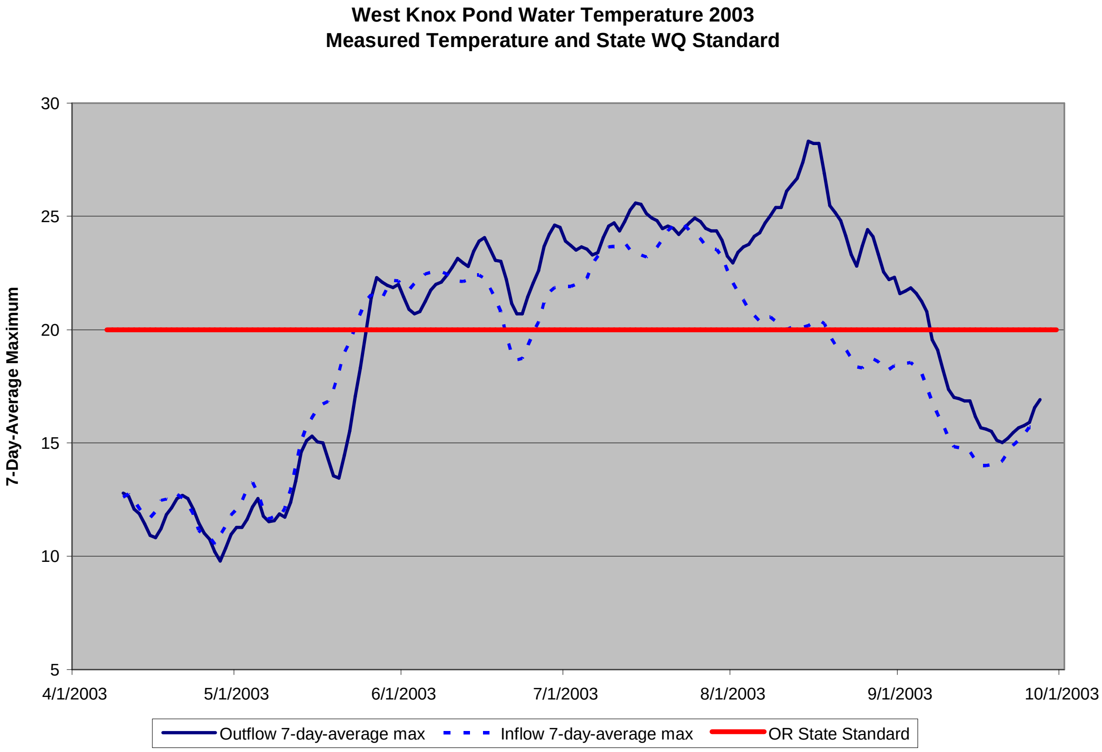


Figure 2. Seven-day-average maximum water temperatures from 2003 at the inflow and outflow of West Knox Pond.

The hourly Hydrolab temperatures in the West Knox Pond outflow for four 96-hour deployments during July through mid-August are plotted by year in Figure 3. The mean temperature during the July through mid-Aug period was 22.8º C in 2002 and 23.5º C in 2003. There was a slightly greater range in 2003 with a maximum temperature of 32º C, compared with a maximum of 29.7º C in 2002. The warm air temperatures in 2003 may have been a factor in the high water temperatures observed in 2003. Despite this difference, water temperatures for the two years were not statistically different during the July through mid-August period.

The Blitzen River is the receiving water for the outflow from West Knox Pond. The 5-Mile Bridge site on the Blitzen is located just upstream of the confluence of the West Knox outflow drain and the river. The 2003 West Knox outflow mean daily temperatures for the 2003 season were 1.9º C warmer than the mean daily water temperatures in the Blitzen River at 5-Mile Bridge. A paired t-test showed that the difference between the wetland outflow and the river was significant (p=0.000). The difference was greatest during the spring and decreased in the summer (Figure 4). When air temperatures increased around mid-May, water temperatures in West Knox Pond responded almost immediately but water temperatures in the Bitzen River at 5-Mile Bridge increased much more slowly, because of the high flows at this time of year. As river flows decreased toward the end of June, water temperatures in the river increased as well and were similar to West Knox Pond water temperatures for the remainder of the season (Figure 4). The quiescent water in the wetland warm more rapidly with increasing air temperatures than the river, especially at higher river flows. 2002 shows a similar pattern, with water temperatures in the West Knox outflow exceeding the river during mid-May and June but close to the river later in the summer.

The West Knox inflow mean daily temperatures for the 2003 season were, on average, 2.1º C higher than the mean daily water temperature in the Blitzen at Page Springs, the initial source of much of the inflow (Figure 4). A paired t-test showed that this difference was significant (p=0.000). Like the outflow and the river, the difference in mean daily temperatures between the wetland inflow and the river at Page Springs was greatest in spring (8 to 10º C) and decreased in summer. This appears to be related to differences in flow at the two sites. The inflow to West Knox, and the flow in Bridge Creek is channelized, regulated, and consistently low. This water warms quickly in the spring. By contrast, the flows in the Blitzen at Page Springs are relatively higher, especially in spring, and do not warm as quickly until the high flows recede. This results in a temperature difference between the two sites that is maximized in spring and diminishes during summer. Flow influences water temperatures throughout the refuge.

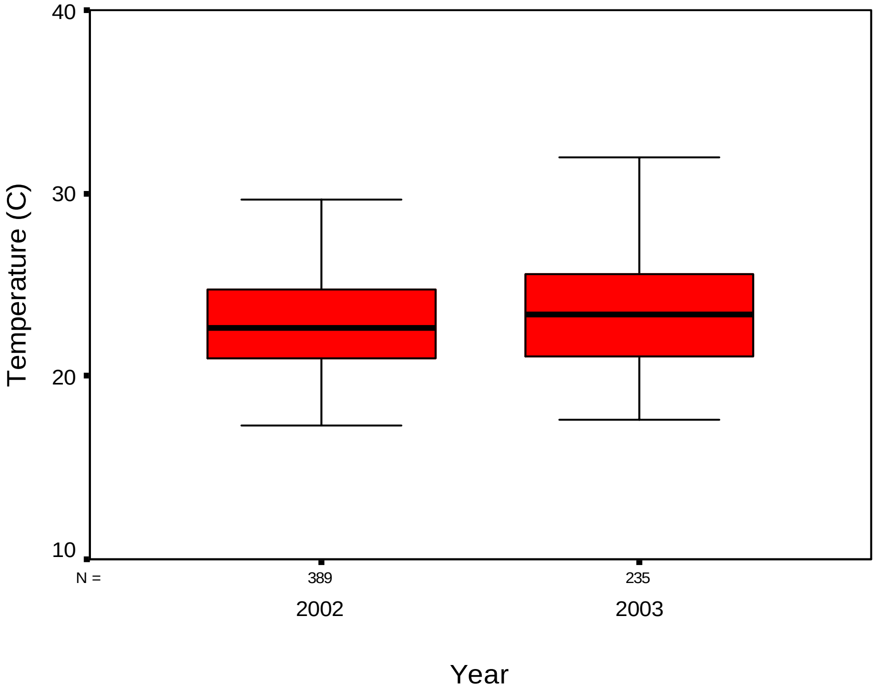


Figure 3. Box plots of West Knox outflow hourly temperatures for July through mid-August in 2002 and 2003. In a box plot, the center line is the 50th percentile or median, the box spans the 25th to 75th percentile and the whiskers span the range of the data.

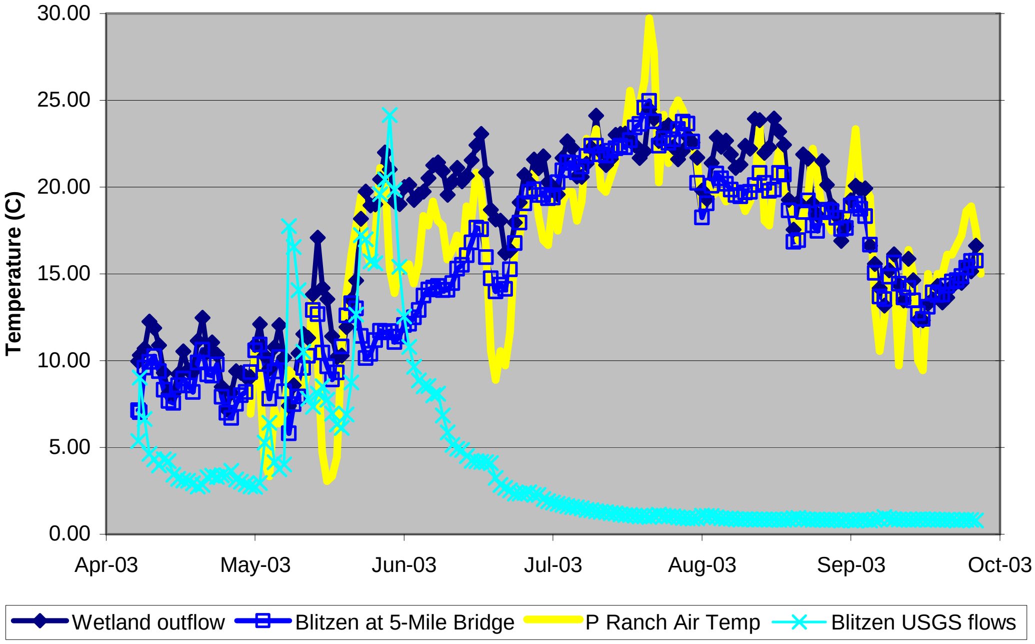


Figure 4. Comparison of Mean Daily Water Temperatures in the Blitzen River at 5-Mile Bridge and West Knox Pond Outflow, Mean Daily Air Temperatures at P Ranch, and Mean Daily Flows at the USGS Site 10396000 Blitzen near Frenchglen, OR 2003

Conductivity

The concurrent Hydrolab measurements at the inflow and outflow in 2002 showed that the outflow conductivity was significantly higher than the inflow (p=0.000). In 2002, the average inflow conductivity was 94 µS/cm and the average outflow conductivity was 167 µS/cm. The higher conductivity in the wetland is due to evaporative concentrations of salts and the dissolution of residual salts in the wetland. There was little change in conductivity over the season in 2002. In contrast, the conductivity of the outflow increased from an average of 133 µS/cm to 189µS/cm from May through August 2003. The seasonal increase in 2003 may have been partly a result of the low volume of outflow from the wetland in 2003.

pH

pH in the wetland outflow averaged 7.8 in 2002 and 8.0 in 2003. pH ranged as high as 10.15 in June 2003, as measured with the Orion pH meter, although maximum values from the Hydrolab only reached about 9.4 that year. Hourly pH as measured with the Hydrolab at the inflow and outflow in 2002 were compared using a Wilcoxon signed rank test. pH was significantly higher in the outflow as compared to the inflow for all periods of deployments (p=0.000). This is due to the greater algal and plant productivity in the wetland. Carbon dioxide is consumed through photosynthesis and results in an increased pH. pH in the wetland outflow also exceeds the pH of the river, for the same reason. The Oregon state water quality standard for pH is 7.0 to 9.0. Wetland outflow exceeded this standard for a small part of the season during both years although the Oregon standard states that waters impounded by dam may have pHs that exceed this.

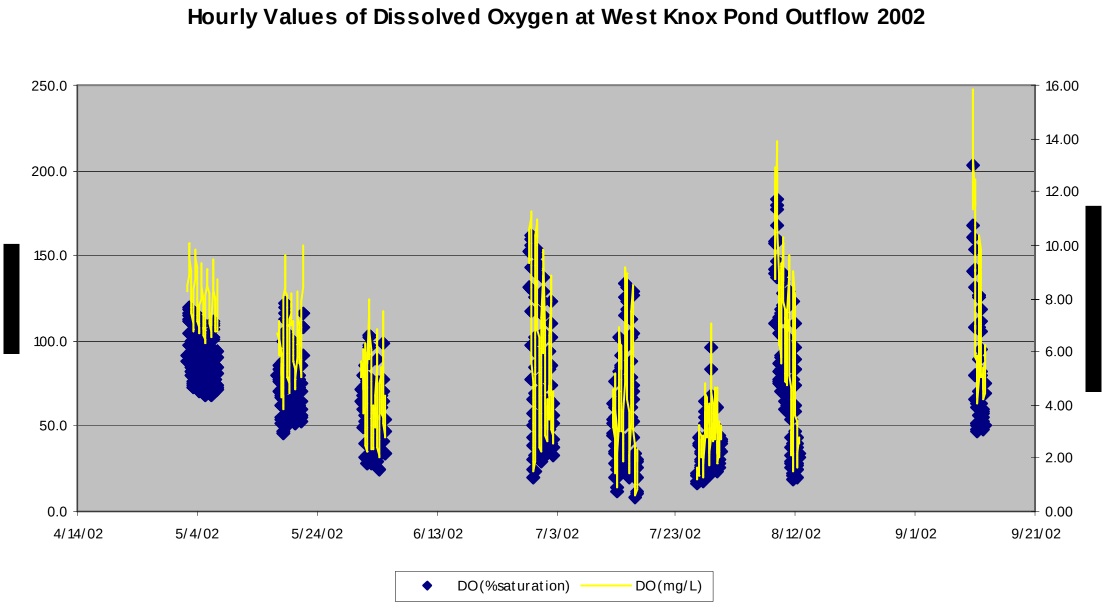
Dissolved Oxygen

Dissolved oxygen concentrations and % saturations differed between spring and summer in both years. Mean concentrations decreased and were significantly lower (p=0.000) in the summer as compared to the spring in both 2002 and 2003 (Figure 5). However, the range of concentrations increased in the summer, with higher maximums and lower minimums. Minimum concentrations were < 1.0 mg/L in July in both years with a slight recovery in late summer. The minimum dissolved oxygen corresponds to the month of maximum water temperatures.

The decrease in means and increase in variability reflect the response to photosynthesis and respiration in the pond. As temperatures warm and solar radiation increases, algal productivity and algal decomposition are increased as well. Algal photosynthesis releases dissolved oxygen into the water column while decomposition of algal biomass consumes it.

Paired measurements of dissolved oxygen concentrations in the inflow and outflow of West Knox Pond were compared in 2002 (Figure 6). Concentrations in the outflow were significantly lower (p=0.000, n=650 paired measurements) than the inflow. The mean inflow concentration was 7.17 mg/L and the mean outflow concentration was

5.64 mg/L. The difference in the means was 1.53 mg/L. The range of concentrations in the outflow exceeded the inflow, especially in summer, reflecting greater algal activity and decomposition in the wetland.


Hourly Values of Dissolved Oxygen at West Knox Pond Outflow 2002

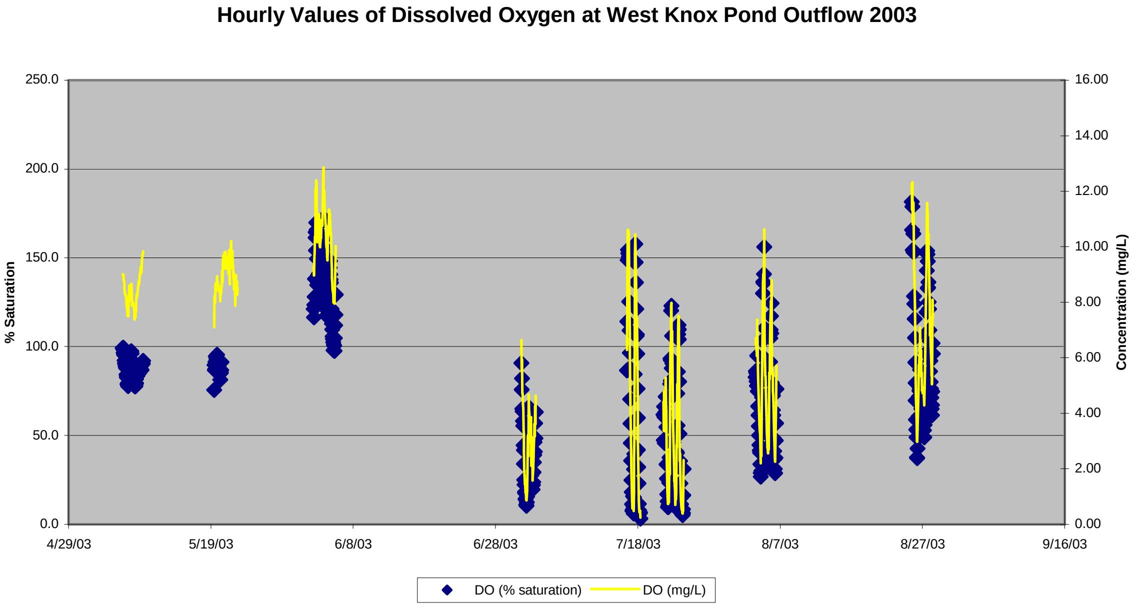

Hourly Values of Dissolved Oxygen at West Knox Pond Outflow 2003

Figure 5. Hourly values of dissolved oxygen at the West Knox Pond outflow in 2002 (top) and 2003 (bottom) as collected by the Hydrolabs. Symbols are percent saturations and lines are concentrations.

Nutrients

Phosphorus is frequently the nutrient that limits primary productivity in freshwater systems (Wetzel, 2001). As a result, when P concentrations are increased, the result is more plant or algae growth. P concentrations greater than 0.1 mg/L are characteristic of eutrophic waters (Smith et al., 1999). Total P and soluble reactive P concentrations in the wetland outflow averaged 0.53 mg/L and 0.25 mg/L, respectively, for both years (Figure 7), indicating the wetland is eutrophic. The two years were similar in terms of concentrations and trends. The outflow concentrations are about an order of magnitude greater than P concentrations in the Blitzen River at 5-Mile Bridge or the West Knox inflow (Figure 7). Blitzen River at 5-Mile Bridge total P and soluble reactive P concentrations averaged 0.064 mg/L and 0.024 mg/L, respectively for both years. West Knox inflow total P and soluble reactive P concentrations averaged 0.053 mg/L and 0.030 mg/L, respectively for both years.

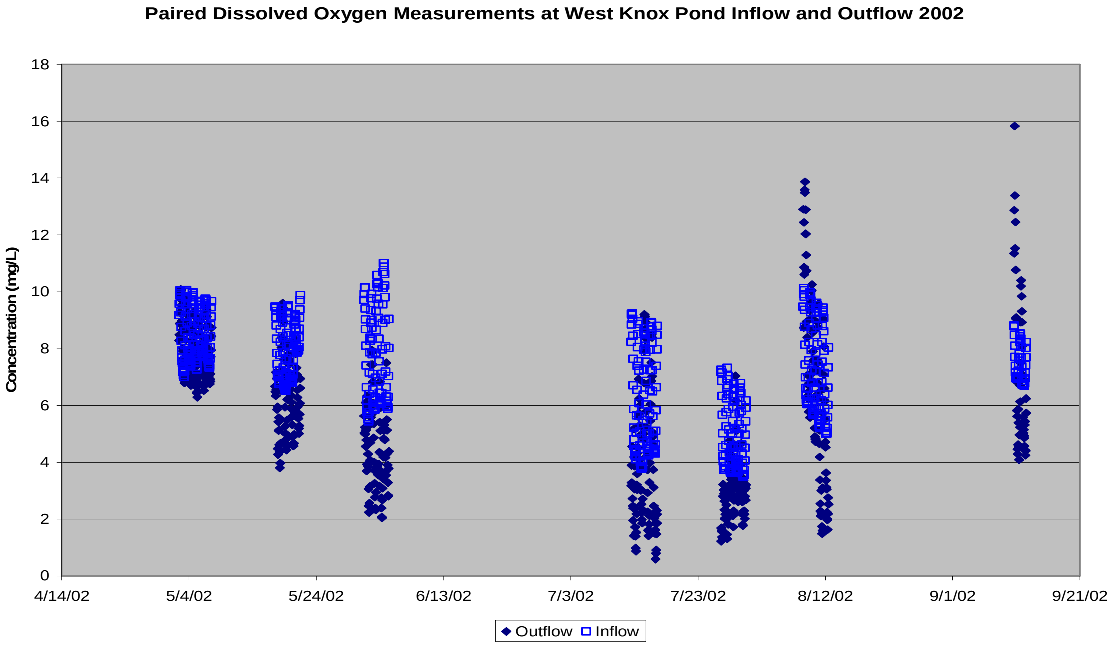


Figure 6. Concurrent measurements of dissolved oxygen concentrations in the inflow and outflow of West Knox Pond in 2002, as measured with the Hydrolabs.

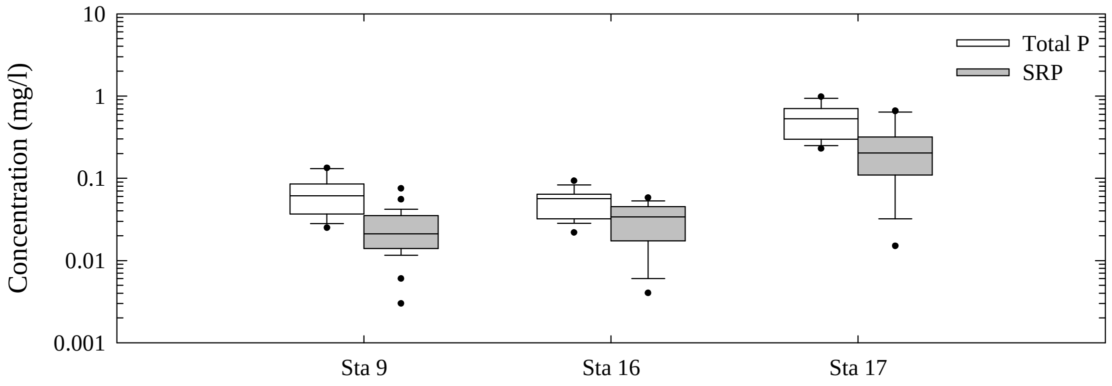
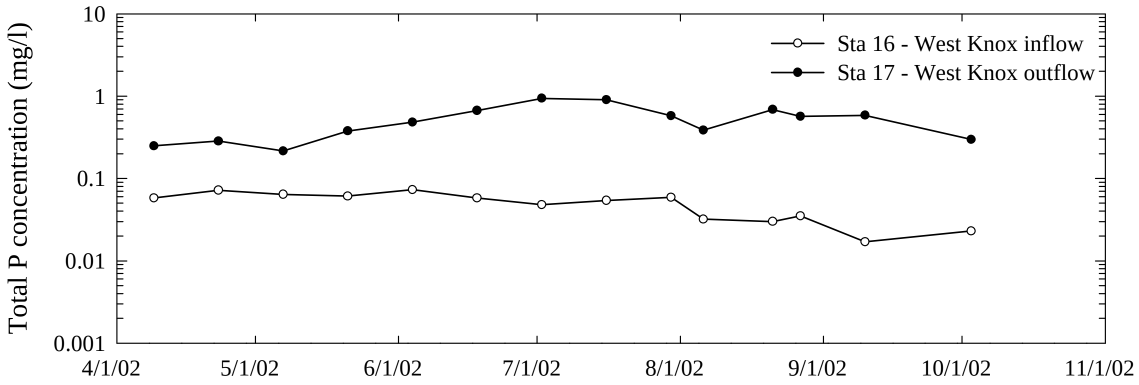


Figure 7. Box plots of total P and soluble reactive P in the Blitzen at 5-Mile Bridge (Sta 9), and West Knox Pond inflow (Sta 16) and outflow (Sta 17), for 2002 and 2003 combined. Note the log scale of the vertical axis.

The trend in P concentrations in the wetland is different from the river and inflow too (Figure 8). Phosphorus concentrations in both years increased in June, peaked in July, and then decreased slowly until the beginning of September. Average total P concentrations increased from about 0.20 mg/L in April to > 0.90 mg/L in July. Phosphorus concentrations in the river and inflow showed no seasonal trends. Crane Pond, another permanently flooded wetland, showed as similar increase in P concentrations mid-season.

An average of 58% of the total P in the inflow and 47% of the total P in the wetland outflow was in soluble reactive form. This is the dissolved form of P, as opposed to the solid form. The fraction of soluble reactive P tended to increase mid-season too so that at the highest concentrations, the fraction of soluble reactive P was greatest. The large fraction of total P in dissolved form may have implications for the chemical behavior and retention of P in the wetland (see Mayer 2005). Soluble reactive P is believed to be immediately bioavailable to plants and algae. It will sorb or precipitate with Fe, Al, and Ca forms under certain conditions. It will remain in solution rather than settling out like particulate P.



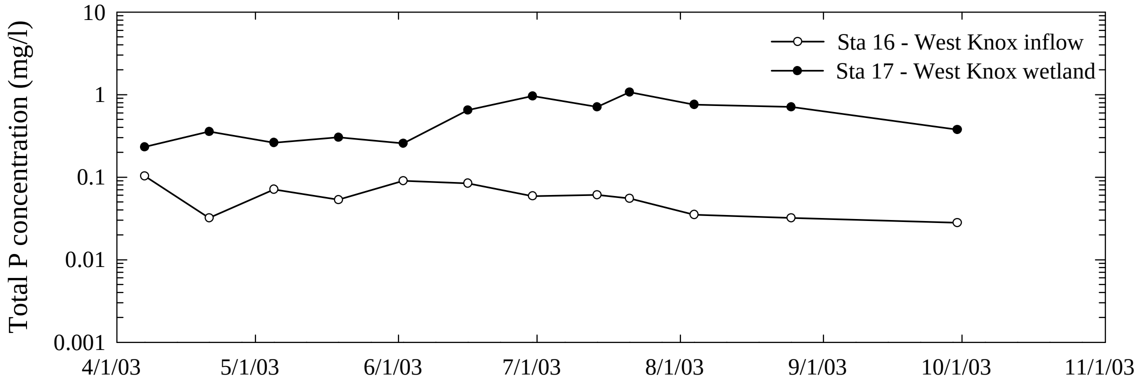


Figure 8. Season trends in total P concentrations in West Knox Pond inflow and outflow in 2002 (top) and 2003 (bottom). Note the log scale of the vertical axis.

Total N concentrations in the wetland outflow were also higher than the Blitzen at 5-Mile Bridge or the West Knox inflow. Concentrations in the wetland outflow averaged 2.07 m/L for both years. Concentrations in the river and inflow averaged 0.42 and 0.38 mg/L, respectively, for both years. Total N also increased from spring to summer in the wetland outflow, similar to P concentrations. No such trend was evident in the river or inflow. Most of the total N was in organic form rather than dissolved form. The average organic N for both years was 89% and there was little variability in this fraction over the season.

Dissolved N (nitrate plus ammonia) concentrations were more variable in the wetland outflow. Ammonia concentrations increased during the 2002 season from an average of 0.046 mg/L early season to 0.310 mg/L mid-season and 0.472 mg/L late season. Ammonia concentrations were generally lower and more constant in 2003. Average concentration were 0.114 mg/L early in the season, 0.193 mg/L mid-season, and 0.075 mg/L late season. Nitrate concentrations were usually low and ranged from non-detectable (<0.010 mg/L) to about 0.1 mg/L in both years.

Nutrient loads

Mass balance calculations showed that the wetland was a source of P and N during 2002. Outflow loads of total P and total N exceeded inflow loads by <300% and 60%, respectively. To some extent, this was due to a release of water from storage over the season. Water levels declined over the irrigation season and this served as a source for some of the exported P and N. In 2003, because of the greatly reduced outflow from West Knox Pond, the wetland retained P and N overall during the season. There was a release of P and N during the period May 1 through June 15, 2003, when there was outflow. Again, some of the nutrient load in the outflow was due to the release of water in storage.

We did not develop a water budget or nutrient budget for the entire year. Based on the data we did collect, it is not possible to say whether the wetlands are acting to retain or release nutrients overall. They do appear to be a source of nutrients when outflow occurs during the irrigation season. The export or retention of nutrients from the wetland is as much as function of water management as it is of chemical or biological processes. When no water is released, the wetlands act to store nutrients. When water is released from storage, the wetlands export nutrients, the quantity depending in part on how much water is released. Mid- or late-season outflows will release more nutrients because of higher concentrations at this time of year. It seems that nutrient concentrations in permanent wetlands at Malheur NWR increase over the summer, based on observations in West Knox Pond and Crane Pond.

Wetland outflow to the river could potentially provide a significant source of nutrients, especially P, to the river system, accelerating primary productivity and further degrading water quality in an already stressed system. There is evidence that the river system becomes progressively enriched in P as it passes through the refuge and this may be in part related to wetland outflows. Median concentrations of total P increase from 0.30 mg/L at the Page Springs Dam to 0.11 mg/L at Sodhouse Dam, almost a fourfold increase. This indicates that the system becomes more eutrophic downstream. Total N increases downstream as well, but only about double the initial upstream concentrations. The increase in P concentrations is greater relative to the increase in N concentrations downstream. The median total N:total P molar ratios decrease from 26 at Page Springs Dam to 12 at Grain Camp Dam and Sodhouse Dam. At the initial P concentrations and N: P molar ratios characteristic of water first entering the refuge, it is likely that P is limiting primary productivity (Wetzel, 2001). However, as the total P concentration increase and the N:P ratios decrease, P is less likely to be limiting downstream.

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Management Strategies for Addressing Water Quality Issues at Malheur National Wildlife Refuge

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INTRODUCTION

The purpose of this report is to summarize the general water quality issues at Malheur NWR, based on the findings from the previous reports, and discuss management strategies to address those issues.

General Findings:

> Based on the results from this study, high water temperatures and low dissolved oxygen concentrations appear to be the most critical water quality issues of concern on the refuge. Water temperatures exceed the state standard even before the Blitzen flows onto the refuge and increase with distance downstream on the refuge. The most rapid increase occurs in the first 5-mile reach on the refuge.
>
> Low dissolved oxygen concentrations are below state standards at downstream sites during the summer baseflow period. Irrigation and wetland return flows are contributing low DO- and higher BOD-waters to the river and may be responsible for some of the low concentrations further downstream. But warmer temperatures downstream also undoubtedly contribute to the DO decreases. Both high water temperatures and low dissolved oxygen concentrations are detrimental to redband trout. Management practices that improve water temperature will also help improve dissolved oxygen.
>
> Other issues of concern are conductivity, turbidity and suspended sediment, total P, and total N. All of these parameters increase on the refuge with distance downstream. Despite the fact that nutrient concentrations increase downstream, there does not seem to be much of a problem with eutrophication and planktonic algae in the river. Concentrations of chlorophyll a are very low throughout the river. This may be because of limited P availability, based on P concentrations and N:P ratios in the river.
>
> Irrigation and wetland return flows are responsible for some of the observed water quality problems but certainly not all of them. The timing of conductivity increases downstream on the river seems to implicate return flows as sources of higher conductivity water. Return flows are also implicated as a potential source of nutrients to the river. Concentrations of total N, total P, and BOD are higher and DO concentrations are lower in return flows.

WATER QUALITY MANAGEMENT

Proposed solutions to address water quality impairment and implications to Refuge management focus mainly on temperature and dissolved oxygen.

The proposed interim solution to restore impaired water quality (temperature, turbidity and dissolved oxygen) in the Blitzen River from Refuge-related management is based upon the concept of “protecting and restoring” ecological function as opposed to attempting to meet numerical standards. Final strategies to address water quality impairment will be developed as part of Total Maximum Daily Load (TMDL) for pollutants that are discharged to the Blitzen River. TMDL studies are conducted on “waters of the United States” that have been identified as having impaired water quality as a result of anthropogenic actions. The TMDL will be conducted by the Oregon Department of Environmental Quality (DEQ) some time in the future. Recent TMDLs conducted or are presently being conducted by DEQ in southeast Oregon focus on addressing ecosystem function to address water quality impairment.

The Oregon Department of Agriculture (ODA) method for addressing water quality impairment in the state is also based upon protecting and restoring function. In fact, the strategy to address water quality impairment from agriculture-related activities on private and State of Oregon administered lands in Harney County is based upon this concept and the implementation of Best Management Practices (BMPs) as opposed to immediate and strict enforcement of numerical standards by ODA and/or DEQ.

Therefore, the approach that Malheur NWR will take to address water quality impairment related to its management will follow suit. The Malheur NWR approach to address water quality will mirror that identified in the Greater Harney Basin Agricultural Water Quality Management Plan (GHBAWQP 2006) and the Alvord TMDL (DEQ). The GHBAWQP and Alvord TMDL identify four areas to address to protect/improve water quality in their respective drainages. They are: 1) Rangeland/upland health; 2) riparian vegetation; 3) stream morphology; and 4) floodplain connectivity. Malheur NWR has little rangeland/upland habitats within the confines of the refuge. The majority of those habitat types that surround Malheur NWR are administered by the Bureau of Land Management or are in private ownership. Therefore, Malheur NWR will focus upon three of the four areas identified.

1) Protect existing riparian shrub/tree communities and/or re-establish riparian tree/shrub communities;

2) Conduct in-stream projects to improve stream channel morphology; and

3) Where feasible, re-establish floodplain connectivity by aggrading the stream channel and/or removing dikes.

In addition, modeling data suggests that increasing base-flows during the warmest periods (July/August) will also lower temperatures in the Blitzen River. Therefore, on or around July 1st, Malheur NWR would reduce the amount of water it diverts and increase "base-flow" in the Blitzen River by 25CFS. This management action would most rapidly address water temperature and possibly dissolved oxygen and turbidity impairment to the river. However, the Refuge's ability to maintain some wetlands into late summer will be reduced.

IMPLICATIONS TO REFUGE MANAGEMENT

The implications to existing Refuge management objectives in the Blitzen Valley, although not quantifiable at this time, may be significant. However, those changes will not run counter to Refuge purpose ("as a feeding and breeding ground for migratory birds and other wildlife.") The impact will be to the current goal of maximizing the total number of acres irrigated each irrigation season and migratory bird (e.g., sandhill crane and waterfowl) production objectives. The historical wetland management strategy of the Refuge has not considered water availability (i.e., snow pack and predicted run off), water quality of the Blitzen River nor aquatic organisms dependant upon the Blitzen River. The Blitzen Valley portion of the Refuge will still provide significant high quality habitat for a wide variety migrating and breeding migratory bird species and other wildlife. However, the total number of acres of wetland habitat that are irrigated into late summer may vary significantly from year to year, more so than present. There will likely be more emphasis placed on managing seasonal wetland habitat than semi-permanent/permanent emergent marsh habitat, also referred to as "brood-rearing" wetlands.

As a result of the changes in irrigation, cessation on or around July 1 vs July 25 (based on stream flow and temperature), there will be changes to the existing haying/grazing program. Haying of meadows will need to occur approximately three weeks to one month earlier than present (July 10 vs Aug 10) to ensure that forage that is harvested remains of sufficient quality to attract local ranchers. If the forage is not of sufficient quality, there would be little reason for local ranchers to harvest the forage. Without the involvement of local ranchers Refuge wetland and meadow management would be severely affected. Changing of the hay dates would also affect permittees because they would need to adjust their operations, especially haying of private lands which typically commences in early July. This type of change in management would have to be gradually implemented.

There will be more mimicking of natural riparian and riparian wetland habitat function than present. The total length of riparian tree/shrub communities along the length of Blitzen River, tributaries, drains, etc will increase considerably from what exists presently to address the lack of shading of the river. Riparian communities along the Blitzen River are on an upward trend. However, the majority of the approximately 40 miles of the Blitzen River is in poor condition. There will need to be more flexibility in management of habitats and more variability in treatment methods and timing.

As a result of these management changes there will be shifting plant communities, some emergent marsh habitats that have formed in meadow habitats will dry out and become dominated by grasses, forbs and smaller rush and sedge species. There should be an increase in the total number of acres of moist and dry meadow and a decrease in wet meadow and emergent (cattail, bulrush & reed canary grass) dominated habitats. How invasive plant species (i.e.,perennial pepper weed, Canada thistle will respond) is unknown. It is suspected that in some areas, these invasive species may spread.

CONCLUSIONS

The bottom line is that current management paradigm in the Blitzen Valley will change by necessity. To comply with water quality standards and to provide acceptable aquatic habitat the Refuge will be required to change its present water/habitat management strategies. To what extent exactly is unknown. However, the Refuge can begin almost immediately to address water quality impairment by implementing some best management practices (BMPs). Some of these BMPs include:

1) Strictly “enforce” our existing voluntary bypass flows at all dams (15-20CFS) and ensure that bypass flows that are part of the settlement agreement are adhered to.

2) Begin to aggressively conduct riparian vegetation “restoration” along the Blitzen River and its tributaries. This includes re-shaping and/or removing dikes to allow better tree/shrub establishment and floodplain connectivity.

3) Conduct in-stream projects to reactivate floodplains in the Blitzen Valley (e.g., P-Ranch restoration project, Bridge Creek restoration, proposed Dunn Dam replacement). These types of projects will also encourage natural riparian tree/shrub establishment and increase survival of planted stock.

Figure 1: Schematic diagram of the Blitzen Valley including current and proposed gaging stations.