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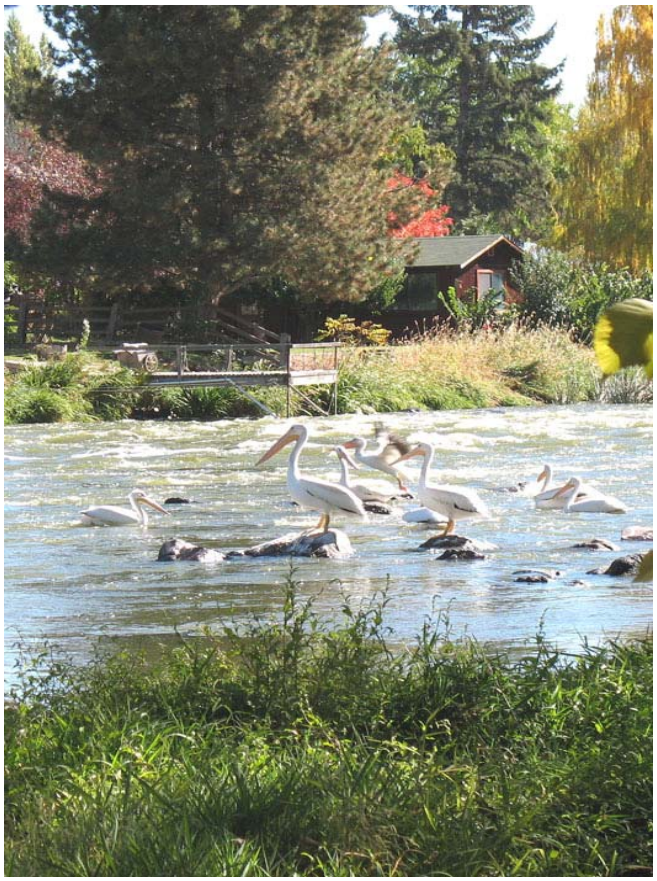
Klamath River Water Quality and Acoustic Doppler Current Profiler Data from Link River Dam to Keno Dam, 2007



Open-File Report 2008–1185

U.S. Department of the Interior
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Front cover (clockwise, from left):

Link River, October 12, 2006; photograph by Scott Miller, Bureau of Reclamation, Klamath Falls, Oregon

Aerial view of Lake Ewauna and the upstream end of the Keno reach of the Klamath River; photograph by Trisha Roninger, U.S. Fish and Wildlife Service

Klamath River from Miller Island, August 28, 2007; photograph by Simon Poulson, University of Nevada, Reno

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Klamath River Water Quality and Acoustic Doppler Current Profiler Data from Link River Dam to Keno Dam, 2007

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
nanometer (nm)	0.00000003937	inch (in.)
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
liter (L)	61.02	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F=(1.8×°C)+32

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations and Acronyms

ADCP, acoustic Doppler current profiler
AFA, *Aphanizomenon flos aquae*
AU, absorbance units
DOC, dissolved organic carbon
LT-MDL, long term method detection limit
M, molarity or moles of solute per liter of solution
µm, micrometer
mg, milligram
mL, milliliter
N, normality, molarity multiplied by the number of protons exchanged in the reaction
NWQL, National Water Quality Laboratory
POC, particulate organic carbon
RL, reporting level
RM, river mile
RPD, relative percent difference
$SUVA_{254}$, specific UV absorbance at 254 nm
TSI, trophic state index
USGS, U.S. Geological Survey
UV, ultraviolet
WWTP, wastewater treatment plant

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Abstract

In 2007, the U.S. Geological Survey, Watercourse Engineering, and Bureau of Reclamation began a project to construct and calibrate a water quality and hydrodynamic model of the 21-mile reach of the Klamath River from Link River Dam to Keno Dam. To provide a basis for this work, data collection and experimental work were planned for 2007 and 2008. This report documents sampling and analytical methods and presents data from the first year of work. To determine water velocities and discharge, a series of cross-sectional acoustic Doppler current profiler (ADCP) measurements were made on the mainstem and four canals on May 30 and September 19, 2007. Water quality was sampled weekly at five mainstem sites and five tributaries from early April through early November, 2007. Constituents reported here include field parameters (water temperature, pH, dissolved oxygen concentration, specific conductance); total nitrogen and phosphorus; particulate carbon and nitrogen; filtered orthophosphate, nitrite, nitrite plus nitrate, ammonia, organic carbon, iron, silica, and alkalinity; specific UV absorbance at 254 nm; phytoplankton and zooplankton enumeration and species identification; and bacterial abundance and morphological subgroups.

The ADCP measurements conducted in good weather conditions in May showed that four major canals accounted for most changes in discharge along the mainstem on that day. Direction of velocity at measured locations was fairly homogeneous across the channel, while velocities were generally lowest near the bottom, and highest near surface, ranging from 0.0 to 0.8 ft/s. Measurements in September, made in windy conditions, raised questions about the effect of wind on flow.

Most nutrient and carbon concentrations were lowest in spring, increased and remained elevated in summer, and decreased in fall. Dissolved nitrite plus nitrate and nitrite had a different seasonal cycle and were below detection or at low concentration in summer. Many nutrient and carbon concentrations were similar at the top and bottom of the water column, though ammonia and particulate carbon showed more variability in summer. Averaged over the season, particulate carbon and particulate nitrogen decreased in the downstream direction, while ammonia and orthophosphate concentrations increased in the downstream direction.

At most sites, bacteria, phytoplankton, and zooplankton populations reached their maximums in summer. Large bacterial cells made up most of the bacteria biovolume, though cocci were the most numerous bacteria type. The cocci were smaller than the filter pore sizes used to separate dissolved from particulate matter in this study. Phytoplankton biovolumes were dominated by the blue-green alga *Aphanizomenon flos aquae* most of the sampling season, though a spring diatom bloom occurred. Phytoplankton biovolumes were generally highest at the upstream Link River and Railroad Bridge sites and decreased in the downstream direction. Zooplankton populations were dominated by copepods in early spring, and by cladocerans and rotifers in summer, with rotifers more common farther downstream.

Introduction

The Klamath River (fig. 1), which flows from Upper Klamath Lake about 255 mi through southern Oregon and northern California, is regulated for flows, irrigation, and hydropower generation. The first dam on the river is Link River Dam, a concrete structure owned by Bureau of Reclamation and operated by PacifiCorp to adjust levels in Upper Klamath Lake, regulate downstream flows, and divert water for irrigation or hydropower use (Pacificorp, 2002). Link River flows for 1 mile downstream of Link River Dam to the 20-mile-long Keno reach of the Klamath River; the first 2 wide and shallow miles of the Klamath River downstream of Link River is named Lake Ewauna. Keno Dam, on the downstream end of the reach, is a concrete reregulating facility owned by PacifiCorp and operated by PacifiCorp in coordination with the Bureau of Reclamation. Keno Dam operations are designed to provide sufficient downstream flow and a steady reservoir elevation through the year. Normal full pool elevation of the Keno reach is 4,085 ft above NGVD 29, and total storage capacity is 18,500 acre ft.

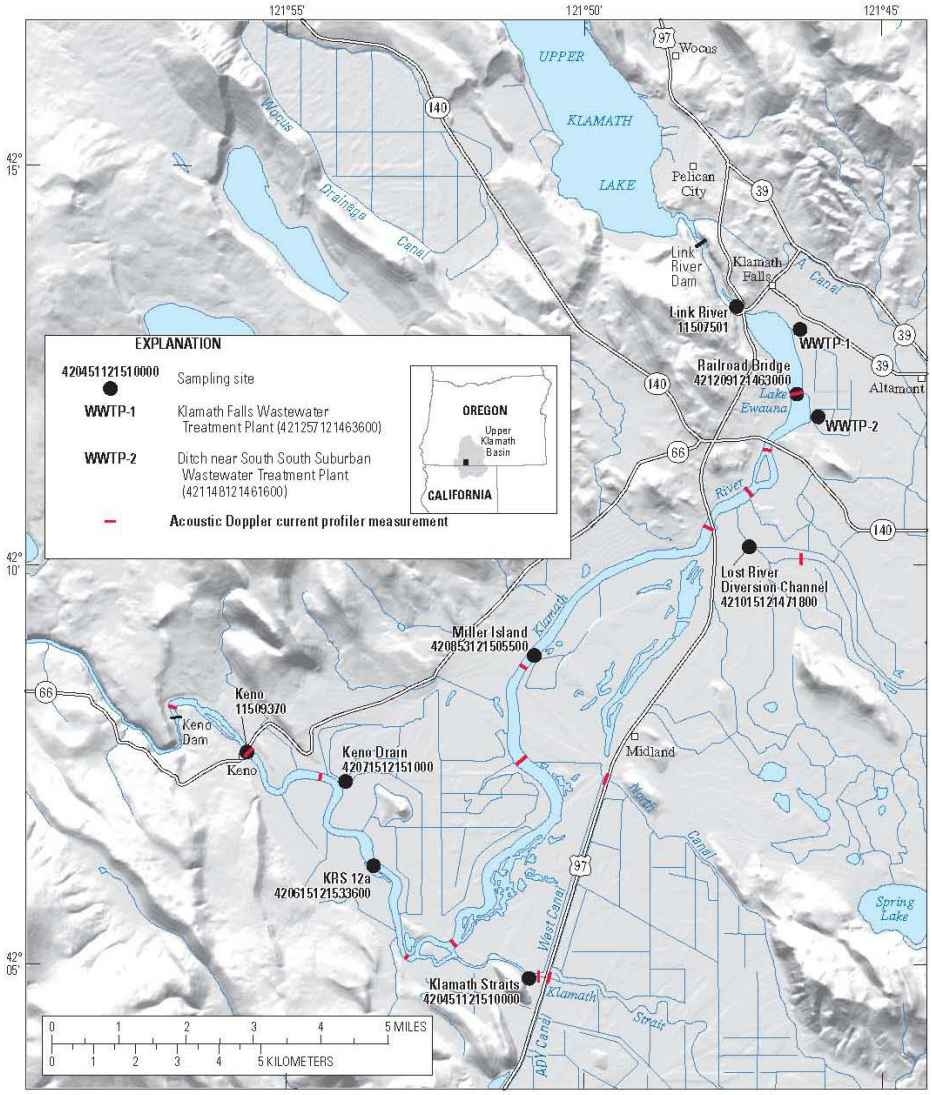

Figure 1. Map of the study area on the upper Klamath River, Oregon, and location of water quality and acoustic Doppler current profiler sites.

The State of Oregon classifies sites in this reach as having "very poor" water quality status, according to the Oregon Water Quality Index (Mrazik, 2007). In addition, the Keno reach has been designated as "water quality limited" on Oregon's 303(d) list for ammonia and dissolved oxygen year-round, and pH and chlorophyll *a* in summer (Oregon Department of Environmental Quality, 2007). To address the 303(d) listing, a total maximum daily load (TMDL) process is under way.

Water quality in this reach of the Klamath River is affected by a number of factors, including upstream conditions, tributary inflows and outflows, climate, and instream processes. For instance, Upper Klamath Lake, upstream of the reach, experiences large annual blooms of the blue-green alga *Aphanizomenon flos aquae* (AFA) (Wood and others, 2006). Inflows to the Keno reach also include two municipal wastewater treatment plants, the Lost River Diversion Channel, and Klamath Straits Drain, which itself is 303(d) listed for ammonia and oxygen year-round, and chlorophyll *a* (indicating excessive algal growth) in summer. To further understand the processes that contribute to water quality conditions in this reach of the Klamath River, a comprehensive suite of water quality constituents, including nutrients and phytoplankton, were measured at sampling intervals less than the travel time through the reach (weekly to biweekly). Acoustic Doppler current profiler (ADCP) work was conducted to increase understanding of flow and velocities in this reach.

The purpose of this report is to present the methods and data from monitoring in Link River, the Keno reach of the Klamath River, and tributaries from early April through early November 2007. Data reported here include ADCP flows and cross sections; water quality field parameters (temperature, pH, dissolved oxygen concentration, specific conductance); concentrations of total nitrogen and phosphorus; particulate carbon and nitrogen; filtered orthophosphate, nitrite, nitrite plus nitrate, ammonia, organic carbon, iron, silica, and alkalinity; specific UV absorbance at 254 nm; phytoplankton and zooplankton enumeration and species identification; and bacterial abundance and morphological subgroups. Results of this project that are more experimental in nature, including a series of 30-day biochemical oxygen demand experiments, will be presented elsewhere. Also, 12 continuous monitors were deployed in the reach measuring hourly water temperature, pH, dissolved oxygen concentration, and specific conductance; when processing is completed, those data will be online at *http://or.water.usgs.gov/proj/keno_reach/monitors.html.* Together, these datasets will support interpretive analysis and model development and calibration in the reach by the U.S. Geological Survey (USGS), Watercourse Engineering, and Bureau of Reclamation, and provide data to others working in the Klamath Basin.

Acoustic Doppler Current Profiler Methods

To better characterize flow in the reach, a series of ADCP measurements were done on May 30, 2007, and September 19, 2007, by USGS with assistance from the Bureau of Reclamation. ADCP technology allows three-dimensional velocity profiles and channel depth to be collected from a moving platform, usually a boat or tethered raft. The instrument's movement, speed, and direction are measured by tracking the channel bottom. When a number of measurements are made in a river in a day, results can be used to check water balances and note occurrences of ungaged inflows or outflows. With measurements made bank-to-bank across a river channel, cross sectional data on velocity and velocity directions are collected.

Measurements were made at locations on the mainstem and major flow inputs and outputs (fig. 1). The four major canal sites, the Lost River Diversion Channel, North Canal, ADY Canal, and Klamath Straits Drain, are monitored by acoustic index meters by the Bureau of Reclamation, and the USGS is currently developing ratings to verify the flows from these gages. Lost River Diversion Channel is located at RM 249.8, and water can be diverted from or returned to the Klamath River through this canal. North Canal removes water from Klamath River at RM 244.4. ADY Canal removes water from the river from

two locations on the river near RM 240.6 and 241.4. Klamath Straits Drain pumps water back into the river at RM 239.8 and 240.4. On the mainstem, Link River and Keno Dam flows have continuous flow gages operated by the USGS.

Three crews made ADCP measurements on each of the days. One crew made measurements from a boat north of Miller Island on the mainstem Klamath River, a second crew made boat-based measurements south of Miller Island, and the third crew made land-based measurements of tributaries. The first crew used a 1,200 kHz Rio Grande ADCP (Teledyne RD Instruments) using Mode 5 or 11 mounted inside an Ocean Science Riverboat; this configuration may have allowed the first crew to measure closer to shore than the second crew. The second crew used a 1,200 kHz Rio Grande ADCP on May 30, and a 600 kHz Rio Grande ADCP on Sept 19; this crew's instrument was physically mounted to the side of the boat. The land-based crew used a StreamPro ADCP 2,000 kHz unit (Teledyne RD Instruments), and a bank-operated pulley system allowed a constant and slow speed across the channel.

A portion of the edge of a cross section close the river banks cannot be measured because of minimum operational depth requirements for the instruments; in general, minimum measurement depth decreases with increasing transducer frequency. Aquatic vegetation on the banks affects the ability of an instrument to measure velocities, and, therefore, in places with thick aquatic vegetation near the shore, the amount of unmeasured flow on the side may have been greater. Edge discharges are estimated using an interpolation method based on the last recorded water velocities and the distance to the edge of water. Usually the estimated edge discharge is relatively small compared to the measured discharge. In addition to the unmeasured sections on the edges, an area near the surface and bottom of the water column is not measurable, due to the transducer depth and blanking distance at the surface and beam reflection issues at the bottom.

On May 30, boat-based measurements were made at 11 locations on the mainstem Klamath River and on the Lost River Diversion Channel. Three canals were measured on land: North, ADY, and Klamath Straits Drain. One boat crew started near the Link River gage, upstream of Lake Ewauna, and headed south to Miller Island. Another boat crew made measurements south of Miller Island. Weather conditions were fairly stable throughout the day, with an increase in wind late in the day.

On September 19, measurements from a boat were made at 10 locations on the mainstem. All four canals were measured on land. One boat crew began at Miller Island and traveled north. The other boat crew measured sites south of Miller Island and made one measurement at Miller Island. Weather conditions this day were not ideal, with weather severity increasing through the day; afternoon winds were near 10 mph with gusts over 20 mph. These deteriorating weather conditions made boat operation difficult and increased the error associated with ADCP measurements on this day.

Final discharge values for a measurement are normally the average of four transects (two in each direction), and if any one transect exceeded 5 percent from the mean discharge for the measurement, four additional transects would usually be obtained. However, due to the time limitations, weather, and nonsteady flow conditions, it was not always practical to obtain more then four transects at each section during this study. Based on measuring conditions, a qualitative judgment of the overall measurement at a site is provided: Good, Fair, or Poor. A measurement rated "Good" is considered to be accurate to ±5 percent, a "Fair" rating is accurate to ±8 percent, and a "Poor" rating is of lesser accuracy (Rantz and others, 1982; Oberg and others, 2005). All flows are reported to three significant digits.

Water Quality Sampling

Site Locations and Frequency

Samples for water quality analysis were collected from five mainstem sites and five tributaries (fig.

1, table 1). Sampling began the first week of April and terminated the first week of November. In general, sampling was conducted weekly at the Link River, Miller Island, Keno, and Klamath Straits Drain sites, and every 2 weeks at the Railroad Bridge and KRS12a sites. The Lost River Diversion channel was sampled in spring and fall, periods when flow was to the Klamath River. The Keno Drain, Klamath Falls WWTP and a ditch near South Suburban WWTP were sampled in mid-August and mid-September.

Table 1. Klamath River mainstem and tributary sampling locations.

[Latitude and longitude format: dd mm ss; **Abbreviations:** RM, River Mile; WWTP, wastewater treatment plant; *, Klamath RM at confluence with tributary]

Site Name	USGS Site Number	Latitude	Longitude	Klamath RM
Mainstem Klamath River				
Link River	11507501	42 13 10	121 47 25	253.2
Railroad Bridge	421209121463000	42 12 09	121 46 30	251.7
Miller Island	420853121505500	42 08 53	121 50 55	245.9
KRS12a	420615121533600	42 06 15	121 53 36	238.3
Keno	11509370	42 07 41	121 55 44	234.9
Tributaries				
Klamath Falls WWTP	421257121463600	42 12 57	121 46 36	252.6*
Ditch near South Suburban WWTP	421148121461600	42 11 48	121 46 16	251.4*
Lost River Diversion Channel	421015121471800	42 10 15	121 47 18	249.7*
Klamath Straits Drain	420451121510000	42 04 51	121 51 00	240.5*
Keno Drain	420715121541000	42 07 15	121 54 10	236.6*

Samples for total nitrogen and phosphorus; particulate carbon and nitrogen; filtered orthophosphate, nitrite, nitrite plus nitrate, ammonia, and organic carbon were collected during most samplings. Phytoplankton species samples were collected during most mainstem samplings near the surface. Bacteria samples were taken at mainstem samplings, every 2 weeks. Zooplankton samples were taken at mainstem sites approximately every 2 weeks. Filtered iron and alkalinity were sampled monthly at Link River, Miller Island, and Keno. Filtered iron, along with filtered silica, was also sampled at Link River weekly from July through mid-October.

Sample Collection

During each sampling, field conditions were noted, and a vertical profile of pH, dissolved oxygen (DO), specific conductance, and water temperature was taken with a YSI 600XLM sonde. Grab water samples were taken with a van Dorn sampler and processed with a churn sample splitter. At most sites, samples were collected at 0.5 m depth. At four mainstem sites, a near-bottom sample was also collected for nutrients. Those samples were taken 1 m from the bottom, which was equivalent to 2.0 to 4.5 m from the surface depending on the site. All samples were kept on ice after collection.

Unfiltered samples collected in the field included total nitrogen and phosphorus, carbon, bacteria, and phytoplankton. Samples for analysis of total nitrogen and total phosphorus were preserved by adding 1 ml of 4.5 N sulfuric acid to each 125 mL sample bottle. Water for further processing of samples for particulate carbon and nitrogen and dissolved organic carbon was collected into 60 or 125 mL amber glass bottles that had been precombusted at 450 ºC to remove any traces of carbon. Bacteria samples were

immediately preserved in 5 percent buffered formalin in 15 mL centrifuge tubes. Phytoplankton species samples were preserved with 1 percent Lugol's solution in 250 mL amber bottles.

Samples filtered in the field included nutrients, iron, silica, and, alkalinity. A Whatman capsule filter with a 0.45 µm pore size, rinsed with 500 mL of deionized water and 500 mL of sample, was used to collect these samples. Filtered samples taken near the bottom of the water column were pumped directly from the van Dorn sampler to the filter to minimize contact with the atmosphere. Filtered nutrients were collected into brown polyethylene bottles. Filtered iron was preserved with 2 mL of 7.7 N Ultrex grade nitric acid added to each 250 mL sample bottle.

Zooplankton samples were taken by vertical tow with an 80 µm mesh Wildco Wisconsin net. The net assembly was rinsed with deionized water and specimens captured in a collector cup and transferred to a 250 mL sample bottle. At Link River, the current was too strong for a vertical tow, so known volumes were taken as grab samples at the surface and then passed through the zooplankton net assembly. Zooplankton samples were preserved in 23 percent isopropyl alcohol.

Immediately upon return to the laboratory, all samples for organic carbon analysis were filtered using precombusted glass fiber filters and a Teflon filter apparatus, according to USGS procedures (Wilde and others, 2004). The filtrate was collected for dissolved organic carbon (DOC) analysis, and the glass fiber filters with retained particulate matter were submitted for analysis of particulate organic carbon (POC) and particulate nitrogen. Glass fiber filters had a nominal pore size of 0.7 µm.

Samples were shipped on ice overnight to the laboratories. Through the season, a few coolers were delayed during shipping and arrived warm at the laboratories: two to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, and two to the USGS microbiology lab in Reston, Virginia. Those samples were analyzed, but results are not reported here.

Quality Control Samples

Quality control samples collected as a regular part of the sampling program included blanks and replicates. Blanks were included to determine whether bias existed from contamination in any step of sampling and analysis. Replicate samples were taken to estimate variability from sampling and analysis. The number of quality control samples taken for each constituent was modified from guidelines from the USGS NAWQA program (Mueller and others, 1997), after considering Bureau of Reclamation guidelines (Bureau of Reclamation, 2005) and project needs.

Field blanks collected at various sites through the season assessed the potential for contamination from the atmosphere, equipment, sample processing, transportation, and laboratory analysis. Lab blanks assessed the potential for contamination from transportation and laboratory analysis. Both field and lab blanks were collected using USGS-certified blank water. Blank results were evaluated in comparison to reporting levels determined by the laboratory for each constituent. For samples analyzed at the NWQL, the laboratory reporting level (RL) is usually equal to twice the long-term method detection level (LT-MDL), which is determined statistically on an annual basis (Childress and others, 1999).

Most field replicates, taken at various sites through the season, were subsamples from the same grab sample. Zooplankton duplicates, collected as sequential replicates, were the exception. Variability between duplicates was analyzed by calculating absolute differences and relative percent differences (RPD):

$$RPD = \left| \frac{(Value1 - Value2)}{(Value1 + Value2)/2} \right| \times 100$$

RPD was calculated for duplicates with concentrations more than 5 times the reporting limit, since percent differences for samples near the reporting limit can be high, even with small absolute differences.

Water Quality Analytical Methods

Nutrients, Particulate Carbon and Nitrogen, Iron, Silica, and Alkalinity

Nutrients, particulate carbon and nitrogen, iron, and silica were analyzed at the NWQL (table 2). Total phosphorus and total nitrogen concentrations were determined by alkaline persulfate digestion (Patton and Kryskalla, 2003). Orthophosphate was determined by colorimetry by reaction with ammonium molybdate in acidic solution to form phosphomolybdic acid, then reduction with ascorbic acid (Fishman, 1993). Nitrite was analyzed by colorimetry via reaction with sulfanilamide under acidic conditions to form a diazo compound that couples with N-1-naphthylethylenediamine dihydrochloride (Fishman, 1993). Nitrate plus nitrate was determined similarly, but nitrate was first reduced to nitrite with cadmium metal. Ammonia was measured by colorimetry through reaction with salicylate and hypochlorite in the presence of ferricyanide ions (Fishman, 1993). Iron was analyzed with inductively coupled plasma atomic emission spectrometry (Fishman, 1993), and silica with the molybdate blue method (Fishman and Friedman, 1989).

Table 2. Analyzing laboratories and method references for water quality constituents.

[**Abbreviations:** NWQL, National Water Quality Laboratory]

Analyte	Laboratory	Method Reference
Orthophosphate, as P	USGS NWQL, Denver, Colorado	Fishman, 1993
Ammonia, as N	USGS NWQL, Denver, Colorado	Fishman, 1993
Nitrate and nitrite, as N	USGS NWQL, Denver, Colorado	Fishman, 1993
Nitrite, as N	USGS NWQL, Denver, Colorado	Fishman, 1993
Total phosphorus	USGS NWQL, Denver, Colorado	Patton and Kryskalla, 2003
Total nitrogen	USGS NWQL, Denver, Colorado	Patton and Kryskalla, 2003
Particulate carbon	USGS NWQL, Denver, Colorado	Zimmerman and others, 1997
Particulate nitrogen	USGS NWQL, Denver, Colorado	Zimmerman and others, 1997
Iron	USGS NWQL, Denver, Colorado	Fishman, 1993
Silica	USGS NWQL, Denver, Colorado	Fishman and Friedman, 1989
Dissolved organic carbon	USGS, Boulder, Colorado	Aiken, 1992
SUVA	USGS, Boulder, Colorado	Weishaar and others, 2003
Total bacterial abundance	USGS, Reston, Virginia	Noble and Fuhrman, 1998; Weinbauer and others, 1998
Alkalinity, as $CaCO_3$	USGS, Klamath Falls, Oregon	Rounds, 2006
Phytoplankton, total density	Aquatic Analysts, White Salmon, Washington	American Public Health Association, 2005; McNabb, 1960
Zooplankton, total density	ZP's Taxonomic Services, Aberdeen, Washington	American Public Health Assocation, 2005

Particulate carbon and nitrogen concentrations were analyzed by combusting particulates retained on glass fiber filters in pure oxygen at 975 ºC (Zimmerman and others, 1997). The combustion products were converted to CO_2, H_2O, and N_2, and detected by thermal conductivity. In some analyses, a second sample filter was precombusted to remove organic carbon, allowing the measurement of particulate inorganic carbon. Particulate organic carbon (POC) is calculated as the difference between total particulate carbon (filter 1) and particulate inorganic carbon (filter 2). In many systems, particulate inorganic carbon is minimal, so measurement of total particulate carbon is equivalent to POC. In pilot work at Link River and Keno, particulate inorganic carbon was always below detection, so total particulate carbon was assumed equal to POC.

NWQL has thorough internal quality assurance protocols, including standard reference samples, blanks, replicates, spikes, and calibration standards. These protocols are documented in Friedman and Erdmann (1982), Jones (1987), and Pritt and Raese (1995), and Maloney (2005). Samples analyzed at NWQL used USGS-certified field supplies during sampling including filters, bottles, and preservatives. Those supplies are subject to testing, inspection, and other quality assurance procedures (U.S. Geological Survey, no date).

Alkalinity was analyzed within 24 hours of sample collection by titration following USGS methods (Rounds, 2006). Samples were run in duplicate, and results are averages of the duplicates. Two alkalinity standards from the USGS National Field Quality Assurance Program were analyzed, and both results were within 1 percent of the standard value.

Dissolved Organic Carbon and Specific UV Absorbance

DOC concentrations were measured using the platinum catalyzed persulfate wet oxidation method on an O.I. Analytical Model 700 TOC Analyzer™ (Aiken, 1992; Schuster, 2003), with the instrument warmed up at least 4 hours before analysis. Samples and standards were loaded onto an autosampler and introduced into the reaction vessel by means of a fixed-volume sample loop. The volume of the sample loop was kept small, usually 1 mL, to maintain linear instrument response (0–50 µg of carbon). The standard, automated analytical conditions called for 0.5 mL of 5 percent by volume phosphoric acid added to the sample. The sample was then purged for 2.0 minutes with nitrogen to remove inorganic carbon, after which 0.5 mL of 0.42 M sodium persulfate solution was added. The standard reaction time of 5 minutes was used for the persulfate oxidation step. The instrument was calibrated with solutions of reagent-grade potassium hydrogen phthalate in distilled water. The standard curve, consisting of a minimum of five standards over the range of interest, was repeated for every 10–12 water samples analyzed in duplicate. All values are the averages of duplicate analyses. Standard deviation for the DOC measurement was ±0.2 mg/L.

Ultraviolet-visible light absorbance analyses (UV-Vis) measurements were made on a Hewlett-Packard Model 8453™ photo-diode array spectrophotometer between λ=200 nm and λ=800 nm with distilled water as the blank using a 1 cm path-length quartz cell. Dissolved organic matter is a complex mixture of organic compounds, and absorbance measurements provide additional insight into its composition. The wavelength of λ=254 nm was chosen because it is the wavelength commonly associated with the aromatic moieties in a sample (Weishaar and others, 2003). Filtered samples at room temperature were analyzed using a quartz cell in the manual mode. The cell was rinsed with a small volume of sample before adding sample for analysis. The cell was then rinsed with distilled water before analyzing the next sample. Standard deviation for a UV absorbance measurement at 254 nm was ±0.002 AU.

Specific UV Absorbance (SUVA), defined as the UV absorbance of a sample measured at a given wavelength divided by the DOC concentration, is an average molar absorbance for all the molecules that compose the DOC in a water sample. SUVA is a parameter that indicates the nature of DOC in a given

sample and has been used as a surrogate measurement of DOC aromaticity (Weishaar and others, 2003). SUVA values at 254 nm ($SUVA_{254}$) are reported here because natural organic matter absorbs strongly at this wavelength, thereby giving increased sensitivity, and because of the strong correlation with the aromatic carbon content of natural organic matter at this wavelength. $SUVA_{254}$ was determined by dividing the UV absorbance determined at λ=254 nm by the DOC concentration of the sample. Values are reported in units of L/(mg-m) and have a standard deviation of ±0.1 L/(mg-m).

Bacterial Abundance and Morphology

Processing of bacteria samples employed modifications of protocols from Noble and Fuhrman (1998), and Weinbauer and others (1998). Samples were stained for 15 minutes in the dark using Sybr Green I stain (Molecular Probes, Eugene, Oregon) at 1:5,000 dilution, and were filtered under gentle vacuum (<10kPa) onto a 0.2 µm aluminum oxide Anodisc 25 filter (Whatman International, Maidstone, England) backed by a 0.45 µm cellulose nitrate membrane filter (Fisher Scientific, Pittsburgh, Pennsylvania). The anodisc filter was mounted on a glass slide with a drop of antifade solution (50 percent glycerol, 50 percent phosphate buffered saline, 0.5 percent ascorbic acid) and a 25 mm-square coverslip. Total cells were enumerated under blue excitation using a Zeiss epifluorescent microscope (Axio A1). At least 250 cells from at least 5 fields were counted per filter. Autofluorescent, bacteria-sized cells were also enumerated using a bandpass filter with emission from 575–640 nm. Attached cells were counted where possible, but early in the season the numbers were too low to get reliable counts.

Three groups of bacteria were enumerated based on size and morphology:

1. Large cells
2. Vibrios
3. Small cocci

Group 1 bacteria were mostly stubby rods (over 90 percent), but also included narrower or longer rods and diplococci > 0.5 µm. Although it is not possible to determine bacterial identification and metabolic function based on morphology, this group could include Gram-negative, respiratory bacteria (aerobes, facultative anaerobes) phenotypically related to members of the genus *Pseudomonas.* Many bacteria in this physiological group are free-living in soil and water, and play an important role in decomposition, biodegradation, and carbon and nitrogen cycles. Some display bioluminesce, such as Photobacteria. Group 1 bacteria could also include gram-positive fermentative bacteria or enteric bacteria.

"Vibrios," which make up Group 2 bacteria, are Gram-negative bacteria that have the cell shape of a curved rod or a comma. Members of the genus *Vibrio* are common in aquatic environments, and have structural and metabolic properties that overlap with both the enterics and the pseudomonads. In aquatic habitats they overlap with the pseudomonads in their ecology (decomposition, biodegradation, and the carbon and nitrogen cycles).

Group 3 bacteria are cocci, spherical or oval bacteria. Their size in this system was mostly 0.1–0.2 µm, with cells larger than or equal to 0.5 µm rare (<1 percent).

Bacteria play a key role in recycling organic and inorganic matter, and constitute part of the pool of organic matter in aquatic ecosystems. Populations and dimensions of the three bacterial morphologies were used to estimate bacterial biovolume, and can be used to estimate bacterial biomass. Separation into morphological groups is important with these calculations because changes in the populations of larger cells may have a disproportional contribution to biovolume.

Phytoplankton Enumeration and Species Identification

Analysis of phytoplankton included enumeration, identification, and estimations of biovolume. Permanent microscope slides were prepared by filtering an aliquot of each sample through a 0.45 µm membrane filter (American Public Health Association, 2005; McNabb, 1960). A section of filter was cut out and placed on a glass slide with immersion oil added to make the filter transparent. A cover slip was placed over the filter section, with nail polish applied to the periphery for permanency. The slides are archived indefinitely; water samples were placed in storage for at least one year.

Enumeration of algal units (defined as discrete particles - cells, colonies, or filaments) was completed by counting along a measured transect of the microscope slide with a Zeiss standard microscope (1,000X, phase contrast). Only algae that were believed to be alive at the time of collection (intact chloroplast) were counted. At least 100 algal units were counted. Algae were identified using an extensive library of literature, including journal reprints, standard reference books, and internet reference sites. Most algae were identified by cross-referencing several taxonomic sources. Algal densities were calculated from the area observed (transect length times diameter of field of view), the effective filter area, and the volume of sample filtered.

The microscope was calibrated using a standard concentration of latex spheres, 12,075 spheres/mL, provided by the U.S. Environmental Protection Agency (Cincinnati, Ohio). Duplicate preparations of the standard spheres were analyzed, with an average result of 11,700 spheres/mL. A computer program used to calculate algal densities compensated for this 3.1 percent error. The analyzing laboratory has participated in the analyses of split algae samples on several occasions, with general agreement between samples in terms of algae density and groups. Also on occasion, independent algae analysts have been contracted by the laboratory for second opinions on some difficult-to-identify algae species.

Average biovolume estimates of each species were obtained from calculations of microscopic measurements of each algal unit, accurate to 0.1 mm with a stage micrometer. The number of cells per colony or the length of a filament was recorded during sample analysis to arrive at biovolume per unit-alga. Average biovolumes and measurements were verified for each sample analyzed.

Trophic State Index (TSI) based upon phytoplankton biovolume was developed from a data set of several hundred lakes located throughout the Pacific Northwest (Sweet, 1986). The index was derived in a similar fashion as Carlson (1977) derived indices for Secchi depth, chlorophyll *a* concentration, and total phosphorus concentration, and values agree well with Carlson's indices. The unitless biovolume index ranges from one for ultraoligotrophic lakes to 100 for hypereutrophic lakes. The index is defined as:

$$TSI(biovolume) = (\log_2(B+1)) * 5$$

where B is phytoplankton biovolume in µm/mL divided by 1,000

Zooplankton Enumeration and Species Identification

Analysis of zooplankton species included identification and enumeration (American Public Health Association, 2005). Samples were first split with a Folsom plankton splitter until an approximate subsample size of 400 total individual arthropods and 100 individuals of the most abundant species were reached. If the initial split did not achieve both of these criteria, then increasingly larger splits were enumerated until both criteria were met, or until the entire sample was counted. All rotifers and protozoans in the split were completely enumerated as well, unless their numbers significantly exceeded 400 individuals, in which case a separate rotifer subsplit was made and counted for rotifers and protozoans. The statistical methodology for this approach was based upon Edmondson and Winberg (1971, p. 178) and assumed that the sampling methods (both in the field and during the splitting) followed

a Poisson distribution. This assumption is violated for larger species such as those of *Chaoborus* and *Leptodora*; thus, all individuals of those taxa found in a sample were enumerated. The selected values of 400 and 100 individuals provided a maximum statistical standard error of the mean of 5 and 10 percent, respectively (the formula used is: $s = 1/\sqrt{N}$, where N is the number of individuals found belonging to the taxon in question). Although the confidence limits for only total numbers and most abundant species were set by this procedure, the standard error of the mean for each species could be determined from the original tallies, using the previous formula for the Poisson distribution. Results are reported in numbers/m^3, and standard errors for each value are included in Appendix B.

Standard zooplankton enumeration was done with a Wild M-3 microscope at 32X magnification. Samples were counted in an open counting chamber with six parallel channels following the procedures described in Edmondson and Winberg (1971, p. 131). Species identifications were made at higher levels of magnification under a compound microscope as needed. General taxonomic identifications followed Edmondson (1959), Pennak (1989), and Thorp and Covich (1991). Specific group references used include Berner (1994), Brooks (1957), Brandlova and others (1972), Deevey and Deevey (1971), DeMont and Hebert (1994), Dumont and Pensaert (1983), Hebert (2001), Korovchinsky (1992), Patterson (1996), Pontin (1978), Ruttner-Kolisko (1974), Stemberger (1979), and Taylor and others (2002). Identifications were to species for all adult and subadult crustaceans, excepting harpacticoid copepods and ostracods, and for most rotifers. Immature copepods through copepodite stage IV were identified as far as their developmental stage allowed. Confirmation of the identifications was made with results from previous investigations in the region of the study area.

For length-frequency analysis, crustacean lengths were taken following the protocols described in Edmondson and Winberg (1971). Specifically, cladocerans were measured from the top of the head (helmet included) to the posterior edge of the carapace excluding any tail spine or mucro, and copepods were measured from the end of the cephalothorax to the end of the caudal rami, exclusive of the setae.

An estimate of the intensity of planktivory based upon the density and relative abundance of the edible species present was made for each sample. Evaluation of the availability of the different zooplankton species as food items for particular species of fish was based upon an ongoing literature review starting with Brooks (1969) and continuing with Kerfoot (1980), Zaret (1980), and Carpenter and Kitchell (1993). This evaluation was kept up-to-date by regular reviews of recently published zooplankton predation studies in Limnology and Oceanography, and the Proceedings of the International Association of Theoretical and Applied Limnology (Verhein International Verein Limnologie), as well as the results of articles such as Eilers and others (2007). The earlier literature has been summarized in Canale and others (1975, 1976).

Quality assurance included microscope calibration, replicate samples, independent analysis, and internal data verification. The basic quality control method used for enumerating zooplankton samples was the standard error value, an estimator of within-sample variability. Quality assurance and control for within-sample variability was maintained by routine re-analysis of 2 to 3 percent of all samples examined. The samples re-analyzed were selected at random, using a random number generator and the unique sequence number of each sample analyzed. Statistical analyses of past replicated counts indicated that the standard error values adequately estimate between 90 and 98 percent of all within-sample variability.

Unlike the statistical parameter standard deviation, standard error does not provide a between-sample estimator of the population variance. Field replicate samples were collected to assess between-sample variability. Between-sample replicates taken at the same time and place have significantly higher variability due to plankton patchiness and species "swarms."

Acoustic Doppler Current Profiler Data Summary

Summary and raw transect data and plots of cross-sectional velocity direction and velocity are included as electronic files in the Appendix A. Local Agrimet weather data are included, as well as provisional Bureau of Reclamation continuous flow data from the canals from May 30 and September 19. A brief summary of the ADCP data is provided below.

May 30, 2007

With one boat crew working from upstream to downstream, a flow of 1,330 ft^3/s was measured downstream of Lake Ewauna at river mile (RM) 251.6 (fig. 2). This measured flow is lower then the flows reported from the Link River gage upstream of Lake Ewauna, which ranged from 1,460 to 1,470 ft^3/s at the time this measurement was made. The next two measurements were made at mile RM 250.6 and upstream of the Lost River Diversion Channel at RM 250; the discharge for both of these was 1,350 ft^3/s. A measurement in the mouth of the Lost River Diversion identified 292 ft^3/s flowing out of Klamath River. This flow can be subtracted from the 1,350 ft^3/s, resulting in a predicted downstream flow of 1,060 ft^3/s. A measurement of 1,110 ft^3/s, made downstream of the Lost River Diversion Channel (RM 249.2), confirmed the predicted downstream flow. The flow measured at Miller Island (RM 245.7) was 1,200 ft^3/s. This flow agrees with the measurement of 1,190 ft^3/s made downstream at RM 244.5 by the second crew.

Starting at the downstream end of the reach, the second boat crew measured flow upstream of Keno Dam (RM 233.5) of 994 ft^3/s, flow near Highway 66 (RM 234.8) of 914 ft^3/s, and flow at RM 236.3 of 978 ft^3/s. The next two measurements made upstream (RM 240.5) and downstream (RM 239.6) of Klamath Straits Drain, were 705 and 1,050 ft^3/s respectively. This flow difference predicts an output from the Klamath Straits Drain of 345 ft^3/s, which was confirmed by the measurement of 340 ft^3/s made in the drain by the third crew. The second crew finished by making a measurement of 1,190 ft^3/s at RM 244.5, on the mainstem upstream of the ADY and North canals. This measurement subtracted from the measurement at RM 240.5 (705 ft^3/s) results in a net reduction of 485 ft^3/s, whereas the total flows for ADY and North canals as measured by the third crew result show a net withdrawal of 346 ft^3/s. There is the possibility of marsh flow or storage between the measuring location on the North Canal and the mainstem Klamath River or withdrawals from other diversions not measured in this study.

Most measurements on this day were rated fair (±8 percent) except for the two farthest downstream measurements, which were rated good (±5 percent), and the measurement at Miller Island (RM 245.7) which was rated poor (>±8 percent) due to afternoon wind affecting surface conditions there.

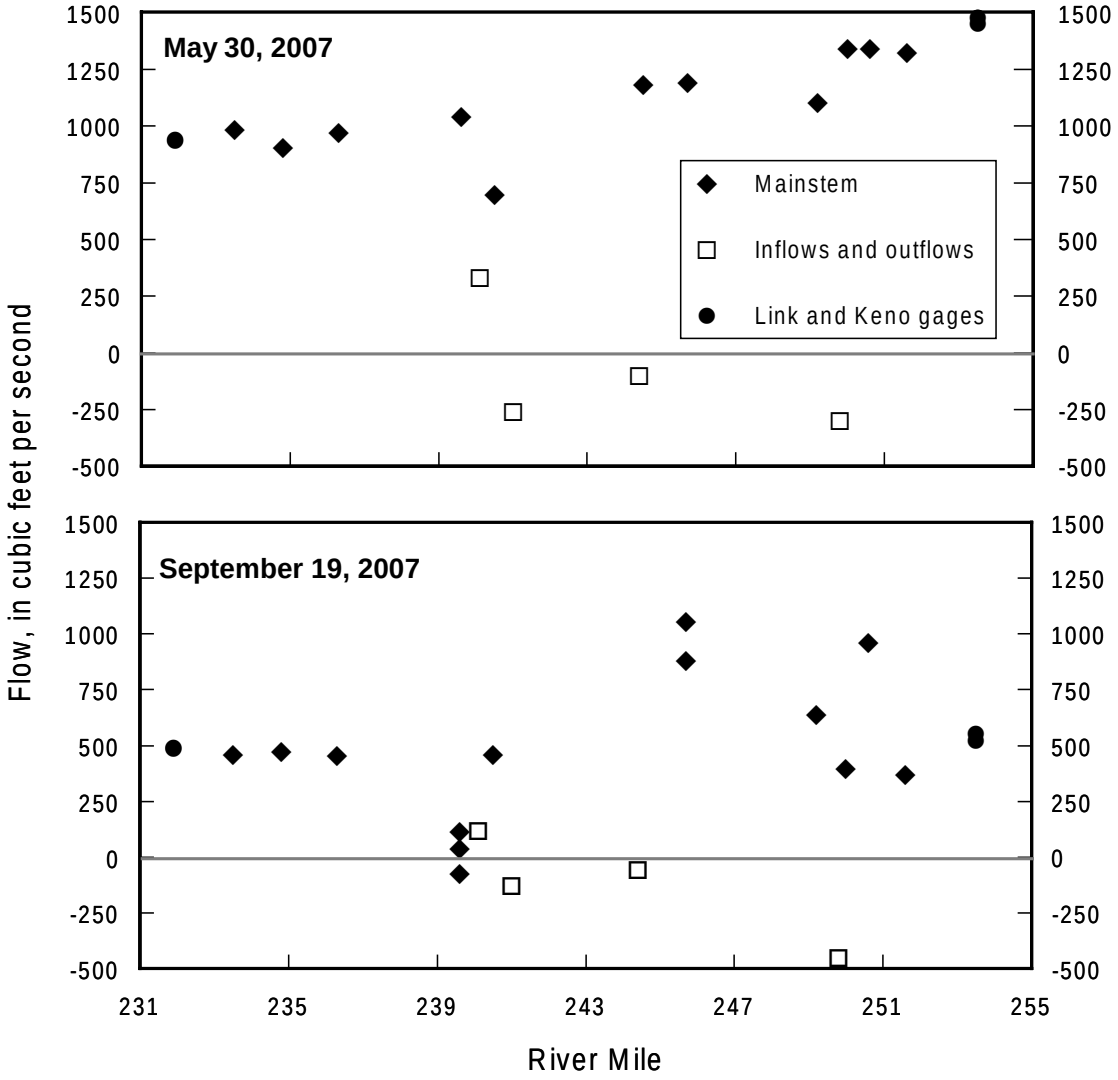

Figure 2. Acoustic Doppler current profiler flow measurements on the Klamath River between Link River Dam and Keno Dam on May 30, 2007, and September 19, 2007, and gaged flows at Link River and downstream of Keno Dam for the same dates.

September 19, 2007

One crew began at Miller Island (RM 245.7), measuring 888 ft^3/s (fig. 2), and then moved upstream. Klamath River flow downstream of the Lost River Diversion Channel (RM 249.2) was measured at 646 ft^3/s, and upstream of Lost River Diversion Channel (RM 250.0), measured flow was 406 ft^3/s. This pattern of higher Klamath River flows downstream of the Diversion Channel and lower flows upstream is inconsistent with measured discharge flowing out of Klamath River in the Diversion Channel measured by the land-based crew (442 ft^3/s flowing out of Klamath River). The boat crew measured 970 ft^3/s upstream at RM 250.6. The main USGS measuring points at Link and Keno stayed relatively constant throughout the day, but a likely explanation for these changing flow patterns was the variable wind during these periods.

The average measurement made downstream of Lake Ewauna at RM 251.6, between 14:41 and 15:28, was 380 ft^3/s; however, the individuals transects ranged from 12.8 ft^3/s (at 14:41) to 775 ft^3/s (at 15:28). During this time the Link River gage, essentially all flow upstream of Lake Ewauna, ranged from only 532 to 564 ft^3/s.

The second boat crew made measurements at Miller Island and sites south of Miller Island, starting at Keno and working upstream. Measured flow above Keno Dam (RM 233.5) was 468 ft^3/s, 482 ft^3/s near HWY 66 (RM 235), and 464 ft^3/s at RM 236.2.

The subsequent measurements, from RM 239.6 downstream of Klamath Straits Drain and RM 240.5 upstream of the drain indicated highly variable flow conditions. Three sets of measurements were completed at RM 239.6 between 14:04 and 14:46, with average flows of 122, –66.4, and 45.8 ft^3/s. An average measurement of 468 ft^3/s was made upstream of the Klamath Straits Drain (RM 240.5), though the individual transects ranged from 64.6 ft^3/s (at 15:01) to 1,000 ft^3/s at (15:26). Measurements at this location by the second crew were made at the same time as the first crew was measuring at RM 251.6, where individual transects also ranged low to high within that same time period. Wind speeds at the Klamath Falls KFLO Agrimet station between 14:00 and 15:30 averaged 8.1 mph with 15-minute peak wind gusts between 12.9 and 22.1 mph (Appendix A). Deployment of several continuously measuring bottom-mounted ADCPs is planned for 2008 to further investigate the effect of weather and wind conditions on flow and circulation in this reach of the Klamath River.

The second boat crew finished by making a second measurement at Miller Island (RM 245.7) of 1,060 ft^3/s. The Miller Island measurement made between 16:16 and 16:39 was higher then the 888 ft^3/s measured by the first crew earlier in the day (11:00–11:30). The land-based crew measured 129 ft^3/s to the Klamath River from the Klamath Straits Drain and 177 and 46.7 ft^3/s leaving the river from the ADY and North Canals, respectively.

Most mainstem boat-based measurements were rated poor (>± 8 percent) due to slow water velocities, relatively fast boat speeds, and the wavy and choppy surface conditions; the exceptions were the two most downstream sites, which were rated fair (±8 percent). All land-based canal measurements were rated fair.

Cross-Sectional Velocity Direction and Magnitude

The direction of velocities across the channel was more homogeneous than the magnitude, which was usually lowest near the channel bottom and sides, and highest near-surface (Appendix A). Many sections showed fairly symmetrical velocities bank-to-bank, with some exceptions, RM 249.2 for example. Measured cross-sectional velocities there on May 30 were between 0 and 0.8 ft/s.

More variability was observed in cross-sectional velocity direction and velocity on September 19. Increased variability due to nonideal measuring conditions and effects of strong wind on circulation was not quantified. Measured cross-sectional velocities had a similar range to those measured on May 30.

Water Quality Data Summary

Water quality data summarized here are provided in appendix tables (PDF and Excel files) that can be accessed through links at the end of the text. A brief data summary is presented below to highlight quality control results, seasonal trends, concentration ranges, differences between concentrations at the top and bottom of the water column, major species, and notable trends between sites.

Quality Control Results

Program-level quality assurance for blanks assumes that when field blank concentrations are less than the reporting level, regular samples are free of contamination. It is further assumed that systematic blank results higher than the RL are notable, whereas a rare random blank higher than the RL is of less concern. For analytes with reporting levels, concentrations in 129 of 130 blanks (>99%) analyzed throughout the sampling season were below the RL (table 3): the only blank above the RL was one

particulate carbon blank of 0.15 mg/L, 0.03 mg/L above the RL of 0.12 mg/L. A reporting level was not designated for UV absorbance, but blank values were near at or near zero, and much lower than all measured values. Blank results show no evidence of systematic contamination.

Table 3. Analyte reporting levels and blank results.

[**Abbreviations:** RL, reporting level; mg/L, milligrams per liter; P, phosphorus; N, nitrogen; >, greater than; NA, no blanks were above RL; *, RL not determined, median and range of all blanks given]

Analyte	Units	RL	Number of blanks	Number of blanks > RL	Value of blanks > RL
Orthophosphate, as P	mg/L	0.006	16	0	NA
Ammonia, as N	mg/L	0.02	16	0	NA
Nitrate and nitrite, as N	mg/L	0.06	16	0	NA
Nitrite, as N	mg/L	0.002	16	0	NA
Total phosphorus	mg/L	0.02	16	0	NA
Total nitrogen	mg/L	0.06	16	0	NA
Particulate carbon	mg/L	0.12	9	1	0.15
Particulate nitrogen	mg/L	0.022	9	0	NA
Iron	mg/L	0.006	6	0	NA
Dissolved organic carbon	mg/L	0.7	10	0	NA
UV absorbance	1/m	*	10	*	median: 0.001 range: 0.000 – 0.007

Analysis of duplicate filtered samples showed low variability (table 4). All duplicates (≥5x RL) for filtered orthophosphate, ammonia, nitrite, DOC, UV absorbance, iron, and alkalinity were below 8 percent RPD, with medians of all duplicates for those analytes 4 percent or less. There was more variability for duplicates of unfiltered samples, that is, those that included particulate matter. The macroscopic size and tendency of AFA to form clumps likely contributed to this variability. There is greater uncertainty with these data due to the inherent difficulties of sampling particulate matter. Several samples for total nitrogen and phosphorus, and particulate carbon and nitrogen that had higher RPD were submitted for reanalysis at NWQL, and all original analyses were confirmed.

Table 4. Results of analyses of duplicate quality assurance samples

[**Abbreviations:** mg/L, milligrams per liter; RPD, relative percent difference; ≥, greater than or equal to; RL, reporting level; pctl, percentile; NA, no duplicate results were ≥5x RL; *, RL was not determined, so RPD was calculated for all duplicates]

Analyte	Duplicates	Units	Difference between duplicates			
			Absolute difference		RPD, % (for duplicates ≥ 5x RL)	
			Median	10^{th} pctl | 90^{th} pctl	Median	10^{th} pctl | 90^{th} pctl
Orthophosphate, as P	15	mg/L	0.001	0.000 | 0.003	1.0	0.0 | 2.1
Ammonia, as N	15	mg/L	0.003	0.001 | 0.007	0.9	0.7 | 2.5
Nitrate and nitrite, as N	15	mg/L	0.001	0.000 | 0.008	NA	NA
Nitrite, as N	15	mg/L	0.000	0.000 | 0.000	0.0	0.0 | 2.0
Total phosphorus	15	mg/L	0.01	0.00 | 0.04	3.5	2.2 | 15.4

Table 4. Results of analyses of duplicate quality assurance samples—continued

[**Abbreviations:** mg/L, milligrams per liter; RPD, relative percent difference; ≥, greater than or equal to; RL, reporting level; pctl, percentile; NA, no duplicate results were ≥5x RL; *, RL was not determined, so RPD was calculated for all duplicates]

Analyte	Duplicates	Units	Difference between duplicates			
			Absolute difference		RPD, % (for duplicates ≥ 5x RL)	
			Median	10^{th} pctl | 90^{th} pctl	Median	10^{th} pctl | 90^{th} pctl
Total nitrogen	15	mg/L	0.06	0.03 | 0.34	4.4	1.3 | 17.0
Particulate carbon	14	mg/L	0.27	0.07 | 1.02	11.5	2.9 | 25.9
Particulate nitrogen	14	mg/L	0.06	0.00 | 0.18	7.2	0.6 | 38.3
Iron	3	mg/L	0.002	0.000 | 0.004	4.0	0.8 | 5.8
Dissolved organic carbon	16	mg/L	0.2	0.0 | 0.5	1.3	0.0 | 3.9
UV absorbance	16	1/m	0.002	0.000 | 0.005	0.5*	0.0 | 2.2*
Bacterial abundance	6	10^6 cells/mL	19.8	7.8 | 45.6	44.0*	14.1 | 62.3*
Alkalinity, as $CaCO_3$	3	mg/L	0.8	0.3 | 1.0	1.7	0.6 | 1.9
Phytoplankton, density	8	number/mL	324	71 | 1,332	9.9*	6.8 | 34.4*
Zooplankton, density	5	number/m^3	8,667	1,444 | 13,555	30.0*	23.5 | 58.6*

Nutrients, Iron, Silica, and Alkalinity

Total nitrogen concentration at mainstem sites was lowest in spring and highest in summer, with a gradual decrease late in the sampling season (fig. 3); concentrations at mainstem sites ranged between 0.70 and 5.85 mg/L. Concentrations at the top and bottom of the water column were generally similar; any notable differences occurred in summer. Tributary total nitrogen concentration (Appendix B) ranged from 0.98 to 26.9 mg/L, with highest values near the wastewater treatment plant outflows.

Particulate nitrogen had seasonal patterns similar to total nitrogen, with mainstem concentrations between 0.08 and 3.93 mg/L. Averaged over the sampling season, the percent of total nitrogen that was particulate decreased in the downstream direction at mainstem sites; this was especially true later in the season. Tributary particulate nitrogen concentrations ranged from 0.08 to 2.49 mg/L.

Ammonia concentrations at Link River were below 0.100 mg/L and fairly constant until after mid-October, when concentrations increased, up to 0.530 mg/L. The seasonal pattern at that upstream site was different from that at other mainstem sites, which experienced increases in ammonia concentrations by early July, with maximums in midsummer. At some of the farther downstream sites, on some dates in summer, ammonia also exhibited large variation (over 100 percent difference) between the top and bottom of the water column. Averaged over the entire sampling season, ammonia concentrations increased in the downstream direction: 0.089 mg/L at Link River, 0.238 mg/L at Railroad Bridge, 0.413 mg/L at Miller Island, 0.501 mg/L at KRS12a, and 0.560 mg/L at Keno. Tributary ammonia concentration ranged from 0.039 to 1.090 mg/L.

Concentrations of nitrite plus nitrate at all mainstem sites were below the reporting level (0.060 mg/L) from June 26 to August 14, with some site's concentration below the reporting level as early as

May 8 (Link River), or as late as September 25 (Railroad Bridge). Concentrations at the top and bottom of the water column were similar. In the Klamath Straits Drain, nitrite plus nitrate concentrations were mostly above detection, ranging between 0.072 and 0.439 mg/L. Other tributary concentrations ranged between below detection and 21.9 mg/L, with highest values from the site near the Klamath Falls wastewater treatment plant.

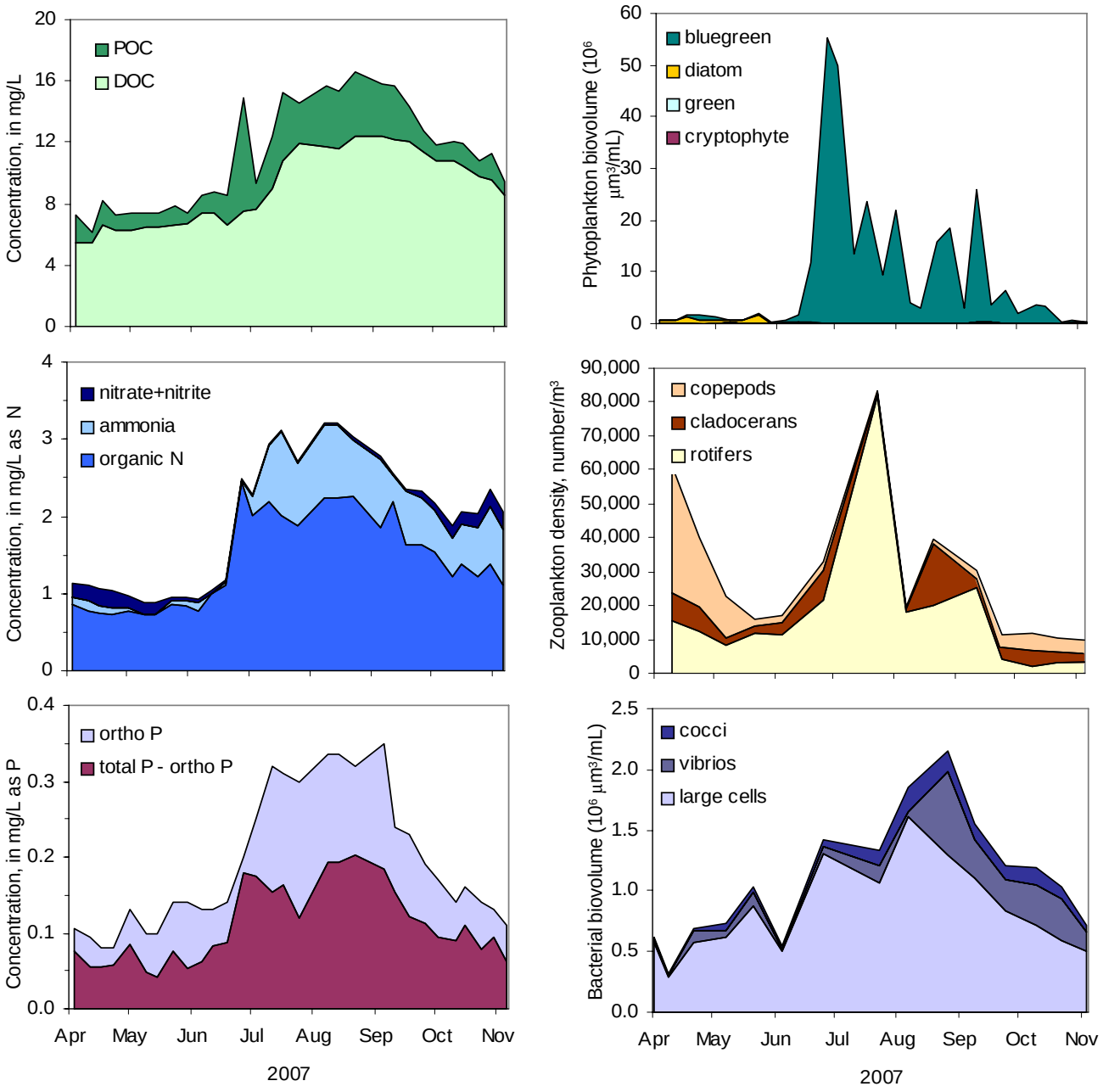

Figure 3. Median concentrations of carbon, nitrogen, and phosphorus species; median zooplankton density; and median algal and bacterial biovolumes from all five mainstem Klamath River sites.

Filtered nitrite, which has a lower reporting level than nitrite plus nitrate, remained above detection at most mainstem sites, though at low concentrations. At mainstem sites concentrations ranged between

0.002 and 0.025 mg/L. The Klamath Straits Drain had nitrite concentrations between 0.003 and 0.112 mg/L. Other tributary concentrations ranged from below detection to 0.085 mg/L.

Total phosphorus concentrations at mainstem sites ranged between 0.05 to 0.50 mg/L, and filtered orthophosphate concentrations ranged between 0.010 and 0.272 mg/L. Both total phosphorus and filtered orthophosphate concentrations at mainstem sites increased into summer and decreased into fall (fig. 3). Overall, orthophosphate increased in the downstream direction (fig. 4). Tributary concentrations ranged between 0.16 and 7.34 mg/L total phosphorus, and 0.013 and 6.07 mg/L orthophosphate, with the higher concentrations from samplings near the wastewater treatment plant outflows.

Filtered iron concentrations at Link River decreased from June through mid-October, from 106 to 22 µg/L. At Miller Island and Keno, concentrations of filtered iron sampled monthly from June through October, were between 93 to 39 µg/L. Concentrations at the top and bottom of the water column at those sites were similar, except for the Miller Island sample on June 19, where the top of the water column had filtered iron concentration of 45 µg/L and the bottom had concentrations of 92 µg/L.

At Link River, filtered silica concentrations ranged from 32.3 to 52.5 mg/L, increasing from July through mid-September.

Alkalinity generally increased in the downstream direction, higher at Miller Island and Keno than at Link River on any sampling date. Alkalinity ranged from 44.6 to 76.6 mg/L as $CaCO_3$. The only tributary sampled for alkalinity was Klamath Straits Drain, with an alkalinity of 136.0 mg/L as $CaCO_3$.

Particulate and Dissolved Organic Carbon

Concentrations of particulate organic carbon (POC) ranged from 0.49 to 17.89 mg/L at mainstem sites; concentrations were generally lowest in spring, increased in June, remained elevated through the summer, and decreased in fall (fig. 3). Concentrations at the top and bottom of the water column were similar in spring and fall, with more variation in summer; when different, POC concentrations were generally higher near the surface, but depending on the site or date, concentrations were sometimes higher at the bottom of the water column. Klamath Straits Drain POC concentrations ranged between 0.75 and 7.15 mg/L through the season, with highest concentrations in April. Other tributary POC concentrations ranged between 0.51 to 15.8 mg/L.

Dissolved organic carbon (DOC) concentrations at mainstem sites ranged between 5.2 and 13.4 mg/L. Like POC, concentrations of DOC were lowest in spring, increased into summer, and decreased in fall (fig. 3). DOC concentrations at the top and bottom of the water column were similar. The Klamath Straits Drain had higher DOC concentrations than the mainstem, ranging from 13.2 to 45 mg/L, with highest concentrations in May and June. Other tributaries had DOC concentrations between 6.0 and 21.5 mg/L.

$SUVA_{254}$, a measure of the aromaticity of DOC, ranged from 2.1 to 3.7 L/(mg-m), was highest in spring and decreased into summer at mainstem sites. $SUVA_{254}$ in the Klamath Straits Drain ranged from 2.5 to 3.2 L/(mg-m), and $SUVA_{254}$ in other tributaries ranged between 1.1 to 2.8 L/(mg-m).

Together, POC and DOC make up total organic carbon (TOC). Averaged over the sampling period, particulate carbon constituted 32 percent of TOC at the Link River and Railroad Bridge sites, 21 percent at Miller Island, 18 percent at KRS12a, and 16 percent at Keno, decreasing in the downstream direction. Depending on the date or site, POC could make up from 6 to 68 percent of TOC.

Bacterial Abundance and Morphology

Total bacterial populations ranged from 1.4×10^6 to 170×10^6 cells/mL, and generally increased

into summer. Group 3 (cocci) was the most abundant bacteria morphotype, averaging 93 percent of total cell counts (at all sites through the season), with a range from 41 to 98 percent of total bacterial abundance. They were the smallest bacteria, with diameters of 0.1 to 0.2 µm. Their diameters were smaller than the filter pore size used for nutrient filtration (0.45 µm) and the pore size used to separate particulate carbon and nitrogen from dissolved organic carbon (0.7 µm).

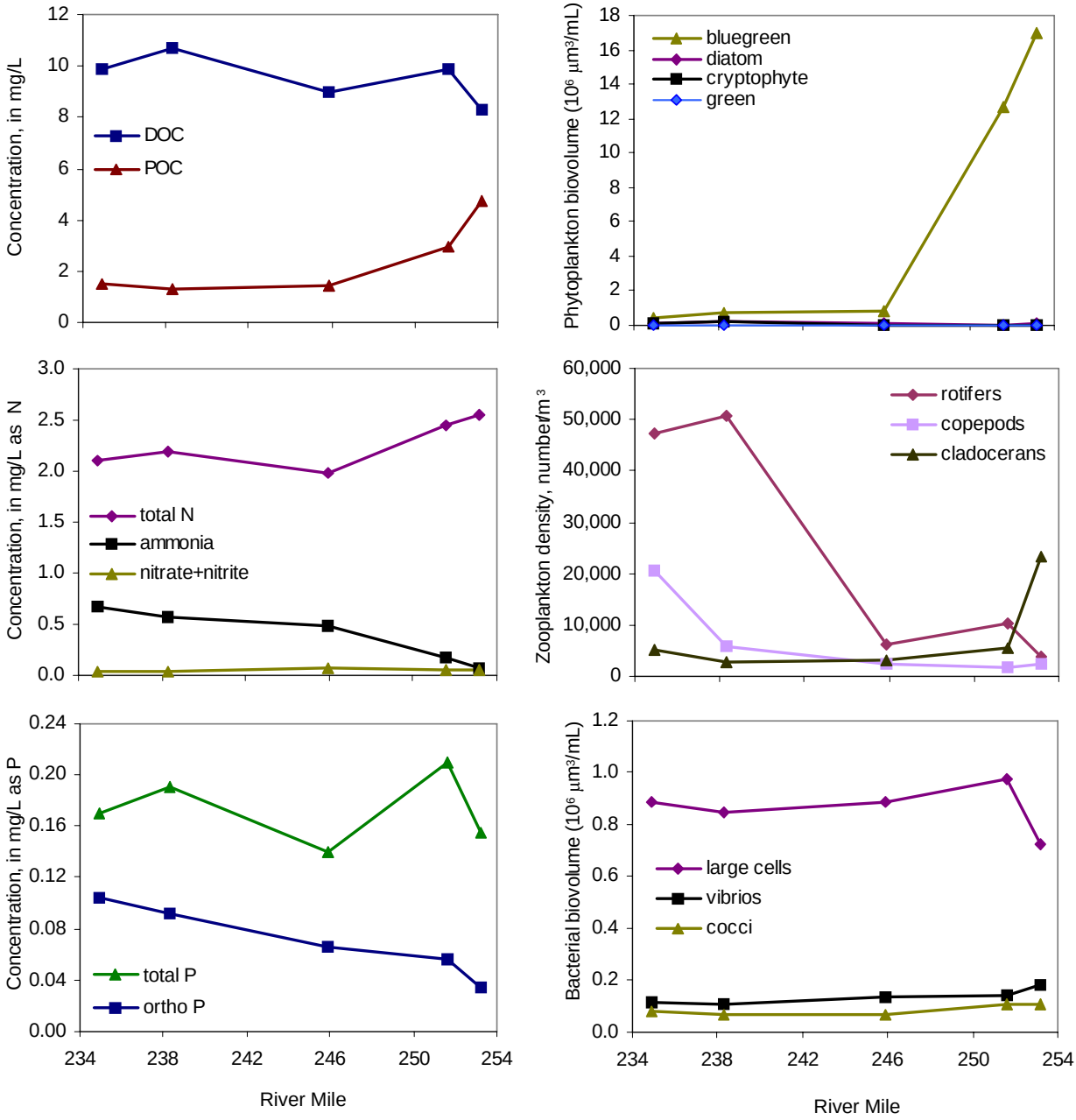

Figure 4. Median concentrations of carbon, nitrogen, and phosphorus species; median zooplankton density; and algal and bacterial biovolumes at the five mainstem Klamath River sites using all data from April through November, 2007

Although cocci were the most numerous bacteria, group 1 bacteria (large cells) made up most of the bacterial biovolume (figs. 3 and 4). The total bacterial biovolume maximum occurred between late June and September, depending on the site. Biovolumes ranged from 127,000 to 10,500,000 µm^3/ml, with an

average for all sites and dates of 1,350,000 μm^3/ml.

There is no simple way to functionally divide the bacteria based on morphology. For instance, no consistent relationship between morphology and autofluorescence was observed. Bacteria cells were observed to attach to living algae and algal debris, and in one instance dense attachment to the nitrogen-fixing nodules on AFA was observed. Cells attached to algae were counted; however, slide preparations had little particulate material. To have a count greater than zero, a particle with attached cells had to appear in one of the counting fields. In some cases, such particles were observed outside the counting fields; these samples are designated as $<0.03 \times 10^6$ attached cells.

Phytoplankton Enumeration and Species Identification

Through the season, 108 species of phytoplankton were identified; most were classified as blue-greens, cryptophytes, diatoms, or greens. AFA, a blue-green alga, was the most frequently identified species and also had the highest overall average density (51 percent), followed by *Cryptomonas erosa* (11.9 percent) and *Rhodomonas minuta* (5.4 percent), both cryptophytes, and *Ankistrodesmus falcatus* (3.1 percent) a green alga.

Phytoplankton biovolumes ranged from 106,000 to 264,000,000 μm^3/mL. Diatoms were the predominant group in spring. By early June, blue-green algae, AFA in particular, became dominant, with biovolumes increasing dramatically (fig. 3), especially at the upstream sites. At Link River and Railroad Bridge, blue green algae made up almost 100 percent of all algae species through late October. With increasing distance downstream, blue-green algae were less dominant after early July. At Miller Island and KRS12a, blue-greens were still common, but periods with notable diatom and cryptophyte populations occurred. At Keno, farthest downstream, there was a mix of blue-greens and crytophytes after early July, as well as populations of diatoms and green algae. Considering the whole sampling season, phytoplankton biovolumes were highest at Link River and Railroad Bridge, and lowest at Keno (fig. 4).

The trophic state index (TSI) for mainstem sites ranged between 33.7 and 90.1. Of the phytoplankton samples collected in this study, 1 sample had a TSI considered “oligotrophic,” 34 as “mesotrophic,” 53 as “eutrophic,” and 44 as “hypereutrophic”, according to the classification system in *Atlas of Oregon Lakes* (Johnson and others, 1985).

Phytoplankton data in the appendix comprise sample identification, total density, total biovolume, TSI, and top five most common algae species and their relative densities. Combined species lists of all species within related groups of samples are provided to allow greater sensitivity in comparing different sites or dates. Algae species are compiled according to their relative densities.

Zooplankton Enumeration and Species Identification

Over the sampling season, 64 taxa of zooplankton were identified; most were cladocerans, copepods, or rotifers. The most frequently identified cladocerans were *Daphnia pulicaria* and *Chydorus sphaericus*, the most frequently identified copepods were copepod nauplii (early stage copepods of undetermined species) and cyclopoid copepodites (intermediate-late stage cyclopoid copepods of undetermined species), and the most frequently identified rotifers were *Keratella hiemalis* and *Euchlanis dilatata*.

Total zooplankton density ranged from 500 to 190,000/m^3. At Link River density was highest in April. At the other mainstem sites, farther downstream, total zooplankton densities were highest in summer. Copepods were dominant at most sites in April (fig. 3). In late spring and summer, at Link River, cladocerans became the most common group, while farther downstream at Railroad Bridge both cladocerans and rotifers were seen in summer. With increasing distance downstream, rotifers became

more common (fig. 4).

Zooplankton data in Appendix B comprise a zooplankton species list, as well as zooplankton densities per species per sample. Total density of the major zooplankton groups present in the samples and the standard error for each species density are also presented.

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Appendix A—Acoustic Doppler Current Profiler Data

Click on the links to retrieve data.

Cross-sections, Link River to Keno Dam (PDF files)

5/30/07

9/19/07

Streamflow, Link River to Keno Dam (Excel files)

5/30/07

9/19/07

Appendix B—Water Quality Data (Excel files)

Constituent analyses

Quality-assurance data

Bacteria summary

Phytoplankton/zooplankton summary

Phytoplankton raw data files

Zooplankton raw data files