Dissolved Oxygen Dynamics in the Carson River, Nevada: Results from field programs during the summers of 2003 and 2004

Carson River at Riverview Park (June 2004, looking from right bank).

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SUMMARY
The Carson River originates in eastern Alpine County, California, where it flows northeast into western Nevada through Carson City, and terminates in the Carson Sink. Periods of low flow and elevated concentrations of nutrients (especially phosphorous) make the river system one that may be susceptible to algal production and biomass accumulation that has the potential to detrimentally affect in-stream dissolved oxygen concentrations. The purpose of the work conducted in the summer of 2003 and 2004 along with water quality modeling was to determine if critical DO concentrations are observed during the summer months and to make a preliminary assessment of the conditions that enhance or attenuate DO dynamics. This report provides data and findings based on the field work and sampling that occurred during 2003 and 2004 and is intended to compliment results and analysis of water quality simulations reported by Latham (2005) and the additional follow on report of Dr. J. Warwick regarding WASP and WASP 7.0 simulations.

INTRODUCTION

The Carson River Watershed

The Carson River Basin extends over an area of approximately 4000 mi^2, most of which is in the state of Nevada (Figure 1). Within the Carson River Basin, the Upper Carson Valley is an alluvial basin trending north through Douglas County Nevada covering approximately 360 mi^2 and stretches southwest into Alpine County, California (Prudic and Wood 1995). The Carson River originates in the eastern Sierra Nevada Mountains directly south of the Lake Tahoe basin and flows northeast into the Carson Valley, where it is bound to the east by the Pine Nut Mountains. After passing Carson City, the river turns east where it forms and passes through Lahontan Reservoir, terminating in the Carson Desert (Figure 1).

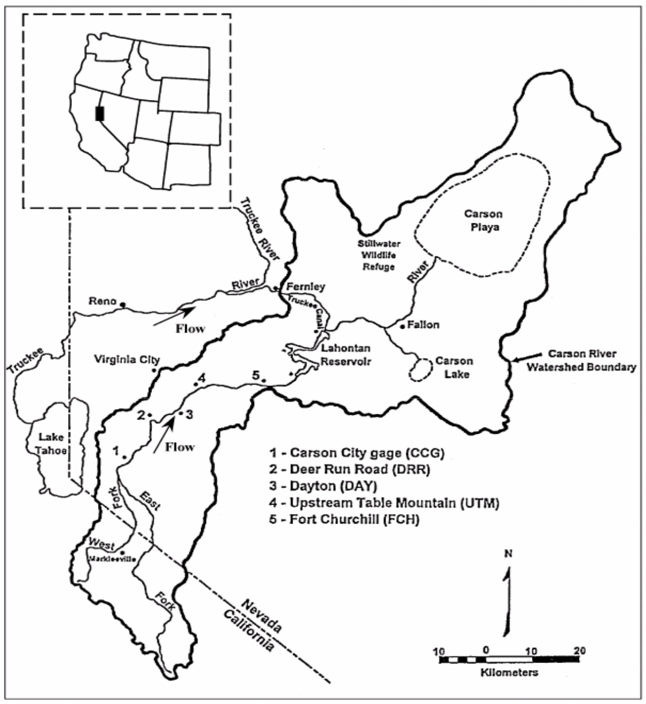


Figure 1. **Location of the Carson River Watershed.**

Headwaters include the East Fork and West Fork of the Carson River, both of which originate in Alpine County, California. The primary source of water for this watershed falls as snow, which is then transported east into the Carson Valley where the East and West Forks converge, directly east of the town of Genoa, Nevada. The headwaters originate in an alpine setting, while the remainder of the river flows through an arid to semiarid climate with hot summers and mild to cold winters.

The amount of precipitation that falls on the Carson River Watershed varies from west to east due to the rain shadow effect caused by the Sierra Nevada Mountains. In the winter, precipitation falls mostly in the form of snow in the headwaters, with the largest amount of monthly average precipitation falling in January (Prudic and Wood 1995). Localized summer thunderstorms are the main source of limited summertime precipitation (Maurer 1997). Precipitation varies greatly in this system with up to 45 inches yr^{-1} falling in headwater areas, 10 inches yr^{-1} on the Carson Valley floor, and 5 inches yr^{-1} (Alvarez and Seiler 2004) accumulating in the Carson Desert. Temperatures in the Carson Valley can range from 80 to 90 ^oF in the summertime with occasional 100 ^oF plus days, to below 0 ^oF in the winter. Daily fluctuations in temperature can be up to 40 ^oF year round (Maurer 1997).

Vegetation in the study area is comprised of a variety of trees, shrubs, and grasses. Higher elevations near the headwaters host forests comprised of Jeffery Pine and Red Fir, while lower elevation forests support Piñon-Juniper stands (Alvarez and Seiler 2004). The valley floor is sparsely covered with high desert sage, greasewood bitterbrush, and rabbit brush where the land is undeveloped. The river corridor and areas along its tributaries support willows, and in a limited number of areas, cottonwood trees. Most of the vegetation types on the valley floor are phreatophytes, vegetation capable of consuming water from the water table (Maurer 1997; Alvarez and Seiler 2004; Carroll et al. 2004).

The geology underlying the Carson River watershed ranges from intrusive granitic rocks along the eastern edge of the Sierra Nevada Mountains, to alluvial fan and basin valley fill deposits in the Carson Valley (Prudic and Wood 1995; Carroll et al. 2004). The Pine Nut Mountains are primarily composed of intrusive granitic rocks, as well as Tertiary age volcanic and sedimentary rocks (Alvarez and Seiler 2004). The Carson River is hydraulically connected to a basin fill aquifer. The rate at which water infiltrates into and out of the basin fill aquifer from the Carson River and irrigation ditches depends on the grain size, degree of sorting, cementation, and consolidation of those basin fill sediments underlying the Carson River basin (Maurer 1997).

Within the Upper Carson River Valley, the study reach begins where the East Fork of the Carson River crosses underneath Genoa Lane, and ends where the Carson River passes underneath the Deer Run Road Bridge. The study reach is approximately 33 km long and flows past two golf courses. Treated sewage effluent is used as a water supply for agricultural fields adjacent to this reach (Alvarez and Seiler 2004).

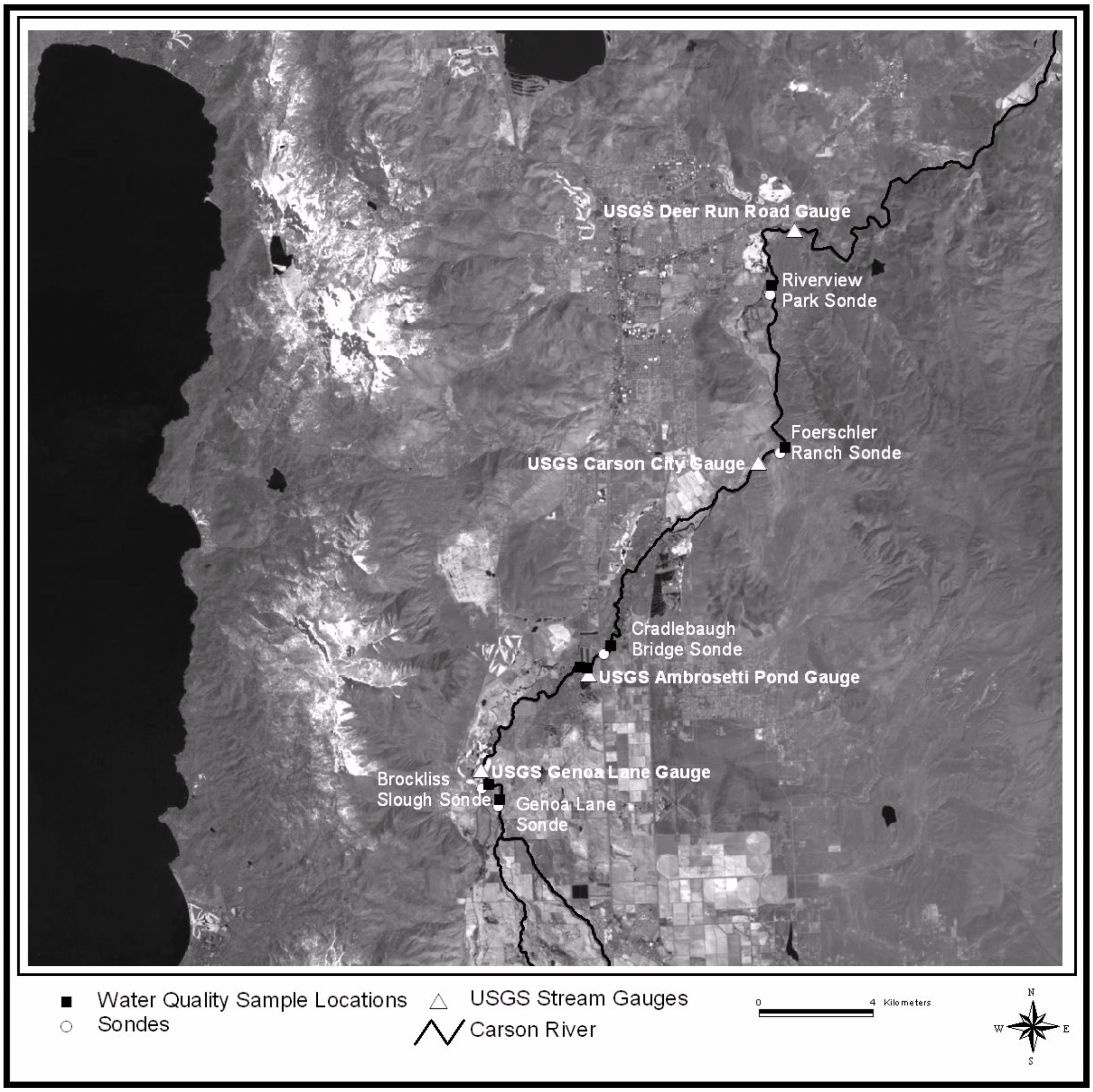


Figure 2. Map of the Carson River Study Reach Indicating Locations of USGS Streamflow Gauges, Water Quality Sampling Locations, and In-Stream Sonde Locations.

Background

Nutrient enrichment in watersheds can enable enhanced algal production and biomass accumulation (Hillebrand and Kahlert 2001), and in some cases, can lead to excess algal growth. Slow moving waters with surplus amounts of algae can create high concentrations of dissolved oxygen (DO) during daytime hours (through photosynthesis) and lower DO concentrations at night (through excessive respiration). When temperature is the dominant factor determining dissolved oxygen concentrations (due to a lack of photosynthetic activity) the diel DO concentrations are opposite of those influenced by abundant algal growth (Allan 1995).

Large diel DO variations can put the health of aquatic life within a river system at risk and DO is one of the primary water-quality constituents that can be used as an indicator of the ecological health of a water body (Ruhl and Jarrett 1999; Feaster and Conrads 2000). In most instances of degraded water quality, algal growth alone is not solely responsible for the transformation of an otherwise healthy system; water temperature can also play a large role in the water quality of a system.

The Federal Clean Water Act (CWA) of 1972 mandated that states develop water quality standards for their regulated bodies of water (Pahl 2004). Shortly after the inception of the CWA, Nevada developed its own set of statutes that applied to only a handful of class waters within the state of Nevada, calling it the Nevada Administrative Code (NAC). Formulation of beneficial use designations within these statutes was often done with limited data, and wording was general and broad, (Pahl 2004). Beneficial uses of water in the reach between Genoa Lane and New Empire Bridge on the Carson River include municipal or domestic supply, propagation of aquatic life, propagation of wildlife, irrigation, watering of livestock, and recreation involving and not involving contact with the water (Pahl 2004).

Over the past three decades, the NAC has gone through many revisions. The most recent set of statutes is contained in the NAC, chapter 445A, February 2003. These statutes apply to both designated and class waters. Designated waters in Nevada are main stem bodies of water, and are described by their high stream order. The Carson River is classified as a designated water (Pahl 2004). Class waters include lower order streams that may or may not be tributaries to the designated waters (Pahl 2004).

The NAC has set the in-stream minimum standard for DO in the Carson River at 5 mg L^{-1} from May through October, and at 6 mg L^{-1} during the rest of the year for the reach between Genoa Lane Bridge and the USGS Carson City gauging station. In this same reach, the NAC set a maximum in-stream temperature standard for November through April equal to or less than 13 ^{o}C, from May through June the maximum temperature standard was set as equal to or less than 17 ^{o}C, and from July through October, the maximum in-stream temperature standard has been set equal to or less than 23 ^{o}C. The minimum in-stream Carson River DO concentration for the reach between the USGS Carson City gauging station and New Empire (Deer Run Road) is 5 mg L^{-1} all year round. The maximum in-stream temperature standard for this reach during November through May has been set equal to or less than 18 ^{o}C, and during July through October, the in-stream maximum temperature has been set equal to or less than 23 ^{o}C.

The last point source loading into the Carson River by the Carson City Wastewater Treatment Plant, was eliminated in 1987 (Warwick et al. 1997). Unfortunately, non-point source (NPS) pollution still exists in the Carson River Valley in the form of elevated phosphorus. Phosphorus concentrations have exceeded the maximum in-stream annual average concentration (0.10 mg L^{-1}) set forth by the NAC (Alvarez and Seiler 2004).

The reach of interest for this study (determined through consultation with NDEP) starts where the West Fork of the Carson River crosses under the Genoa Lane Bridge, to the intersection of the Carson River with the Deer Run Road Bridge (Figure 2). This reach coincides with areas that have been identified as exceeding the phosphorus standard and is one that has little shading due to a lack of large riparian plants and trees. Prior work indicating that portions of this reach may have DO values below the in-stream standard (Horvath 1996; Warwick et al. 1997, Pahl 2004), high phosphorus and little riparian vegetation were among the factors that lead to the reach being selected for study.

Potential non-point source of nutrients, with documented high nutrient concentrations, (Horvath 1996; Nevada Division of Environmental Protection 2002; Alvarez and Seiler 2004), notable amounts of attached algae in isolated locations, and an apparent lack of shading along the study reach appeared to be conditions that were conducive for creating in-river environments where low DO concentrations could be produced. Given these observed conditions, the field work of 2003 and 2004 was conducted to:

1. Determine DO dynamics in the Upper Carson River system (above Carson City to Genoa Lane) to determine if critical DO concentrations are observed during the summer months,
2. Document the plant community biomass and community metabolic activities (respiration and photosynthesis) at different sites along the river,

and

3. Make a preliminary assessment of the macro nutrients during the study in order to place the findings of DO dynamics and algal biomass accumulations in context of previous assessments of the river's water quality.

METHODS

Dissolved Oxygen and Temperature

During July through early October 2003, YSI Sonde water quality monitoring devices were placed at six locations within the Carson River reach from Genoa Lane to Riverview Park (Figure 2) to document temporal changes in DO, temperature, pH, specific conductivity and turbidity. Data were stored internally within each sonde, and logged at 15-minute intervals. During June through July of 2004, two YSI Sonde water quality monitoring devices were placed at the Riverview Park and Cradlebaugh Bridge locations to document DO dynamics earlier in the season than was monitored during the 2003 field work. Sondes were deployed at two week intervals at which time they were retrieved, data were collected, each unit was cleaned, sensors were recalibrated, and sondes were redeployed. Calibration of each of the four probes located on the sondes was done as specified in the YSI Environmental Monitoring Systems Operations Manual. Re-calibration on site was performed in a few instances to check on the difference between calibrations conducted at two locations. Within all on-site re-calibrations, differences in the percent DO between the laboratory and the on-site procedures were less than 1%. DO readings with calibrated sonde probes achieved an accuracy of +/- 2 % of the reading or 0.2 mg L^{-1}.

Algal Biomass

Algal biomass samples were collected at six sonde locations in 2003, as well as at two sonde locations during summer 2004. Biomass was sampled over a distance of five times the width of the river at each sonde location. Episammic samples were collected using a petri dish of a known diameter and volume and a thin metal spatula. Epilithic samples were collected by selecting three rocks at random which were then scrubbed with a wire brush into a plastic tub. Filtered stream water (FSW; GFF filtered) was used for washing and rinsing the wire brushes and the plastic tubs of all algae into pre-cleaned HDPE Nalgene bottles. The dimensions of all three axes on all three rocks were recorded in order to normalize all sample analysis to the area sampled. Approximately six samples were collected at each sampling location.

In-stream hydraulic habitat types were classified by different velocity regimes within the river. Examples include riffles, glides, pools, and bank-shore transition areas. The type of habitat sampled and number of samples taken within each habitat was determined randomly (using the random function in a Texas Instruments TI-89 calculator). Substrate composition within a habitat was usually homogenous, comprised of either course sand or gravel to cobble sized stones. After sampling, each sample was put on ice immediately, and transported to the Systems Microbial Ecology Lab at Desert Research Institute (DRI) for analysis. All epilithic and episammic periphyton samples were analyzed for chlorophyll-a (chl-a), ash free dry weight (AFDW). Carbon, nitrogen, and phosphorus (PP) content were measured on a subset of the samples from each sampling location.

Chlorophyll *a* Analysis

Epilithic samples were inverted several times to ensure a homogenous mixture for subsampling and a filterable amount of the sample was immediately removed from the bottle with a pipette. The subsample was then filtered onto a clean filtered stream water (FSW) washed 25 mm Whatman GF/F with ~180 mm Hg vacuum using FSW to rinse the sides of the filter funnel to ensure that all periphyton was on the filter. The filter was then removed from the filter tower, folded to ensure no loss of sample in transfer, and placed in a 20 ml borosilicate glass scintillation vial with white urea cap and cone-shaped plastic liner for storage and extraction. The total volume and volume filtered were recorded before the filters and vials were stored in the –80 °C freezer. Samples were then taken out of a –80 °C freezer, extracted in 10 mL of boiling 95% EtOH, vortexed for 5 seconds, and put in a -20 °C freezer over night with aluminum foil covering all samples.

Individual episammic samples were emptied onto a large petri dish and were homogenized and weighed. After recording this total weight, subsamples of known weight were taken for analysis of chl-a, AFDW, carbon, nitrogen, and particulate phosphorus. Episammic samples also were extracted with boiling 95% EtOH.

Fluorescence of EtOH extracts was determined using a 10AU Turner designs fluorometer and fluorescence was used to determine chlorophyll *a* concentrations according to Welschmeyer (1994). Known concentrations or pure chlorophyll *a* (*Anacystis nidulans*, Sigma Corp.) were used for calibration.

Ash Free Dry Weight Analysis

AFDW was determined using standard methods for water analysis (APHA 1998). Briefly, sub-samples were filtered onto 47 mm Whatman GF/F filters that had been pre-combusted at 510°C for one hour. Approximately 180 mm Hg of vacuum was used for filtering and the filter funnel was rinsed with FSW to ensure that all periphyton was on the filters. The AFDW filters were then placed in aluminum weigh boats and placed in a drying oven at 105°C for a minimum of 24 hours. The dry weight of each sample was determined using an analytical balance capable of at least 1mg resolution. These samples were then placed in a muffle furnace and combusted for one hour at 510°C. Samples were removed from the muffle furnace and weighed on the same 1 mg resolution analytical balance. The AFDW was calculated as the difference between the pre- and post-combustion dry weights.

Carbon and Nitrogen Analysis

Chilled samples for epilithic scrapings were filtered onto pre-combusted (510 ^oC for 1 hour) 25 mm Whatman GF/F filters. Filters were dried at 105 ^oC for at least 24 hours and fumed with Hydrochloric acid for 24 hours before particulate carbon and nitrogen was analyzed using a PerkinElmer 2400 series II CHNS/O analyzer (PE2400). Tin disk and filter blanks were subtracted from the total signal. Carbon and nitrogen content of episammic samples were done very similarly, with only the initial processing steps differing from those used for epilithic samples. Specifically episammic samples were dried at 105 ^oC and ground to a fine powder using a ball mill and C and N content was determined using the PE2400 on known amounts of the resulting episammic powder.

Particulate Phosphorus Analysis

Epilithic samples were collected on acid rinsed GF/Fs and dried. Samples were then extracted using a method based on Karl et al. (1991) for particulate phosphorus analysis and the resultant reactive phosphorus was then determined using with a Lachat® QC 8000 FIA (Lachat® Quikchem method 12-115-01-1-F). Episammic phosphorus content was also measured using a similar approach; only the extractions were conducted directly on a subsample of the sediment.

Algal Microscopy

A portion (approximately 20 milliliters) of each periphyton sample was preserved in 1% gluteraldehyde and stored for quantitative taxonomic identification to genera for diatoms, and division for soft algae. Microscopy and taxonomic identification were accomplished using the combination of Nomarski (differential interference) and epifluorescence microscopy on an Olympus BX-60 microscope, equipped with digital imaging and image analysis software (Image Pro-plus). A target of 400 natural units was enumerated at several magnifications (100x to 400x). Both general algal taxonomic authorities as well as more specific taxonomic keys were used in the identification of algal taxa (e.g. Patrick and Reimer 1966, Prescott 1978, Cox 1996, Wehr and Sheath 2003).

Photosynthesis to Respiration

Dissolved oxygen concentrations vary as a function of temperature, aeration, pressure, photosynthesis and respiration. Therefore, by measuring the change in dissolved oxygen over a discrete time period, estimation of photosynthesis and respiration (P-R) can be made once changes due to aeration (which is a function of temperature, pressure and turbulence) are taken into account (e.g. Hauer and Lamberti 1996, Chapra 1997, APHA 1998).

Using dissolved oxygen, and temperature data collected from the Sondes, P-R estimates were determined as:

$$P - R = -\frac{\partial O2}{\partial t} - (Ka * Cs - Co) \qquad \textbf{(xx)}$$

(Hauer and Lamberti 1996) where P is the rate of oxygen production through photosynthesis and R is the rate of oxygen utilization due to total community respiration. K_a is the gas exchange coefficient that is calculated according an energy dissipation model (Tsivoglou and Neal 1976). Gas exchange coefficients were estimated using the surface renewal model that takes the general form of

$$K_a = C_1 * \frac{U^{c2}}{H^{c3}}$$

where C_1, C_2, and C_3 are coefficients that vary depending on units, depths and velocities. For these calculations measurements for velocity and depth are required and were gained from direct measurements and ratings between measurements and USGS gauge discharges. Velocity transects were performed using USGS methods (Buchanan and Somers 1969).

Nutrients

Water quality samples were collected at eight primary sites in 2003 and 2004. Samples were taken with a depth-integrated sampler, put on ice until delivery to the DRI water lab 2-3 hours later, and analyzed for macronutrients by the Desert Research Institute's water quality lab. The resultant data set was augmented with samples collected and analyzed by the Carson Valley Conservation District (CVCD) at six sites in 2003. In combination, samples from >3 sites were collected two times a month from late May 2003 to late October 2003, and weekly from May 9, 2004 to July 13, 2004. In addition to this discrete sampling, samples were collected and analyzed by DRI during a Lagrangian sampling and time of travel study on June 18, 2004 that followed the same parcel of water down the river and analyzed the associated changes in nutrients during transit from Genoa Lane to Riverview Park.

RESULTS
Flow Records

Flows recorded for 2003 and 2004 at the USGS Carson River near Carson City gauge, generally fell within the 90th and 10th percentiles of the 63 year record at this station (Figure 3 and Figure 4). However, flows from June to October of 2004 were lower than the median flows and were at the 10th percentile (Figure 4).

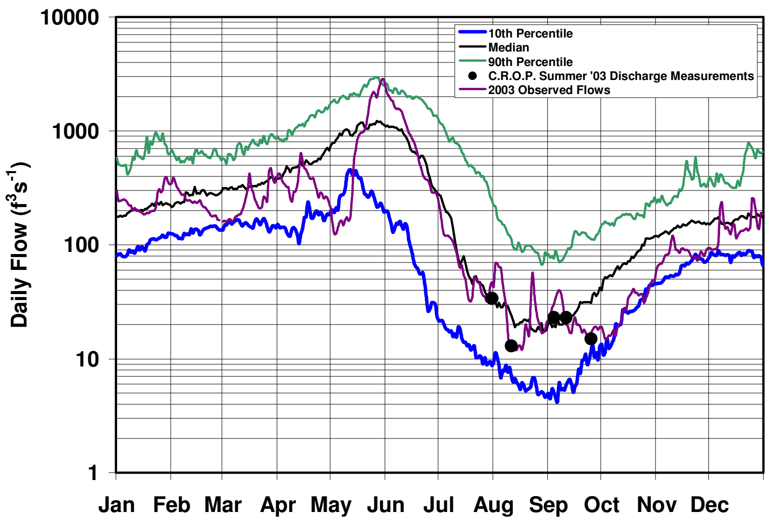


Figure 3. 2003 Daily Flow Statistics for the USGS Carson City Gauge.

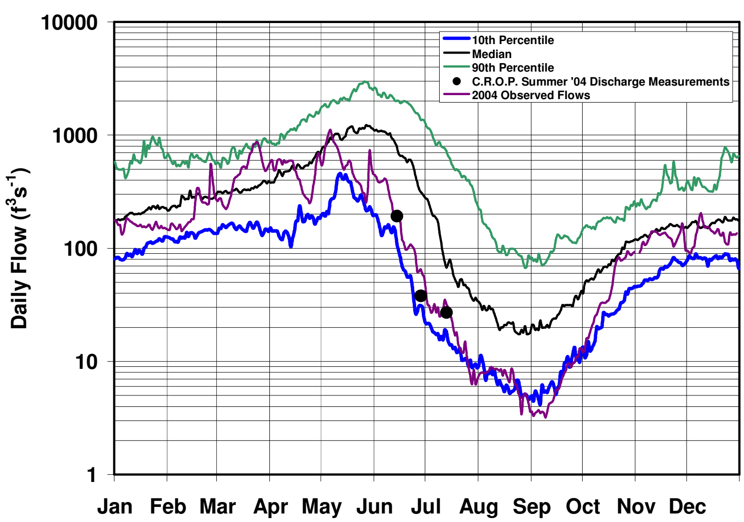


Figure 4. 2004 Daily Flow Statistics for the USGS Carson City Gauge.

Discharge measurements at discrete times showed direct correspondence to those reported by the USGS gauging station (Figure 3 and Figure 4).

Dissolved Oxygen Dynamics

Willowbend

The sonde deployment at the site just downstream of the Genoa Lane Bridge (Willowbend) recorded diel changes in DO concentrations on the order of 3 to 5 mg L^{-1} during July to October of 2003 (Figure 5). DO concentrations only dropped below the in-stream minimum standard of 5 mg L^{-1} for a five day period during mid August and again in late September. The range of DO changes at this site were among the largest out of the five sites monitored in 2003.

Water temperatures ranged between 19 to 29 °C during July and peaked at 29.40 °C in late July at the Willowbend site. An overall decreasing trend in average daily water temperatures was apparent from August to October- with daily averages reaching 17 °C in late September. The diel temperature fluctuations were generally smaller (8 to 10 °C) during the beginning of July, and increased (up to a 15 °C change) as flows in the river dropped to their minimum in late September and October.

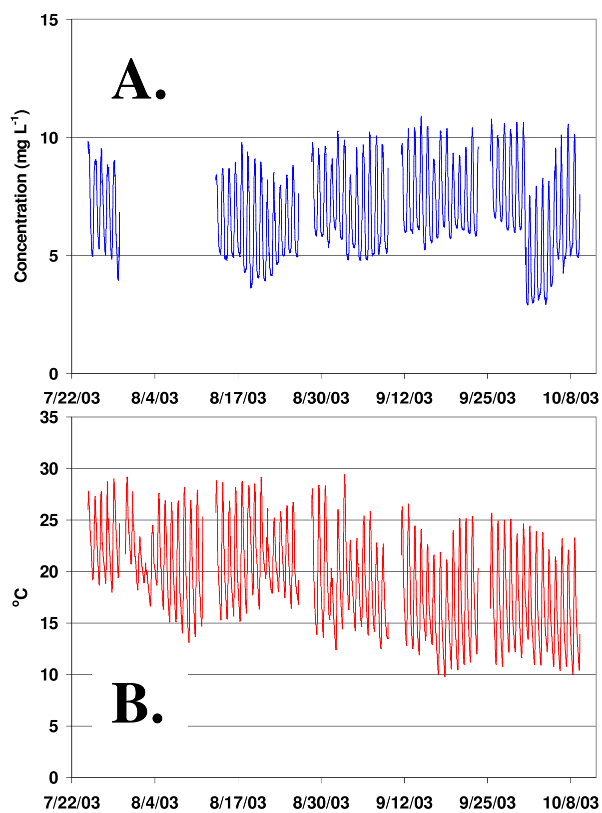


Figure 5. In-stream dissolved oxygen concentrations (A) and temperatures (B) recorded at the Willowbend site (located downstream of Genoa Lane; see Figure 2)).

Brockliss Slough
The sonde in the Brockliss Slough recorded DO concentrations that stayed relatively constant at 6 to 8 mg L^{-1} throughout the deployment with the exception of a drastic reduction in recorded DO concentrations over a 3 day period starting on July 22 (Figure 6A). This sharp and sustained decrease in DO cannot readily be attributed to a malfunctioning sonde as the probes (DO, pH, temperature) all showed proper calibration upon recovery. Given the duration and magnitude of the decrease it is likely that algal or macrophytic debris became entrained in the probe guard which can cause stagnation of water in the probe housing that can become depleted in oxygen through the degradation of the biomass.

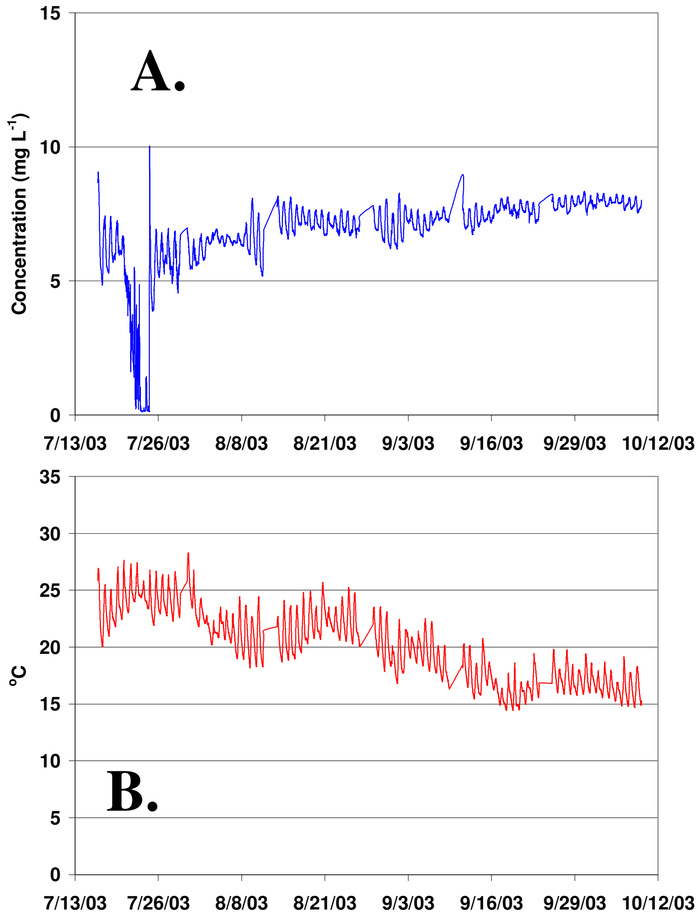


Figure 6. In-stream dissolved oxygen concentrations (A) and temperatures (B) recorded at the Brockliss Slough from late July to October 2003.

Average daily water temperatures in the Brokliss Slough exhibited a trend similar to that recorded at the Genoa lane site- with averages starting at 23 °C in July and decreasing to 17 °C by October (Figure 6B). Diel temperature swings at this location were much smaller when compared to all other locations.

The peculiarities of the DO and temperature dynamics at this site are notable and can be attributed to the low head dam approximately 30 meters upstream of the sonde location. This particular low head dam has a spillway of ca. 1.5 meters that undoubtedly served to aerate and entrain oxygen in the water as it cascaded over the spillway. Moreover, the slough upstream of the dam is a slow moving, deep irrigation canal. These combined characteristics don't allow for the same daily temperature changes that are observed in a channel with a higher surface area to volume ratio. It should be noted that this sonde deployment was originally picked as a site that could help constrain the boundary conditions for the diagnostic WASP modeling exercises (described in Latham 2004).

Cradlebaugh Bridge

Diel swings in DO were relatively small (~1 mg L^{-1}) at the beginning of the monitoring period (July) at the Cradlebaugh Bridge field site and increased throughout the summer (up to 4 mg L^{-1} change over a diel period) of 2003 (Figure 7A). Minimum values were constantly above the NAC threshold.

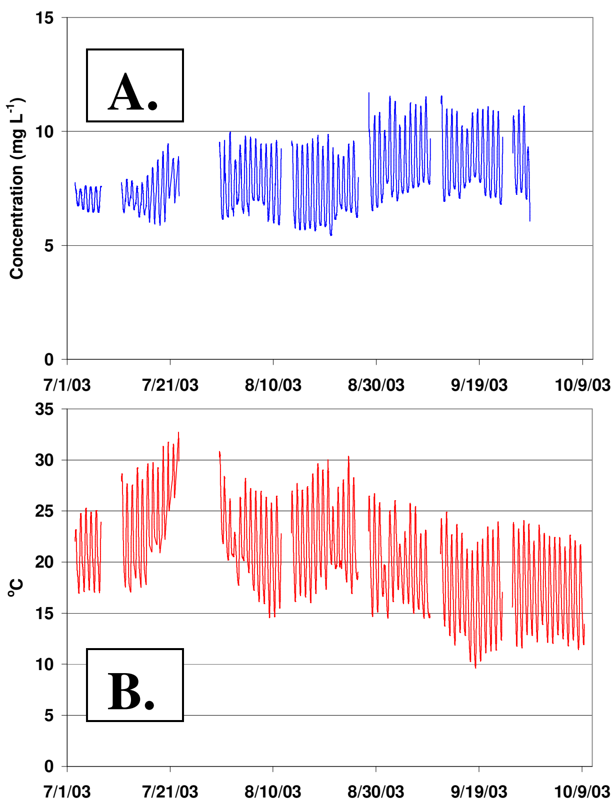


Figure 7. In-stream dissolved oxygen concentrations (A) and temperature (B) recorded at Cradlebaugh Bridge in 2003.

Temperatures at the Cradlebaugh Bridge field site peaked at 32.69 °C in the third week of July 2003 (Figure 7B) and temperatures exceeded the in-stream maximum standard of 23 °C for 25.13% of sonde deployment time. River-wide decreasing water temperatures were also recorded in temperatures from the end of July through the beginning of October 2003. Differences in diel maximum and minimum temperatures observed at this site were over 10 °C on average.

Diel changes in DO concentrations at Cradlebaugh Bridge in 2004 showed a similar pattern to those observed in 2003, with the diel swings increasing in magnitude during the deployment period (June to late July, Figure 8A). Average daily DO concentrations decreased slightly between June to late July of 2004 and average concentrations generally stayed near 7 mg L^{-1}. Again, the minimum values remained above the in-stream DO standard except for a few days in mid-to-late July where DO values reached 4.8 mg L^{-1} for brief periods at night.

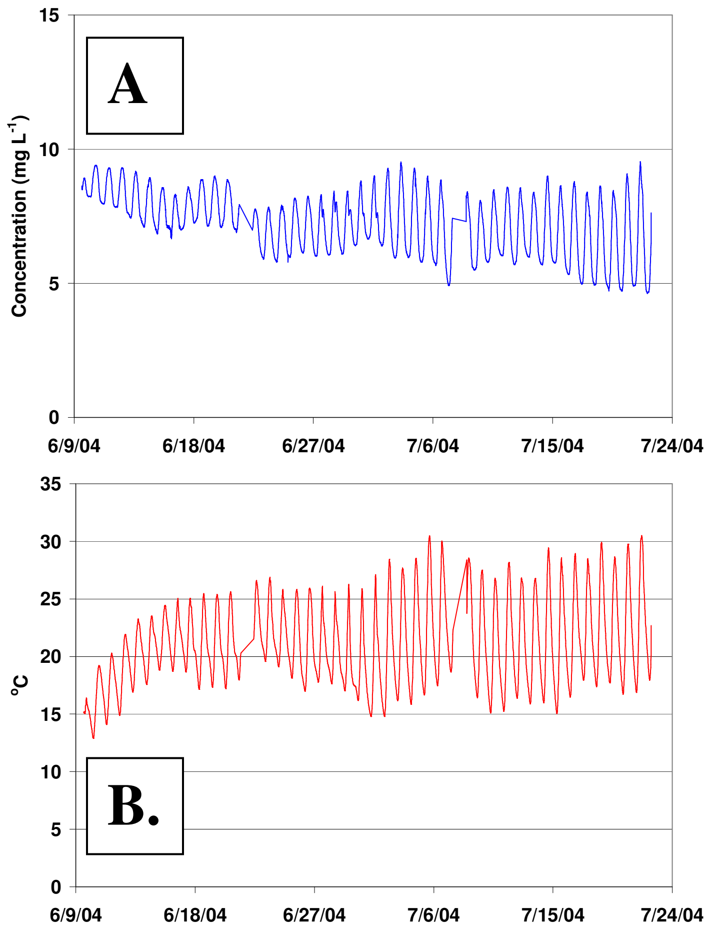


Figure 8. Observed dissolved oxygen concentrations (A) and temperatures (B) at the Cradlebaugh Bridge field site in 2004.

Water temperatures at Cradlebaugh Bridge in 2004 increased from the beginning to the end of the data collection period (Figure 8B). Diel swings increased in magnitude and values exceeded the June in-stream maximum temperature of 17 °C, and the July in-stream maximum temperature of 23 °C for a combined total of 64.05% of the sonde deployment period. The maximum temperature recorded here was 30.50 °C and was recorded on July 22, 2003.

Foerschler Ranch

DO concentrations at the Foerschler Ranch field site (approximately 1 km downstream of the USGS Carson River near Carson City gauge) generally remained between 5 and 10 mg L^{-1} (Figure 9A) during 2003 sonde deployments. Diel DO changes were on the order of 2.5 to 3 mg L^{-1} and average daily values were at 7 mg L^{-1} in mid July and increased by to ca. 8 mg L^{-1} in August 2003. The maximum observed DO value was 11.19 mg L^{-1}, while the minimum was 0.67 mg L^{-1} recorded on July 31 at 0230 hours. This low value appeared to be an excursion on that night as nights prior to and after did not show these low values. Moreover, temperature fluctuations on that night were atypical and may be indicative of a brief clogging of the probe encasement. Nightly lows for DO were more typically at 5.5 mg L^{-1} (Figure 10a).

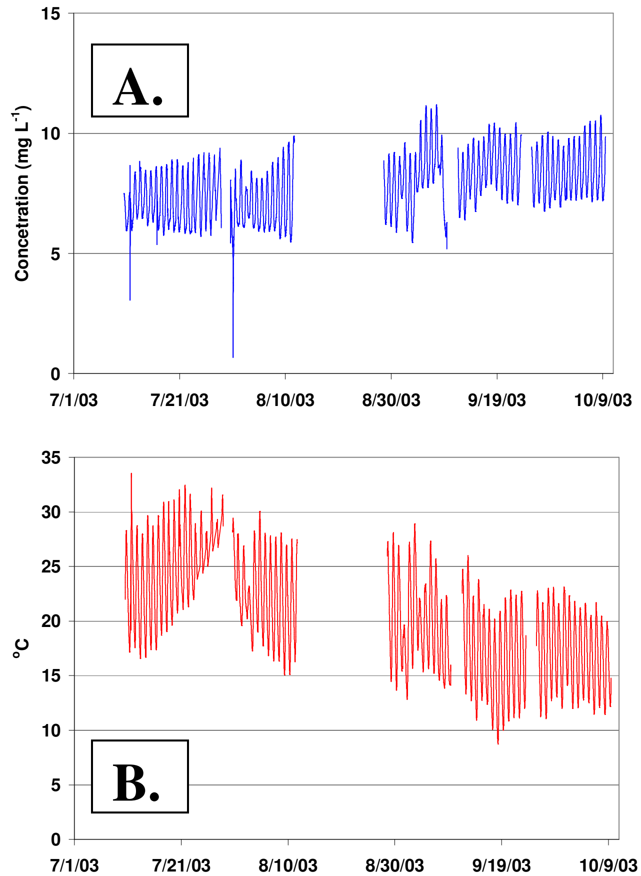


Figure 9. In-stream dissolved oxygen concentrations (A) and temperatures (B) recorded at the Foerschler Ranch site during 2003.

The general trend in temperatures recorded at Cradlebaugh Bridge was also seen at this site where temperatures increased throughout July, and then decreased until October 2003 (Figure 9B). Water temperatures peaked at 32.4 °C on July 21st.

Riverview Park

The location farthest downstream monitored in this study was at the Riverview Park. DO concentrations at this location during 2003 approached the in-stream minimum of 5 mg L^{-1} during early July (Figure 10A). An increasing DO trend was evident after the first sonde deployment that corresponded to the general cooling trend that was evident throughout all the river monitoring sites- including Riverview Park (Figure 10B). In addition to the increasing average daily DO concentrations, the range in the diel changes in DO also increased slightly (by approximately 0.5 to 1.0 mg L^{-1}).

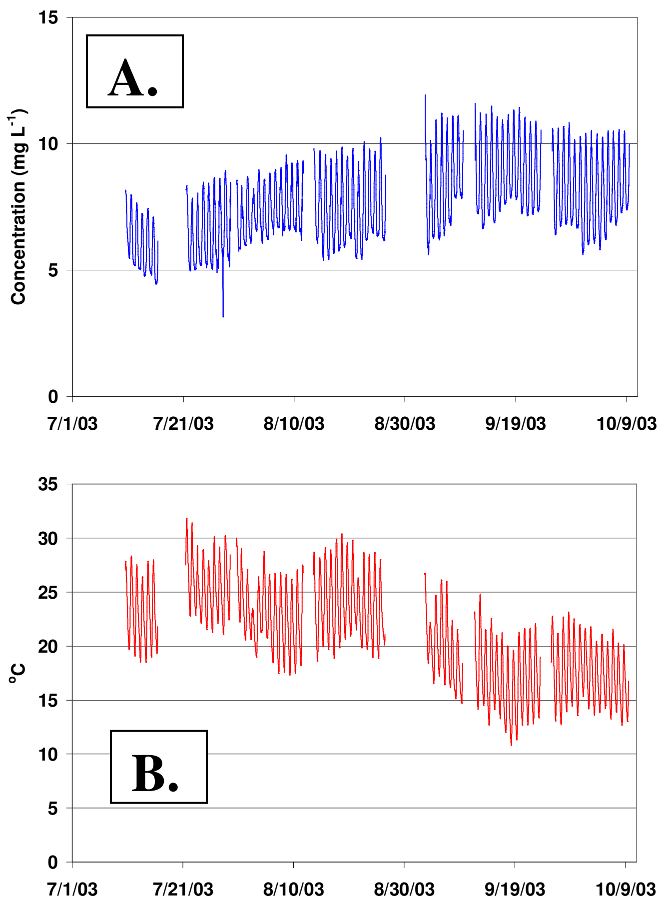


Figure 10. In-stream dissolved oxygen concentrations (A) and temperatures (B) recorded at Riverview Park in 2003.

DO concentrations recorded at Riverview Park (Figure 11A) during June and July of 2004 fell well below 5 mg L^{-1} on a daily basis. Only the first three days of the monitoring period recorded continual DO concentrations above 5 mg L^{-1}. The diel swings in DO were much greater (dial swing on the order of 10 mg L^{-1}) than the diel swings recorded in the previous year from July to October (on the order of 4 to 5 mg L^{-1} greater). Oxygen minima dropped below 3 mg L^{-1} in early July over a three day period when water temperatures increased to 30 °C for the first time during that summer season (Figure 12B).

Average daily water temperature (Figure 11B) was near 17 °C in early June and increased to 25 °C by mid to late July 2004. The highest recorded temperature was 31.8 °C in late July and the difference between maximum and minimum observed temperatures was 21.0 °C (Figure 11B).

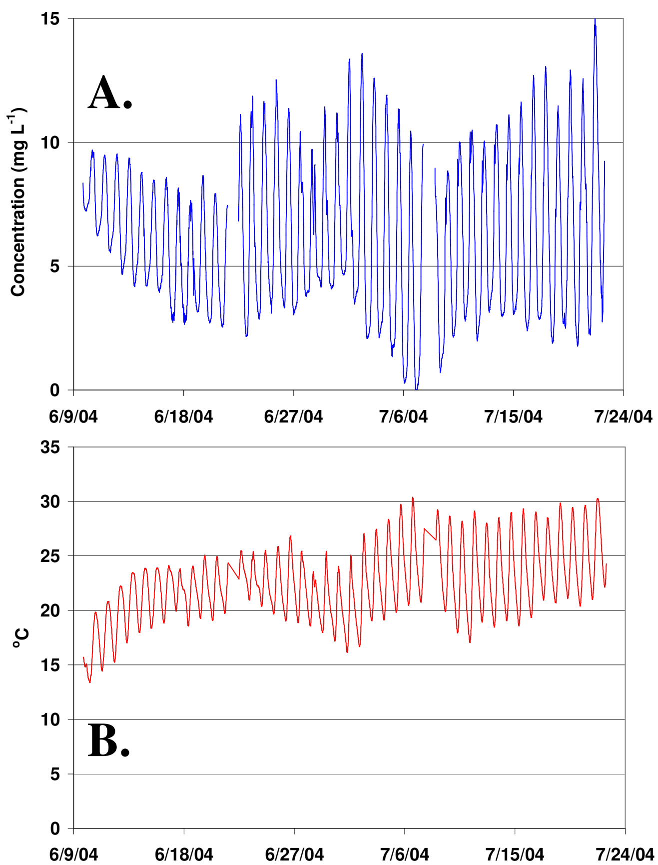


Figure 11. Observed dissolved oxygen concentrations (A) and temperatures (B) at the Riverview Park field site in 2004.

DO and Temperature Discussion

Water temperature and DO dynamics throughout the river during 2003 and 2004 were indicative of expected re-occurring seasonal trends. Specifically, water temperatures at all locations showed an increase from July to August with a cooling trend evident in late August to September. In respect to temperature standards for the river, the water temperatures were above the in-stream standard a considerable amount of the time that the sondes were deployed in 2003 (28-32%) and 2004 (47-60%).

The dissolved oxygen dynamics in 2003 also showed general trends at all sites that can be attributed to the seasonal increase in water temperature. Specifically, all sites showed a general increase in daily averaged dissolved oxygen concentrations as the water temperatures decreased from July to September. Hence, seasonal oxygen dynamics in the river responded to seasonal temperature fluctuations in a fashion that is generally expected in temperate river systems.

Beyond the general seasonal dynamics that can be attributed to the physical warming of the river it is important to note the range in the daily fluctuations as opposed to the average- as it is the range in the daily fluctuations that are driven by the combination of aeration, temperature, metabolic activities and the volume of water in the channel. Hence, increases in the daily range of dissolved oxygen that were observed at the Cradlebaugh bridge (2003 and 2004, Figures 7 and 8), Foerschler Ranch (2003, Figure 10) and Riverview Park (2003 and 2004, Figures 10 and 11) sites over time are likely to have been due to the combination of increases in overall community metabolism as well as decreases in river volume (flow).

During 2003 it was recognized that the initial sonde deployments did not occur as the water temperatures were rising to their summer highs and the sondes were not in place in locations where dense algal felts and biomass accumulations were observed during reconnaissance trips. Therefore, additional field work in 2004 targeted the earlier summer period in an attempt to capture the seasonal warming and the associated dissolved oxygen dynamics. The difference between the temperature and oxygen dynamics between 2003 and 2004 at Cradlebaugh and Riverview Park sites indicates that the early seasonal algal or plant metabolic activity increased from June until July of 2004 and the much larger range in DO concentrations in 2004 (Figure 12) would seem indicative of higher stocks of oxygen producing (plants and algae) and consuming biota in the stream during 2004 compared to 2003. However, because the flows were substantially lower in 2004, (for example flows were 200 cfs on July 1, 2003 and 30 cfs on July 1, 2004, Figures 3 and 4) the dramatic difference in the diel DO changes are also due in part to the change in the volume of water in which the biota produced and consumed oxygen.

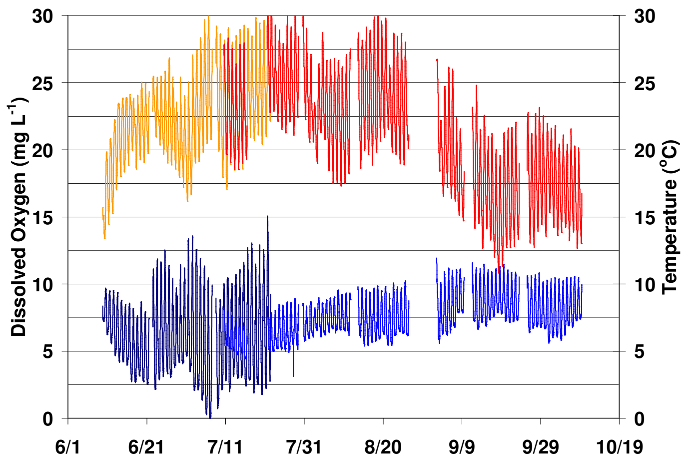


Figure 12. Seasonal temperature (orange and red) and dissolved oxygen recordings (blues) at Riverview Park in 2003 (red and light blue) and 2004 (orange and dark blue) combined to illustrate the seasonal dynamics as well as the relative differences in the range of DO changes between the years.

Regardless of the mechanisms that produced the large changes in the DO concentrations observed in 2004 it is clear that the Riverview Park area had a considerable amount of time when oxygen was below the in-stream standard of 5 mg L^{-1} in 2004. The summary statistics for the amount of time that each site exceeded the temperature or oxygen standard during the deployment periods (Tables 1 and 2) show that the Carson river system has the propensity to have water temperatures exceed the in-stream standard (for a cold water fishery) for 20-30% of the time when flows are near the historical mean with some exceedences occurring at least for some portion of most every

Table 1. Summary statistics for DO and temperature monitoring at Carson River study sites during summer 2003.

2003		Dissolved Oxygen				Temperature		
	Time	% Time Below	% Time Above			% Time Above		
Site	Deployed (d)	Standard	Saturation	Max	Min	Standard	Max	Min
Genoa Lane	67.93	13.02	27.40	10.89	2.9	21.33	29.40	9.78
Brockliss Slough	75.91	5.71	15.82	10.03	0.13	21.04	28.32	14.44
Cradlebaugh Bridge	66.21	0.00	49.42	11.70	5.43	25.13	32.69	9.64
Foerschler Ranch	64.94	0.00	47.56	11.19	3.19	27.74	33.19	8.73
Riverview Park	71.86	1.77	44.15	11.93	3.15	32.34	31.81	10.81

Table 2. Summary statistics for DO and temperature monitoring at Carson River study sites during summer 2004.

2004		Dissolved Oxygen				Temperature		
	Time	% Time Below	% Time Above			% Time Above		
Site	Deployed (d)	Standard	Saturation	Max	Min	Standard	Max	Min
Cradlebaugh Bridge	40.85	3.65	44.19	9.54	4.62	64.05	30.50	12.89
Riverview Park	40.98	42.76	36.17	15.06	0	47.15	30.37	13.38

day during the summer. The 2004 monitoring also would suggest that when the flows are low both temperature and oxygen standards can be exceeded on a daily basis (Figures 11 and 12 and Table 2) and the times over which these values are exceeded can be substantial (e.g. DO value exceeded for 64% of the time at River view park in 2004, Table 2).

Algal Biomass

Measures of algal biomass yielded a considerable amount of chlorophyll *a* variation throughout all of 2003 with a range from 4.4 to 59.2 ug chla cm^{-2} (Table 3) with the average value at 29 ug chla cm^{-2}. Higher values were recorded at Brockliss slough in July and August and at Cradlebaugh bridge in early September. Average AFDW covaried with chla standing stocks in 2003 with a ratio of 288 (w/w) which falls in a range that is indicative of AFDW variations being driven primarily by living algae (APHA 1989). However, high AFDW ratios on an individual sample basis show that the non-algal contribution to AFDW was prevalent as the average ratio was 1,197 which is indicative of detritus-based organic matter.

Temporal differences in AFDW or Chla were not significant or evident at most of the sites throughout the July to September time frame. However, given the large variability in the biomass at any given time, sampling on a monthly basis and sampling only three times in 2003 makes the detection of any temporal trends extremely tenuous.

Sampling in 2004 at Cradlebaugh and Riverview Park aimed to document temporal dynamics in the early summer. With the exception of the chla values at Riverview park, both AFDW and chla exhibited initial increases from low values in June to an apparent peak in late June to early July. The initial value of 35 ug chla at the Riverview location on June 10th does not appear to be consistent with the dynamics in AFDW nor with the levels of chla documented at the site throughout the rest of the study. However, this site had a notable amount of filamentous green algal accumulations that were associated with woody debris and other objects that could snare drifting material. Since the sampling targeted river bottom substrates it is possible that the sampling did not fully capture the variability and high chla values during the early season. Moreover, because these early samples could have been composed predominantly of filamentous algae, the non-covariance in AFDW and chla at this time may be indicative of the samples not containing much detrital organic matter relative to living algal biomass. The average AFDW:Chla ratio of 488 at this time is much lower than that measured throughout the study, yet is still over two-fold higher than a ratio of 200 that is held to be indicative of living algal biomass alone (APHA 1998).

Algal cells have carbon to chla ratios ranging from 20 to 200 (wt/wt) which vary depending on their level of pigments produced during photo-acclimation or in response to nutrient deficiencies. The biogeochemical composition measures on the benthic samples collected in this study yielded average C:chla values greater than 400 (Table 4) that were much higher than those that would be expected from algae alone and are likely the result of the prevalence of detrital and terrigenous matter along with living algal cells. The C:N ratio averaged 13.1 mol C:mol N which is indicative of material that is relatively enriched in polysaccharides or lipids relative to proteins. Values of C:N on the order of 10 to 100 are expected from river sediments containing terrigenous matter, detritus or perhaps nitrogen deficient algae. N:P ratios were extremely low with values ranging from 0.31 to 3.0 and averaging 1.63. Redfield matter has a N:P of 16:1 while the optimal value for periphyton growth is similar (Hillebrand and Sommer 1999). Values of N:P lower than 12 have been invoked as an indicator of phosphorous excess and thus nitrogen limitation in phytoplankton and mixed cultures of periphyton (Hillebrand and Sommer 1999). Thus, the values of N:P in the Carson samples would seem to indicate a N-limitation for algal growth-if these values were to be solely indicative of the periphyton. However, these extremely low values are also likely to be due in part to the methodology that may have extracted some phosphorous from the sediments that were in most of the samples collected during the study (even the epilithic samples often had accumulations of lithic sedimentary material entrained within the organic biomass). Excess phosphorous in the Carson River and its sedimentary organic matter is not unexpected given the high values in historical databases that typically exceed the in-stream standard (e.g. Glancy and Katzer 1975, Alvarez and Seiler 2004).

Table 3. Standing stocks of Chlorophyll *a* and AFDW (average +/- standard deviations and number of replicates,) listed according to sampling locations and time of sampling. Ratios of C:chla (wt/wt), C:N (mol:mol) and C:P (mol:mol) are also provided.

Year/Site	Day	Chl*a* (μg cm^{-2})	AFDM (mg cm^{-2})	C:Chl*a* (μg:μg)	C:N (mol:mol)	C:P (mol:mol)	N:P (mol:mol)
2003							
Willowbend	30-Jul	21.6± 18.9 (10)	22.1± 10.3 (10)	2945± 7329 (10)	9.7± 4.1 (10)	12.8± 8.9 (10)	1.2± 0.5 (10)
	2-Sep	13.1± 8.5 (6)	15.8± 5.8 (6)	625± 393 (6)	11.5± 2.5 (6)	8.8± 2.6 (5)	0.7± 0.1 (5)
	2-Oct	23.2± 22.5 (6)	15.5± 4.4 (6)	233± 106 (5)	10.1± 1.8 (5)	17.8± 10.1 (5)	1.9± 1.3 (5)
Brockliss	30-Jul	41.7± 74.1 (4)	38.8± 23.9 (4)	1587± 1284 (3)	12.7± 1.1 (3)	27.6± 16.1 (3)	2.1± 1.1 (3)
	2-Sep	46.4± 40.7 (3)	23.3± 4.5 (3)	321± 220 (3)	13.1± 3.6 (3)	15.3± 7.4 (3)	1.1± 0.3 (3)
	2-Oct	4.4± 1.4 (3)	15.9± 8.1 (3)	844± 402 (3)	9.4± 2.5 (3)	9.6± 3 (3)	1± 0.2 (3)
Cradlebaugh	31-Jul	24.9± 23.8 (5)	14.3± 4.5 (5)	673± 720 (4)	8.3± 0.6 (4)	9.3± 0.9 (4)	1.1± 0.2 (4)
	2-Sep	59.2± 34.2 (5)	22.7± 8.6 (5)	216± 134 (5)	9.4± 1.4 (5)	14.2± 3.1 (5)	1.5± 0.2 (5)
	30-Sep	27.9± 11.2 (6)	16.5± 5.3 (6)	260± 113 (6)	10.6± 0.6 (6)	12.1± 2.6 (5)	1.1± 0.3 (5)
Foerschler Ranch	31-Jul	24.3± 12 (6)	19.1± 7 (6)	402± 201 (6)	9.3± 1 (2)	14.1± 5.1 (5)	1.2± 0 (1)
	4-Sep	23± 14.8 (6)	20.7± 6 (6)	453± 208 (6)	11.1± 2 (6)	13.6± 8.4 (5)	1.2± 0.7 (5)
	30-Sep	19.2± 19.9 (6)	21± 6.2 (5)	680± 410 (6)	11.6± 2.3 (6)	12.5± 7.2 (6)	1.2± 0.8 (6)
Riverview	30-Jul	13.8± 9.8 (7)	15.6± 14.8 (7)	376± 276 (5)	10± 2.4 (5)	18± 4.9 (5)	1.9± 0.7 (5)
	4-Sep	12.3± 10.7 (6)	8.3± 11.2 (6)	203± 119 (6)	9.3± 0.4 (6)	24.9± 13.1 (6)	2.6± 1.4 (6)
	30-Sep	29.2± 15.8 (5)	18.7± 13.7 (5)	317± 233 (5)	10.2± 1.3 (5)	21.7± 8 (4)	2.1± 0.9 (4)
2004							
Cradlebaugh	9-Jun	2.7± 3.5 (8)	4.4± 4.9 (6)	19058± 21373 (8)	15.4± 8.6 (8)	14.6± 9.8 (8)	1.4± 1.4 (8)
	28-Jun	1.7± 0.8 (4)	4± 7 (4)	416± 314 (4)	9.2± 2.4 (4)	21.7± 13.4 (4)	2.1± 1.2 (4)
	7-Jul	5.4± 3.8 (6)	10.8± 5.5 (6)	583± 556 (5)	11.7± 2.1 (5)	3.7± 0.7 (5)	0.3± 0.1 (5)
	12-Jul	7± 5.1 (5)	5.9± 6.4 (5)	226± 65 (5)	10.9± 2.2 (5)	24.3± 20.5 (5)	2.1± 1.6 (5)
Riverview	10-Jun	35.1± 37.6 (5)	14.7± 9.3 (5)	248± 324 (5)	12.6± 3.2 (5)	29.3± 24.8 (5)	2.1± 1.7 (5)
	21-Jun	10.4± 8 (6)	22.7± 15.8 (5)	4165± 8138 (6)	15± 4.6 (6)	16.4± 9 (4)	1.3± 0.5 (4)
	28-Jun	13.4± 8.1 (7)	23.4± 13.9 (7)	679± 209 (7)	12± 3 (7)	22.6± 15.7 (6)	2± 1.4 (6)
	7-Jul	7.9± 7.3 (7)	20.1± 24 (6)	548± 449 (7)	10.5± 2.5 (7)	24.9± 9.9 (7)	2.4± 1.1 (7)
	12-Jul	5.4± 4.1 (6)	8.6± 11.1 (6)	377± 138 (6)	7.6± 0.8 (6)	23.2± 15.3 (6)	2.9± 1.9 (6)

Macronutrients

Average total nitrogen concentrations ranged between 0.3 and 0.59 mg L^{-1} in the study reach during the 2003 summer season and exhibited an increase from Willowbend to the Cradlebaugh location (Figure 13a). This increase is consistent with the addition of the water from non-point sources but also is consistent with the addition of water from Ambrosetti creek that had TN concentrations 2 to 4 times higher than those in the main stem of the river (Figure 13a and Table 2, Appendix A). TN decreased at sites downstream of the Cradlebaugh location. Total phosphorous had a similar relative spatial distribution as TN and ranged between 0.175 and 0.28 mg L^{-1} (Figure 13b, Table 2- Appendix A). Again, the increase at the Cradlebaugh location is partially due to the addition of Ambrosetti creek water with TP concentrations that were on the order of 0.4 to 0.5 mg L^{-1} during 2003 (and 2004, Figure 14).

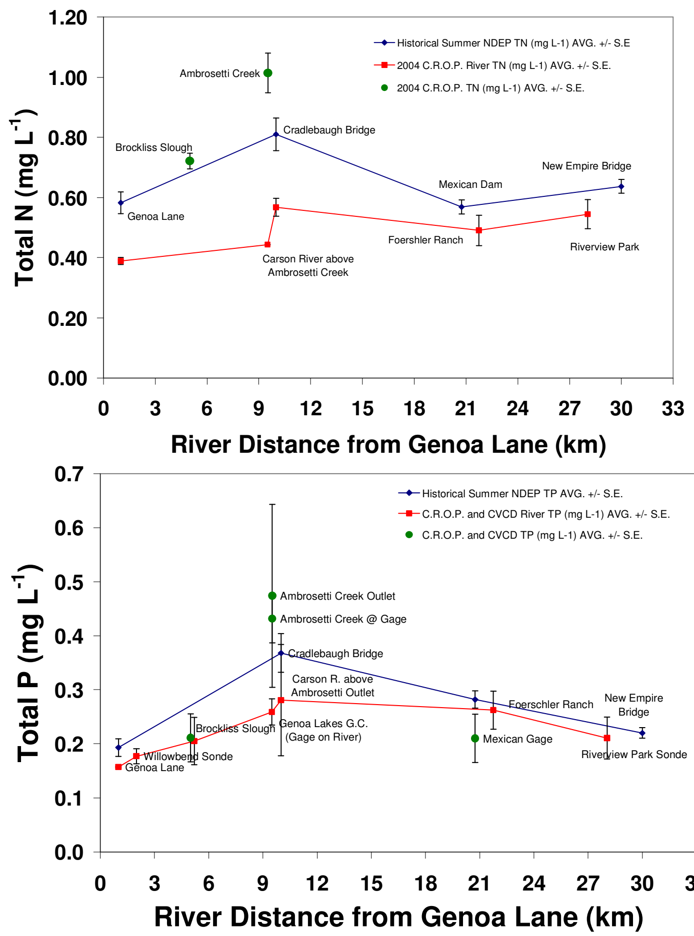
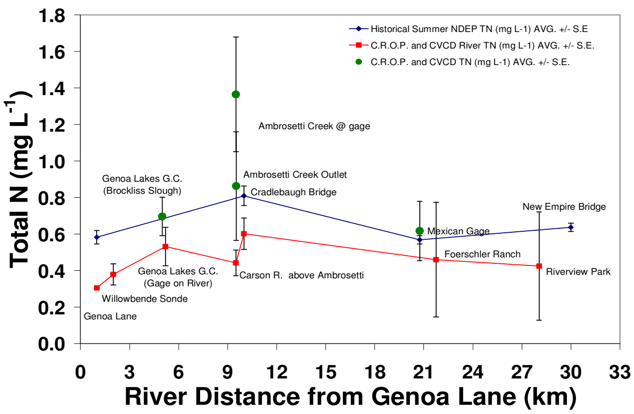


Figure 13. Average total nitrogen and total phosphorous concentrations at monitoring sites during the summer of 2003 compared to the average values over the same months from 1989 to 2000 (Individual measured values presented in appendix A).

The general patterns of increased values for TN and TP between the upstream locations and Cradlebaugh and lower values at Mexican Dam, Foerschler Ranch and Riverview Park during summer are consistent with the general trends documented in the historical measures of these water quality constituents between 1989 and 2000 (Figures 13 and 14) and the TP concentrations measured during the summer months of the 2001-02 water years (Alvarez and Seiler 2004). Despite the relative trends being similar, the actual values were lower than the historical mean for the summer seasons.



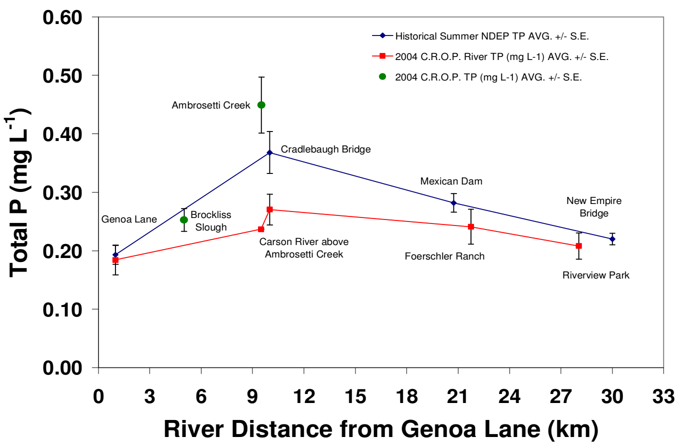


Figure 14. Average total nitrogen and total phosphorous concentrations at monitoring sites during the summer of 2004 compared to the average values over the same months from 1989 to 2000. Individual measures are presented in appendix A.

Soluable total Kejldahl nitrogen comprised the majority of the total nitrogen (70 to 100%; Table 2, Appendix A) measured. Ammonium and nitrate were less than 1% of the total soluble nitrogen and measured nitrate was generally lower than ammonium concentrations in 2004 and more variable (yet still below 0.05 mg L^{-1}) in 2003.

Total soluble phosphate comprised a substantial proportion of the TP (average of ca. 75%) in the water quality samples and orthophosphate comprised the majority of the soluble P. TN:TP ratios (mol:mol) ranged between 2.5 to 14.9 and averaged 6.4

(Appendix A- Table 2)- these values being indicative of a system that is highly enriched in P (over nitrogen) relative to the demands for algal growth.

Algal Taxa and Observations

Observations in 2003 and 2004 indicated that felts and filamentous algae were common throughout the study area. Macroscopic filamentous growths were especially prevalent and noticeable downstream of Mexican Dam in June of 2004 (Figure 15). The macroscopic filamentous forms were commonly comprised of *Cladophora* (Figure 15B and 15D and Figure 16) with occurrences of *Oedogonium*. Filamentous cyanobacteria were prevalent throughout all samples observed via microscopy and showed a number of cyanobacteria species beyond the common filamentous *Oscillatoria*, *Anaebena* (Figure 16D) (see appendix B for images and a listing of common genera). Throughout 2003, the cyanobacteria genera were the most numerically abundant filamentous forms of periphyton at most sonde locations. Cladophora was the most abundant filamentous form in the early season of 2004 .

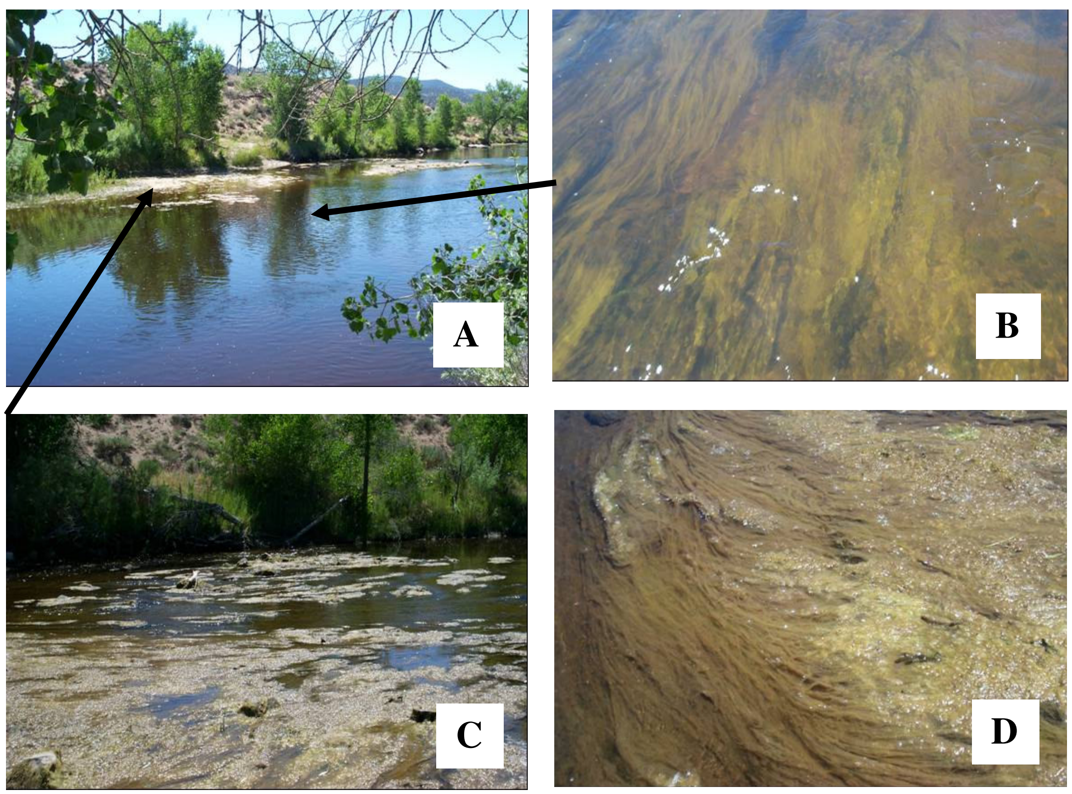


Figure 15. Macroscopic forms of filamentous algae at Riverview Park- June 22, 2004.

Several epiphytic diatoms co-occurred with the filaments of the *Cladophora* (Figure 16A), most common was the *Cocconeis* species (Figure 16A and Figure XD of Appendix B). *Navicula* (a highly siltation tolerant genera) was common throughout the river and often dominant whereas *Karayevi* (Figure 16B) and *Fraglleria* were also common at other locations. Several community-based metrics were calculated on a select number of samples (Appendix C) and are based on autecological information for the taxa. These metrics can be used in comparisons with other systems. Notable among the metrics was the relative abundance of the cyanobacteria at all sites examined. The siltation index showed a preponderance of siltation genera at most sites with the lower scores occurring at Riverview Park (which is downstream of a low head dam- which may

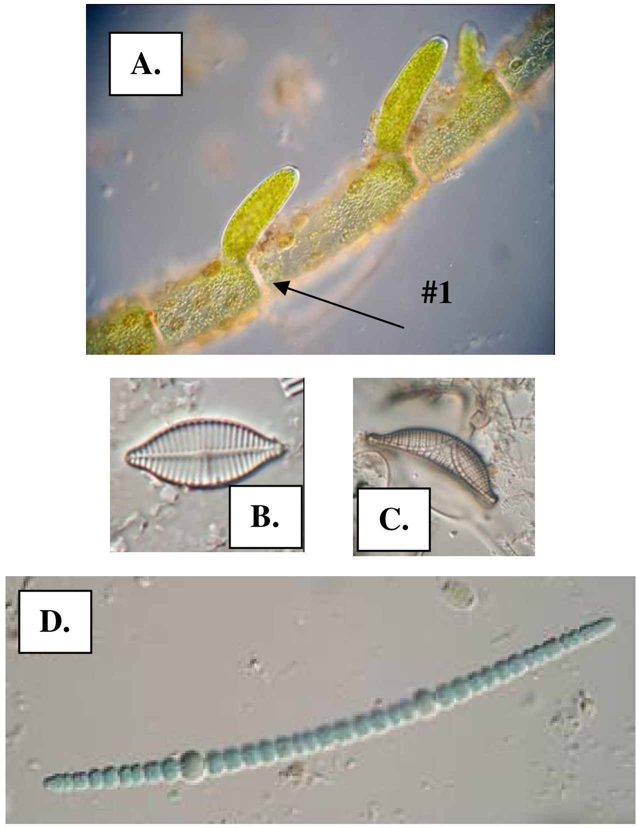
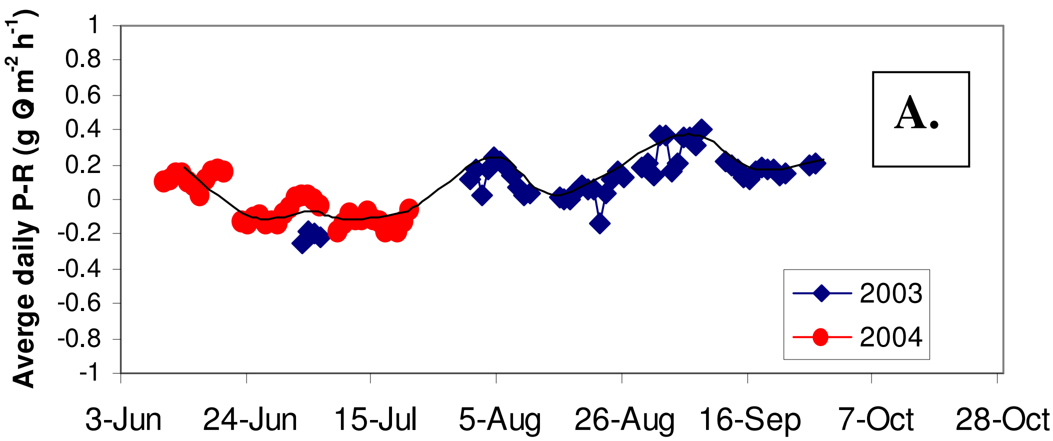


Figure 16. A) ***Cladophora sp.*** **with the epiphytic** ***Cocconeis sp.*** **attached (#1) from Riverview Park, B)** ***Karayevia sp.*****; Cradlebaugh bridge, C)** ***Epithemia sorex*****; Riverview Park, D)** ***Anabeana sp.*****; Willowbend (images by C. Davis- DRI).**

be retaining sediments. The Eutraphentic scores ranged from 0.15 to 0.91 with the high value measured at the Brockliss Slough location. The wide range in these scores is comparable to the range of values that have been found on the Truckee River (Davis and Fritsen 2004) and may be indicative of local conditions. Overall, however the diatom-based metrics seem to reflect the general status of the system as one that has a considerable amount of sedimentation and has water quality conditions (warm temperatures and low N:P ratios) that are conducive for the proliferation of cyanobacteria in the summer. The proliferation of filamentous macroscopic Cladophora appears to occur in the early season (as noted by microscopy and general observation) downstream of Mexican Dam where substrates appear to be more conducive for their establishment. Observations of the Cladophora beds that showed a dull brown color (Figure 15D) and microscopic examinations that showed degrading cells are consistent with the notion that the Cladophora growths begin to senesce when temperatures exceed ca. 25 ^{o}C (Dodds 1992). Cladophora senescence occurred at the end of June of 2004 and was coincident with the extremely low oxygen concentrations recorded in the first weeks of July (Figure 11A).

Community/System Primary Production and Respiration

Net oxygen production and consumption that can be ascribed to biotic processes (photosynthesis, P and respiration, R) at Cradlebaugh and Riverview Park showed contrasts between 2003 and 2004. Specifically, the Cradlebaugh site showed P to be in excess of R on a daily basis later in the season and R was in excess of P during late June and early July (Figure 17A). During early to June of 2004 P was in excess of R. The Riverview Park location, in contrast, showed that the balance of photosynthesis (P) and respiration (R) proceeded from a time (prior to July 18) when R was in excess of photosynthesis to a time when P was in excess of R (Figure 17B). Riverview Park generally showed community metabolism rates that were larger on average than those at the Cradlebaugh bridge location. For instance, calculated respiration rates at night at Riverview Park during June of 2004 reached values of 1 to 1.25 g 0_2 m^{-2} h^{-1} whereas calculated values at the Cradlebaugh bridge had community respiration rates that were approximately one-half of those at Riverview Park (i.e. 0.2-0.5 g 0_2 m^{-2} h^{-1}) at their maximum.



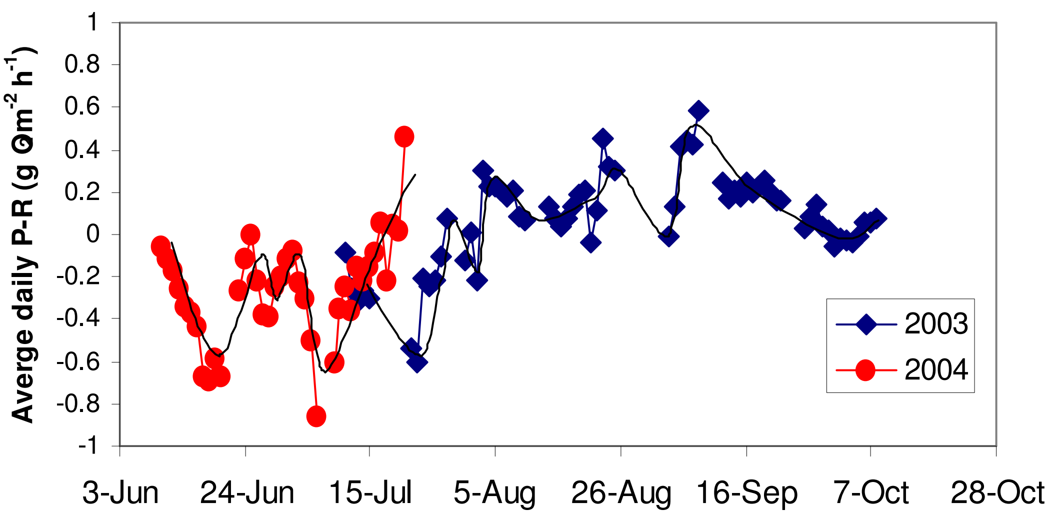


Figure 17. Average daily rates of net oxygen production/consumption (P-R) for Cradlebaugh bridge (A) and Riverview Park (B) monitoring sites during 2003 (blue diamonds) and 2004 (red circles). Curved lines included only to aid in the viewing of the temporal dynamics and were hand drawn.

Using diel oxygen dynamics and velocity transects conducted at the monitoring sites on September 2nd to 4th 2003, rates of oxygen production and consumption were compared among all of the monitoring sites (Figure 18, the Brockliss Slough site was excluded because of the aeration by spillway of the low head dam). This comparison indicates that the peak daytime rates of production were comparable among all sites, ranging from ca. 1.25 to 1.7 g O_2 m^{-2} hr^{-1}. Although the rates of production during the day were comparable among all of the sites, the Willowbend and the Riverview Park locations had much higher rates of night-time respiration at ca. 0.8 to 1 g O_2 m^{-2} hr^{-1} compared to the respiration rates at Cradlebaugh and Foerschler Ranch (~ 0.1 g O_2 m^{-2} hr^{-1}). Thus, the net daily rates of production were higher and positive for Cradlebaugh and Foerschler Ranch and net production was nearly balanced at Willowbend and Riverview Park at this time.

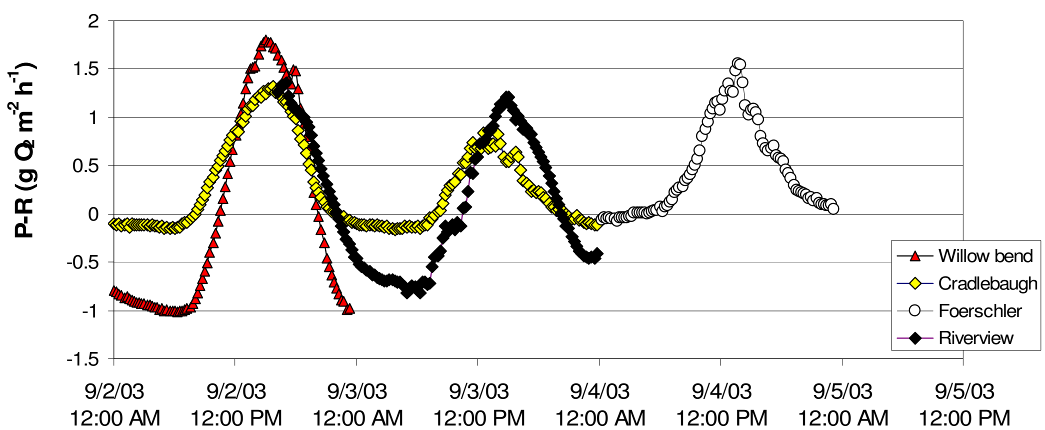


Figure 18. Rates of net oxygen production/consumption (P-R) for monitoring sites from September 2nd to 4th 2003.

SUMMARY AND CONCLUSIONS

The observations and monitoring confirmed previous measures and suspicions that the Carson River system between Genoa Lane and Deer Run Road has the propensity for dynamics that can lead to low DO values below critical standards. The temperatures measured in the system were especially high during the monitoring period with temperatures exceeding 25 ^{o}C on a daily basis throughout the summer- especially during the day. Despite these high temperatures, the productivity of the river system kept DO concentrations high during the daylight hours when oxygen solubility was at the lowest. Night time temperatures decreased in the system to values of 15-17 ^{o}C- yet DO values in most locations in 2003 remained above the 5 mg L^{-1} benchmark. Riverview Park and Willowbend locations appear to have been the sites that were more prone to low DO values.

TP measures would place this river among those temperate rivers considered to be in a eutrophic state (a propsed mesotrophic-eutrophic boundary being at TP values greater than 0.075 mg L^{-1}; Dodds et al. 1998). Benthic Chla values in excess of 7 μg cm^{-2} also place the river in the eutrophic category when based on benthic periphyton biomass (Dodds et al 1998). These values recorded for benthic chla and AFDW in the river are at levels that exceed threshold that have been suggested for the protection of aquatic life and recreational uses in other systems (Nordin 1985).

Rates of nighttime respiration on the order of 1 g O_2 m^{-2} hr^{-1} also illustrate that the Carson River system can have extremely high rates of oxygen consumption at some locations. For perspective, the consumption of 1 g 0_2 m^{-2} hr^{-1} in a water column of 0.5 m depth and at initial saturation of 8.45 mg L^{-1} at 15^{o}C would deplete the oxygen in the water column of oxygen in 4.2 hours in the absence of aeration. When placed in context of the amount of measured benthic biomass, the rates would suggest that the turnover times of the periphytic organic mater is on the order of 3-5 days. Fortunately, aeration occurs in the system and respiration is not constant in decreasing oxygen environments. However, these estimated rates do point to the capacity of the Carson River's algal and biotic population to rapidly deplete oxygen and grow to nuisance levels.

Gross photosynthetic rates also can be estimated from P-R curves assuming constant respiration rates throughout the day (an assumption that is probably not valid- yet can be made in order to place rates in context of biomass in order to estimate potential growth rates) and scale to ca. 10 g O_2 m^{-2} day^{-1}. Assuming C:Chla values for the benthic algae of 200 (wt/wt) and a benthic chla of ca. 20 ug chla cm^{-2} (a value often measured in the river, Table 4) yields an algal carbon standing stock estimate of approximately 40 grams of algal carbon per square meter of benthos. If the productivity quotient is 1:1 for moles of carbon fixed per mole of oxygen produced then the estimated production to biomass (P:B) ratio would scale to ca. 0.16 per day- a rate that lies well within the maximum rates at which algae are known to grow at the observed in-situ temperatures (Eppley 1972, Chapra 1997). Although estimates of P:B and turnover times of biomass can be estimated, it should be noted that these estimates are not well constrained (as biomass measures showed a large degree of variation within and between sites) and are more illustrative of the timescales over which the interactions of algal biomass, photosynthesis and respiration rates can affect the DO and nutrients within the system. A more in depth analysis of the system's interactions are provided through water quality simulations as reported by Latham (2005).

Despite the study reach having levels of periphyton biomass (chla) and TP values that are considered to be indicative of a eutrophic system and the system has high water temperatures, the DO concentrations throughout most of the sampling sites in 2003 remained relatively high and above 5 mg L^{-1}. This result was somewhat surprising to the *a prior* expectations. The river chemistry measures during 2003 and 2004 did not appear to be substantially different than previously reported (Alvarez and Seiler 2004) and given that the flows in 2003 were similar to the historical mean this result suggests that the river within the study area may be experiencing limited DO impairment when flows are near normal. In contrast, the 2004 field results illustrated the capacity of the system to have extremely low DO values when flows were between 40 and 100 cfs and with water temperatures at ca. 25 ^{o}C. The extent to which the DO slumped in 2004 also is likely to have been due to the die off of the Cladophora beds that had already become established by early June (when flows were 200-400 cfs). Cladophora die offs are known to cause DO slumps when water temperatures exceed ca. 25 ^{o}C (Dodds 1992). Moreover, Cladophora growth and accumulation requires suitable substrate for sustained attachment. Thus, the areas on the Carson River that have cobble or gravel substrates or woody debris that allow the development of these beds and experience reduced flows are more likely to be at risk of impairment due to low DO concentrations than those without suitable substrates for periphyton attachment (a hypothesis that remains untested).

The field work illustrates the capacity and risk of the study reach to experience DO impairment- the risk being due to the growth and accumulation of periphyton and degradation of organic matter. What factors limit periphyton growth and accumulation remains to be determined. However, extremely high phosphorus concentrations in the river suggest that P is not likely to be limiting periphyton growth rates. The extremely low N:P ratios in the system suggest that nitrogen could limit periphyton growth in the absence of other limiting environmental factors (e.g. temperature, substrate stability, light, etc..). Even if nitrogen is not a limiting facto for growth and accumulation the balance of N:P and high temperatures are highly conducive for the growth and accumulation of cyanobacteria- which were extremely prevalent during the study period. Growth and accumulation of certain forms cyanobacteria in river systems can pose additional impairments to waters (beyond their influence on oxygen dynamics) through their ability to contribute to nitrogen loading through nitrogen fixation, create taste and odor problems, produce toxins and change lotic food web structure. Thus, the loading of the Carson River and high phosphorus content of system may not only be posing concerns for water managers through the affects on biomass but in the indirect affects on the river's ecosystem's structure.

OUTSTANDING QUESTIONS

The upper river above the study area in this report has different conditions producing algal accumulations and flows in channels of a bifurcated water system. Oxygen has been shown to become depleted on a nightly basis in several areas of this system upstream of Genoa Lane (Pahl 2006). The growth of algal populations upstream of the study reach may also affect the nutrient loading to the lower river and the effects of the upper river's dynamics on the river downstream of Genoa Lane remains unstudied. In the summer of 2007 the Systems Microbial Ecology Lab (SMEL) of DRI expects to conduct surveys of DO, water chemistry and algae within the reaches upstream and downstream of Genoa lane in order to better document and determine the extent to which flows, algal biomass and temperatures can be prescribed in order to maintain DO concentrations above the 5 mg L^{-1} standard. In addition, the SMEL will be conducting additional surveys of the extent and identities of cyanobacterial growths in the river system during the summer and will be assessing the role that benthic substrate type and stability has on the limitation of biomass accumulation. This work shall aid in the future management of the Carson River corridor.

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Appendix A. Macronutrients

Table A1. Water quality sampling sites in the Carson river study and their associated abbreviations.

Site Name/Description	Abbreviation
Carson River, East Fork @ Sewage Plant (1 sample only)	DRI_SEW
Carson River, East Fork @ Hwy. 88	CV88
Brockliss Slough @ Mottsville Ln.	CVBS
Brockliss Slough @ Genoa Lakes Golf Course Sonde	DRI_BSS
Carson River @ Genoa Lane Bridge (USGS 10310405)	DRI_GLB
Caron River @ Willowbend Sonde	DRI_WBS
Carson River @ Genoa Lakes Golf Course Gage (USGS 10310407)	CVGL
Carson River Above Ambrosetti Creek	DRI_CAA
Ambrosetti Creek @ Gage (USGS 10310448)	CVA
Ambrosetti Creek @ Outlet to Carson River	DRI_ACO
Carson River @ Cradlebaugh Bridge Sonde	DRI_CBS
Carson River @ Mexican Dam Gage (USGS 10311002)	CVMG
Carson River @ Foerschler Ranch Sonde	DRI_FRS
Carson River @ Riverview Park Sonde	DRI_RVS

Table A2. Water Quality measures during the 2003 and 2004 study period.

Sample Site	Sample Date	Data Source	OPO4-P (mg L^{-1})	TPsol (mg L^{-1})	TP-P (mg L^{-1})	NH4-N (mg L^{-1})	TKNsol (mg L^{-1})	TKN (mg L^{-1})	NO3-N (mg L^{-1})	NO2-N (mg L^{-1})	TN (mg L^{-1})	TIN (mg L^{-1})	TN:TP (mol:mol)
2003													
CVBS	05/21/03	CVCD	0.02	NR	0.29	<0.1	NR	1	0.14	<0.01	1.15	NR	8.75
CV88	05/21/03	CVCD	0.01	NR	0.30	<0.1	NR	0.5	*0.09*	<0.01	0.6	NR	4.41
CVGL	05/21/03	CVCD	0.02	NR	0.37	<0.1	NR	0.8	*0.05*	<0.01	0.86	NR	5.13
CVA	05/22/03	CVCD	0.25	NR	0.43	<0.1	NR	2.8	*0.09*	<0.01	2.9	NR	14.89
CVDR	05/22/03	CVCD	0.04	NR	0.29	<0.1	NR	0.9	*0.04*	<0.01	0.95	NR	7.23
CVMG	05/22/03	CVCD	0.04	NR	0.28	<0.1	NR	0.9	*0.06*	<0.01	0.97	NR	7.65
CVA	06/16/03	CVCD	0.26	NR	0.33	<0.1	NR	1.2	*0.06*	<0.01	1.27	NR	8.49
CVBS	06/16/03	CVCD	0.02	NR	0.06	<0.1	NR	0.3	*0.03*	<0.01	0.34	NR	12.51
CVGL	06/16/03	CVCD	0.04	NR	0.15	<0.1	NR	0.4	*0.03*	<0.01	0.44	NR	6.47
DRI_GLB	06/27/03	DRI WL	0.07	0.098	0.16	0.015	0.26	0.33	0.044	0.002	0.306	0.061	4.30
DRI_CBS	06/27/03	DRI WL	0.10	0.137	0.18	0.009	0.43	0.47	0.031	0.003	0.464	0.043	5.75
DRI_SEW	06/27/03	DRI WL	0.02	0.031	0.04	0.006	0.12	0.10	0.062	0.002	0.184	0.07	10.69
DRI_ACO	06/27/03	DRI WL	0.07	0.100	0.13	0.006	0.27	0.35	0.219	0.010	0.499	0.235	8.74
CVBS	07/16/03	CVCD	0.10	NR	0.16	<0.1	NR	0.7	*0.05*	<0.01	0.76	NR	10.48
CV88	07/16/03	CVCD	<0.01	NR	0.04	<0.1	NR	0.3	*0.08*	<0.01	0.39	NR	21.52
CVA	07/17/03	CVCD	0.52	NR	0.63	<0.1	NR	1.2	*0.02*	<0.01	1.23	NR	4.31
CVDR	07/17/03	CVCD	0.15	NR	0.18	<0.1	NR	0.5	*0.04*	<0.01	0.55	NR	6.74
CVGL	07/17/03	CVCD	0.11	NR	0.13	<0.1	NR	0.3	*0.05*	<0.01	0.36	NR	6.11
CVMG	07/17/03	CVCD	0.15	NR	0.18	<0.1	NR	0.4	*0.04*	<0.01	0.45	NR	5.52
DRI_CBS	08/05/03	DRI WL	0.27	0.362	0.38	0.008	0.73	0.73	0.004	0.005	0.739	0.017	4.25
DRI_CAA	08/05/03	DRI WL	0.12	0.153	0.22	0.018	0.60	0.64	0.003	0.003	0.61	0.024	5.97
DRI_ACO	08/05/03	DRI WL	0.60	0.658	0.81	0.019	1.59	1.59	0.005	0.006	1.601	0.03	4.37
DRI_FRS	08/05/03	DRI WL	0.20	0.287	0.31	0.014	0.76	0.78	0.004	0.005	0.769	0.023	5.41
DRI_BSS	08/05/03	DRI WL	0.12	0.158	0.30	0.014	0.88	0.96	0.002	0.004	0.886	0.02	6.56
DRI_RVS	08/05/03	DRI WL	0.16	0.243	0.27	0.006	0.51	0.52	0.002	0.005	0.517	0.013	4.21
DRI_WBS	08/05/03	DRI WL	0.09	0.106	0.15	0.012	0.32	0.30	0.004	0.003	0.327	0.019	4.84
CVA	08/21/03	CVCD	0.20	NR	0.34	<0.1	NR	1	*0*	<0.01	1.01	NR	6.56
CVGL	08/21/03	CVCD	0.23	NR	0.31	<0.1	NR	0.5	*0.03*	<0.01	0.54	NR	3.84
DRI_CAA	09/04/03	DRI WL	0.17	0.212	0.25	0.020	0.31	0.34	0.005	0.002	0.317	0.027	2.82
DRI_ACO	09/04/03	DRI WL	0.56	0.635	0.72	0.031	1.06	1.12	0.005	0.003	1.068	0.039	3.30
DRI_FRS	09/04/03	DRI WL	0.21	0.262	0.30	0.008	0.38	0.45	0.004	0.003	0.387	0.015	2.85
DRI_BSS	09/04/03	DRI WL	0.07	0.104	0.18	0.026	0.52	0.57	0.001	0.002	0.523	0.029	6.31
DRI_RVS	09/04/03	DRI WL	0.15	0.194	0.22	0.014	0.52	0.54	0.003	0.002	0.525	0.019	5.20
DRI_WBS	09/04/03	DRI WL	0.13	0.169	0.19	0.015	0.31	0.33	0.003	0.003	0.316	0.021	3.67
CV88	09/23/03	CVCD	<0.01	NR	0.02	<0.1	NR	0.4	*0.03*	<0.01	0.44	NR	48.56

Sample Site	Sample Date	Data Source	OPO4-P (mg L-1)	TPsol (mg L-1)	TP-P (mg L-1)	NH4-N (mg L-1)	TKNsol (mg L-1)	TKN (mg L-1)	NO3-N (mg L-1)	NO2-N (mg L-1)	TN (mg L-1)	TIN (mg L-1)	TN:TP (mol:mol)
CVA	09/24/03	CVCD	0.30	NR	0.47	0.200	NR	0.8	*0.06*	<0.01	0.87	NR	4.09
CVDR	09/24/03	CVCD	0.09	NR	0.10	<0.1	NR	0.4	*0*	<0.01	0.41	NR	9.05
CVGL	09/24/03	CVCD	0.12	NR	0.16	<0.1	NR	0.4	*0.1*	<0.01	0.51	NR	7.04
CVMG	09/24/03	CVCD	0.11	NR	0.17	<0.1	NR	0.4	*0.02*	<0.01	0.43	NR	5.58
DRI_CAA	10/09/03	DRI WL	0.20	0.264	0.31	0.009	0.40	0.40	0.002	0.001	0.403	0.012	2.92
DRI_ACO	10/09/03	DRI WL	0.19	0.238	0.25	0.010	0.28	0.30	0.002	0.001	0.283	0.013	2.54
DRI_FRS	10/09/03	DRI WL	0.11	0.149	0.17	0.001	0.22	0.26	0.002	0.001	0.223	0.004	2.85
DRI_BSS	10/09/03	DRI WL	0.06	0.089	0.15	0.015	0.68	0.80	0.001	0.001	0.682	0.017	9.90
DRI_RVS	10/09/03	DRI WL	0.08	0.108	0.14	0.002	0.23	0.30	<.001	0.001	0.231	0.003	3.69
DRI_WBS	10/09/03	DRI WL	0.10	0.145	0.19	0.021	0.49	0.58	0.003	0.001	0.494	0.025	5.68
CVA	10/22/03	CVCD	0.22	NR	0.39	0.200	NR	0.9	*0*	<0.01	0.91	NR	5.15
CVBS	10/22/03	CVCD	0.03	NR	0.05	<0.1	NR	0.3	*0.02*	<0.01	0.33	NR	14.57
CVGL	10/22/03	CVCD	0.06	NR	0.11	<0.1	NR	0.4	*0.07*	<0.01	0.48	NR	9.63
2004													
DRI_CBS	06/09/04	DRI WL	0.08	0.103	0.14	0.008	0.30	0.32	0.019	0.003	0.322	0.03	5.15
DRI_ACO	06/09/04	DRI WL	0.21	0.266	0.29	0.017	0.74	0.80	<.001	0.003	0.743	0.02	5.69
DRI_CAA	06/09/04	DRI WL	0.07	0.097	0.14	0.011	0.28	0.30	0.018	0.003	0.301	0.032	4.75
DRI_FRS	06/09/04	DRI WL	0.10	0.110	0.16	0.009	0.32	0.35	0.009	0.003	0.332	0.021	4.67
DRI_BSS	06/09/04	DRI WL	0.08	0.153	0.25	0.029	0.68	0.78	<.001	0.003	0.683	0.032	6.10
DRI_RVS	06/09/04	DRI WL	0.09	0.108	0.15	0.018	0.30	0.34	0.004	0.003	0.307	0.025	4.58
DRI_WBS	06/09/04	DRI WL	0.01	0.035	0.06	0.009	0.09	0.12	0.033	0.001	0.124	0.043	4.49
DRI_BSS	06/25/04	DRI WL	0.09	0.183	0.26	0.023	0.78	0.8	0.013	<.001	0.793	0.036	6.86
DRI_GLB	06/25/04	DRI WL	0.05	0.104	0.13	0.018	0.34	0.4	0.010	<.001	0.350	0.028	6.13
DRI_CAA	06/25/04	DRI WL	0.11	0.216	0.26	0.017	0.45	0.53	0.017	<.001	0.467	0.034	4.03
DRI_ACO	06/25/04	DRI WL	0.21	0.424	0.45	0.032	1.16	1.26	0.011	0.001	1.172	0.044	5.72
DRI_CBS	06/25/04	DRI WL	0.16	0.298	0.33	0.022	0.76	0.85	0.016	0.001	0.777	0.039	5.23
DRI_FRS	06/25/04	DRI WL	0.10	0.243	0.27	0.017	0.68	0.77	0.003	<.001	0.683	0.02	5.56
DRI_RVS	06/25/04	DRI WL	0.11	0.250	0.27	0.017	0.70	0.73	0.001	<.001	0.70	0.018	5.84
DRI_BSS	07/01/04	DRI WL	0.12	0.174	0.17	0.014	0.60	0.64	0.012	<.001	0.61	0.026	7.99
DRI_GLB	07/01/04	DRI WL	0.12	0.175	0.21	0.011	0.41	0.41	0.011	<.001	0.421	0.022	4.34
DRI_CAA	07/01/04	DRI WL	0.13	0.171	0.23	0.013	0.41	0.51	0.021	0.001	0.432	0.035	4.07
DRI_ACO	07/01/04	DRI WL	0.33	0.447	0.46	0.016	1.02	1.08	0.012	0.001	1.033	0.029	4.97
DRI_CBS	07/01/04	DRI WL	0.17	0.233	0.27	0.017	0.56	0.61	0.024	0.001	0.585	0.042	4.75
DRI_FRS	07/01/04	DRI WL	0.15	0.148	0.24	0.011	0.50	0.56	0.029	0.001	0.53	0.041	4.83
DRI_RVS	07/01/04	DRI WL	0.12	0.130	0.21	0.011	0.73	0.67	0.009	<.001	0.739	0.02	7.96
DRI_BSS	07/08/04	DRI WL	0.10	0.147	0.26	0.022	0.74	1.06	0.02	0.001	0.761	0.043	6.59
DRI_GLB	07/08/04	DRI WL	0.10	0.193	0.24	0.011	0.46	0.46	0.014	<.001	0.474	0.025	4.45
DRI_CAA	07/08/04	DRI WL	0.16	0.269	0.33	0.012	0.49	0.65	0.014	<.001	0.504	0.026	3.40
DRI_ACO	07/08/04	DRI WL	0.41	0.622	0.65	0.025	0.98	1.10	0.012	0.001	0.993	0.038	3.38

Sample Site	Sample Date	Data Source	OPO4-P (mg L^{-1})	TPsol (mg L^{-1})	TP-P (mg L^{-1})	NH4-N (mg L^{-1})	TKNsol (mg L^{-1})	TKN (mg L^{-1})	NO3-N (mg L^{-1})	NO2-N (mg L^{-1})	TN (mg L^{-1})	TIN (mg L^{-1})	TN:TP (mol:mol)
DRI_CBS	07/08/04	DRI WL	0.21	0.322	0.37	0.015	0.54	0.69	0.012	0.001	0.553	0.028	3.31
DRI_FRS	07/08/04	DRI WL	0.16	0.266	0.30	0.017	0.50	0.62	0.007	<.001	0.51	0.024	3.69
DRI_RVS	07/08/04	DRI WL	0.11	0.203	0.23	0.018	0.51	0.51	0.005	<.001	0.515	0.023	4.96
DRI_BSS	07/13/04	DRI WL	0.11	0.166	0.31	0.018	0.74	1.03	0.006	0.001	0.747	0.025	5.28
DRI_GLB	07/13/04	DRI WL	0.13	0.191	0.23	0.016	0.32	0.36	0.011	<.001	0.331	0.027	3.20
DRI_CAA	07/13/04	DRI WL	0.14	0.225	0.27	0.014	0.46	0.75	0.006	<.001	0.466	0.02	3.84
DRI_ACO	07/13/04	DRI WL	0.33	0.429	0.46	0.023	0.94	0.99	0.017	0.002	0.959	0.042	4.65
DRI_CBS	07/13/04	DRI WL	0.24	0.291	0.33	0.016	0.59	0.83	0.009	0.001	0.6	0.026	4.04
DRI_FRS	07/13/04	DRI WL	0.17	0.242	0.28	0.012	0.41	0.54	0.005	<.001	0.415	0.017	3.32
DRI_RVS	07/13/04	DRI WL	0.15	0.212	0.22	0.020	0.45	0.51	0.011	<.001	0.461	0.031	4.58

NR indicates that a value was not reported.
Italicized values are estimated and below the laboratory reporting limit of 0.1 for Nitrate-N.

Table A3. Water Quality measures during the 2004 Lagrangian study of 6/18/2004.

Sample Site	Sample Time	Data Source	OPO4-P (mg L^{-1})	TPsol (mg L^{-1})	TP-P (mg L^{-1})	NH4-N (mg L^{-1})	TKNsol (mg L^{-1})	TKN (mg L^{-1})	NO3-N (mg L^{-1})	NO2-N (mg L^{-1})	TN (mg L^{-1})	TIN (mg L^{-1})	TN:TP (mol:mol)
Lagrangian time of travel survey on 6/18/04													
DRI_GLB	8:35	DRI WL	0.07	0.081	0.12	0.021	0.36	0.42	0.004	0.003	0.367	0.028	6.86
DRI_CBS	8:52	DRI WL	0.18	0.190	0.23	0.016	0.54	0.62	0.006	0.003	0.549	0.025	5.20
DRI_BSS	10:10	DRI WL	0.18	0.189	0.28	0.031	0.72	0.76	0.009	0.003	0.732	0.043	5.79
DRI_CAA	16:30	DRI WL	0.15	0.166	0.20	0.011	0.48	0.51	0.006	0.003	0.489	0.02	5.51
DRI_ACO	16:45	DRI WL	0.34	0.370	0.39	0.015	1.18	1.26	<.001	0.004	1.184	0.019	6.65
DRI_CBS	17:30[r]	DRI WL	0.18	0.199	0.23	0.008	0.57	0.84	0.003	0.002	0.575	0.013	5.64
DRI_CBS	17:30[t]	DRI WL	0.18	0.196	0.22	0.008	0.58	0.63	0.003	0.003	0.586	0.014	5.77
DRI_CBS	17:30[l]	DRI WL	0.18	0.191	0.23	0.006	0.54	0.59	0.005	0.002	0.547	0.013	5.37
DRI_FRS	18:02	DRI WL	0.16	0.168	0.20	0.009	0.47	0.52	0.004	0.002	0.476	0.015	5.33
DRI_RVS	23:59	DRI WL	0.16	0.170	0.18	0.008	0.54	0.56	<.001	0.002	0.542	0.01	6.68

[r] indicates sample was collected near right bank,
[t] indicates sample was collected at thalweg
[l] indicates sample was collected near left bank

Appendix B. Common Algae, the Carson River

Table B1. Common Algae Genera in Carson River study area.

Bacillariophyta	Chlorophyta	Cyanophyta
Acnanthes	***Cladophora***	***Anabaena***
Amphipleura	*Closterium*	*Chroococcus*
Amphora	*Cosmarium*	*Cylindrospermum*
Caloneis	*Micrasterias*	*Eucapsis*
Cocconeis	*Microspora*	*Nostoc*
Cymatopleura	*Oedogonium*	***Oscillatoria***
Cymbella	*Pediastrum*	Xenococcus
Diatoma	*Scenedesmus*	
Epithemia	*Spirogyra*	
Fragilaria	*Staurastrum*	
Gomphoneis		
Gomphonema		
Gyrosigma		
Karayevia		
Melosira		
Navicula		
Nitzschia		
Pinnularia		
Planothidium		
Pleurosigma		
Reimera		
Rhoicosphenia		
Rhopalodia		
Sellaphora		
Stauroneis		
Surirella		
Synedra		

Table B2. Algal-based metrics derived from periphyton samples taken at different study locations. PTI, pollution tolerance index; SI, siltation index ; EI, eutrophication index. Diatom genera richness is the total number of diatom genera found at the site. % Cyano is the proportion of all taxa (diatoms and all soft algae) that were cyanobacteria.

Date	Site	PTI	SI	EI	Shannon Diversity	Diatom Genera Richness	% Cyano
9/2/2003	Will	2.68	0.16	0.15	1.34	16	0.17
10/2/2003	Will	2.43	0.37	0.34	1.64	18	0.17
9/2/2003	Brock	2.71	0.27	0.91	1.50	13	0.44
9/2/2003	Crad	2.18	0.48	0.36	2.13	18	0.57
9/30/2003	Crad	2.58	0.27	0.54	1.86	12	0.54
9/30/2003	Foer	2.53	0.25	0.72	1.65	18	0.58
9/4/2003	Park	2.53	0.17	0.64	2.06	13	0.64
9/30/2003	Park	2.83	0.10	0.84	1.90	15	0.52

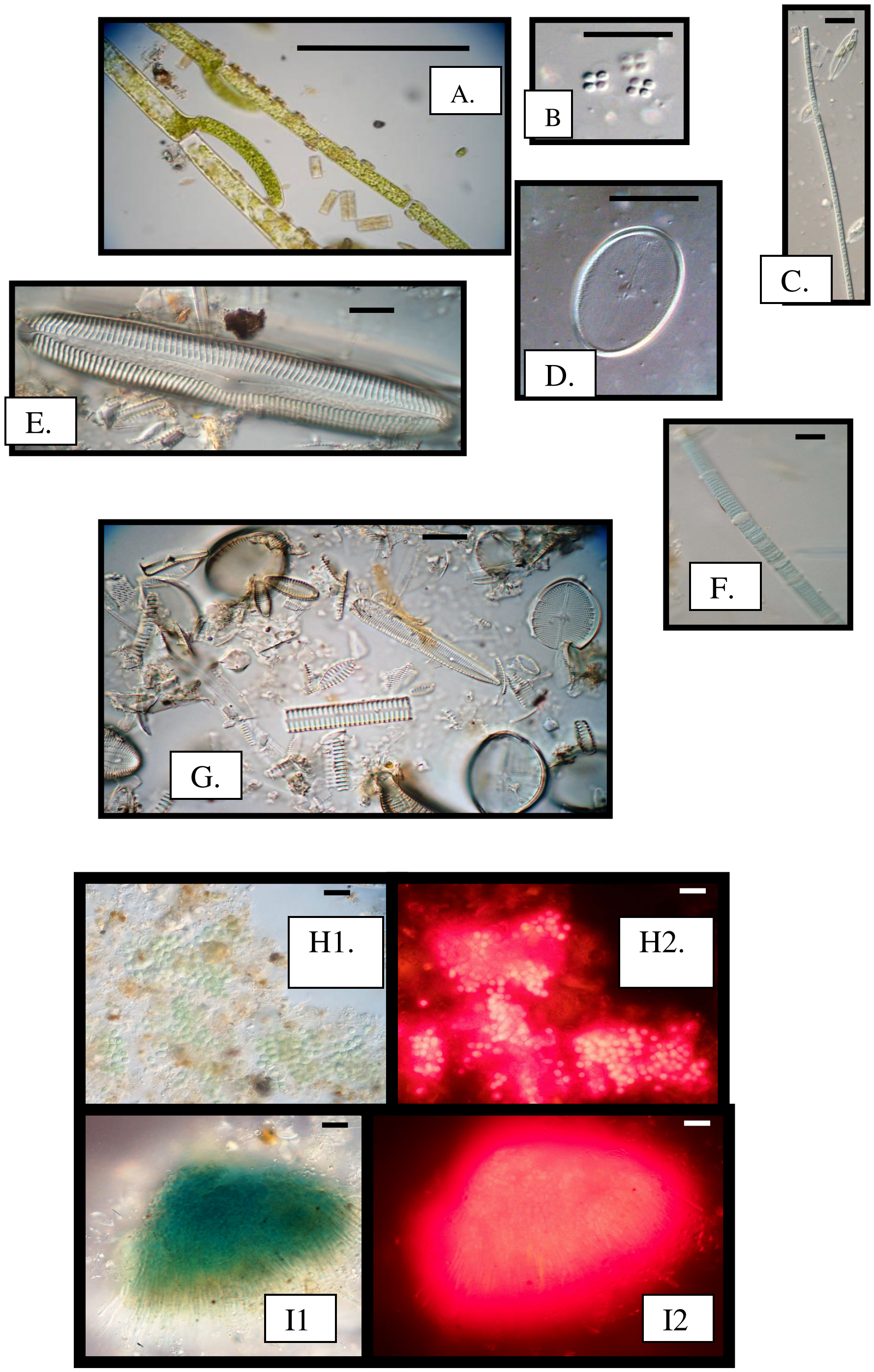

Figure B1. A) *Cladophora sp.* (with epiphytic *Cocconeis sp*.), B) *Eucapsis sp.*, C) *Oscillitoria sp.*, D) *Cocconeis sp*., E) *Pinnularia sp*., F) *Nodularia sp*., G) Representative diatom assemblage, H) *Aphanocapsa sp.* (H.1= D.I.C, H.2 = Epiflourescence) I) *Calothrix sp.* (I.1= D.I.C, I.2 = Epiflourescence). . Scale bars = 10 micrometers, except for A (Scale bar = 500um)