Chapter 2

Light Attenuation and Nutrients in the Jordan River and Their Relationship to Periphyton and Phytoplankton Communities

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August 2019

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Introduction

The lower reaches of the Jordan River were assessed as being impaired for low dissolved oxygen (DO) in 1998. As such, the Utah Division of Water Quality is currently preparing the TMDL. The TMDL is required to identify the sources of the impairment as well as allocate pollutant load reductions that will improve the DO deficiency and restore fully supporting status to the impaired reach.

The Jordan River represents the first TMDL for a Utah stream that is nearly completely "urbanized". Straightened, narrow channels with highly restricted floodplains and frequent dredging characterize such streams and particularly the Jordan River. The prevalent private ownership and the zoning laws has allowed considerable commercial and housing development and parking lot construction immediately adjacent to the main stem and its many tributaries as they leave Forest Service land and enter the Salt Lake Valley. Consequently, the riparian corridor is severely restricted and mostly non-functional. This allows extensive bank erosion and incision of the main and tributary channels, which become most obvious during spring and stormwater runoff. The river also suffers from severe hydrologic modification, including several points of diversion (including 85% to 95% diversions by the Turner and Point Dams in the narrows, followed by tributary, groundwater, storm water and POTW inflow and then another diversion of 50 to >90% to the surplus canal near the 2100 South crossing.

Another significant problem with the Jordan River is the delivery of high concentrations of algae and TSS from shallow (mean depth ~2 m), eutrophic, Utah Lake. Water leaving Utah Lake contains 45 to 100 mg L^{-1} TSS and 15 to about 90 ug L^{-1} (depending on season), chlorophyll a. Total volatile suspended solids (VSS) at the Utah Lake outlet is consistently near 10 mg L^{-1}) (Wasatch Front Water Quality Council data, 2009, 2014, Cirrus Environmental 2009).

Another factor that strongly influences the persistence, effect and fate of the TSS in the Jordan River is the steady decline in the stream gradient. This gradient ranges from approximately 15 ft per mile (3 m per km) through the narrows to approximately 1.5 ft per mile (0.3 m per km) at its terminus as it enters the impounded wetlands of Farmington Bay. Substrate size distribution responds appropriately with large gravel, cobble and boulders dominating the narrows (between Thanksgiving Point and about 14600 South). There is a gradual decline in substrate size to mostly large gravel interspersed with occasional cobble from 14600 to approximately 7200 South, large and medium gravel from 7200 South to approximately 5400 South and a gradual decline from medium gravel to sand between 5400 South and 2100 South (Bio-West (1980; personal observations; see Chapter 1). Below 2100 South (after an average of about 85% of the flow has been diverted to the surplus canal), the substrate is dominated by silt and clay with some areas of sand. This dramatic decline in volume results in a decline in velocity (in addition to the ever-declining stream gradient) and allows for the TSS and most of course particulate organic matter (CPOM) transported in the water column or as part of the bedload to begin settling at the bottom. As such, the last 15 miles (25 km) of the river channel is overwhelmingly a depositional reach as the velocity slows to 5 - 15 cm s^{-1} and the bottom is increasingly dominated by unstable silts and clays filled with settling particulate organic matter. These various impacts on the Jordan River are critically important in dictating the degree to which Utah lake phytoplankton persists in the river as well the ability of periphyton to colonize the various substrates that are scoured in upstream sections and smothered in downstream sections.

The presence of these severe habitat impairments complicates the determination of just what further impacts might be attributed to the four POTWs that discharge considerable loads of phosphorus and nitrogen to the Jordan River. These POTWs are located at approximately 13500 South, 7200 South, Mill Creek/Jordan River near 3100 South and just below Center St. in Bountiful. The two southern most plants, Jordan Basin and South Valley are design with BNR and thus discharge at or below 1 mg P/L. These point sources of nutrients help in raising and maintaining P to 0.1 to 0.5 mg L^{-1} and total nitrogen (mostly as NO_3) intermittently up to about 5 mg L^{-1}. These concentrations of nutrients have the potential to maintain or even increase the high concentrations of chlorophyll a that are delivered from Utah Lake.

It is apparent that these adverse factors induce inhibitory responses with regard to primary production and standing crop of both the Utah Lake phytoplankton as well as periphyton growth within the river. This chapter investigates the relationships between turbidity, unstable substrate and nutrients and the ability to grow or support both phytoplankton and periphytic growth of algae in the Jordan River.

In the first year of our studies (1999), our objectives were three-fold: 1) to understand the contribution of Utah Lake phytoplankton to the water column biomass and its proportion of the water column algal community in Jordan River; 2) and how far downstream do these species occur in the river; and 3) Are these assemblages influenced by the South Valley and Central Valley water reclamation facilities? These observations prompted the measurement periphyton growth both on artificial substrate (slate tiles) as well as on natural ambient cobble-sized substrate.

In addition, the characteristic high turbidity and calculations that predict the potential for much higher Chl a concentrations (based on instream P concentrations), led to the hypotheses that light limitation and unstable substrate significantly impede periphyton and phytoplankton growth in the river. To begin testing these hypotheses, we measured water column light intensity at several stations throughout the Jordan River during the summer of 2010.

Methods

Light Measurements

Twenty-one stations were selected for light measurements to represent the entire distance of the Jordan River, including immediately downstream from the Utah Lake outlet, within the narrows, and multiple locations throughout the middle and lower reaches of the river (Table 1.). In addition, one site was sampled on the Surplus Canal about 3 miles downstream from the 2100 S. diversion for comparison of transparency of the water left in the river channel.

Sites were selected that provided open exposure to the water surface (no shading from trees or the stream bank) and measurements were made between the hours of 1000 and 1500 and at times absent of cloud cover in order to capture the highest intensity of the daylight hours.

The sensor frame was mounted to a 2 m aluminum rod, which allowed the frame to be held in a stable position to a maximum depth of about 1.2 m. Irradiance values were measured every 0.2 m from the surface to the bottom or to 1.2 m.

Light attenuation coefficients were calculated for each curve developed at each sampling event, using the equation:

$$I_z = I_o e^{-kz}$$

Where I_o is the irradiance just below the water surface, I_z is the irradiance at a specified depth (z) in question, and k is the light extinction coefficient of the waterbody. We calculated the extinction coefficient by using the same exponential model but derived from the regression curves of measured depth profile data. We then used the median values for k and the I_o (y intercept) values to calculate a final extinction equation and subsequent I_z values and the associated percentage of surface irradiance at various depths.

Periphyton and Phytoplankton Measurements

Water column algae samples were collected monthly during 2009 from the Utah Lake outlet, the narrows near Thanksgiving Point, and near the bridges at 14600 S, 9000 S, 7800 S, 6400 S, 3300 S, 2100 S, 900 S, 400 S, 300 N, 1800 N, Center St, Legacy Nature Preserve and Burnham Dam. Some sampling was also conducted upstream and downstream from the Central Valley Reclamation Facility discharge in Mill Creek. Samples were collected in 500 mL plastic bottles, immediately stored on ice and delivered to the Rushforth Lab on the day of sampling.

During 2010, we installed artificial substrate samplers, which consisted of 12-inch (30.5 cm) square slate tiles from a local hardware store. These tiles were fastened to steel brackets that were constructed from 1-inch angle iron and these brackets were fastened to stakes made from ½-inch rebar (see Figure 3). Two tiles were fastened to each rebar stake such that the bottom tile lay flush with the sediment surface and the top tile was set at about 15 cm above the bottom but at a right angle to the bottom tile. We chose this arrangement to evaluate the influence of either scouring by the mobile bed load material or smothering by sediment deposition as compared to a tile suspended at about mid-depth, which hypothetically, would not be exposed to such severe scouring or burial. One tile was positioned upstream and one downstream from the stake to avoid shading. Tiles were placed at the same locations as for the water column samples. The tiles were placed in the river on about June 6 and sampling began three weeks later. We also collected periphyton samples from natural cobble substrates at each site, where available, for comparison with the periphytic community that developed on the artificial substrate.

Sample collection included the use of a small section of 2-inch (5.1 cm) PVC pipe or a similar-sized hole in flexible gasket material that served as a template to identify a quantitative area to determine growth and standing crop on an aerial basis. Samples were collected in triplicate and composited. The periphyton was removed using a razor blade or toothbrush followed by rinsing the brushed area into a 500 mL sample bottle. Where natural (ambient), cobble-sized, stable, substrate occurred in the vicinity of the tile placement, a similar scraping was collected from the exposed surface of the rock. Samples were transported on ice to the South Valley Water Reclamation Facility lab where the Chlorophyll a was collected on glass fiber filters and analyzed using the ethanol extraction method (EPA Method 446). Sample collection occurred approximately every two weeks until October 9, 2010.

Grab samples for nutrient analysis were collected during each sampling event to determine if there was any relation between Chlorophyll a and nutrients discharged to the river. A chain of custody sheet was prepared for each sampling event and delivered to the appropriate lab. The Chl *a* samples were frozen until analysis, which was within about 30 days. Portions of the water quality samples were immediately filtered upon arrival for the determination of dissolved P. These samples were transported to the Central Valley Water Reclamation Facility Lab. Nutrients and other basic parameters have been sampled each month since May, 2009. This intense sampling was intended to describe monthly, seasonal and annual variability that might be associated with flows and the annual growing, senescing and dormant seasons.

Results

Light Transmissivity

Sample sites included from the Utah Lake outlet to downstream from Burnham Dam. Between two and seven measurements were made at each sampling location between July and October. Representative graphs of the light extinction profiles are depicted in Figure 1, determined at the 3300 South Site. Depending on the date and specific location, the depth was between 1 and 1.2 m. The equation reflects the August 19 measurements and the R^2 value (0.99) is typical of the regression curves generated from these data throughout this study. Regression plots of the remainder of the sampling sites are listed in the appendix of this chapter.

A summary of the maximum depth that light transmission was measured and other important endpoints of light intensity are presented in Table 2. The 5% and 1% depths are listed because these represent the range of values reported as the compensation point (where primary production = respiration; see Discussion). Note that in all cases, except for the narrows site, greater than 1% of the surface light reached the bottom or the maximum measurable depth (1.2 m). Also, except for two of the most downstream stations (Center St., and 500 m below Burnham

Dam), and the Surplus Canal, light at the bottom of the remaining sites was at or above 5% of surface irradiance. In other words, the calculated depth at which the 5% level would be reached is deeper than the depth of the river at most of the sampling stations. This is important in that is indicates that most of the river should in a net positive state of primary production. Alternatively, however, other critical physical characteristics such as scouring and particularly smothering or burial at downstream sites could preclude the river from achieving net primary production. Hogsett and Goel, as discussed in Chapter 5, examined this possibility further.

Table 2. Sample locations and number of individual light profiles measured in the Jordan River and the Surplus Canal.

Site	Number of Times sampled			
	July	August	Sept.	Oct
Utah Lake outlet	3	2		
Narrows (Thanksgiving Point)	3	2	1	
14600 South	3	2	1	1
9000 South		2	1	
7800 South	3	3		
7200 South	3	3		
6400 South		2		
5400 South	3	3		
3900 South		3		
3300 South	3	3		
2100 South	3	3	1	1
1700 South		2		
California Ave (1300 South)	3	3		
900 South	3	3		
400 South		1		
North Temple		1		
300 North		2		
1800 North		2		
Center Street (Bountiful)	2	3		1
500 m downstream of S. Davis S. POTW		2		
500 m downstream of Burnham Dam		3		
Surplus Canal near airport	2	3		

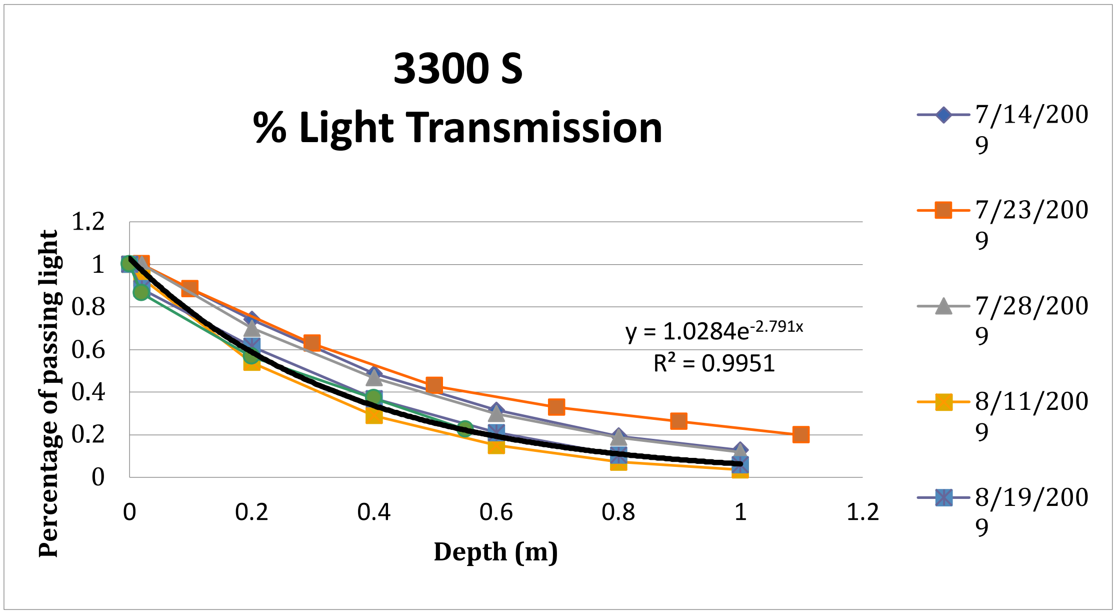


Figure 20. Light extinction profiles measured in the Jordan River at the 3300 South site. Measurements are reported as a percentage of reduction of light intensity at increasing depths. The displayed equation represents light attenuation values measured on Aug. 19, 2009.

Table 3. Maximum depth of light intensity measured at each sampling location and the associated percentage of the surface light intensity. For comparison, depths at which 5% and 1% intensity are reported as calculated from the light extinction curve. Note that nearly all sites, except at the Narrows, retained at least 5% of surface irradiance all the way to the bottom (see text).

Site	Max depth (m)	% of surf. Ir. at bottom (m)	Depth at 5% of Surf. Ir. (m)*	Depth at 1% of Surf. Ir.* (m)
Utah L. outlet	1	5	1.0	1.5
Narrows	1.2	0.5	0.7	1.1
14600 S.	1.0	5	1.0	1.5
9000 S.	0.4	35	1.1	1.7
7800 S.	0.9	13	1.3	2.0
7200 S.	0.8	16	1.3	1.9
6400 S	0.6	21	1.3	2.0
5400 S.	0.6	24	1.2	1.9
3900 S.	0.4	26	0.9	1.4
3300 S.	1.1	8	1.3	2.1
2100 S	0.8	24	1.6	2.4
1700 S.	0.8	11	1.1	1.7
900 S.	1.0	7	1.15	1.8
North Temple	0.5	27	1.1	1.6
300 N.	0.5	23	0.85	1.3
1800 N.	0.6	17	1.0	1.5
Center St.	1.0	3	0.8	1.3
500 m Bl. S. Davis S. POTW	0.8	5	0.8	1.2
500 m Bl. Burnham Dam	1.0	2	0.75	1.2
Surplus Canal at airport	1.0	3	0.8	1.3

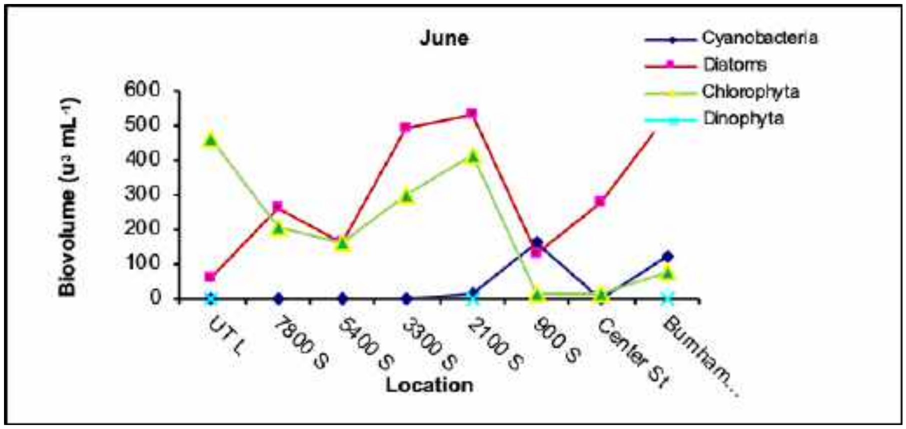
*These are predicted values derived from the regression equation.

Phytoplankton and other Algae Suspended in the Water Column

Identification and quantification of phytoplankton and periphyton data are summarized by Rushforth and Rushforth (2009a and 2009b). These reports are appended to this report. Monthly samples of the water column indicated that a majority of the suspended algal community in the Jordan River water column came from Utah Lake and these taxa clearly dominated the community throughout the entire River length (Figure 2). The only exception was the month of June, when the biomass of suspended algae was relatively very low. In this sample, soft algae (Chlorophyta) dominated upstream sites (delivered from Utah Lake) while diatoms mostly dominated downstream sites. Notably, however, the diatoms that were present largely consisted of periphyton (attached) taxa that had become dislodged from benthic substrate. This supports the hypothesis that periphyton is continually being scoured by the moving bedload material.

The community continued to shift with summer succession as the population of in Utah Lake experienced a large bloom of Cyanobacteria (mostly Aphanezomenon) starting in July. The population of Chlorophytes and diatoms remained relatively stable as the Aphanezomenon population grew from non-detectable to several orders of magnitude larger that the other algae. The dramatic reduction in the Cyanobacteria downstream at 7800 S (Figure 2) is the result of the average of 97% diversion of the river by Turner Dam, followed by dilution with groundwater as well as several tributaries. Evidence of large groundwater entry has been described by CH2MHill (2005). Also, locally placed piezometers have demonstrated positive hydrostatic pressure at several locations in the upper and middle reaches of the river, suggesting positive groundwater inflow to the river (Mitch Hogsett, University of Utah, personal communication).

Another key observation is that after the reduction in biovolume at Turner Dam, there was no further reduction of these taxa, even at locations downstream from 2100 S., Chl *a* values followed a similar pattern (Figure 2). Further, it is notable that the 25 ug/L Chl *a* concentration in Utah Lake outlet water is indicative of eutrophic (nutrient enriched) conditions. But yet, following the Turner Dam diversion, the 10 ug/L Chl *a* concentration is actually indicative of oligotrophic to mesotrophic conditions (i.e. nutrient poor to a medium trophic status). But in this transition from a lake to a river environment, one would expect algal growth to transition from a phytoplankton-dominated/lake community to a periphyton-dominated stream community (See next section). Finally, the fact that we did not see any significant reduction in biovolume downstream from the Turner Dam diversion, and including downstream from the Surplus Canal diversion, provides notable evidence that settling of these algal cells is minute and immeasurable. Consequently, these sources of organic matter provide a very minor contribution to the very high sediment oxygen demand- values that were measured by Goel 2010; Chapter 5).



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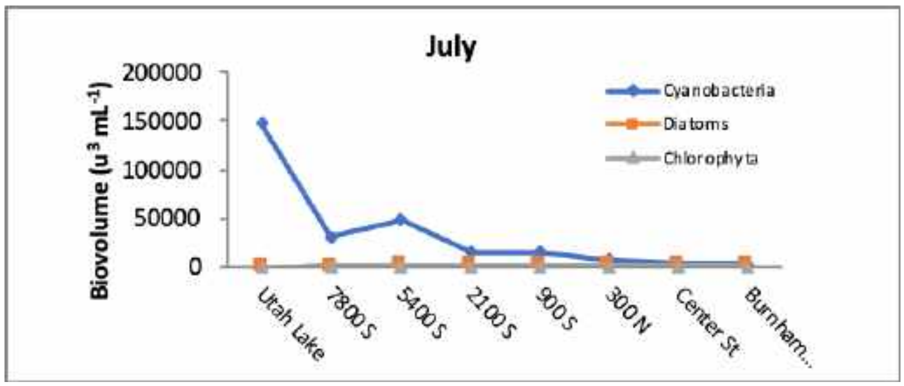

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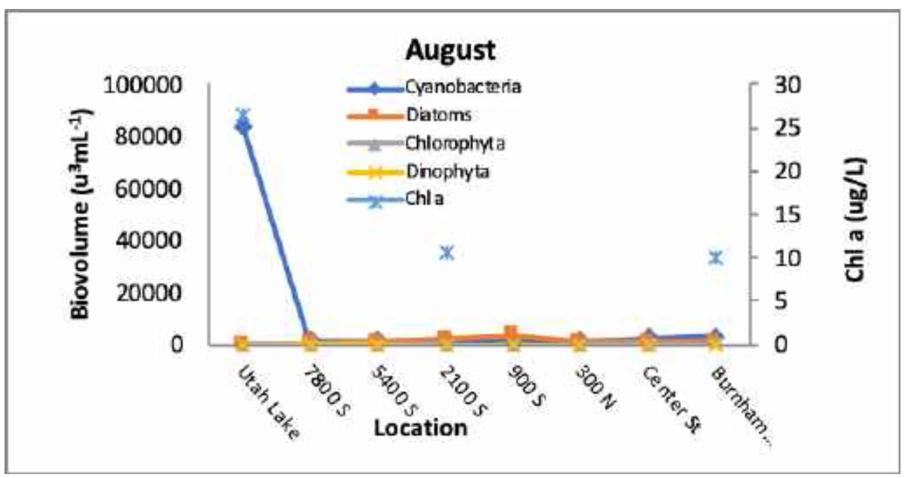
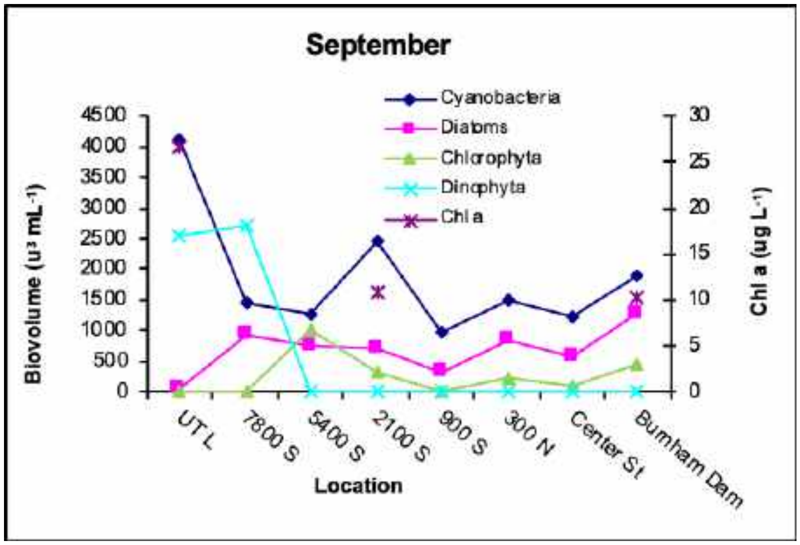


c.

Figure 21. A summary the biovolumes (times 1000) of major taxa groups in water column measured at select sites representing the upper, middle and lower reaches of the Jordan River. Note different units in the Y -axis scale between June and July as the Cyanophyte population in Utah Lake began to bloom. Yet, biovolumes of Cyanobacteria declined by nearly 2 orders of magnitude as it traveled down the river in July and August. Although diatoms increased from about 100,000 to 900,000 between Utah Lake and 2100 S in July, this biovolume was only about 0.6% of that of the Cyanobacteria. In addition, the increase in diatoms was largely composed of dislodged pennate diatoms. Note Chlorophyll a followed the same trend as the Cyanobacteria. Data were compiled from Rushforth and Rushforth (2009).



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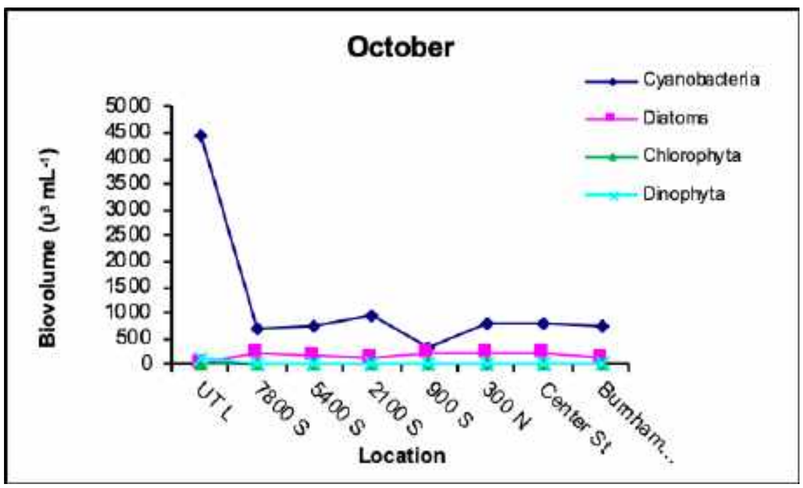

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Figure 2. Continued.

Periphyton Growth on Natural and Artificial Substrates

Periphyton biomass was measured on an approximate biweekly basis from June 6 to October 1, 2010. Samples were collected from slate tiles and natural cobble-size substrate, when it was present, at each sampling site. The tiles were installed during the week of June 7 and the sample collections at each location convened on June 29. This provided an initial incubation of 22 days prior to sampling. A Summary of Chl *a* concentrations for each site is presented in Figure 3. Initial observations indicated that periphyton colonization was just beginning to occur at all sample locations. The greatest Chl a density occurred on the ambient substrate at 9000 S, 7800 S (upstream from the South Valley Facility discharge) and 5400 S (downstream from the South Valley Facility discharge). Chl *a* concentrations on both the suspended and bottom tiles at each sample site were substantially lower than the ambient substrate, suggesting that even 22 days were not sufficient for the artificial substrates to reach equilibrium with adjacent natural substrates. At sites upstream from 2100 S, algal growth remained minimal (less that 50 mg/m^2)

until early to mid-August. This was unexpected, but is probably related to the exceptionally variable runoff that occurred during the spring and early summer (Figure 4). Flows periodically reached about 3 times that of normal flows, and at times fell below normal flows. These erratic flows would mobilize and scour substrates, followed by periods of deposition and then repeating - restricting periphytic growth until flows stabilized in the middle of July.

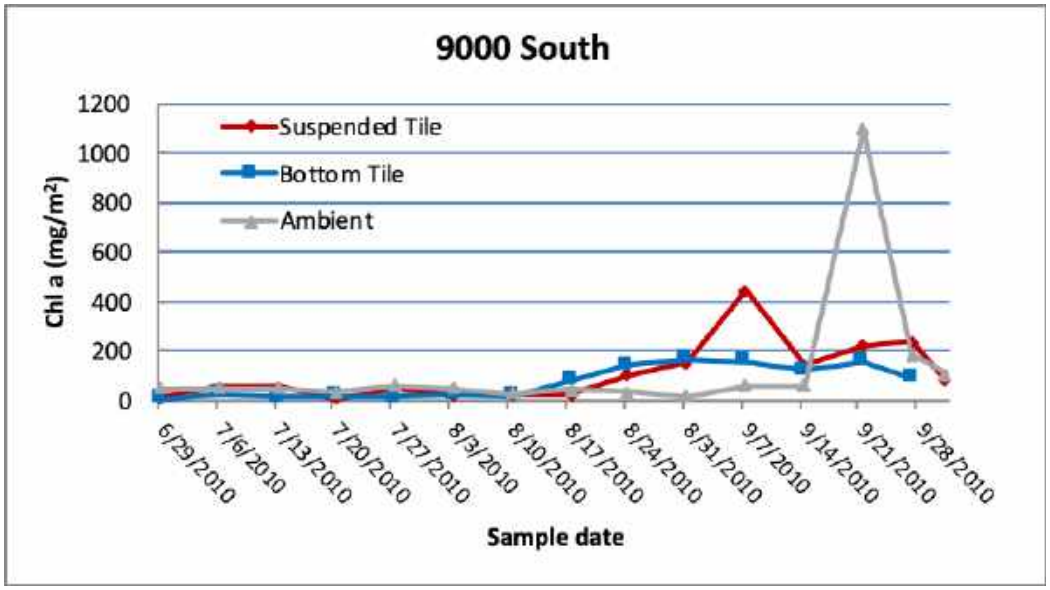
Despite the low Chl *a* values in the early samples, the suspended tiles contained slightly higher concentrations than the bottom tiles, supporting the hypothesis that the periphyton colonies established on the bottom tiles were more impacted from scouring or sedimentation. The only exception to this trend was the samples collected at Legacy Nature Preserve. The tile placed at this LNP site consistently showed greater Chl *a* concentrations than the suspended tile. Initially, this might appear to support the idea that suspended algae, from Utah Lake, or dislodged algae from upstream locations are finally settling out of the water column at this calm, depositional location. However, measurements of Chl a, biovolume and cell counts throughout the length of the Jordan River indicate that the algal cells remain suspended in the water column, even in this slow-moving segment of the river (Figure 2; Rushforth and Rushforth, 2009). Moreover, Chl *a* concentrations rapidly fell from ca. 60 to 90 ug L^{-1} at the Utah Lake outlet down to 10 -25 ug L^{-1} at the bottom of the Narrows and remain at this oligotrophic to mesotrophic range for the entire length of the River (Cirrus 2009).

Samples collected later did not show a relationship between suspended and bottom tiles. Only two of the sample locations (1700 S and LNP), demonstrated significant differences (two-tailed T-test; $p < 0.05$) between the suspended and bottom tiles placed at each site. Of these however, only the samples collected from the 1700 S site supported the hypothesis that suspended tiles would provide for greater growth of periphyton because of less bedload scouring or deposition and perhaps slightly greater light conditions.

Bedload movement and settling were key factors periphyton colonization and is directly in flow velocity. Figure 4 shows the variability in flows that occurred downstream from The Surplus Canal Diversion Dam and this diversion dam greatly stabilizes downstream flows in the channel. This stability in the channel is misleading in that the greater flows that reach the diversion dam are still transporting high bedloads. But the fact that the gate that controls releases to the channel releases flows at the bottom, while the diverted water releases flows over the top of the weir, directs the bedload to the channel, resulting to a nearly continual supply of unstable sand, silt and clay (Figure 5). Moreover, due to the mandate for flood control through the Rose Park community in Northern Salt Lake City, excess flows from spring runoff or summer storms, are nearly completely diverted to the Surplus Canal. Because the gate at the dam is manually operated, increased flow diversion may begin after elevated flows begin. As well, however, dewatering of the channel may occur in anticipation of flooding flows or because post-storm adjustment to widen the gate may be delayed. In turn, flow variability is likely the major cause of the very large variability in our periphyton samples.

The highly variable flow began to stabilize by about mid-July. Hence, the repeating pattern of settling, then resuspension of bedload material clearly diminished. This is the likely reason for such a late season peak in benthic algal biomass, for both artificial and natural substrates. The peak in algal biomass values occurring after the first part of August also indicates that the scouring or smothering are dominant stressors on the periphyton community when flows are normal to above-average. In other words, this peak in biomass occurred 4 to 6 weeks after summer solstice, when the photoperiod and sun angle had diminished substantially, but could still provide for growth in primary production. However, this peak was very short-lived. By mid-September, Chl *a* values had diminished substantially, reflecting the shorter photoperiod and lower sun angle during the fall season as flows remained relatively stable.

There were two notable exceptions to this trend: 1) At the 2100 site, periphyton growing on the ambient rock was always less than 100 mg Chl *a* m^{-2} (i.e. it never experienced the July peak as with most of the other sites) and was most often below 50 mg Chl *a* m^{-2}. These values were not only low compared to the tiles at this site but were low compared to the other sites as well. We attributed these low values to the moving/scouring bedload as well as extreme embeddedness of the cobble-sized substrate by sand and silt that filled the interstitial spaces. Indeed, during most visits the bottom tile was covered with sand that had been recently deposited at this site since the previous sampling visit (i.e. we carefully removed the sand or silt material from the tile after each sample event to allow potential periphyton colonization), showing how mobile and available this material is to either scour or deposit (Figure 5) and even when river flows are at average summer levels. In addition, the rebar stake and tile clamps frequently accumulated large amounts of debris, including branches and strands of macrophytes. This material could also have scoured the tiles (by sweeping back and forth in the current), or perhaps shaded the tiles – which also could have caused the widely variable results. However, the similar low biomass on the ambient cobbles suggests that scouring is the primary cause of low tile colonization, as well as on the ambient substrate. The second notable exception occurred at the Legacy Nature Preserve site, where the bottom tile nearly always had greater Chl *a* concentrations and often had 3-4 times more Chl *a* than the top tile. Further, although organic-rich sediment accumulated on both the top and bottom tiles (Figures 3 and 5), there was substantially more sediment (several cm) accumulated on the bottom tile. We initially considered the high Chl *a* values on the bottom tiles to be an artifact of the elevated deposition rates and possibly the settling of dead or dying algae (See Figure 5) (e.g. Baker (2010, reported similar high values for Chl *a*). However, Dr. Sam Rushforth (personal communication) suggested that there are motile species of a type of the golden diatoms, Division Chrysophyta that could be responsible for the high Chl *a* measurements. Members of this group are highly adapted to organic-rich sediments in that they have flagella, and hence are motile – even within the sediments. In addition, if they are covered or shaded, they can assume a heterotrophic existence where they can obtain organic carbon from particulate and dissolved organic matter, rather than photosynthesis when they can actually contribute to the sediment oxygen demand. Conversely, they can also migrate to the sediment surface where, because they have retained their Chl *a*, they can rapidly convert to an autotrophic existence and photosynthetically acquire their energy. This could explain how very high concentrations of Chl *a* occur in an area that is characterized as depositional but consists of high proportions of organic matter. This will receive additional attention in summer of 2019.



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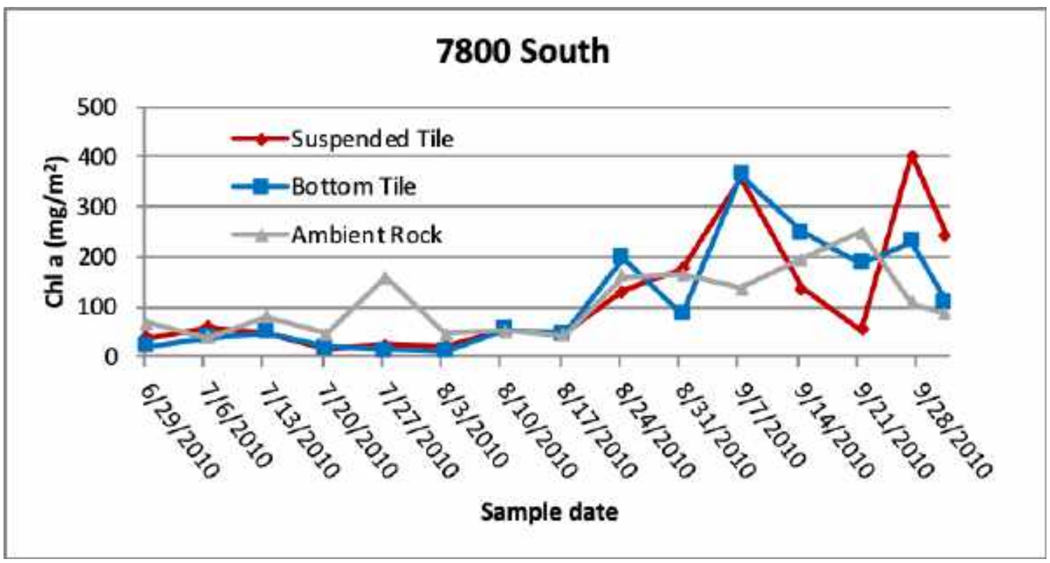

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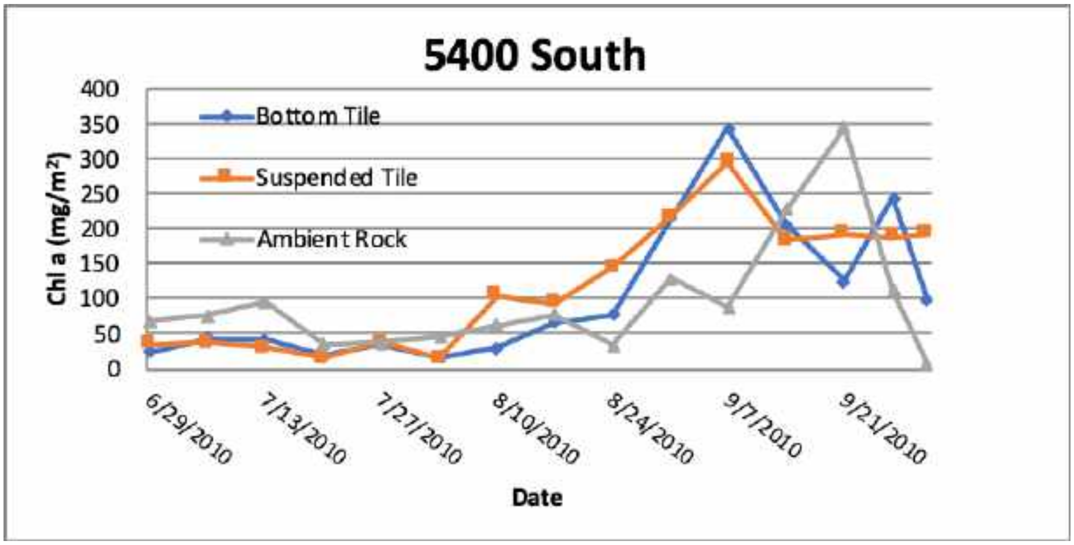
Figure 22. Benthic chlorophyll a measurements collected throughout the growing season from artifical (slate tile) substrates and from natural cobble stones located at various locations upstream and downstream from the Surplus Canal diversion at 2100 South; at 9000 S (a.), 7800 S (b.), 5400 S (c.), 2100 S (d.), 1700 S (e.), 300 N (d.) and in the Legacy Nature Preserve (e.). Tiles were deployed on approximately June 6. At each site, one tile was attached at the bottom to conform to the natural substrate surface so that it would experience the scouring (or burial) effects similar to that of the adjacent substrate. A second tile was suspended approximately 15 cm above the bottom to avoid these "bottom affects." Ambient samples were collected from adjacent natural cobble-sized rock. These rocks were difficult to find at 1700 and were nonexistant at further downstream sites. All samples were collected in triplicate and each triplicate sample was analysed in triplicate in the South Valley Water Reclamation Facility Laboratory.



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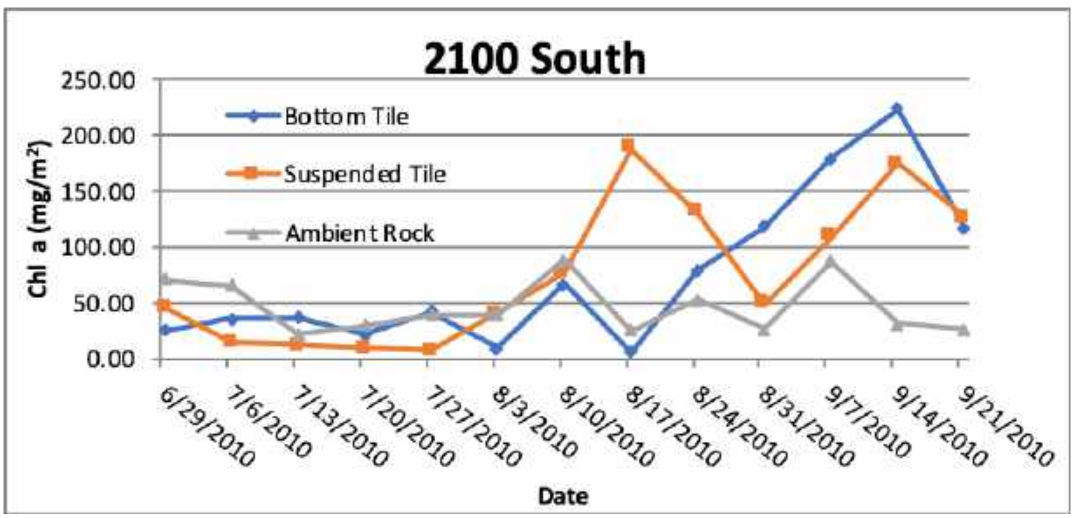

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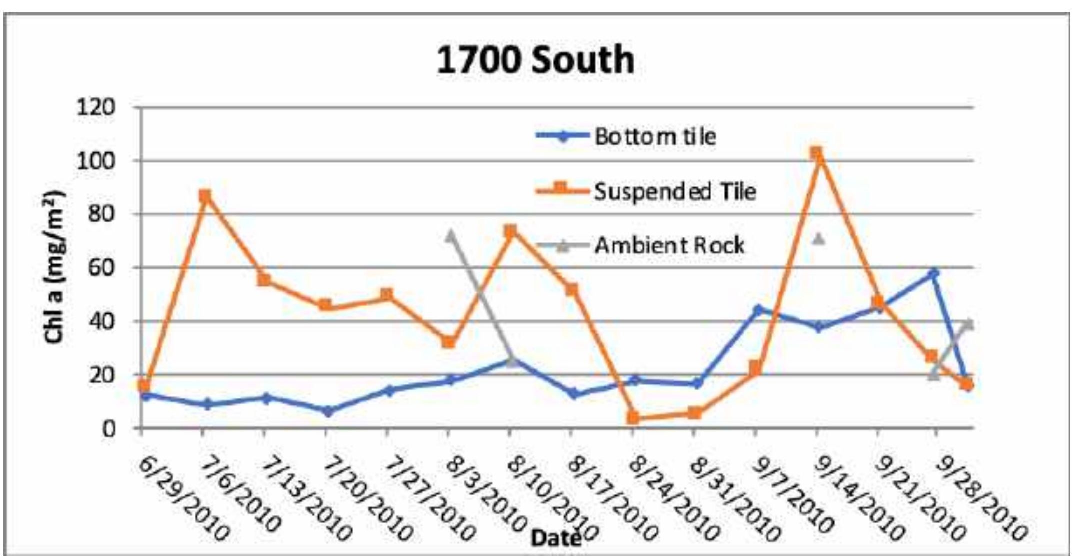

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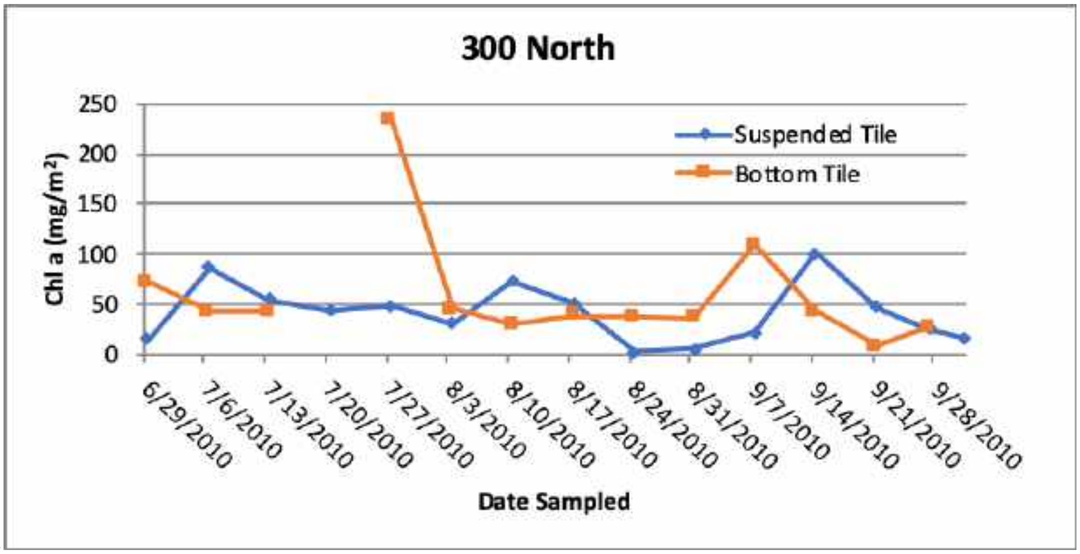
Figure 3. Continued.



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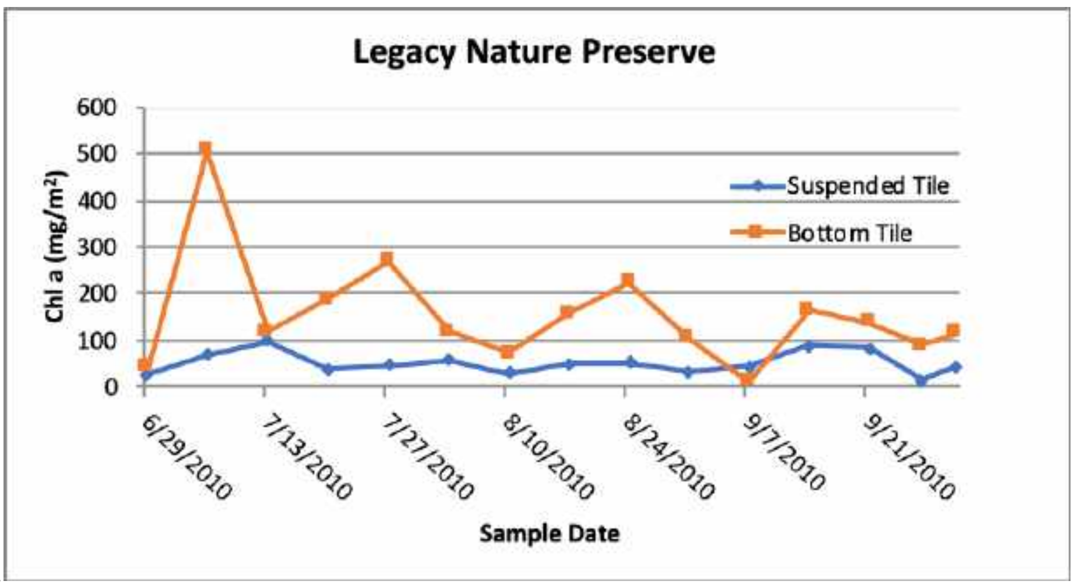

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Figure 3. Continued.

The middle photograph depicts the typical conditions at 2100 S during July. Sand would continually accumulate on the tiles, precluding the possibility of substantial periphyton growth. The bottom photograph illustrates the deposition of fine inorganic sediments mixed with fine organic material from the disintegration and partial decomposition of organic matter. The location of the triplicate samples can be identified in the top and bottom photographs.

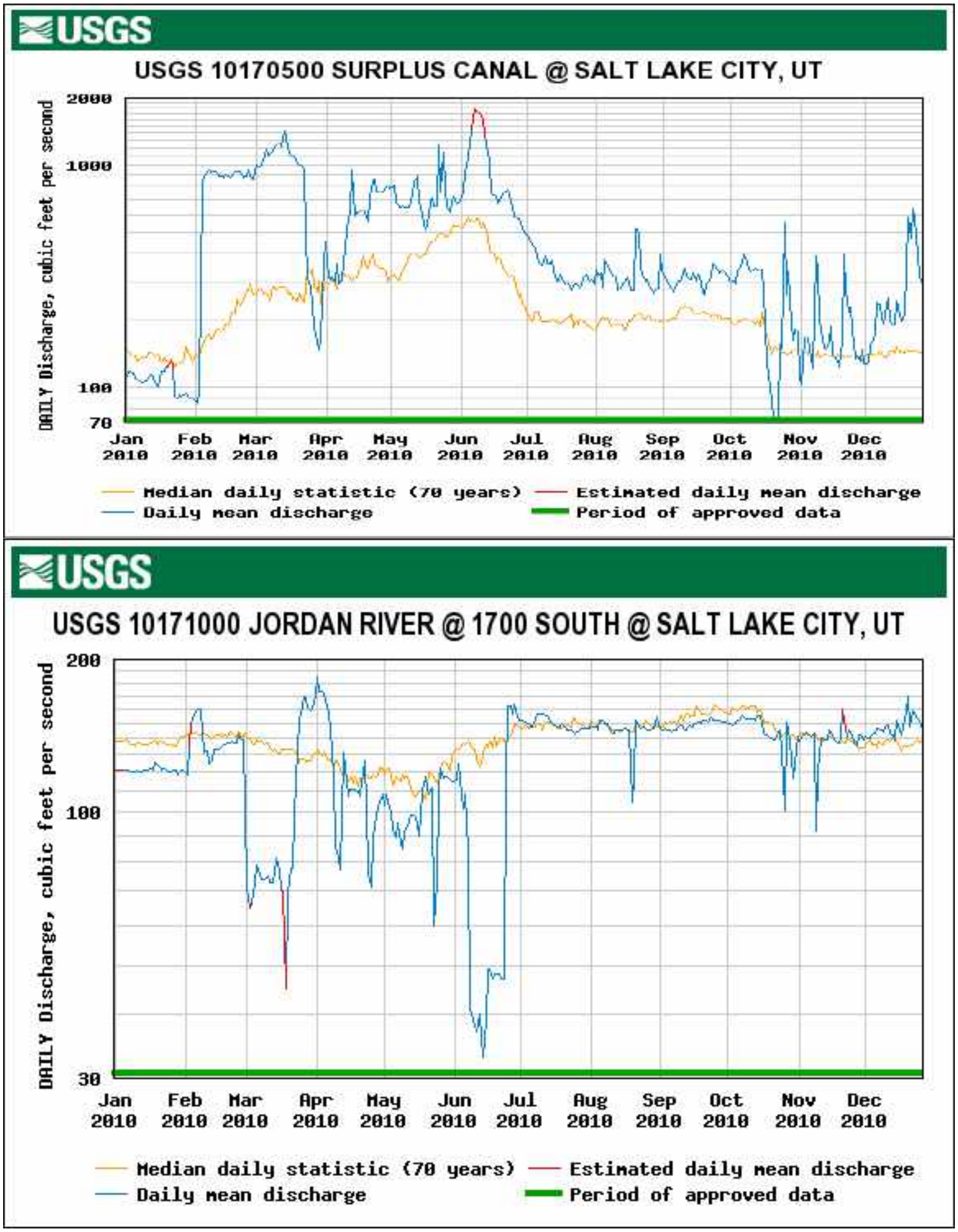


Figure 23. Flow measurements in the Surplus Canal and at 1700 S during 2010. Flows were unusually highly variable upstream and downstream from the diversion.

Figure 24. Representative photographs of periphytic algal growth and types of sediment deposition that occur in the Jordan River. Top: Tile retrieved from the river at 5400 South. Middle: Tile retrieved from the river immediately downstream from the 2100 S diversion. Bottom: Tile retrieved from the river in the Legacy Nature Preserve. Note triplicate samples have been collected in the top and bottom photos.

As an interesting comparison, Utah DWQ has conducted a public survey using photographs of benthic algal growth, as a potential assessment tool, to determine if there is an aesthetic threshold based on the appearance of the growth or density of benthic algae (DWQ 2012). This survey was fashioned after the Montana DEQ public survey of fishermen and other recreationists (Suplee et al. 2009). Montana DEQ has actually adapted this survey technique into an assessment tool. Both the Montana and Utah surveys identified the threshold chlorophyll a concentration to be at 150 mg Chlorophyll a m^{-2} (the percent of respondents identifying favorable conditions fell from about 78% desirable to about 35% desirable between 150 and 200 mg chlorophyll a m^{-2} (see Figures 6, 7 and 8). The Chl *a* samples collected from the deposits on the bottom tile at Legacy Nature Preserve often exceeded that collected from the substrate depicted in Figures 7 (150 mg m^{-2}) and 8 (240 mg m^{-2}). Yet, there were no visible algae on the Legacy NP sample. These illustrations clearly demonstrate the variety of benthic algae and the different conditions where they may flourish. Obviously, an assessment tool based on a visual assessment of green algae would not be appropriate where organic-rich sediments occur in depositional zones. Future studies on the biological and oxygen dynamics in this depositional reach will continue and will include verification of the presence and activity of these unique diatoms.

Overall, these data and photographs, demonstrate the inability of the Jordan River, both upstream and downstream from 2100 S to support extensive communities of periphyton. Most samples from the tiles and natural substrate contain much less Chl *a* than the Montana photographs that depict even hyper-eutrophic conditions. These data support the suggestion that the Jordan River, particularly downstream from 2100 S is severely habitat limited as a result of erratic flows, dewatering, and accumulation of inorganic and organic sediments.

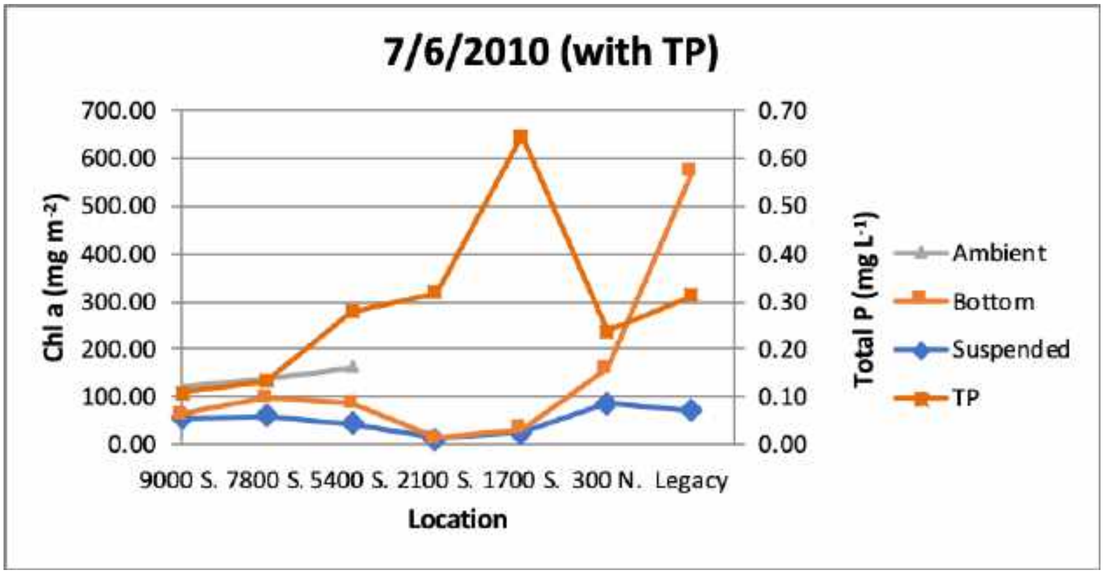
Figure 25. Photograph used by Montana DEQ and Utah DWQ to depict 150 mg chlorophyll *a* m^{-2} of benthic algae in the public survey of recreational users of rivers and streams.

Figure 26. Photograph used by Montana DEQ and Utah DWQ to depict 200 mg Chlorophyll *a* m^{-2} of benthic algae in the public survey of recreational users of rivers and streams.

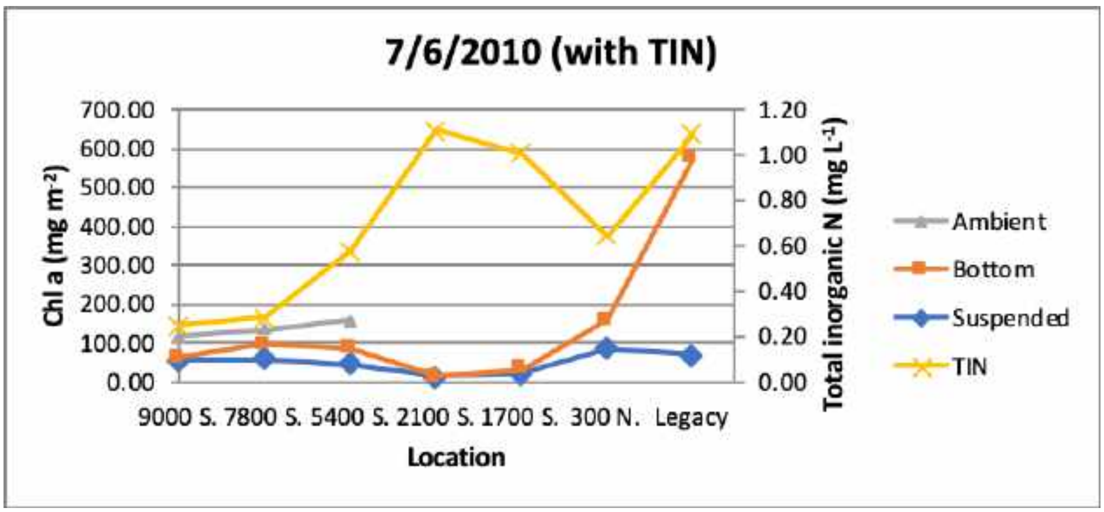
Figure 27. Photograph used by Montana DEQ and Utah DWQ to depict 240 mg chlorophyll *a* m^{-2} of benthic algae in the public survey of recreational users of rivers and streams.

The second question we asked was: Do the nutrient inputs from the South Valley Water Reclamation or the Central Valley Water Reclamation Facilities alter (enhance) the algal biomass downstream from their respective discharge points. The South Valley facility discharges at about 7600 South, downstream from the 7800 South sampling station and about three miles upstream from the 5400 South sampling station. The Central Valley facility discharges to Mill Creek approximately 600 m upstream from the Mill Creek confluence with Jordan River. Other than during spring runoff, the Central Valley discharge, which averages about 80 CFS, comprises the majority of flow in lower Mill Creek. Mill Creek enters the Jordan River approximately 4500 m (3 miles) downstream from the 5400 South sampling station and about 1200 m upstream from the 2100 South sampling site. Mill Creek comprises between 1/5 and 1/3 of the Jordan River, depending on season and upstream flow.

I arranged the data to illustrate the upstream/downstream differences during each sampling event to determine whether there were any changes in algal biomass downstream from these two discharges. The mean summer total inorganic nitrogen (TIN) and total phosphorus (TP) are also plotted for comparison to benthic algal biomass (Figures 9, 10, 11, 12, 13, 14 and 15). Mean summer nutrient values are plotted for purposes of simplification and the fact that there was little variability in nutrient concentrations across the summer months (i.e. The standard deviation of the summer (May to September) total P concentrations was consistently about 1/10 of the mean values at all sampling stations; The standard deviation of the nitrate and ammonia concentrations were consistently about ¼ to 1/3 of the mean summer values at all stations). Regression analysis was performed between TIN or TP and each sample type (suspended tile, bottom tile and ambient substrate) for each date. There were no significant relationships between nutrient concentrations and any of the sample types for any of the dates sampled ($p>0.1$). Rather, field observations (e.g. Figures 4 and 5) and Chl a values indicated that there were frequent episodes of scouring or smothering by sand or organic silts and clays that inhibited periphyton colonization and chlorophyll a concentrations. Overall, the samples collected at 9000 and 7800 exhibited the most consistently high values for Chl a. These sites were located above the South Valley POTW. This occurred despite the fact that downstream sites have much higher nutrient concentrations. Undoubtedly, the repetitive scouring and deposition played a significant role in impeding periphyton growth in the river.



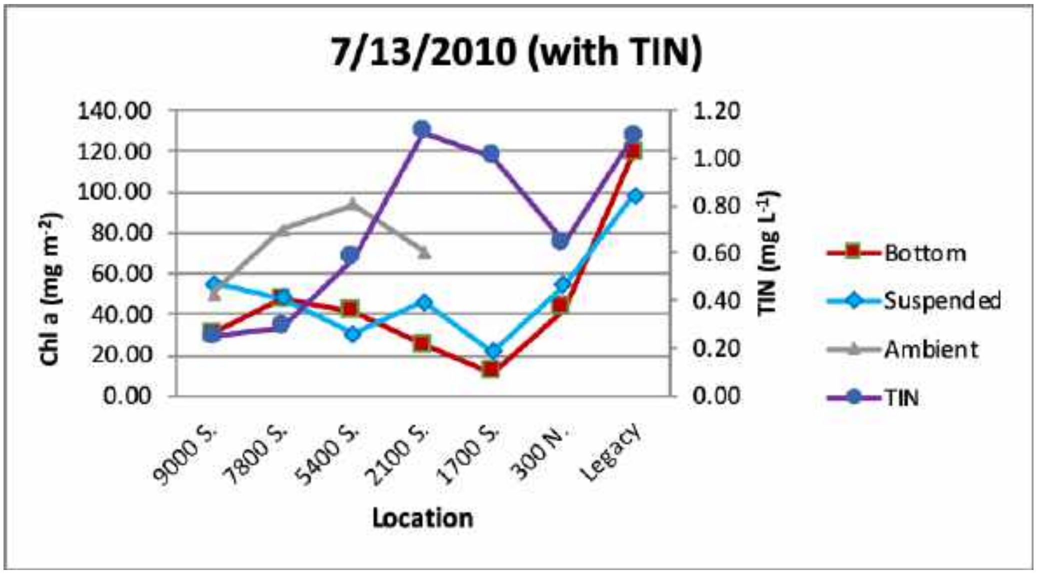
a.



b.

Figure 28. Benthic Chl *a* measured on July 6, 2010 and mean summer (monthly, May to September), values for total phosphorus (TP; a.) and total inorganic nitrogen (TIN; b.) at selected locations along the Jordan River. Ambient natural substrate could not be found at or below 2100 S on this date.

a.



b.

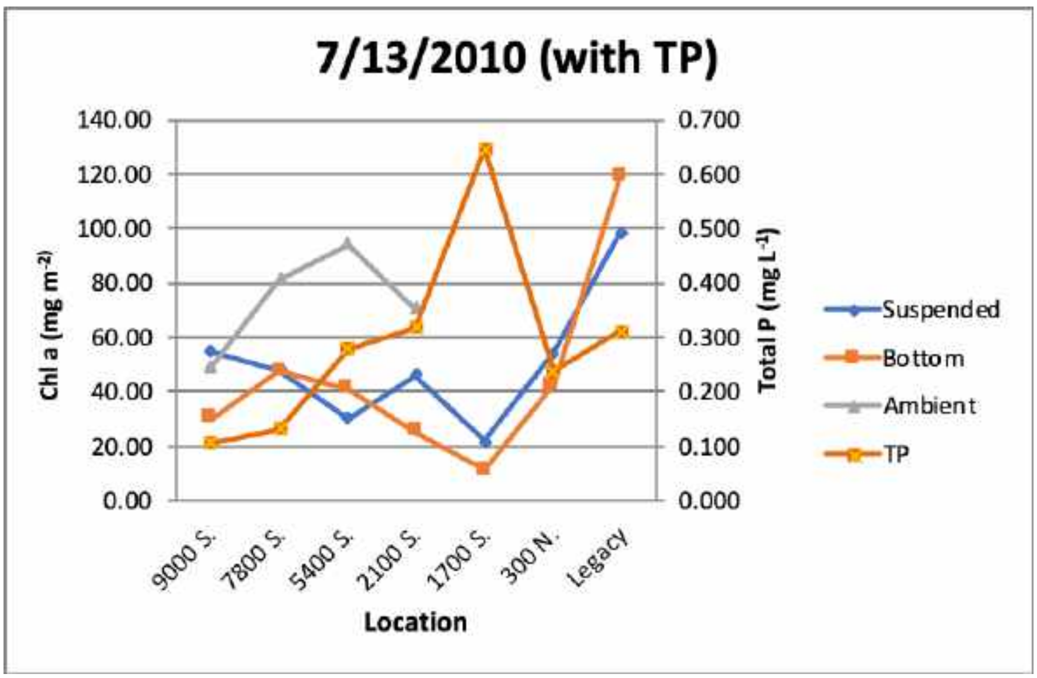
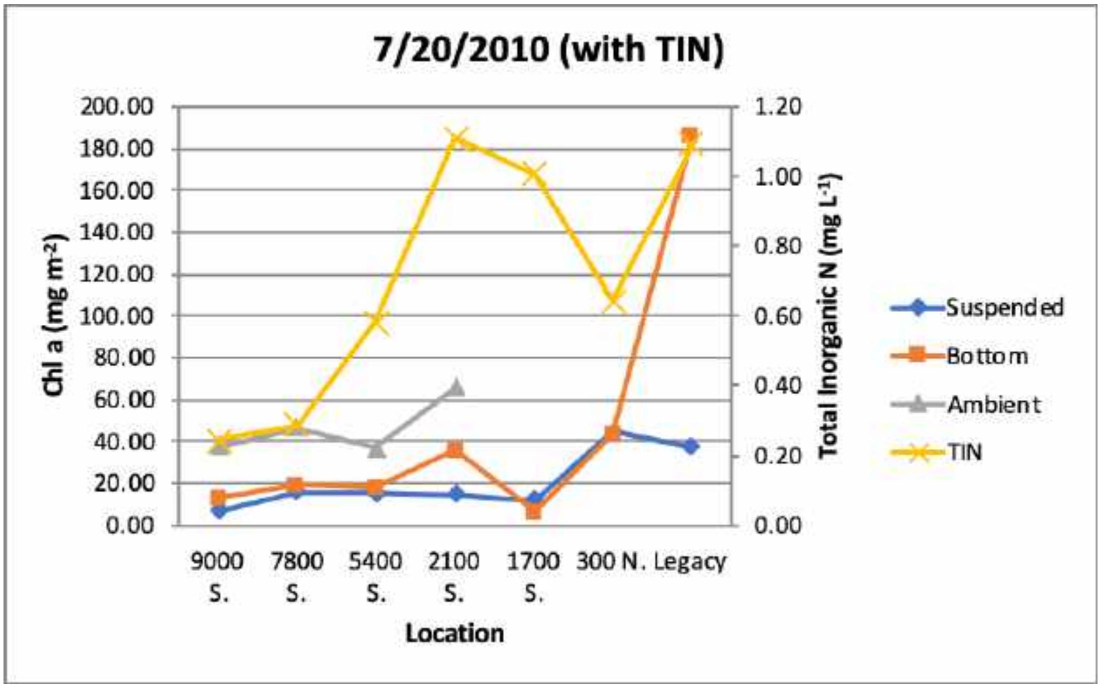
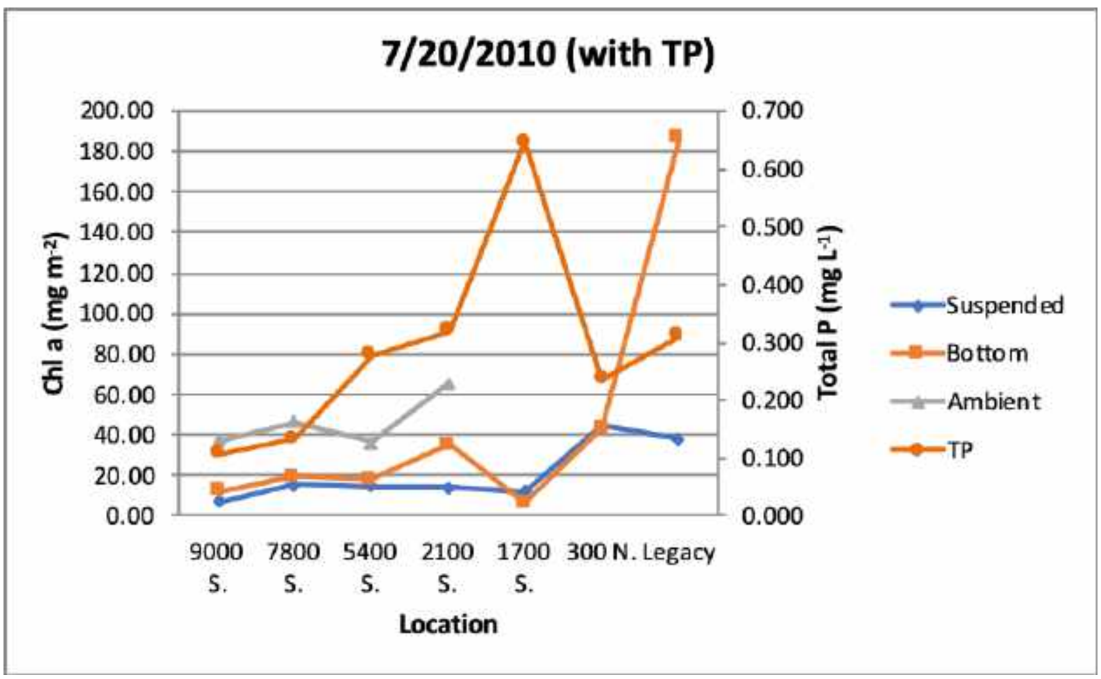


Figure 29. Benthic chlorophyll a measured on July 13, 2010 and mean summer (monthly, May to September), values for total inorganic nitrogen (TN) and total phosphorus (TP; b.), at selected locations along the Jordan River. Ambient natural substrate could not be found at sampling sites below 2100 S.

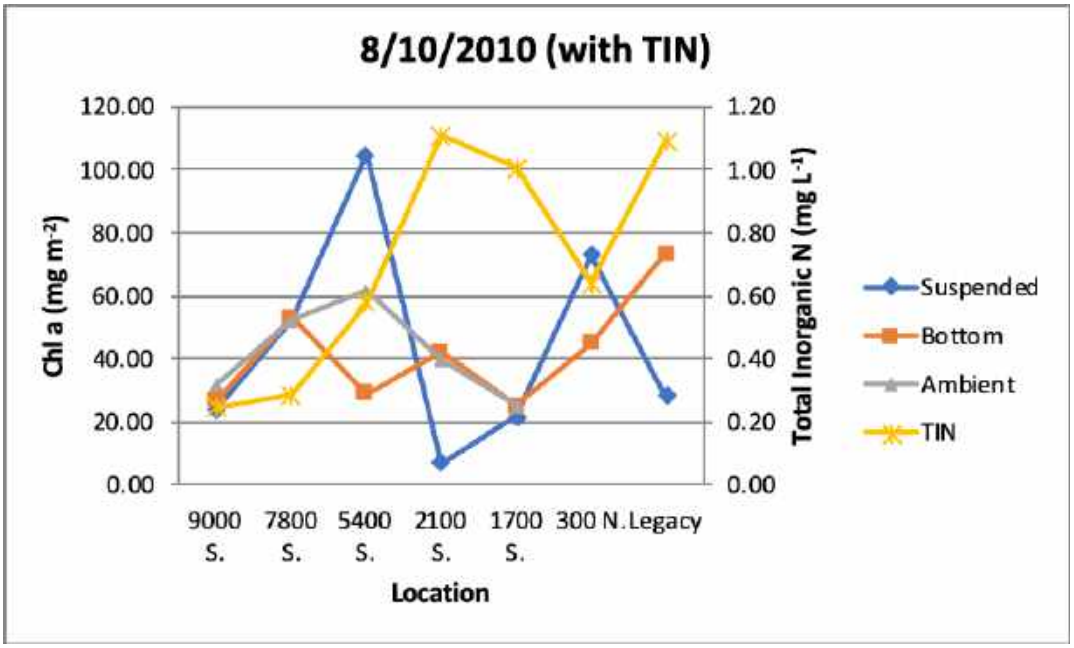


a.

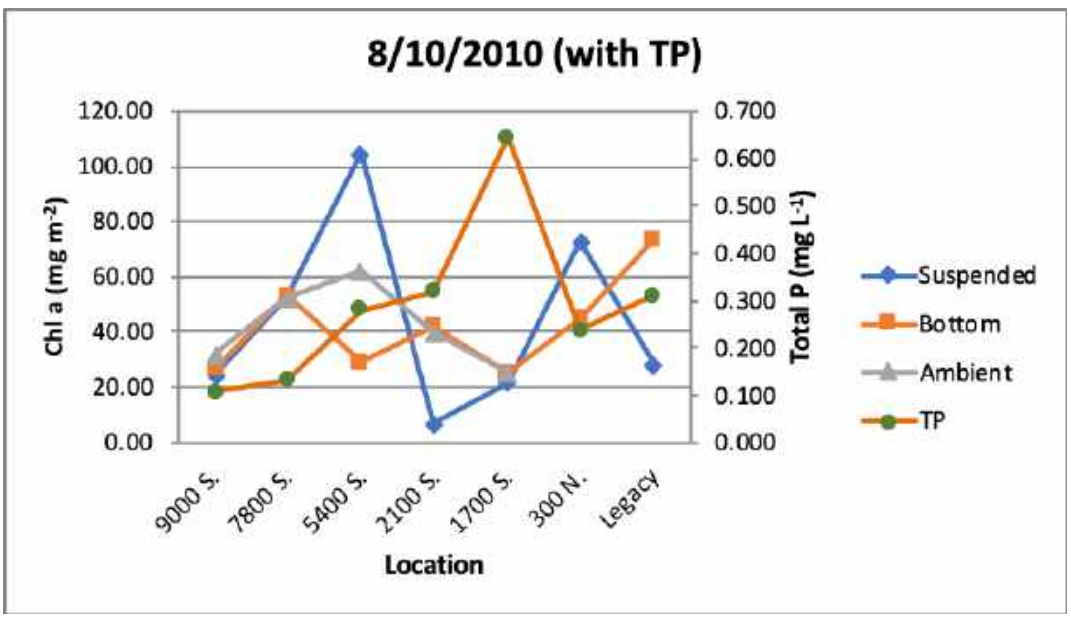


b.

Figure 30. Benthic chlorophyll a measured on July 20, 2010 and mean summer (monthly, May to September), values for total inorganic nitrogen (TN a.) and total phosphorus (TP; b.), at selected locations along the Jordan River. Ambient natural substrate could not be found at sampling sites below 2100 S.

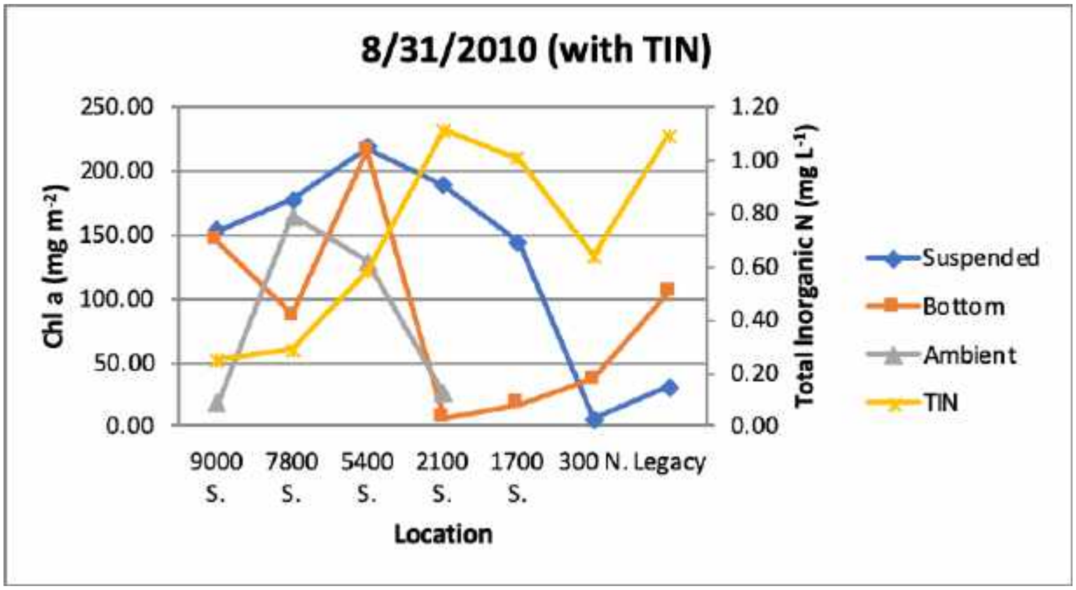


a.

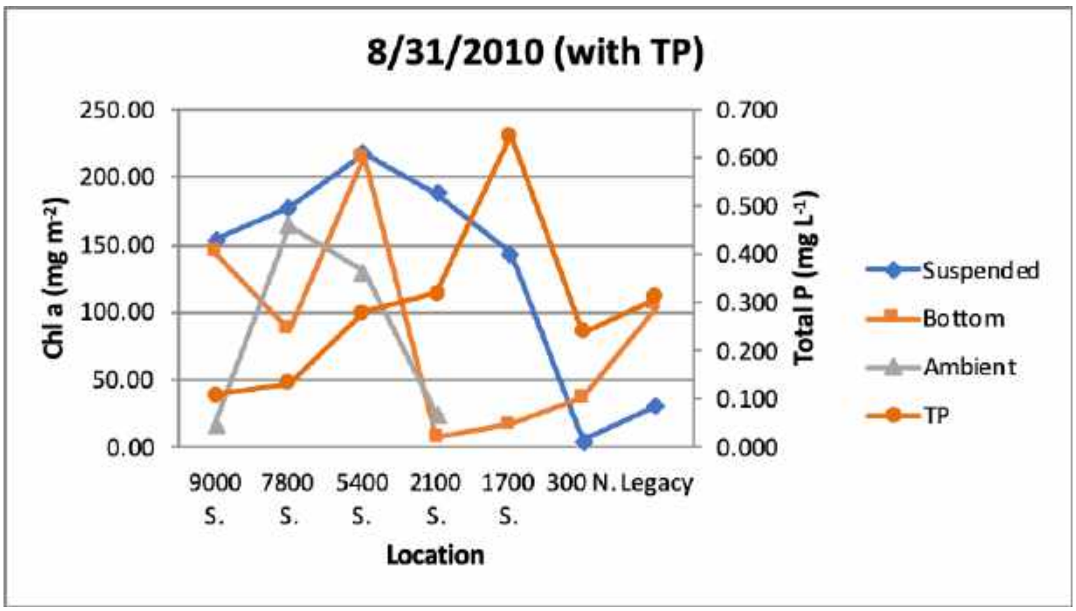


b.

Figure 31. Benthic chlorophyll a measured July 20, 2010 and mean summer (monthly, May to September), values for total inorganic nitrogen (TN; a.) and total phosphorus (TP; b.), at selected locations along the Jordan River. Ambient natural substrate was found as far downstream as 1700 S on this date, although little colonization by periphyton had occurred.

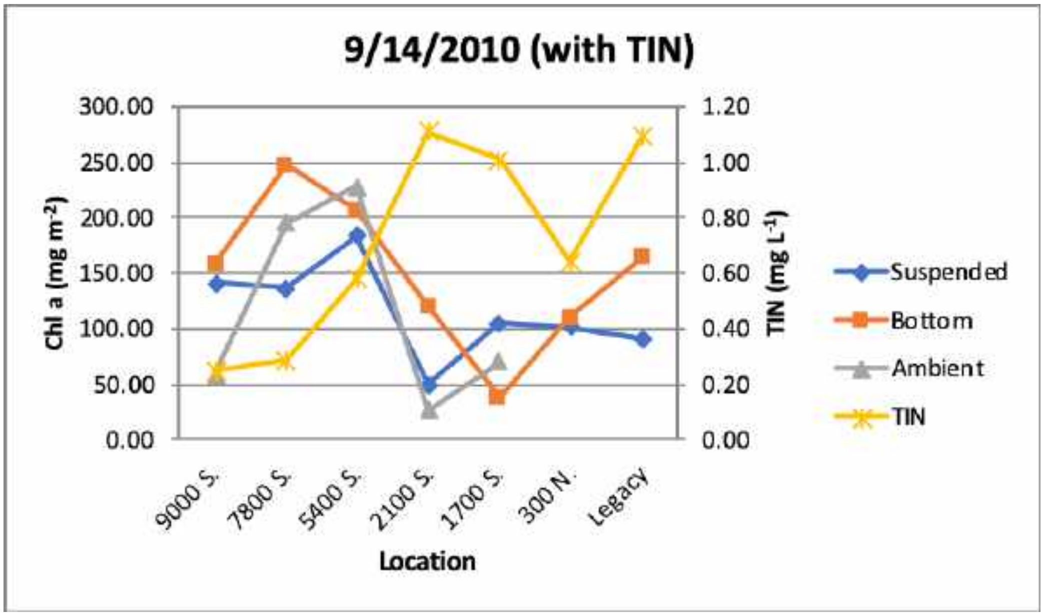


a.

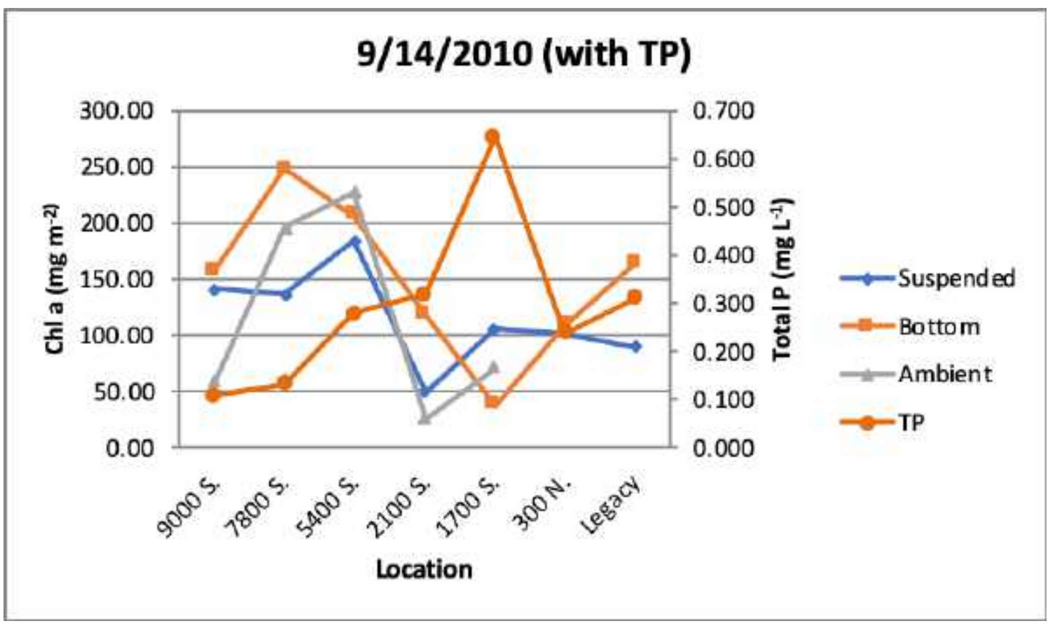


b.

Figure 32. Benthic Chl *a* measured on July 20, 2010 and mean summer (monthly, May to September), values for total inorganic nitrogen (TN; a.) and total phosphorus (TP; b.), at selected locations along the Jordan River. Ambient natural substrate could not be found at sampling sites below 2100 S at this time and chlorophyll a values at 2100 S were relatively very low – suggesting that considerable scouring was still occurring. The suspended tile at 2100 S and 1700 S accumulated about as much Chlorophyll a as upstream sites at this time, suggesting that bedload sand and silt was still scouring the bottom tile and the ambient substrate.

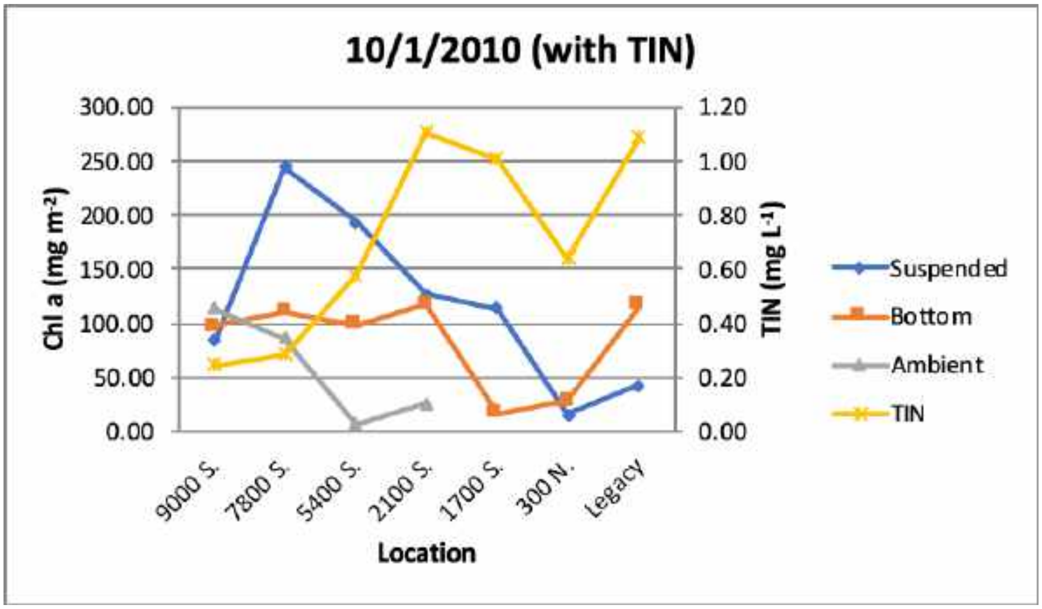


a.

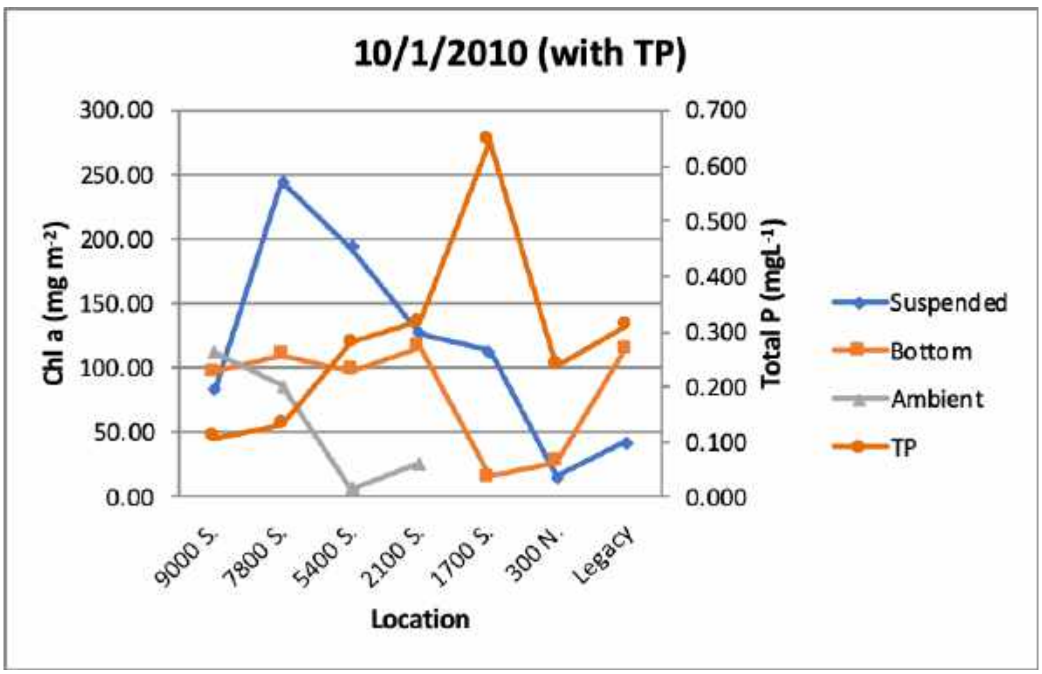


b.

Figure 33. Benthic chlorophyll a measured on September 14, 2010 and mean summer (monthly, May to September), values for total inorganic nitrogen (TN; a.) and total phosphorus (TP; b.), at selected locations along the Jordan River. Ambient natural substrate could be found as far downstream as 1700 S at this time although chlorophyll a values at 2100 S and 1700 were relatively low compared to upstream samples – suggesting that considerable scouring was still occurring. Similarly, the accumulation on the suspended tile at 2100 S and 1700 S declined considerably from the previous sample on 8/31 (Figure 12), perhaps due to a scouring event or to declining intensity and length of the photoperiod during this fall sample.



a.



b.

Figure 34. Benthic Chl *a* measured on September 14, 2010 and mean summer (monthly, May to September), values for total inorganic nitrogen (TN; a.) and total phosphorus (TP; b.), at selected locations along the Jordan River. Ambient natural substrate could be found as far downstream as 21 S at this time although chlorophyll a values at 2100 S and 5400 S were relatively low compared to upstream samples and samples from the previous month. The suspended tile at 7800 S was the only sample that was comparable to previous months. This again suggests that considerable scouring was still occurring, although further declining photoperiod and sun angle could also play a role.

Additional Water Quality Monitoring

As mentioned above, there was little temporal change in phosphorus or nitrogen during the 2010 Tile experiments. Yet, we have continued to monitor the various nutrient concentrations as well as the parameters that are related to the low DO impairment other parameters throughout the last 10 years in order to elucidate any long-term trends that might be occurring. In summary, of this information, I chose to report summary data from 2010, 2011, 2013, 2015, 2016 and 2018. These years represent flows during normal years, drought years and above-normal years. For example, 2010 flow was very near the multi-year average (Figure 16). Year 2011 was a notable very wet year, 2013 was very dry and 2015, 2016 and 2018 also had below average flows but were nearer to the long-term average. It was important to determine if these variable flows had any influence on constituent concentrations, such as increased dilution (reduction in concentrations) or in concentrating constituents during drought years. Notably, there was no reduction in TSS or VSS with the elevated flows recorded in 2011. Rather TSS was elevated at all sites, and even with the slight dilution from Little Cottonwood and Big Cottonwood Creeks TSS concentrations increased to new highs at downstream locations.

Notably, VSS remains very low and stable at about 5 mg L^{-1}. Furthermore, during 2015 and 2016, The VSS in Mill Creek was actually much lower than that in Jordan River, indicating that the Central Valley WRF often dilutes and improves the quality of Jordan River with respect to VSS and TSS. This is important in that the Phase I TMDL identified VSS as the primary pollutant of concern with the recommendation that reductions in VSS could be used to control the DO deficit. As such, the TMDL identified the POTWs as necessary to reduce VSS by several fold in order to reduce the DO deficit. Furthermore, the fact that VSS concentrations in every year are either maintained or actually increase (e.g. 2011) at lower Jordan River sites indicates that there is no net loss or significant settling of VSS to contribute to the sediment oxygen demand, as was also assumed in the Phase I report. Therefore, this data suggests that any reduction in VSS in the adjacent POTWs, at a potential cost of many 10s of millions of dollars would likely have no positive impact on VSS or DO. Additional evidence for this misunderstanding is provided in subsequent sections and chapters that discuss organic matter budgets and coarse particulate matter.

The inorganic nitrogen species and TKN are shown in Figure 17. With the exception of nitrate values, there was no difference in the nitrogen species between the normal or elevated flows of 2010 and 2011 compared to the subsequent low-flow drought years. Nitrate values were generally about 50% less during 2010 and 2011 than during other years. In all years following 2011 (drought years), nitrate was consistently between 4 and 5 mg L^{-1}. With the exception of the State Canal, ammonia remained consistently less than 1 mg L^{-1}. Ammonia in Mill Creek ranged up to about 1 mg L^{-1} and the site in the State Canal, below the SDSD N ranged up to about 2 mg L^{-1}. Notably the discharge from the S. Davis North Plant is only 900 m above the final diversion and distribution of State Canal water to impoundments of the FBWMA. This is worth mentioning as the healthy community of benthic nitrifiers and denitrifiers in the impoundments rapidly drop the ammonia to less that 1 mg L^{-1} and nitrate to non-detectable in most samples – rendering the impoundments nitrogen limited. This will be discussed further in the wetlands chapter that will be reported in Volume III of this update.

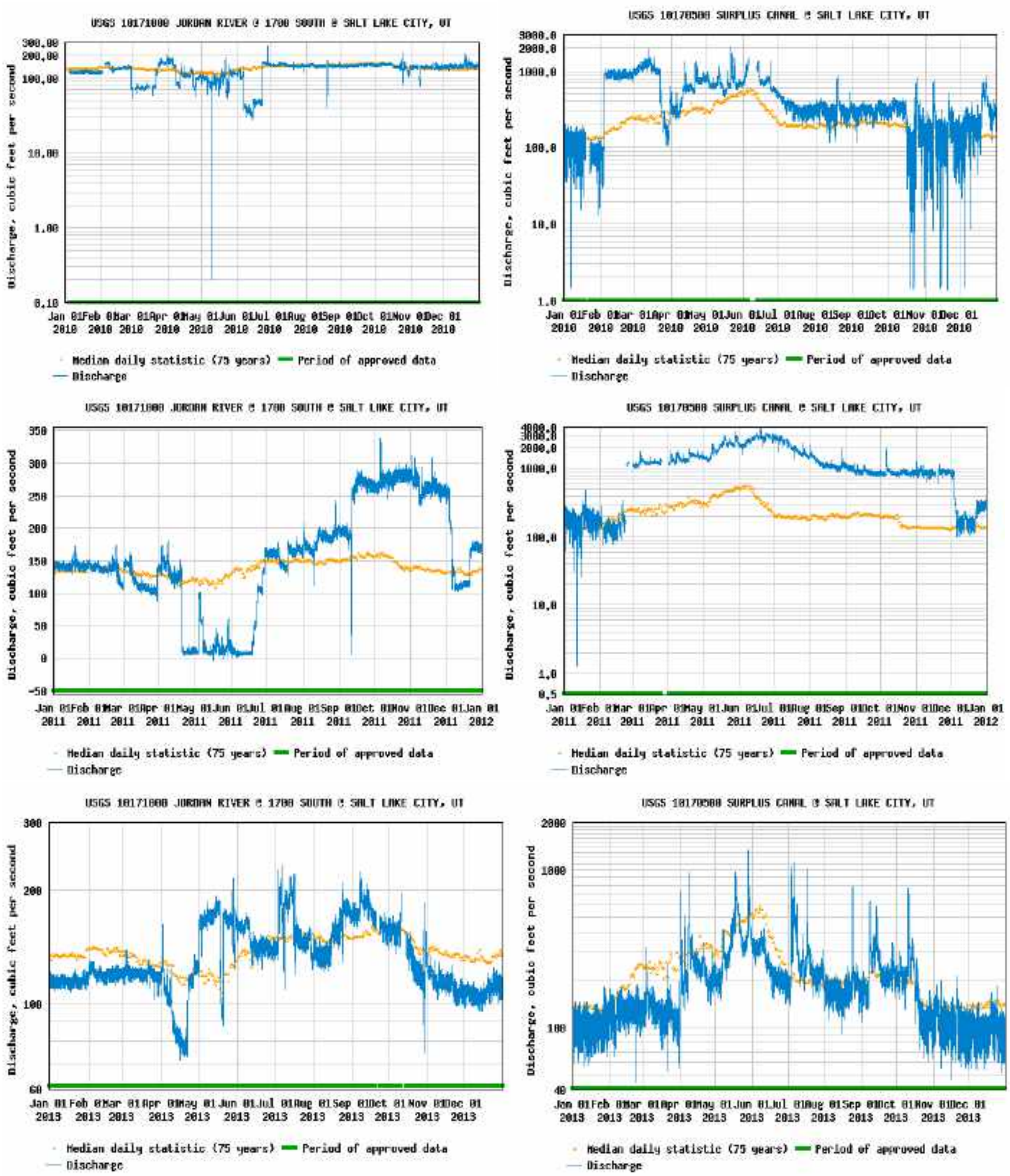
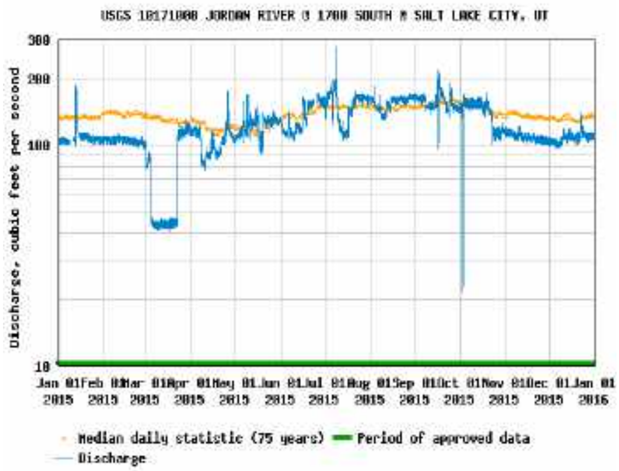
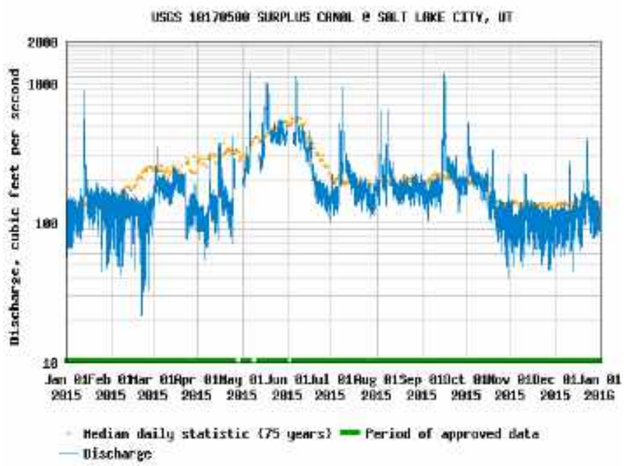


Figure 35. Monthly (Blue) and long-term average flows (Gold) for the Jordan River at 1700 S. (left) and the Surplus Canal (right) for 2010, 2011, 2013, 2015, 2016 and 2018.


USGS 10171000 JORDAN RIVER @ 1700 SOUTH @ SALT LAKE CITY, UT
Discharge, cubic feet per second
300
200
100
10
Jan 01 2015
Feb 01 2015
Mar 01 2015
Apr 01 2015
May 01 2015
Jun 01 2015
Jul 01 2015
Aug 01 2015
Sep 01 2015
Oct 01 2015
Nov 01 2015
Dec 01 2015
Jan 01 2016
Median daily statistic (75 years)
Period of approved data
Discharge


USGS 10170500 SURPLUS CANAL @ SALT LAKE CITY, UT
Discharge, cubic feet per second
2000
1000
100
10
Jan 01 2015
Feb 01 2015
Mar 01 2015
Apr 01 2015
May 01 2015
Jun 01 2015
Jul 01 2015
Aug 01 2015
Sep 01 2015
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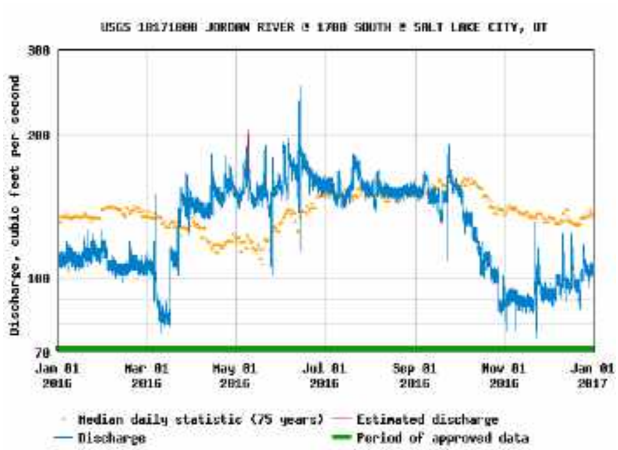
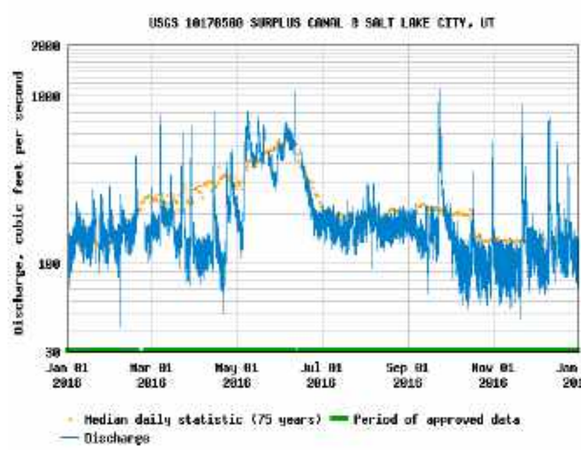
Jan 01 2016
Median daily statistic (75 years)
Period of approved data
Discharge


USGS 10171000 JORDAN RIVER @ 1700 SOUTH @ SALT LAKE CITY, UT
Discharge, cubic feet per second
300
200
100
70
Jan 01 2016
Mar 01 2016
May 01 2016
Jul 01 2016
Sep 01 2016
Nov 01 2016
Jan 01 2017
Median daily statistic (75 years)
Estimated discharge
Discharge
Period of approved data


USGS 10170500 SURPLUS CANAL @ SALT LAKE CITY, UT
Discharge, cubic feet per second
2000
1000
100
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Jan 01 2016
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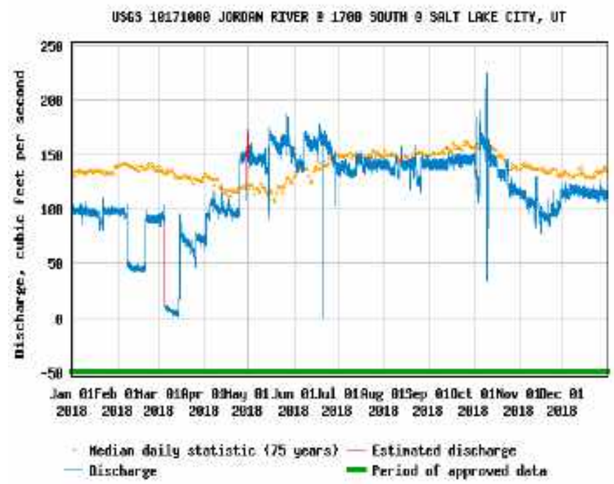
May 01 2016
Jul 01 2016
Sep 01 2016
Nov 01 2016
Jan 01 2017
Median daily statistic (75 years)
Period of approved data
Discharge



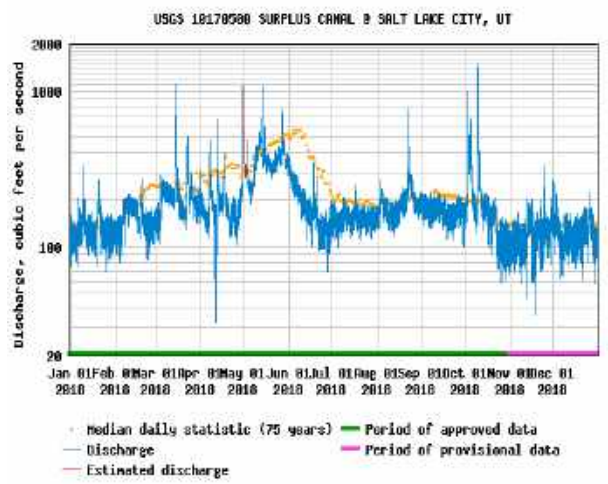


Figure 16, Continued

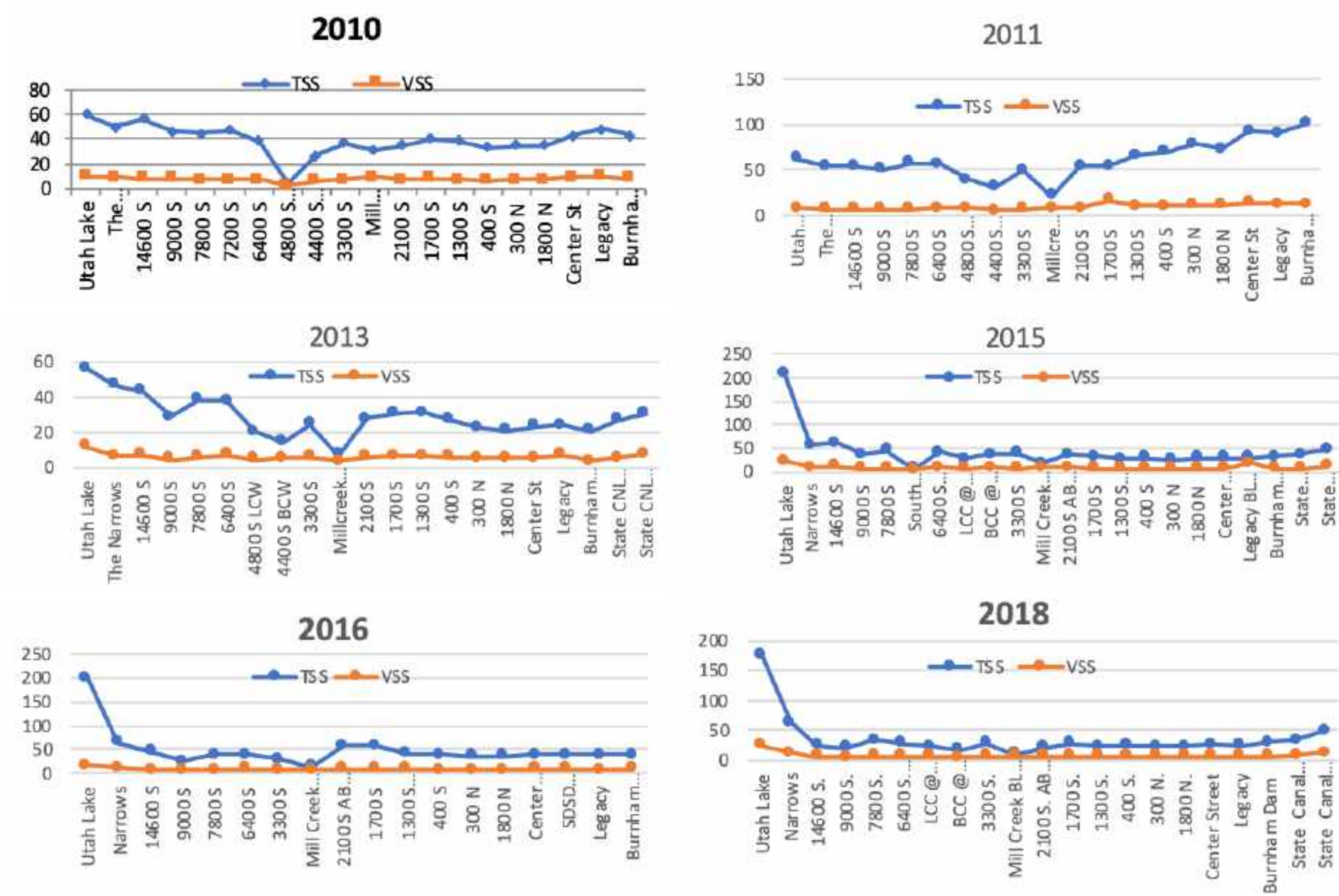


Figure 36. Annual average total suspended solids (TSS) and volatile suspended solids (VSS) at the mainstem sampling sites and at the mouth of Big and Little Cottonwood Creeks during 2010, 2011, 2013, 2015, 2016 and 2018. All values are in mg L^{-1}. Note: scales differ.

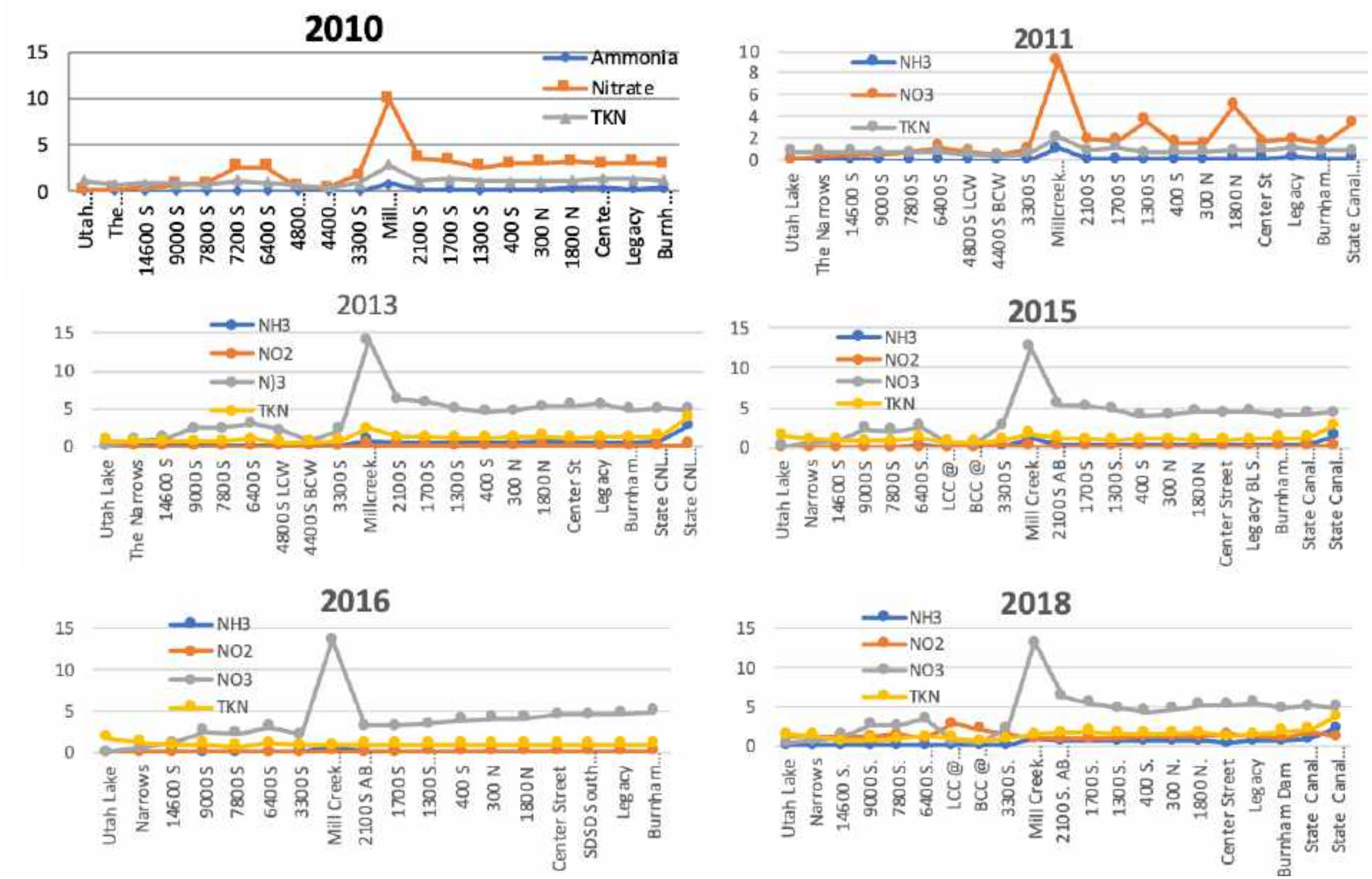


Figure 37. Annual average ammonia, nitrite, nitrate and TKN at the mainstem sampling sites and at the mouth of Big and Little Cottonwood Creeks during 2010, 2011, 2013, 2015, 2016 and 2018. All values are in mg L^{-1}. Note: scales differ.

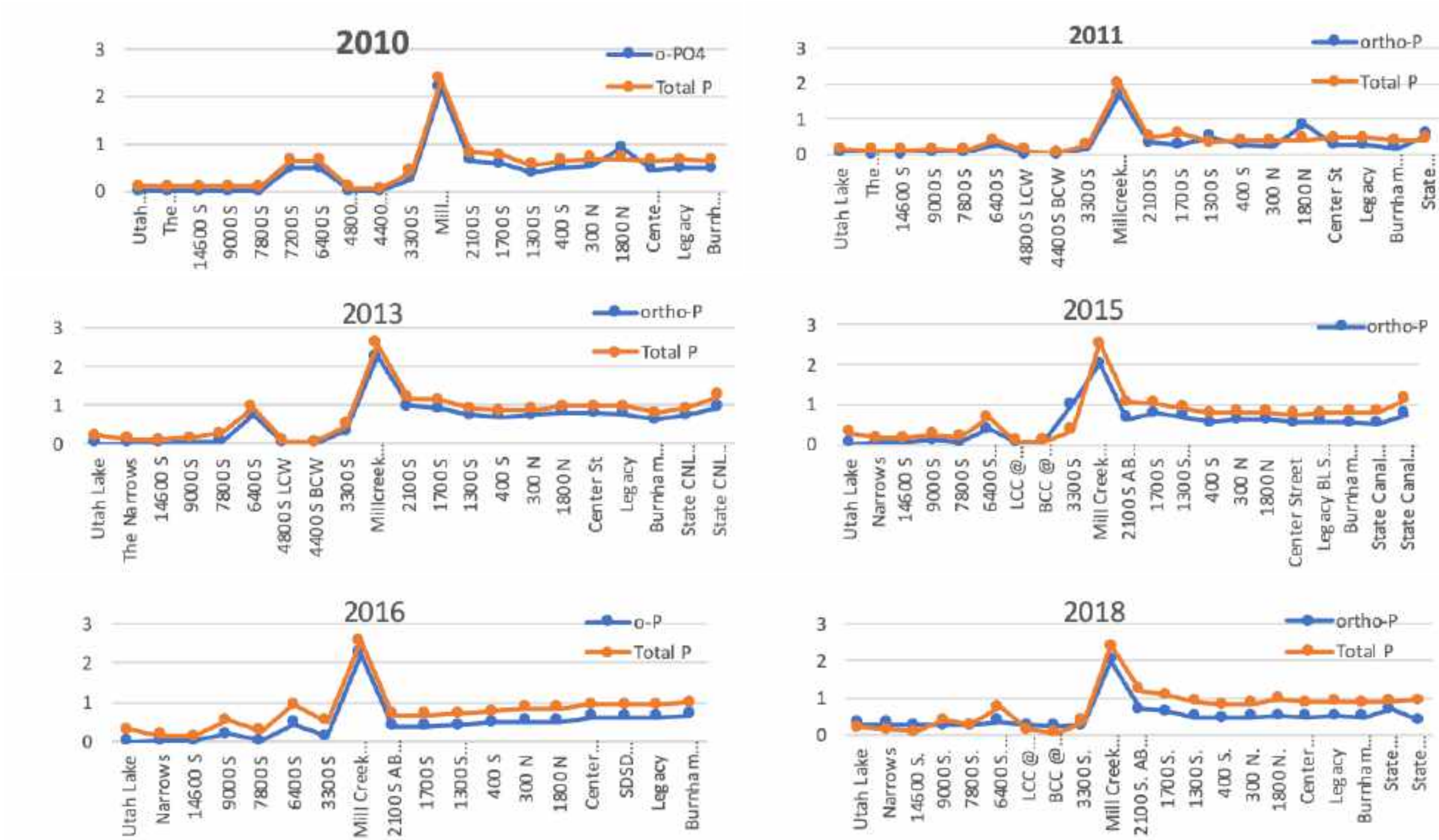


Figure 38. Annual average total and ortho-phosphate at the mainstem sampling sites and at the mouth of Big and Little Cottonwood Creeks during 2010, 2011, 2013, 2015, 2016 and 2018. All values are in mg L^{-1}. Note: scales differ.

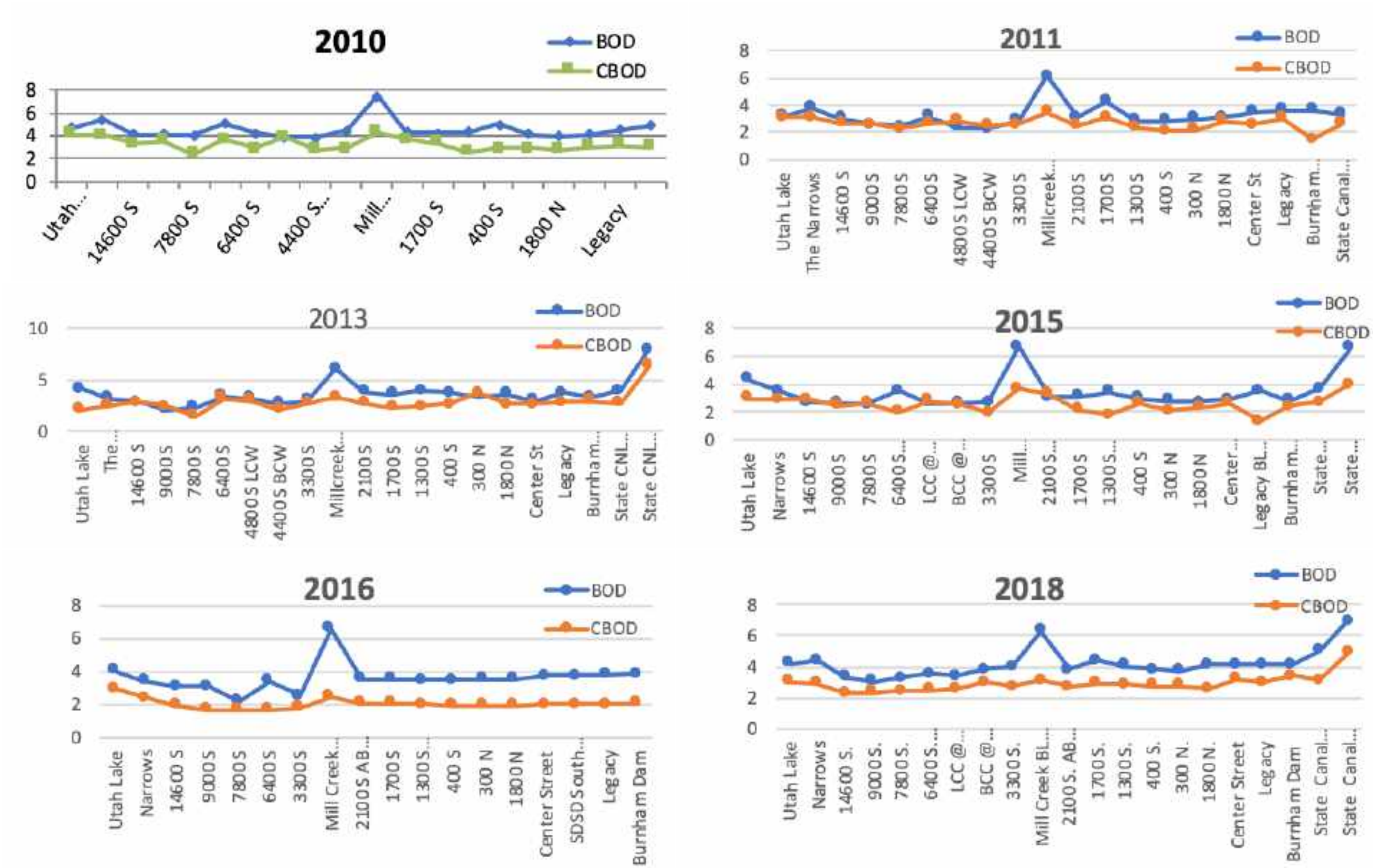


Figure 39. Annual average BOD and CBOD at the mainstem sampling sites and at the mouth of Big and Little Cottonwood Creeks during 2010, 2011, 2013, 2015, 2016 and 2018. All values are in mg L^{-1}. Note: scales differ.

The concentrations of total and ortho-P behaved similar to the nitrogen species throughout the study period. During 2011 the peak in P in Mill Creek was about 0.5 mg L^{-1} lower during 2011, while P concentrations at most river sites was about ½ those measured during 2011.

Discussion

While we believe the impedance of light by the turbidity is an important factor limiting primary production in the water column, reduction in Chl a in the upper portion of the river appears largely to be the result of the approximate 95% diversion of river water by Turner Dam, followed by dilution with shallow ground water and downstream tributaries. Notably however, despite this dilution in Chl a, turbidity itself remains quite stable throughout the entire river. For example, Rushforth and Rushforth (2010) recorded a dramatic decline in water column algae at progressive distances downstream. The biovolumes of Utah Lake species fell to about 1% of those at the Utah Lake outlet. Further, although Cyanobacteria dominated the phytoplankton community, the water column began carrying a substantial amount (up to 500,000 u^3 L^{-1}) of dislodged periphytic diatoms, suggesting that the periphyton was being scoured off of the substrate. Similarly, recent studies by Baker (2009) found that artificial nutrient-diffusing substrates acquired highly variable results during 21-day incubations at 20 locations in the main stem and tributaries. Generally, some samplers that were placed upstream from 2100 S. had quite high amounts of Chl *a*, while other samplers had very little. Overall these variable results were independent of where samplers were placed with regard to the location of the POTW discharges (i.e. whether placed upstream or within reaches that had elevated nutrients). Most of the higher amounts of Chl *a* were measured in the higher gradient portions upstream from all the POTW discharges. This high variability also supports the random likelihood that samplers were being scoured by the TSS or bedload sand, silt and clay particles.

The primary focus of this study is to understand the attenuation of light in the water column at various locations on the Jordan River and its effect upon the algal growth in the river. The hypothesis being tested is that light limitation inhibits phytoplankton and periphyton growth in the river vs the effect of scouring or smothering by the mobilized (upstream sites) or settling (downstream sites). Yet, the evidence indicates that all three factors are at play in the Jordan River. The rapid attenuation of light to near the compensation point at the bottom at all sites clearly indicates that substantial light limitation is occurring, while the embeddedness (at upstream sites) – suggesting that significant scouring is occurring upstream and the complete smothering (at downstream sites) also clearly reduce the ability for periphyton production. Furthermore, this is part of the larger hypothesis that periphyton and phytoplankton primary production and biomass in the river is not sufficient to cause excessive respiration or decomposition that leads to the oxygen deficits/DO impairment experienced at downstream locations. Rather, oxygen deficits result from sediment oxygen demand (SOD) that results from organic matter delivered to the river from urban sources, including seeds, leaves, grass clippings, etc. from adjacent properties and storm drains throughout the urbanized valley that reaches the river and its tributaries (see Chapters 4 and 6). Although the light attenuation curves reported here are relatively steep, and light intensity near the bottom is greatly diminished, they do indicate that sufficient light to support net primary production reaches nearly all of the river bottom. This suggests that under the normal flows of summer, but particularly during winter, when Utah Lake water is shut off, (the clearest water and lowest flow conditions), there is sufficient light penetration to support net positive primary production by both phytoplankton and periphyton communities. This phenomenon has been confirmed by the many measurements of SOD and water column OD by Hogsett (2015; Chapter 6).

In other words, the light reaching the bottom was generally greater than the estimated intensity needed to maintain the compensation point (threshold for net positive primary production). These estimates range from 1% to 5% of the incident radiation striking the surface. For example, Hill and Fanta (2007) exposed periphyton communities to various combinations of low light intensities and phosphorus in large flow-through laboratory streams. Growth rates became limited by light ranging from 12-88 umole m^{-2} s^{-1}. Among all of our sampling stations, the 1% of surface light intensity ranged from 7 to 16 umole m^{-2} s^{-1} and the 5% light intensity ranged from 66 to 85 umole m^{-2} s^{-1}.

Notably, these ranges are also similar to the threshold for light measured for the filamentous periphyton, *Cladophora glomerata* in natural stream and lake populations. Graham et al. (1982) and Lester et al. (1998) found light limitation occurred at 25 to 44 umole m^{-2} s^{-1}. Lorenz et al. (1991) used these light intensities to predict and effectively map the distribution of *Cladophora* stands in littoral zones of the Great Lakes. This narrower range marks the 2% to 4% range of surface light intensity under direct sunlight measured in the Jordan River. By comparison most of the measurement sites in the Jordan River experienced higher irradiance values near the bottom. Therefore, while some light limitation may occur, most of the river's water column and sediment surface receive sufficient light for net accumulation of periphyton or phytoplankton.

Despite the presence of sufficient light, the phytoplankton populations from Utah Lake rapidly and drastically diminish at successive sites below the Utah Lake outlet (Figure 2). The biovolume of the most common taxa, Cyanobacteria, decreases by more than 99% within the first approximate 30 miles of the river (ca. 1.5 travel days).

These data suggest that there is considerable divergence between the photosynthetically available light throughout the water column, and the decline of the phytoplankton biomass, including cyanobacteria, downstream from the Utah Lake outlet. This indicates that the Turner Dam diversion removes the great majoring of phytoplankton and that it never recovers at downstream sites. Further, although some periphyton is dislodged from the stable upstream substrates, this scouring doesn't nearly replace the biomass that is delivered from Utah Lake and this is despite sufficient, although perhaps not optimal light intensity penetrating the entire water column. For example, Cyanobacteria don't become light-limited until the intensity falls below 12-18 umol m^{-2} s^{-1} or the 1% light level (Van Liere and Walsby 1982) and are also well known to tolerate the relatively intense light near lake surfaces, e.g. Whitton and Potts (2000). Further, the turbidity (measured as both TSS or light attenuation curves) remains relatively consistent from the Utah Lake outfall to the Jordan River terminus (see Appendix) – suggesting that these algae are exposed to similar light conditions as that of Utah Lake.

In addition to the major diversion at Turner Dam, there is also considerable dilution from returning ground water, tributaries and POTW discharges (CH2MHill 2005, Borup and Haws, 1999). Notable evidence that supports this "diversion and dilution" concept is the very large number of the same species, *Anabaena spiroides* and *Aphanizomenon flos-aquae,* in the east side tributaries and their occurrence in the same ratio as water leaving Utah Lake. This also suggests that there may not be a lot of die-off – even as water is diverted and carried in the canals and eventually returned in at least two of the main tributaries to the Jordan River (Little Cottonwood and Mill Creeks; Rushforth and Rushforth 2010). Therefore, although there appears to be sufficient light intensity to maintain the Utah Lake phytoplankton populations, there doesn't appear to be additional growth of phytoplankton in the river.

The relatively low production by periphyton was also very dynamic. For example, common periphyton taxa, including pennate and centric diatoms and the ubiquitous green alga, *Cladophora glomerata,* do become marginally established where stable substrate occurs in the upper river reaches. However, periphyton communities remain sparse, even where suitable cobble and boulder substrates occur and particularly in relation to the apparent availability of light and the elevated concentrations of nitrogen and phosphorus. This scarcity, particularly in light of the abundant P and N concentrations, confirms the hypothesis that: 1) The elevated concentrations of suspended and bedload sediments from Utah Lake, bank erosion and various nonpoint sources, remain in dynamic equilibrium between suspension in the water column and being transported as bedload throughout the entire river. Therefore, there is a continual source of unstable sand, silt and clay that is carried by even normal stream flows (Bio-West 1987, personal observations). This unstable sediment serves to continually dislodge the developing periphyton communities, which then become suspended in the water column (Figure 3; Rushforth and Rushforth, 2010) and also cause extreme embeddedness of 80 to 90% of the substrate that is stable-further reducing the available surface area for colonization; 2) Numerous observations and our periphyton scrapings indicated that substantial quantities of sand, silt and clay material had become embedded/entangled even within the periphyton strands and stalks themselves. For example, the mucilaginous secretions of diatoms provide for a "sticky" biofilm that can accumulate silt and clay particles (personal observations). Such particles also become entrapped by the branched filaments of *Chladophora*, apparently limiting its filamentous growth to just a few cm in length.

With the exception of the 1700 S. area, nearly the entire river bottom below 2100 S is depositional in nature. Attempts to perform periphyton colonization studies using nutrient diffusing substrates (Baker 2009) resulted in nearly all of the canisters becoming covered with 1- 4 cm of sediment and several samplers were lost in the accumulating sediment. Samplers placed upstream from 2100 S. yielded extremely variable results with some of the artificial substrate samplers accumulating substantial quantities of Chl a, while other samplers accumulating only traces of Chl a (Baker 2009).

The settling and shifting of fine organic and inorganic sediments appear to be the primary reasons why periphyton colonization does not occur in the downstream reaches. Rather, these reaches are dominated by a heterotrophic microbial system that is based on the decomposition of organic matter delivered from upstream sources, including Utah Lake and the many tributaries (Chapters 4 and 6).

Overall, the light profiles provide valuable information relating to primary production in the river. Generally, while light rapidly attenuates through the water column, sufficient light (remaining above the compensation point) occurs to provide for periphyton or phytoplankton growth throughout the entire river, and particularly at depths shallower than 2 m. The other constraining factor is that the river is likely too turbulent for the phytoplankton to fully optimize their morphological and physiological acclimation to the light [e.g. Kohler (1992) suggested that *Microcystis* takes two days to adapt to the high irradiances typical of surface blooms]. Even in the slow-moving portions of the river, the turbulence would randomly transport phytoplankton between the top and bottom several times each day. The extent that this differs from the turbulence on Utah Lake plankton is unknown. However, because TSS, VSS and the light profiles remain quite stable as the water travels downstream, light and turbulence conditions in the Jordan River likely remain quite similar to those in Utah Lake.

These data also help elucidate the question of the contribution of either phytoplankton or periphyton growth in the upper and middle reaches of the river toward the organic loading and potential for deposition downstream from 2100 S. For example, the Jordan River TMDL Phase II: Draft Technical Memo: Critical Conditions, Endpoints, and Permissible Loads on the Jordan River (Stantec and Cirrus 2010) suggests: "nutrients may be responsible for increased algal growth and subsequent detritus levels within the Jordan River above 2100 South that add to the loads of TSS." However, a review of Figure 2 and the original data from Rushforth and Rushforth (2010) indicate that the greatest reduction of Utah Lake algal biomass occurs upstream from 2100 south. Further, these cells would be collected in the monthly VSS and TSS samples, which again remain stable or slightly increase with distance downstream, indicating that there is very little or no additional particulate organic carbon being delivered to the river from autochthonous sources (above that which is already being delivered to the river by Utah Lake). Finally, the biomass of diatoms actually increases slightly downstream from 2100 S. This is contrary to the hypothesis that these cells are dying and depositing and adding to the SOD downstream. Rather, this slight increase could be supplied from the three tributaries in this reach that are likely also contributing dislodged diatoms to the Jordan River. These and the other tributaries including the return of Utah Lake water from exchanges with Mill Creek and Big Cotton Creeks. are likely replacing the VSS that is being removed by the large diversions. Sources of this additional/replacement VSS are likely the partially decomposed leaves, seeds, grass litter and perhaps from the many tributaries and stormwater flows.

Notably, the concentrations of VSS do not vary (settle) substantially from upstream to downstream sites, nor from month to month or year to year (Figure 17). Alternatively, we have a large data set documenting the delivery and settling of CPOM in the lower Jordan River (Chapter 3). Sparse populations of periphyton in reaches that possess both ample light and relatively stable substrate suggest that the benthic community is largely influenced by the continual or intermittent settling and scouring of the unstable sand, silt and clay material. Further evidence of this characteristic is the low numbers of macroinvertebrate grazers such as members of the caddisfly and mayfly orders (Peterson and Miller 2010, Bio-West, Inc., 1987, 1992). But perhaps most damaging to this ecosystem is the continual need to dredge the channel at various locations (e.g. near the mouth of Mill Creek, Little Cottonwood Creek and 1700 S.) and along most of the downstream channel, every few years. This degradation of Jordan River habitat has been discussed in greater detail by Filbert and Holden (1992), Biowest, et al. (1987) and Holden and Crist (1986) and in several of our Chapters in Volume II: Biological Integrity. This present study, in conjunction with those of Rushforth and Rushforth (2009) and Baker (2009) adds important information that helps us understand the complex interactions within this urban river. Based upon this new information, additional studies were initiated to focus on:

1. Quantifying the proportion of VSS or fine particulate organic matter (FPOM) at the Utah Lake outlet and subsequent delivery of FPOM and CPOM from downstream tributaries. We need to understand the fraction of the organic material that is composed of living cells vs. detritus (Chapter 6).
2. Quantifying the components of primary production/community respiration/SOD in reaches that possess quantifiable periphyton vs reaches that are primarily depositional in nature, This should be performed using both the two-station – upstream-downstream technique for primary production and community respiration as well as the more site-specific respirometer method (chamber technique) to compare individual site primary production/respiration in reaches located upstream and downstream from 2100 S. (See Bott, 2007; Chapter 6).

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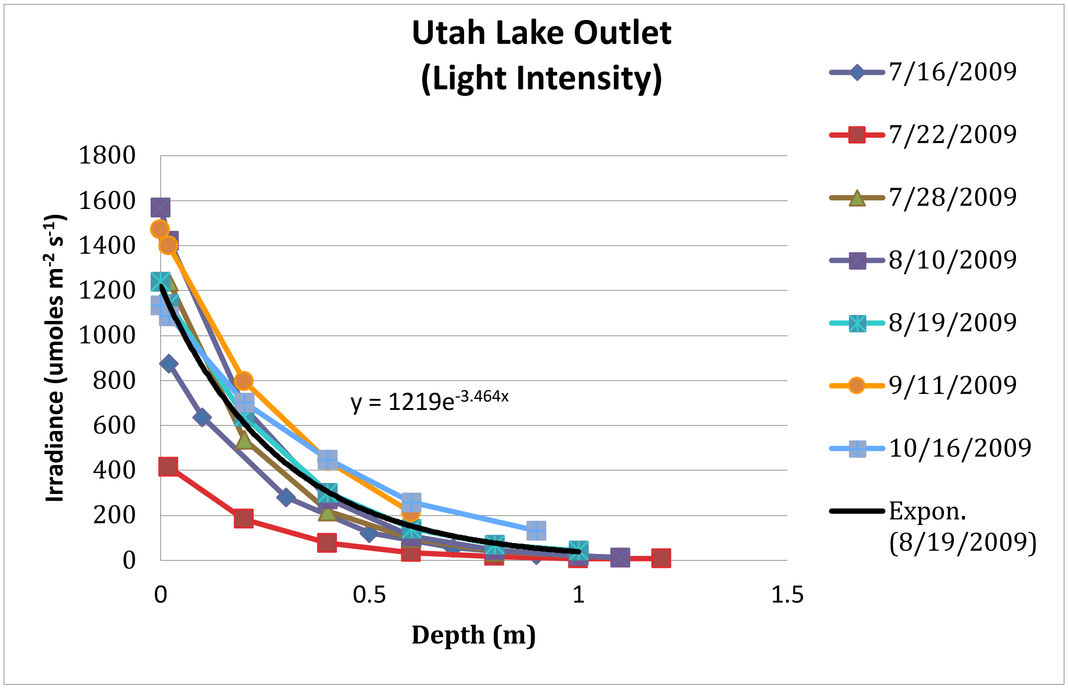
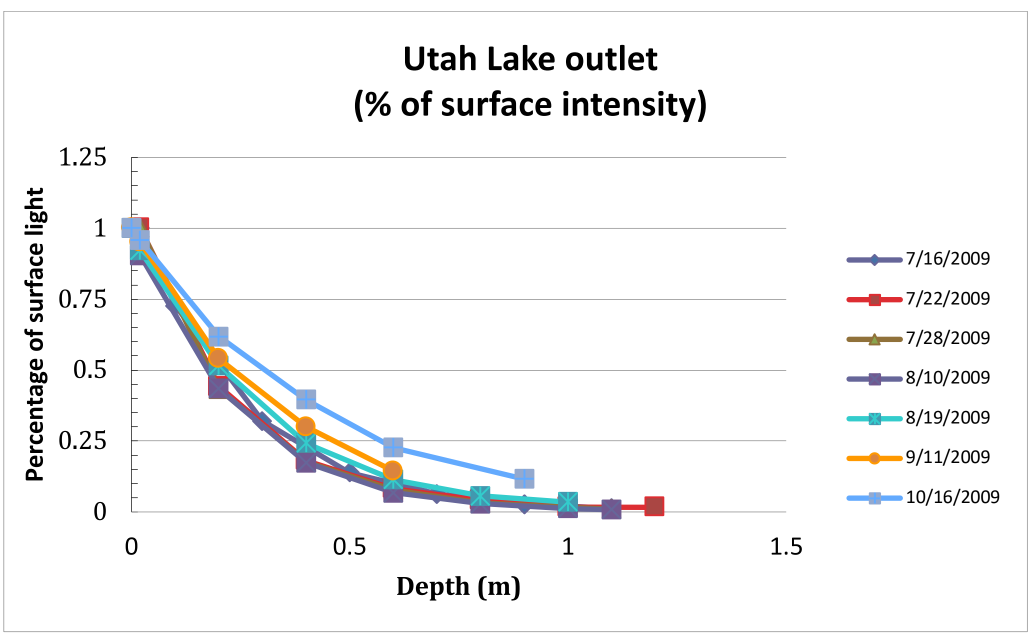
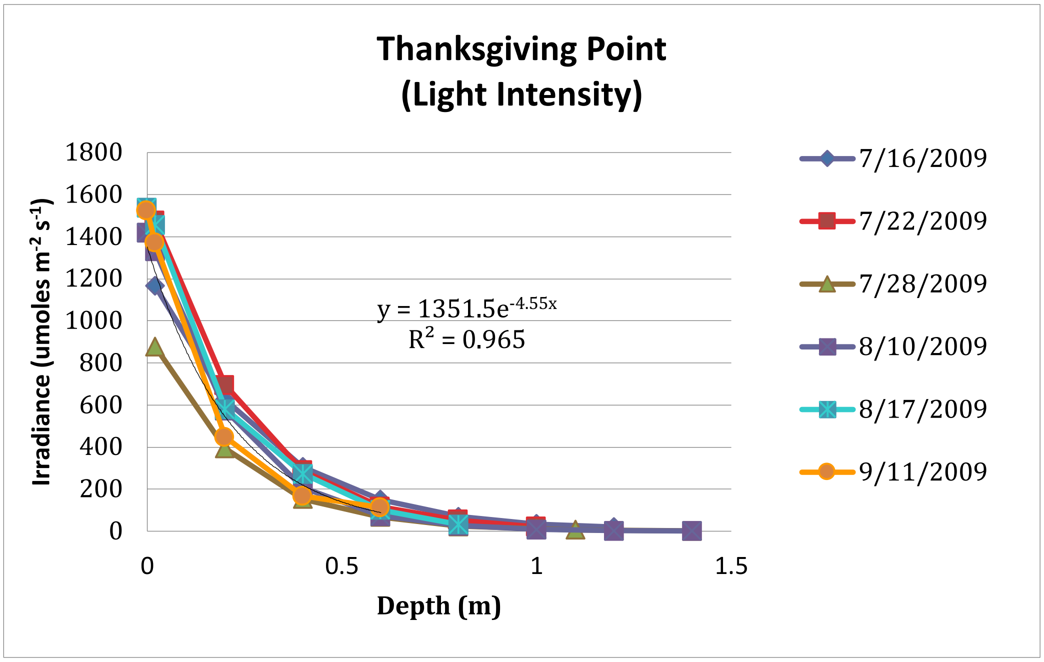
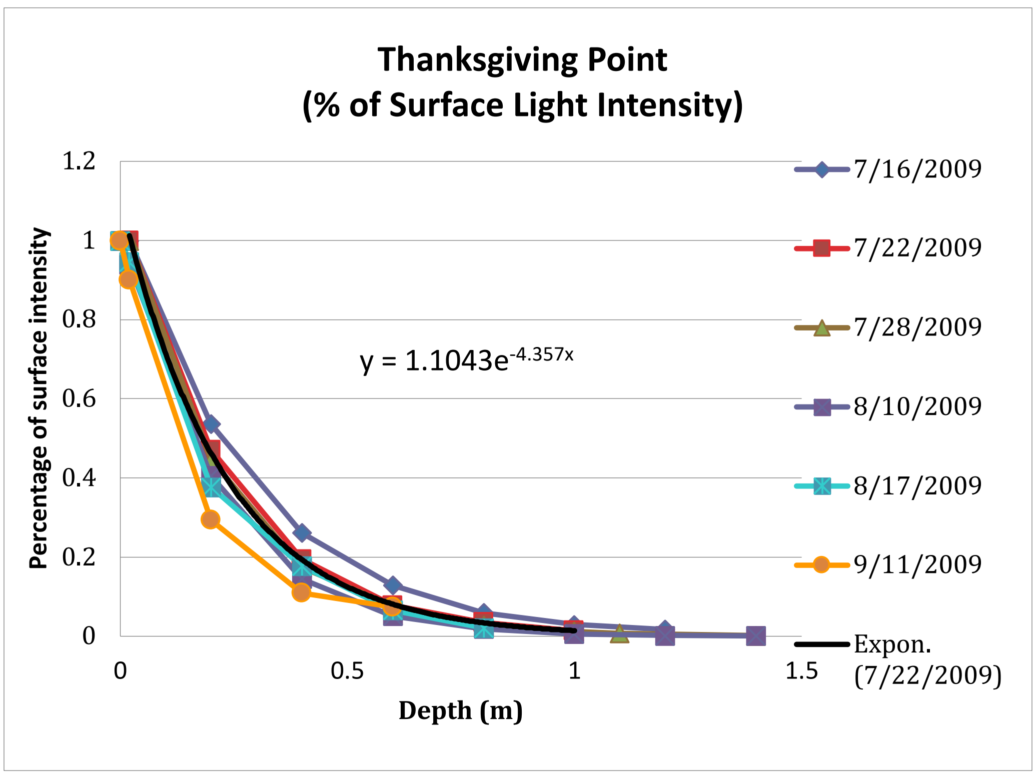
Appendix

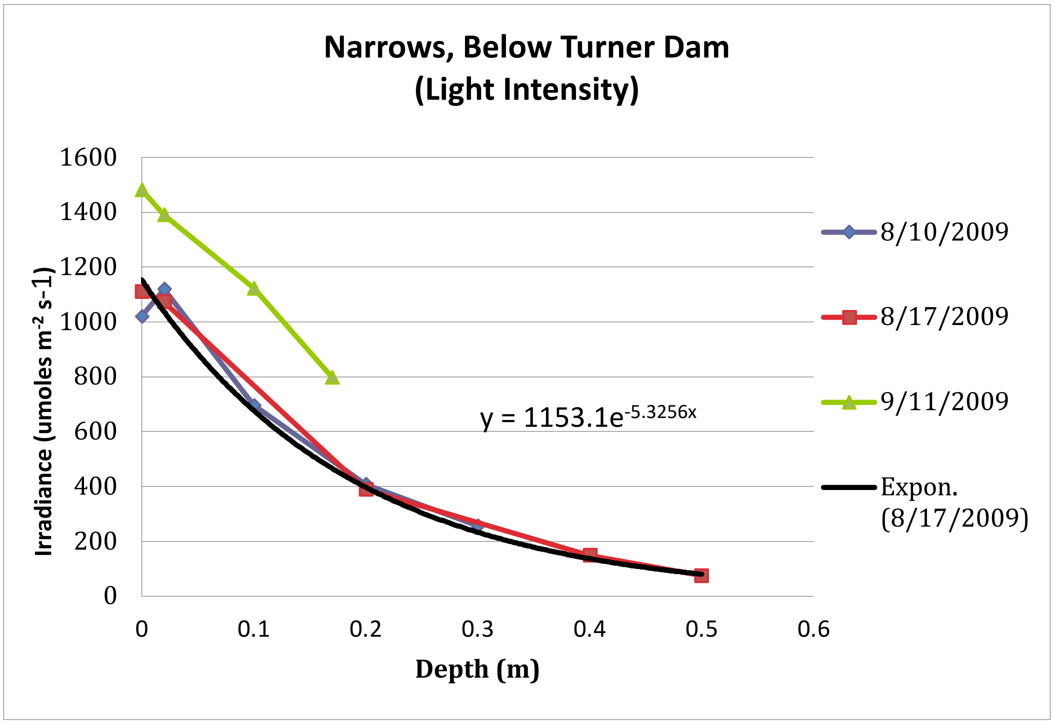
The following graphs summarize the light extinction profiles at the water quality sampling stations in the Jordan River and the Surplus Canal during summer and fall, 2009. The graphs include measured light intensity values as well as percentage of light intensity as a function of depth. The equations posted on the graphs represent an exponential regression model for one of the listed attenuation curves.

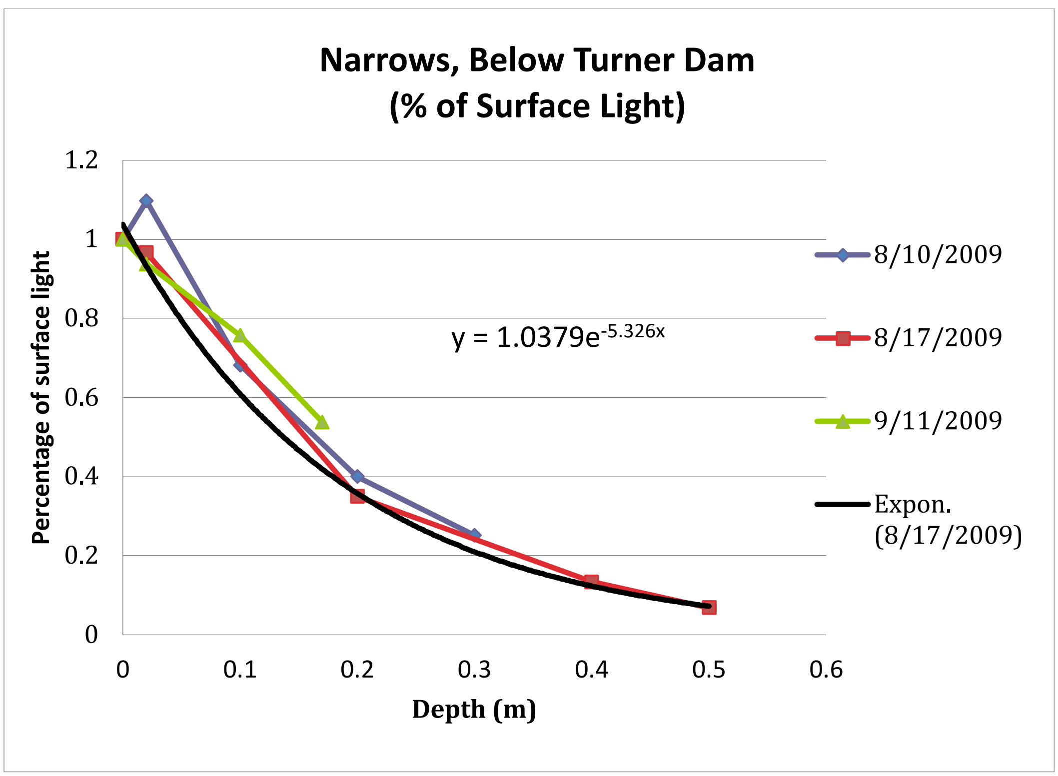


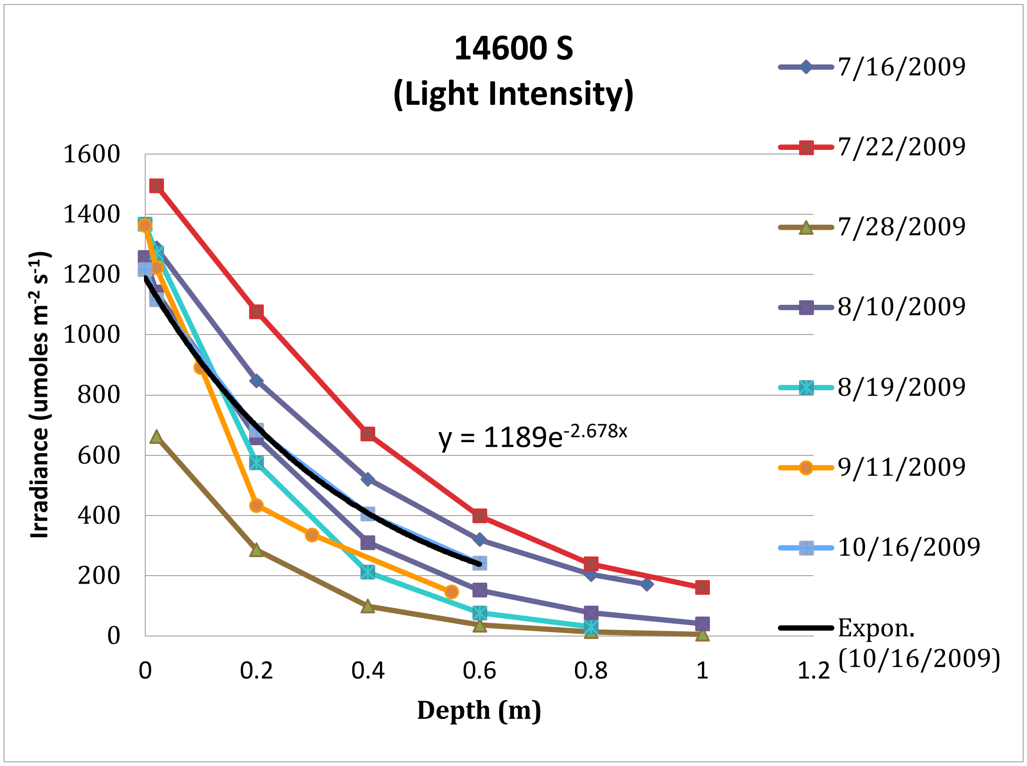



Thanksgiving Point
(Light Intensity)
Irradiance (umoles m-2 s-1)
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.5
1
1.5
Depth (m)
y = 1351.5e-4.55x
R² = 0.965
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/17/2009
9/11/2009

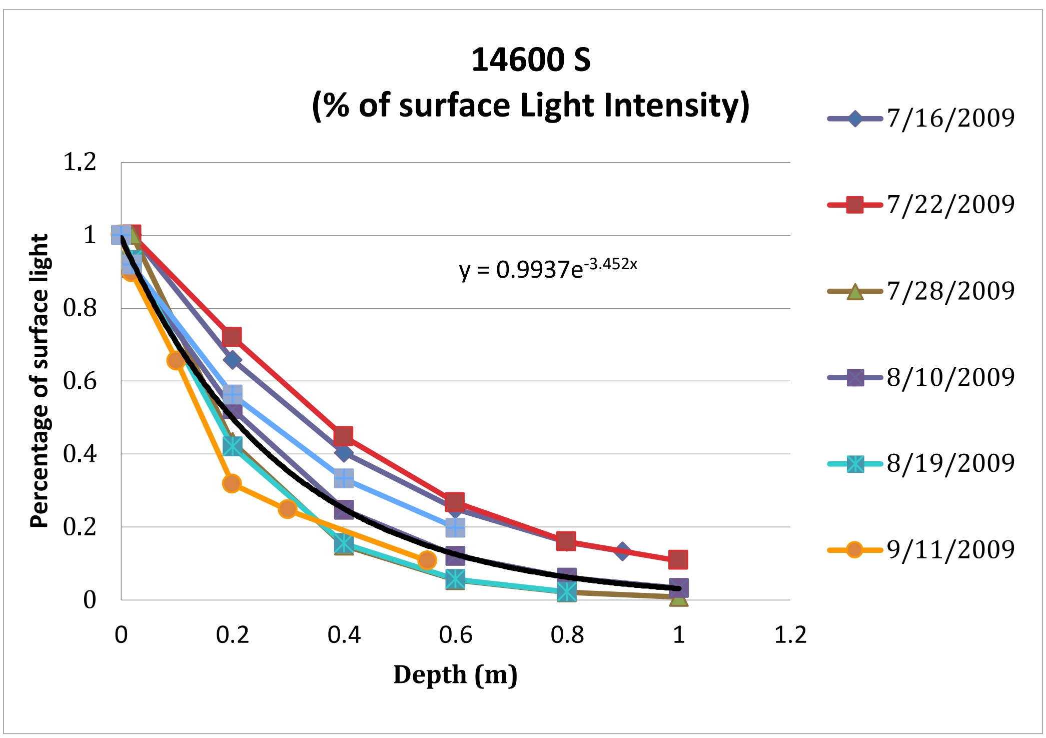

Thanksgiving Point
(% of Surface Light Intensity)
Percentage of surface intensity
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
Depth (m)
y = 1.1043e-4.357x
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/17/2009
9/11/2009
Expon. (7/22/2009)


Narrows, Below Turner Dam
(Light Intensity)
1600
1400
1200
1000
800
600
400
200
0
Irradiance (umoles m-2 s-1)
0
0.1
0.2
0.3
0.4
0.5
0.6
Depth (m)
y = 1153.1e-5.3256x
8/10/2009
8/17/2009
9/11/2009
Expon. (8/17/2009)

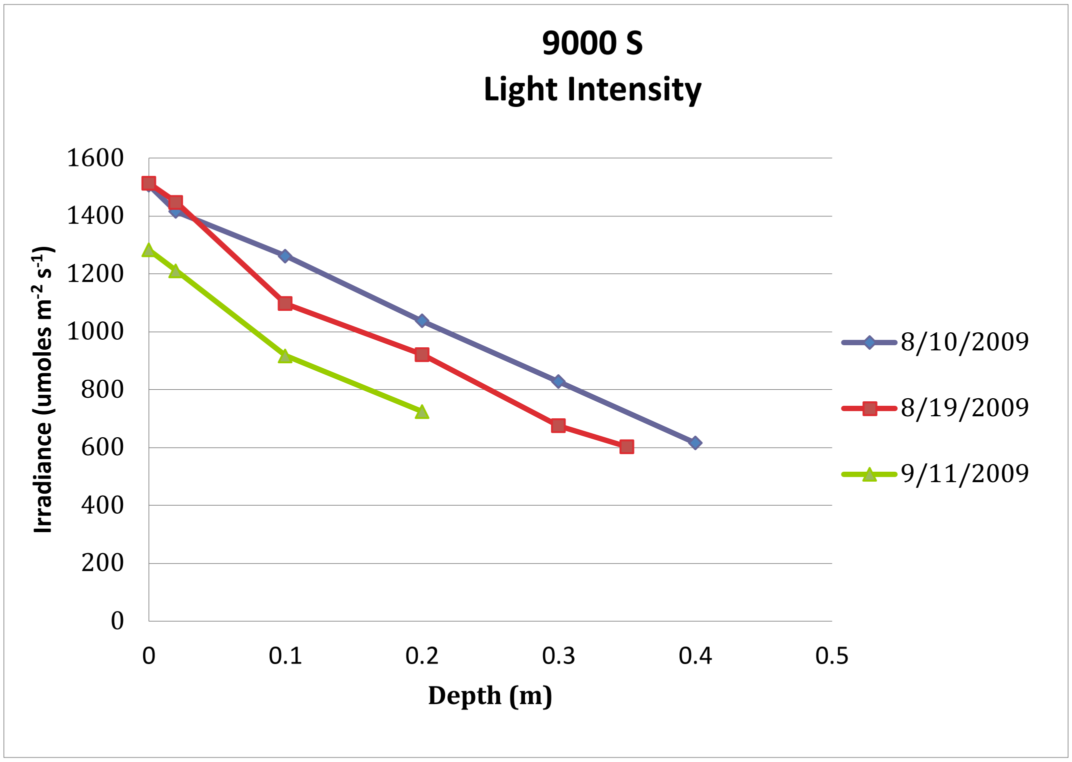

Narrows, Below Turner Dam
(% of Surface Light)
1.2
1
0.8
0.6
0.4
0.2
0
Percentage of surface light
0
0.1
0.2
0.3
0.4
0.5
0.6
Depth (m)
y = 1.0379e-5.326x
8/10/2009
8/17/2009
9/11/2009
Expon. (8/17/2009)

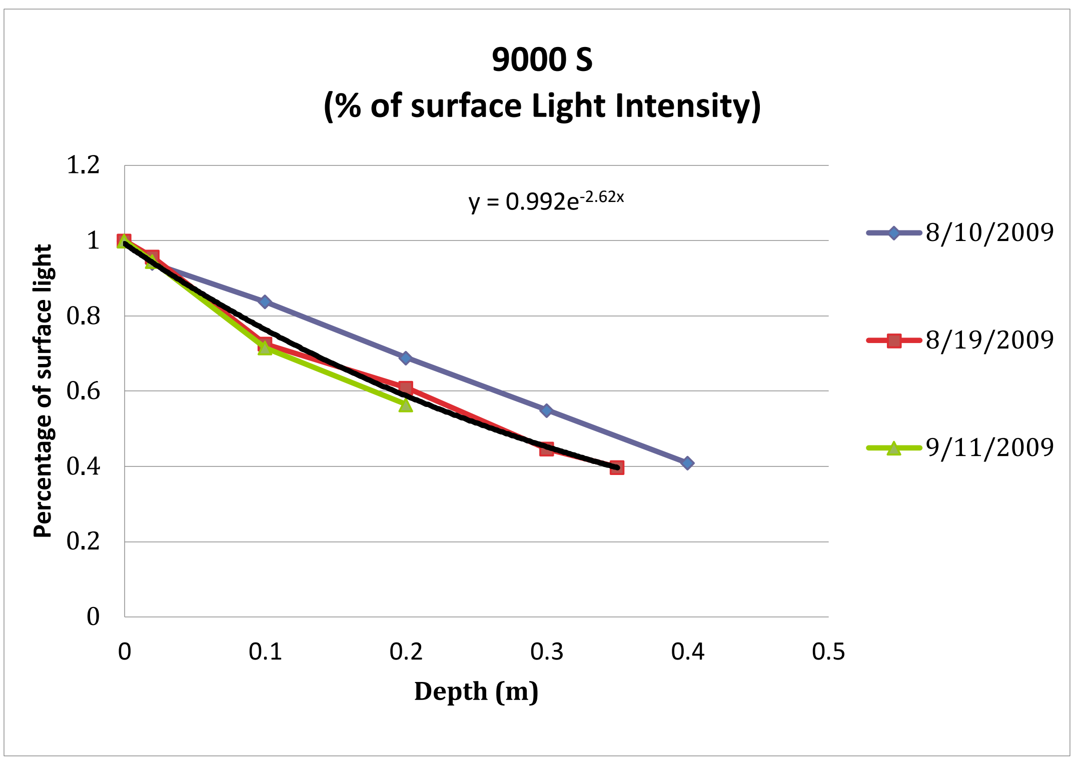


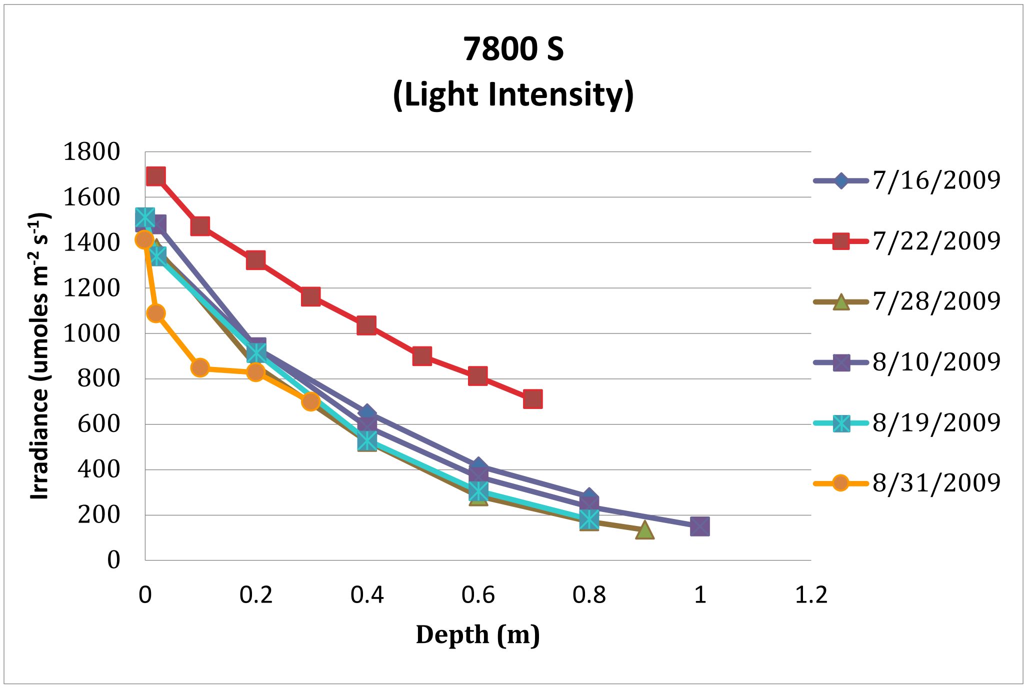
14600 S
(Light Intensity)
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
9/11/2009
10/16/2009
Expon. (10/16/2009)
y = 1189e-2.678x
Irradiance (umoles m-2 s-1)
Depth (m)
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
1.2

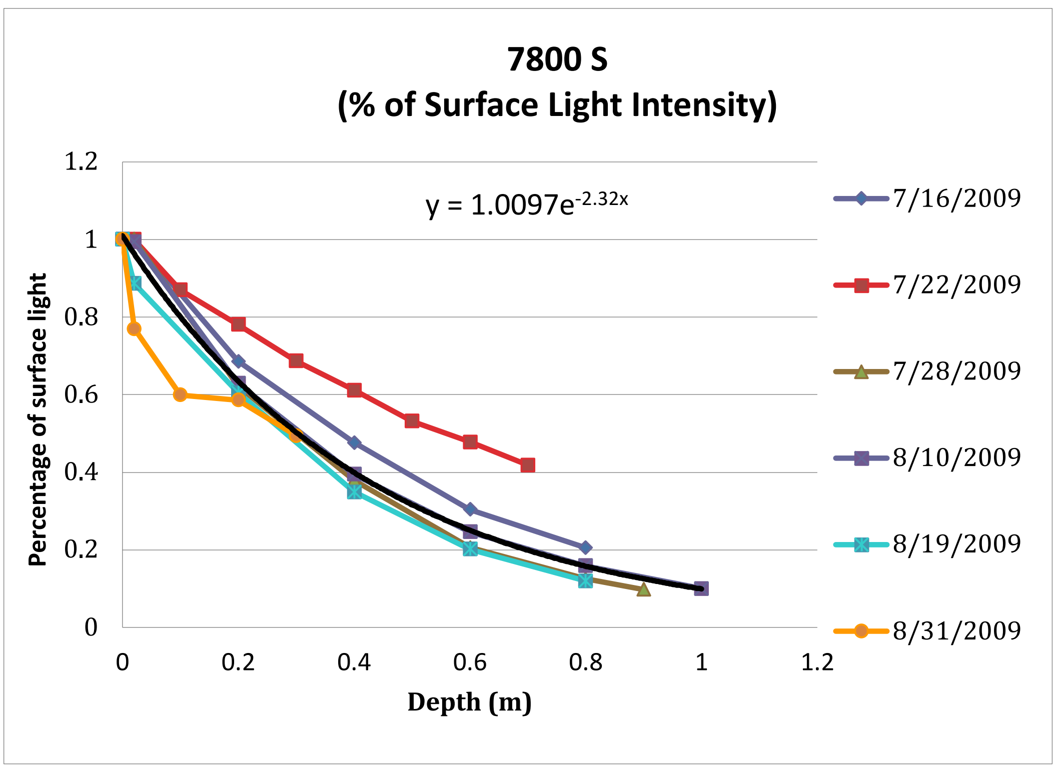


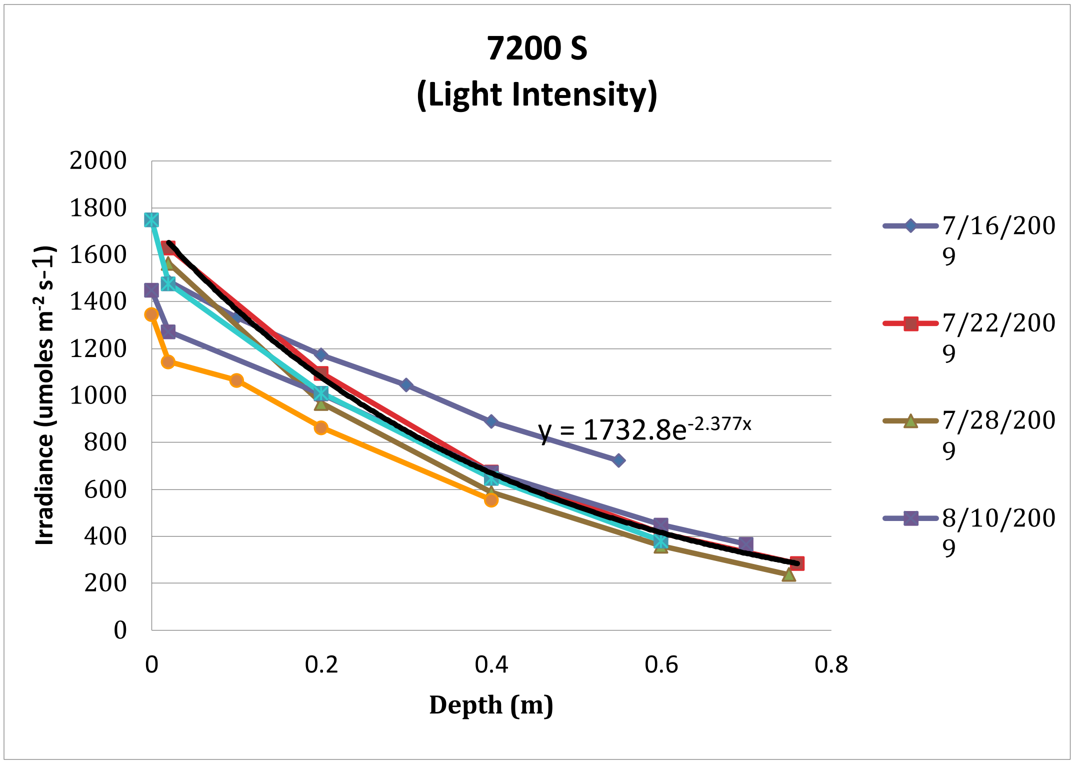
14600 S
(% of surface Light Intensity)
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
9/11/2009
y = 0.9937e-3.452x
Percentage of surface light
Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2


9000 S
Light Intensity
Irradiance (umoles m-2 s-1)
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
Depth (m)
8/10/2009
8/19/2009
9/11/2009

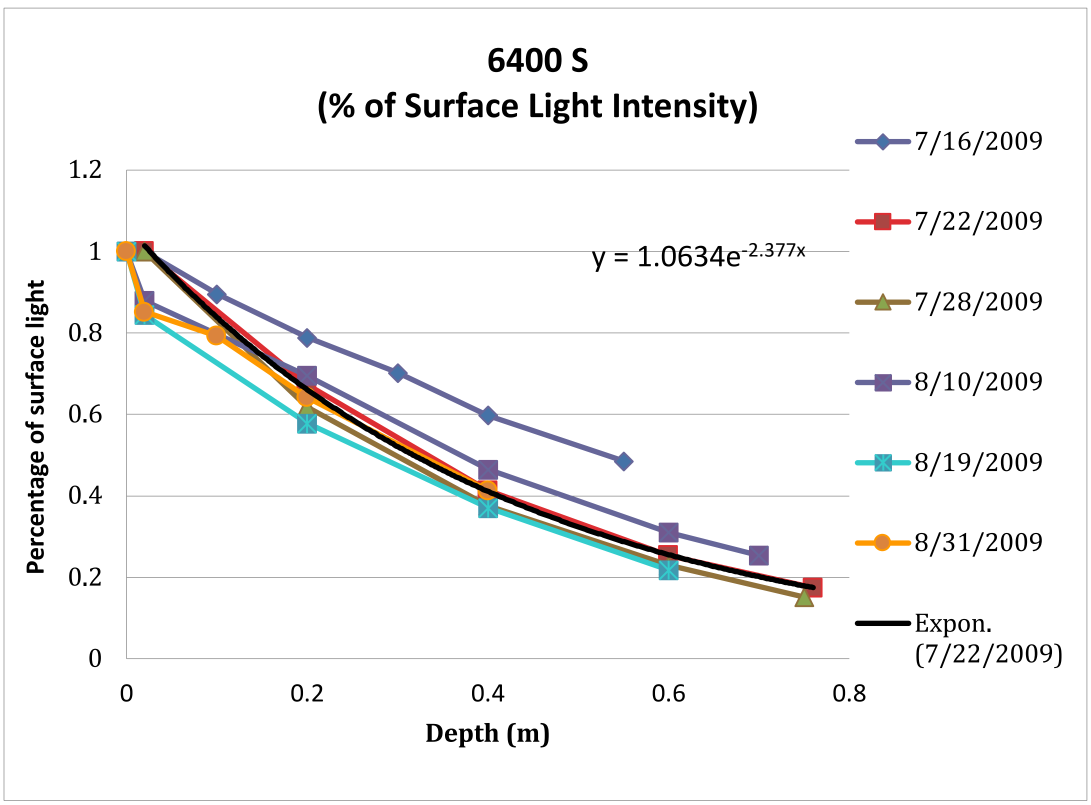

9000 S
(% of surface Light Intensity)
y = 0.992e-2.62x
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
Depth (m)
8/10/2009
8/19/2009
9/11/2009


7800 S
(Light Intensity)
Irradiance (umoles m-2 s-1)
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
8/31/2009

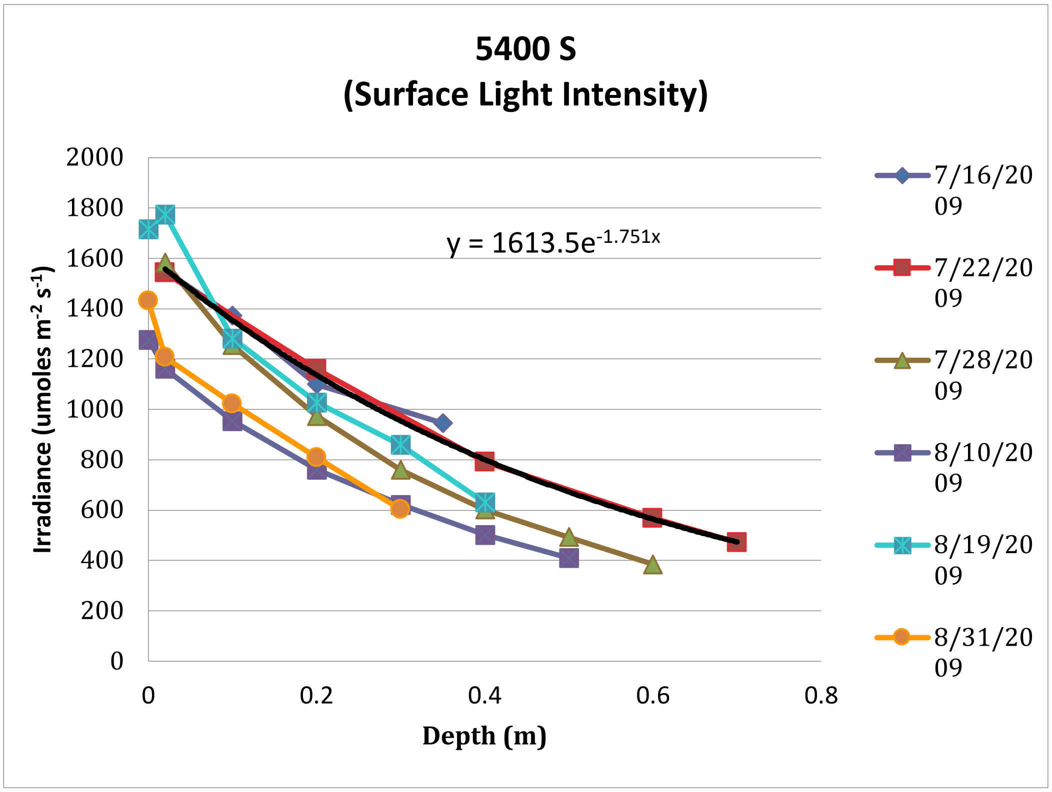

7800 S
(% of Surface Light Intensity)
y = 1.0097e-2.32x
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
8/31/2009



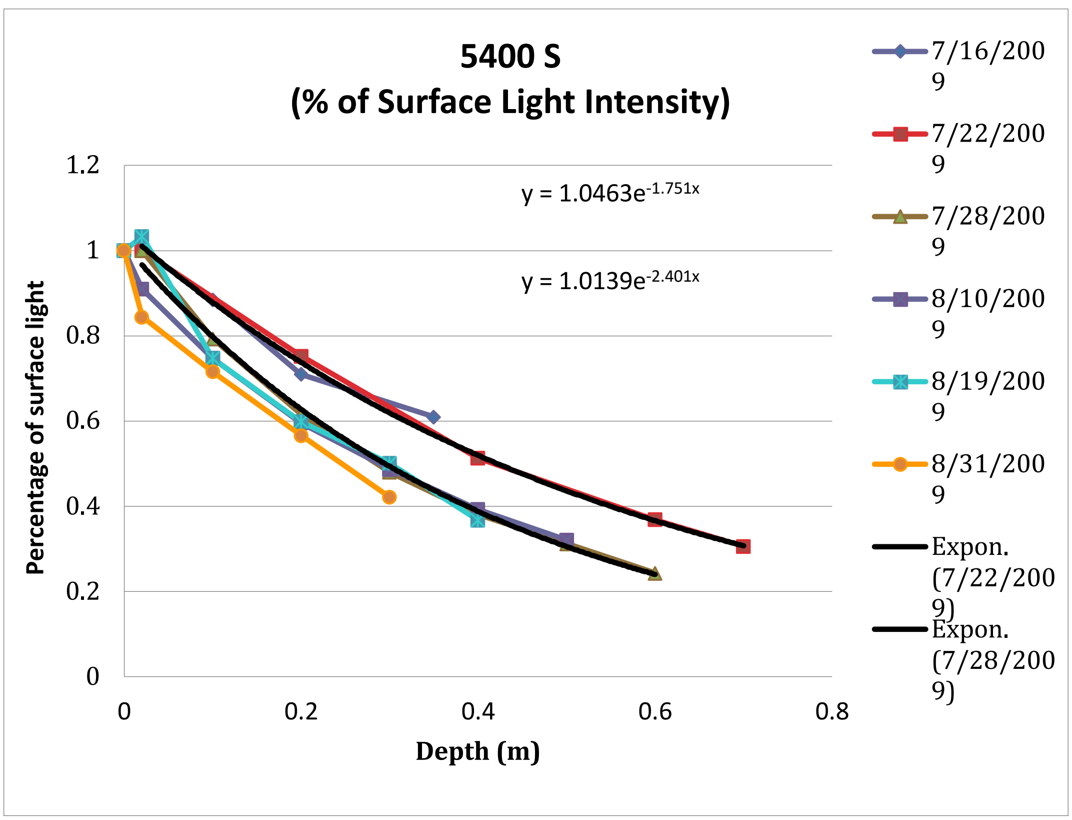
7200 S
(Light Intensity)
Irradiance (umoles m-2 s-1)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
Depth (m)
y = 1732.8e-2.377x
7/16/2009
7/22/2009
7/28/2009
8/10/2009



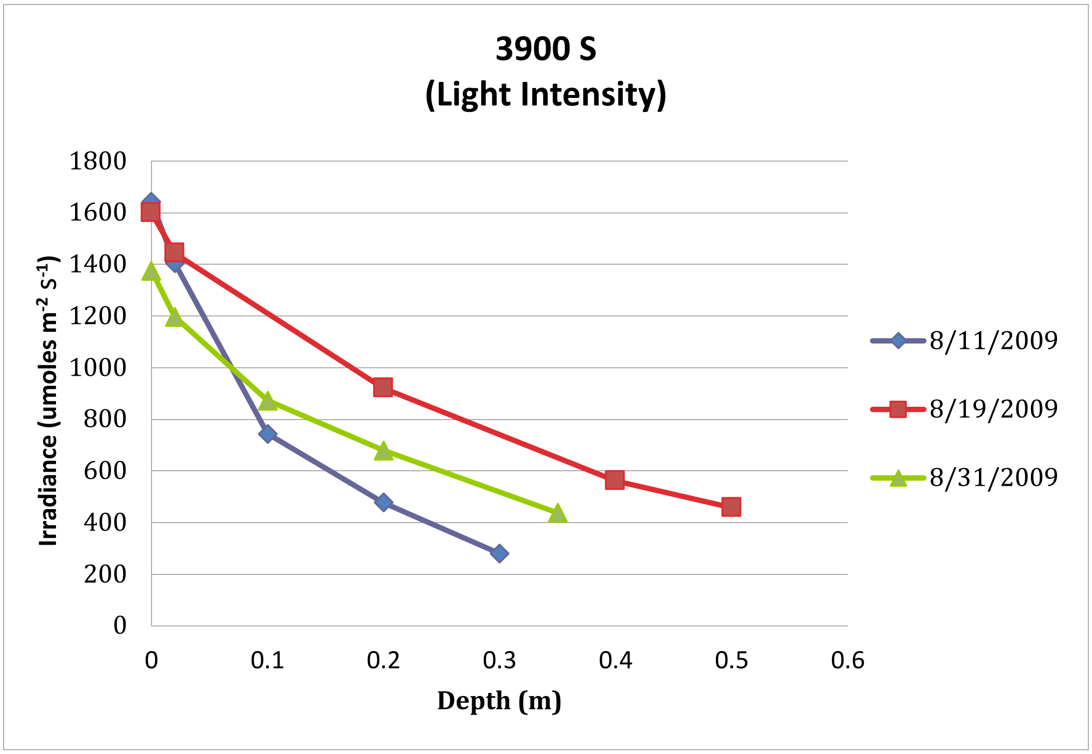
6400 S
(% of Surface Light Intensity)
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
Depth (m)
y = 1.0634e-2.377x
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
8/31/2009
Expon. (7/22/2009)

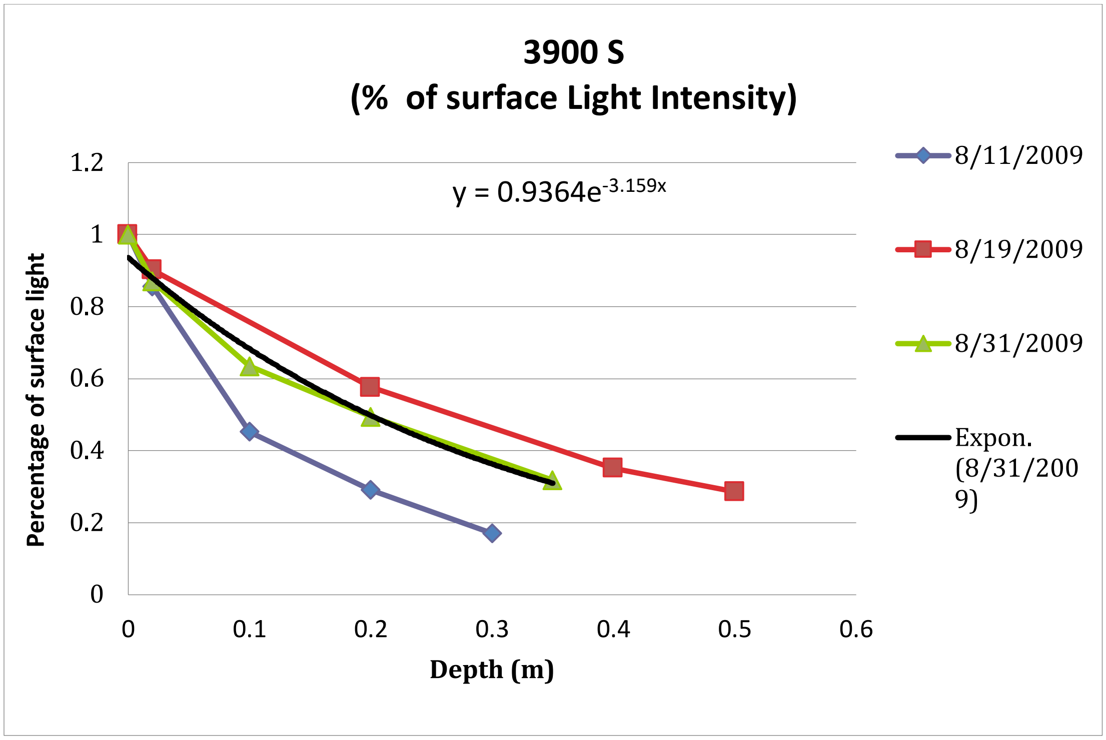


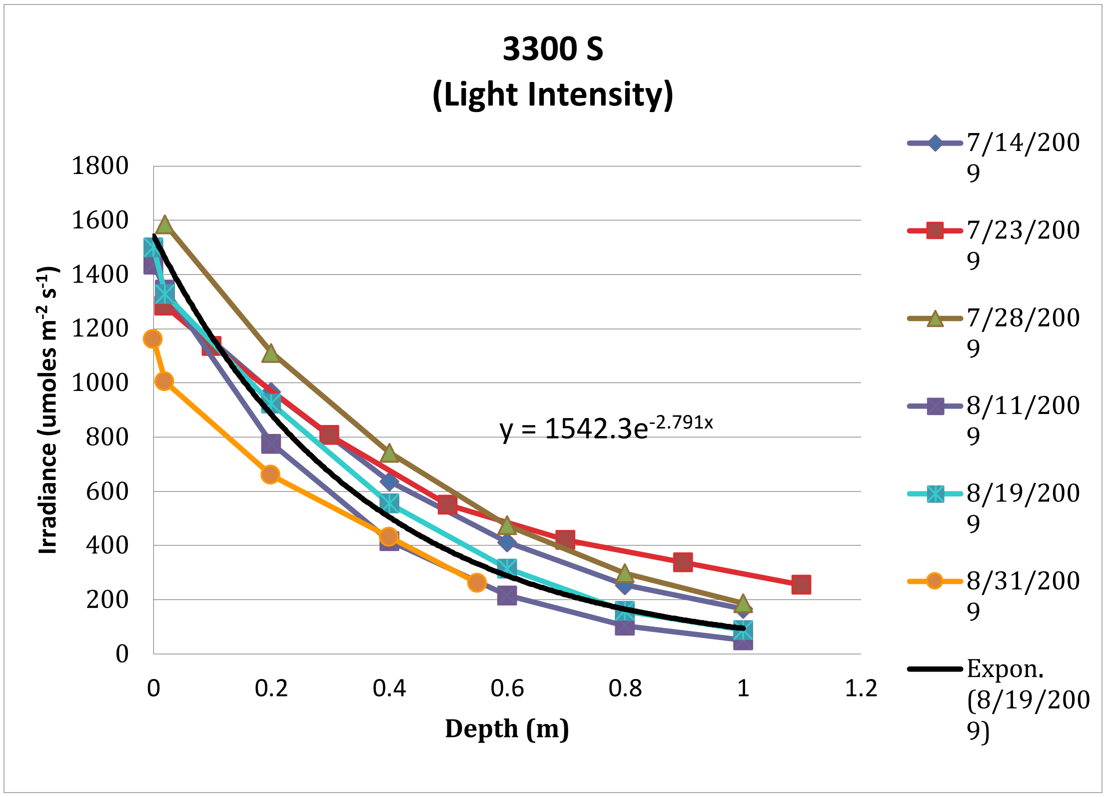
5400 S
(Surface Light Intensity)
y = 1613.5e-1.751x
Irradiance (umoles m-2 s-1)
Depth (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
8/31/2009

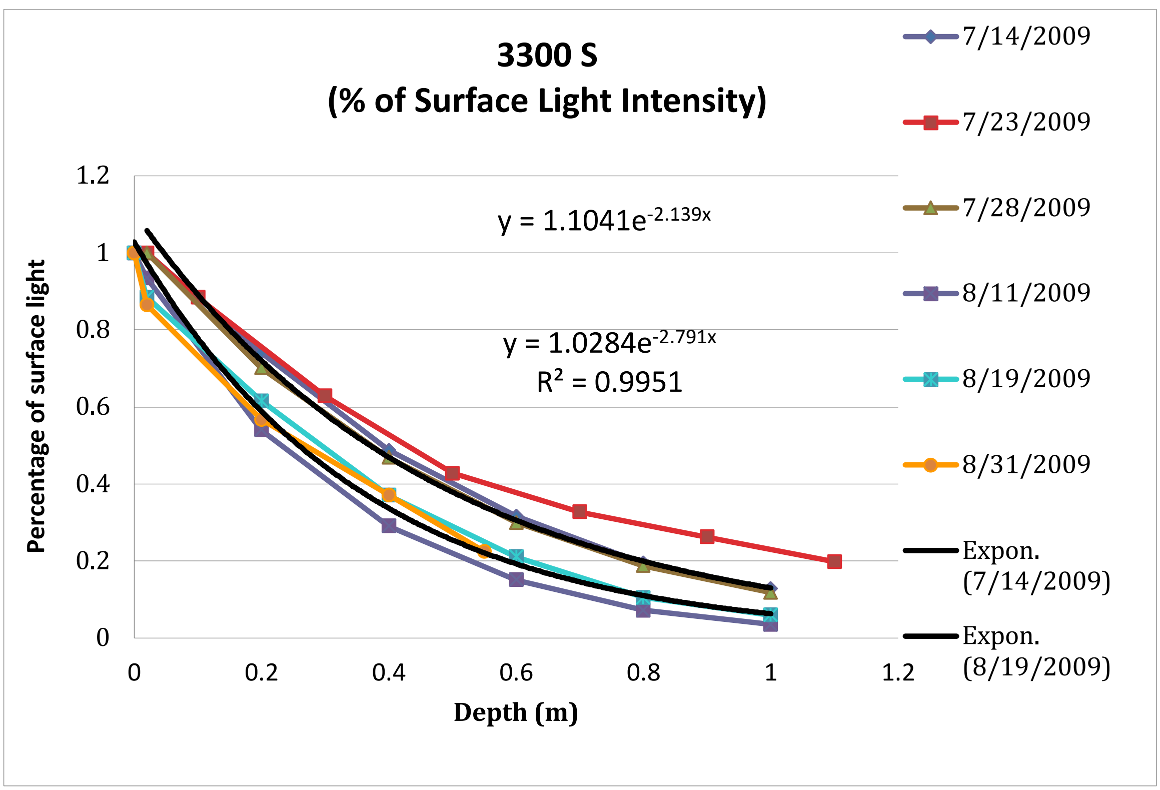


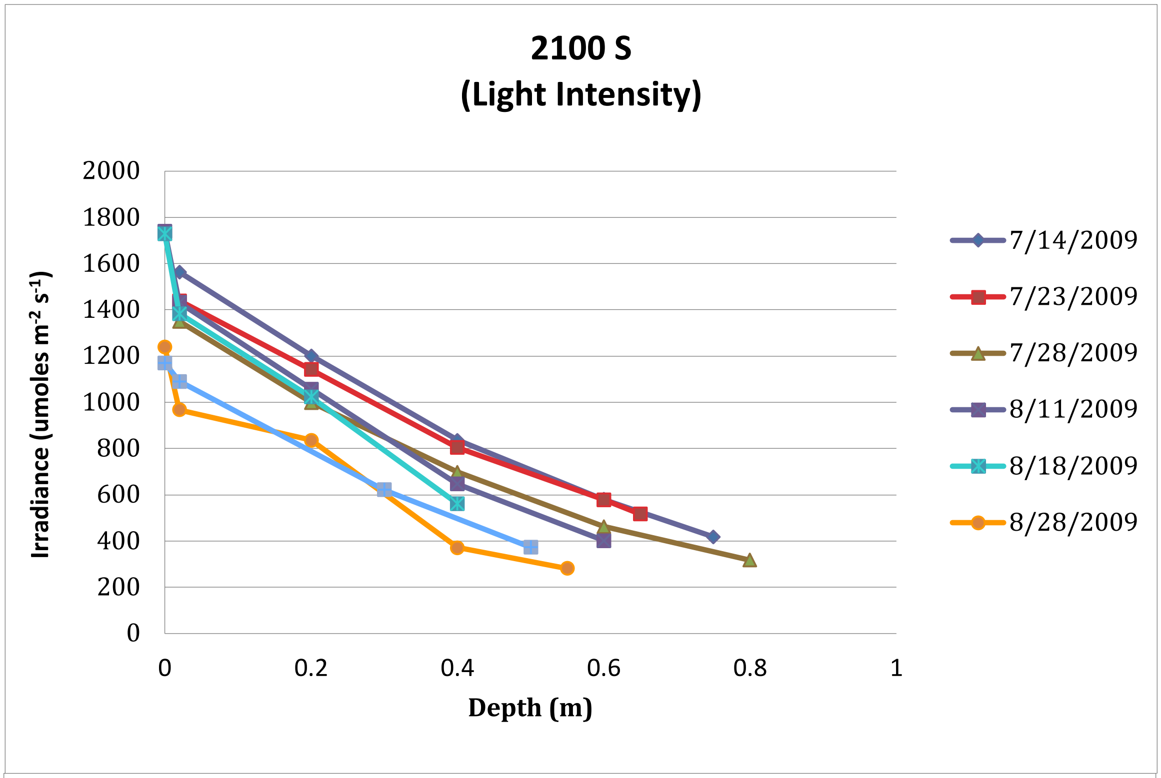
5400 S
(% of Surface Light Intensity)
y = 1.0463e-1.751x
y = 1.0139e-2.401x
Percentage of surface light
Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
7/16/2009
7/22/2009
7/28/2009
8/10/2009
8/19/2009
8/31/2009
Expon. (7/22/2009)
Expon. (7/28/2009)

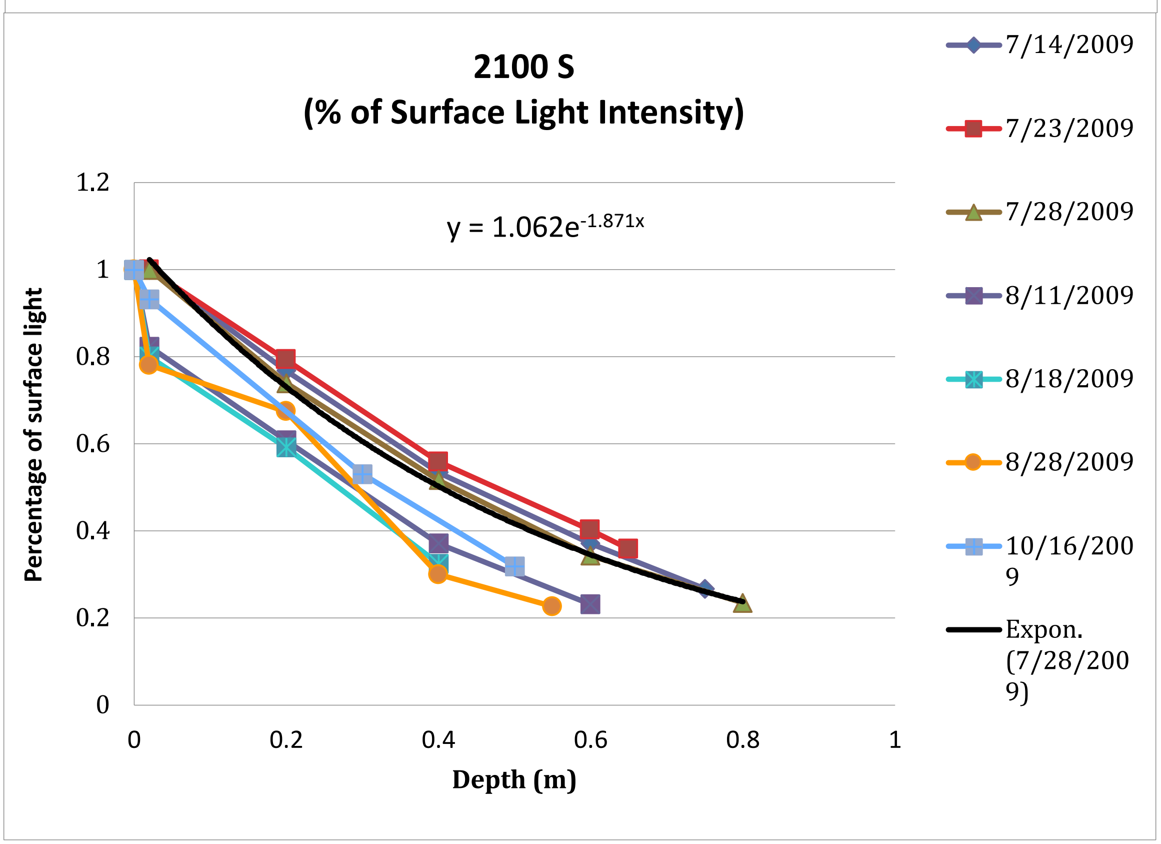

3900 S
(Light Intensity)
Irradiance (umoles m-2 S-1)
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depth (m)
8/11/2009
8/19/2009
8/31/2009

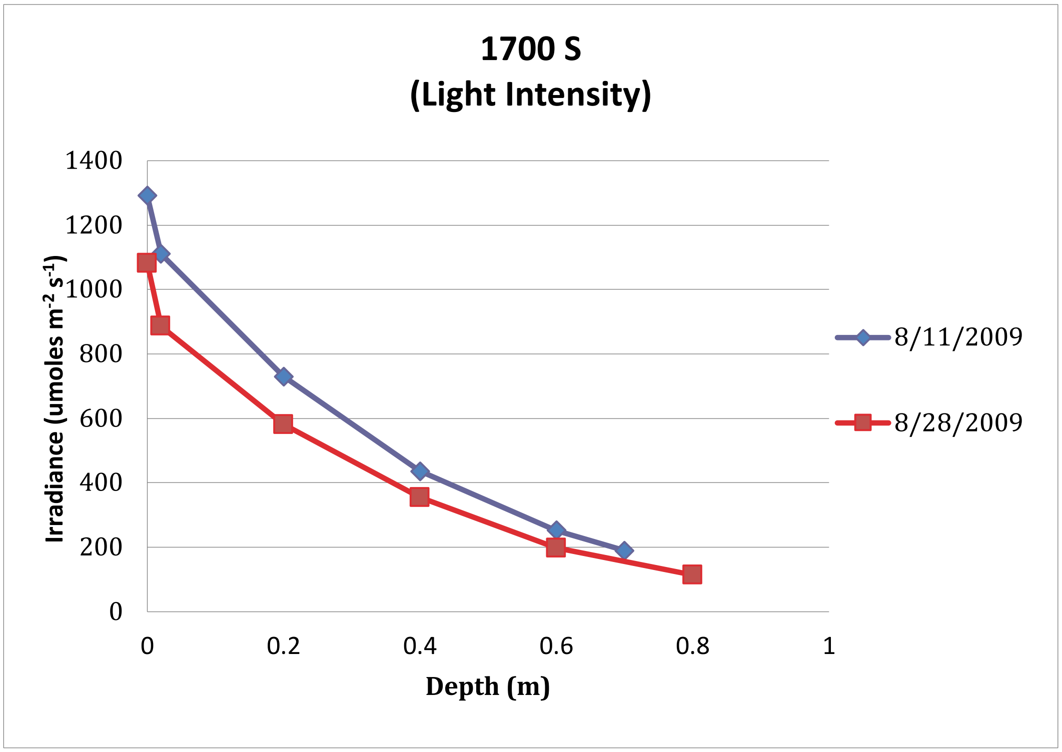

3900 S
(% of surface Light Intensity)
y = 0.9364e-3.159x
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depth (m)
8/11/2009
8/19/2009
8/31/2009
Expon. (8/31/2009)

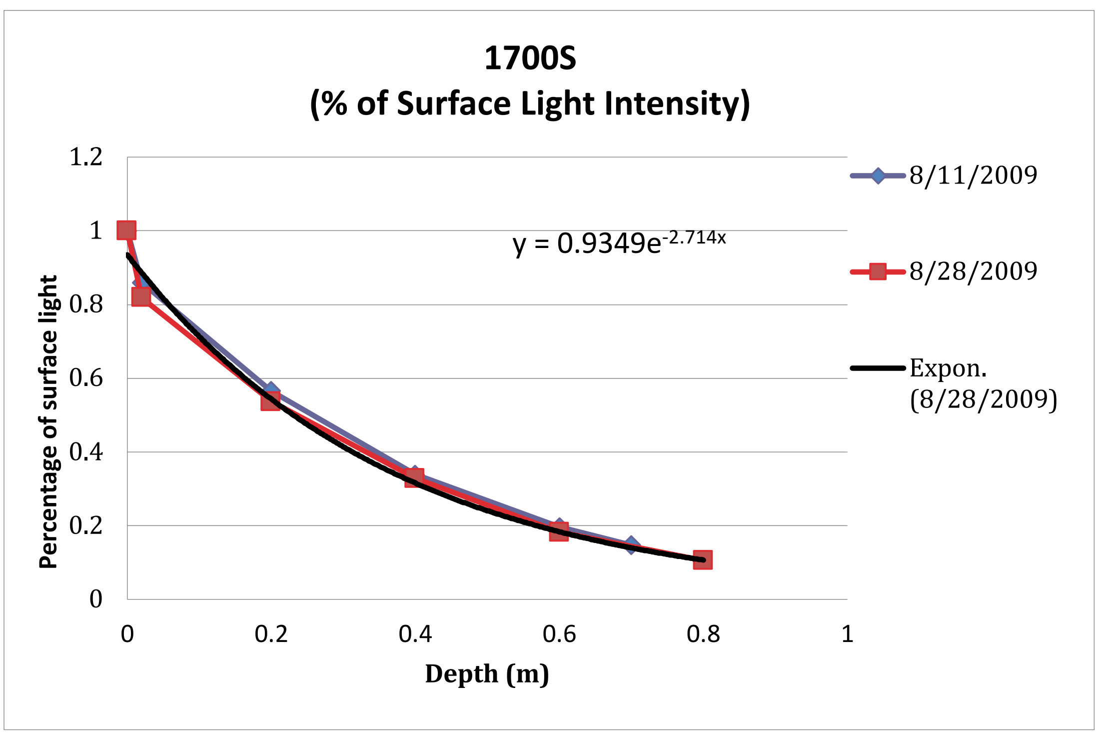

3300 S
(Light Intensity)
Irradiance (umoles m-2 s-1)
Depth (m)
y = 1542.3e-2.791x
7/14/2009
7/23/2009
7/28/2009
8/11/2009
8/19/2009
8/31/2009
Expon. (8/19/2009)

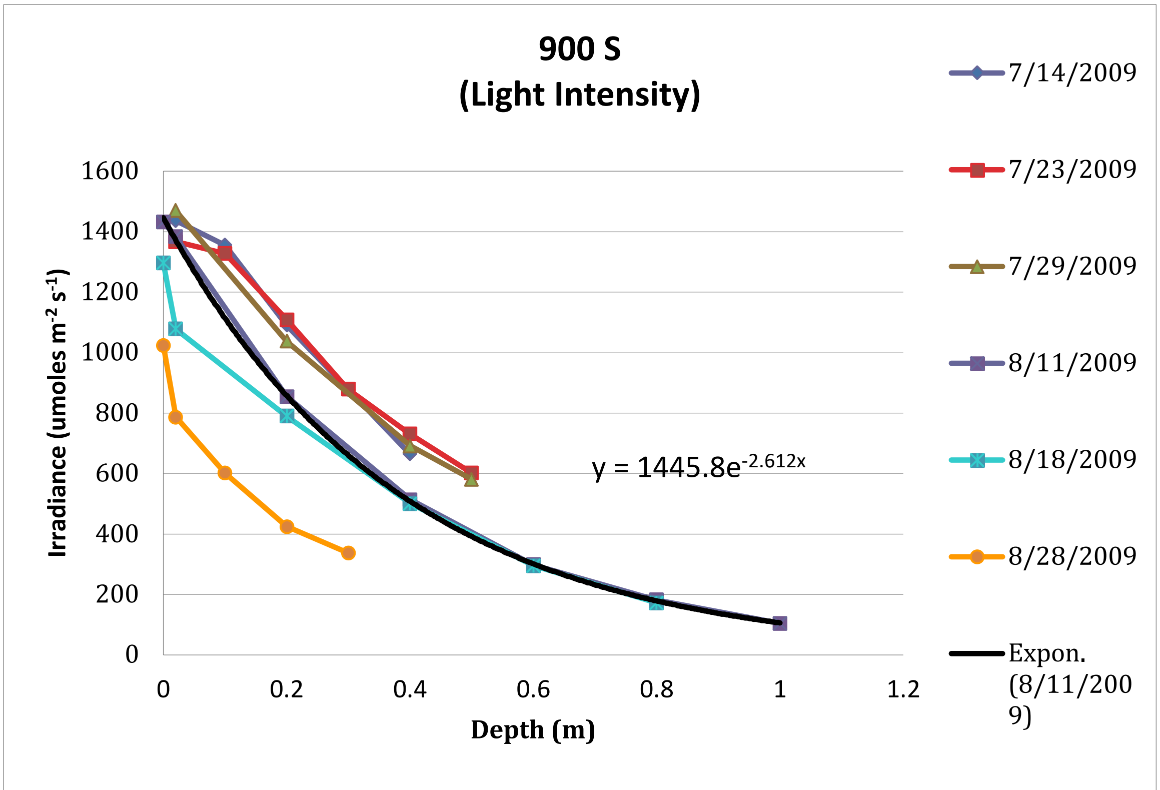

3300 S
(% of Surface Light Intensity)
Percentage of surface light
Depth (m)
y = 1.1041e-2.139x
y = 1.0284e-2.791x
R² = 0.9951
7/14/2009
7/23/2009
7/28/2009
8/11/2009
8/19/2009
8/31/2009
Expon. (7/14/2009)
Expon. (8/19/2009)

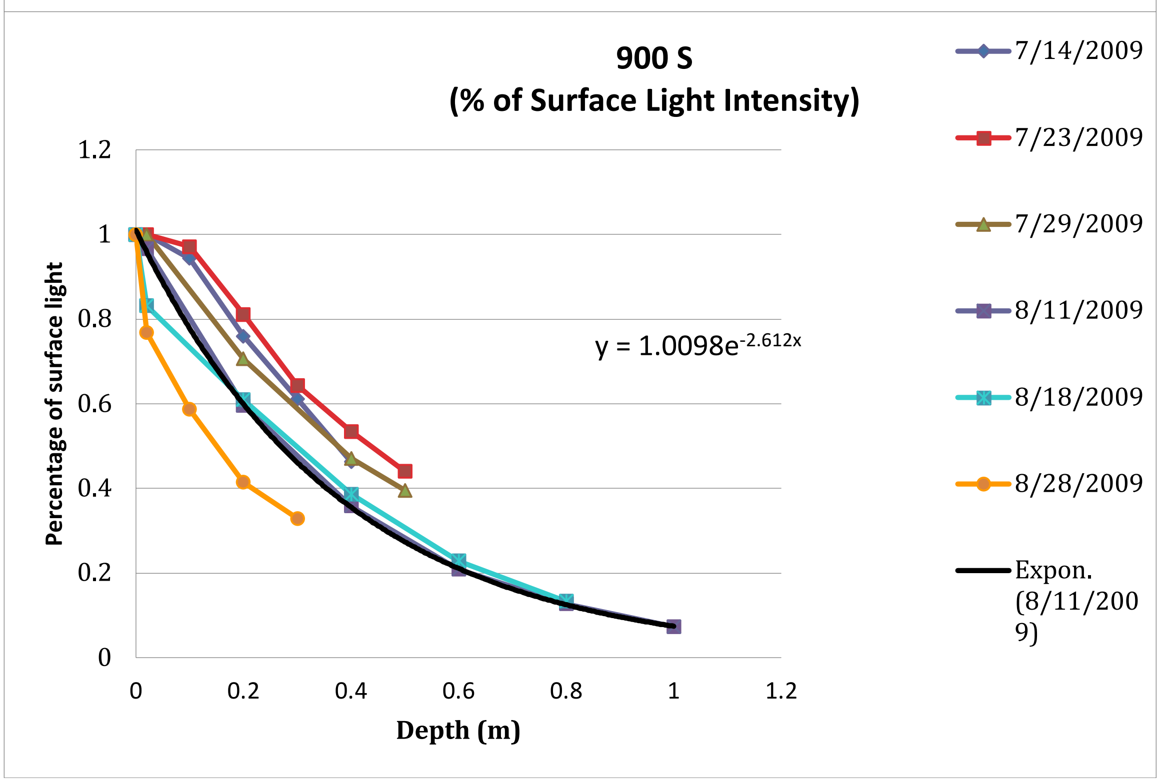

2100 S
(Light Intensity)
Irradiance (umoles m-2 s-1)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
Depth (m)
7/14/2009
7/23/2009
7/28/2009
8/11/2009
8/18/2009
8/28/2009

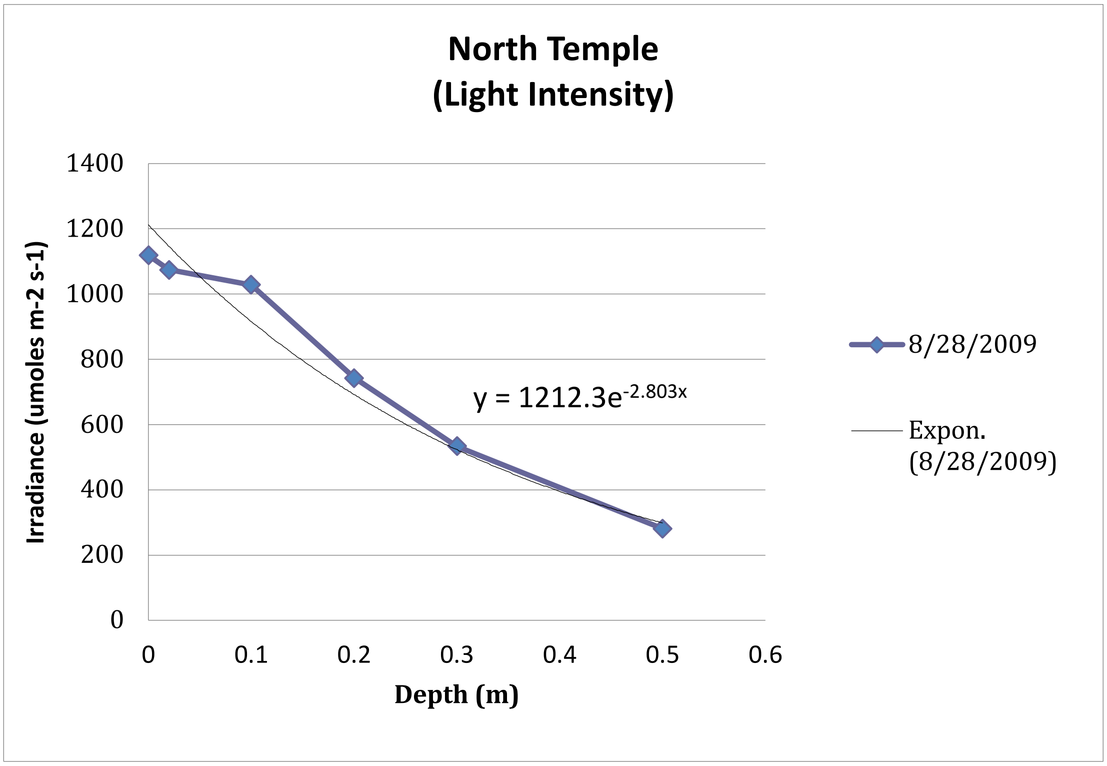

2100 S
(% of Surface Light Intensity)
y = 1.062e-1.871x
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Depth (m)
7/14/2009
7/23/2009
7/28/2009
8/11/2009
8/18/2009
8/28/2009
10/16/2009
Expon. (7/28/2009)

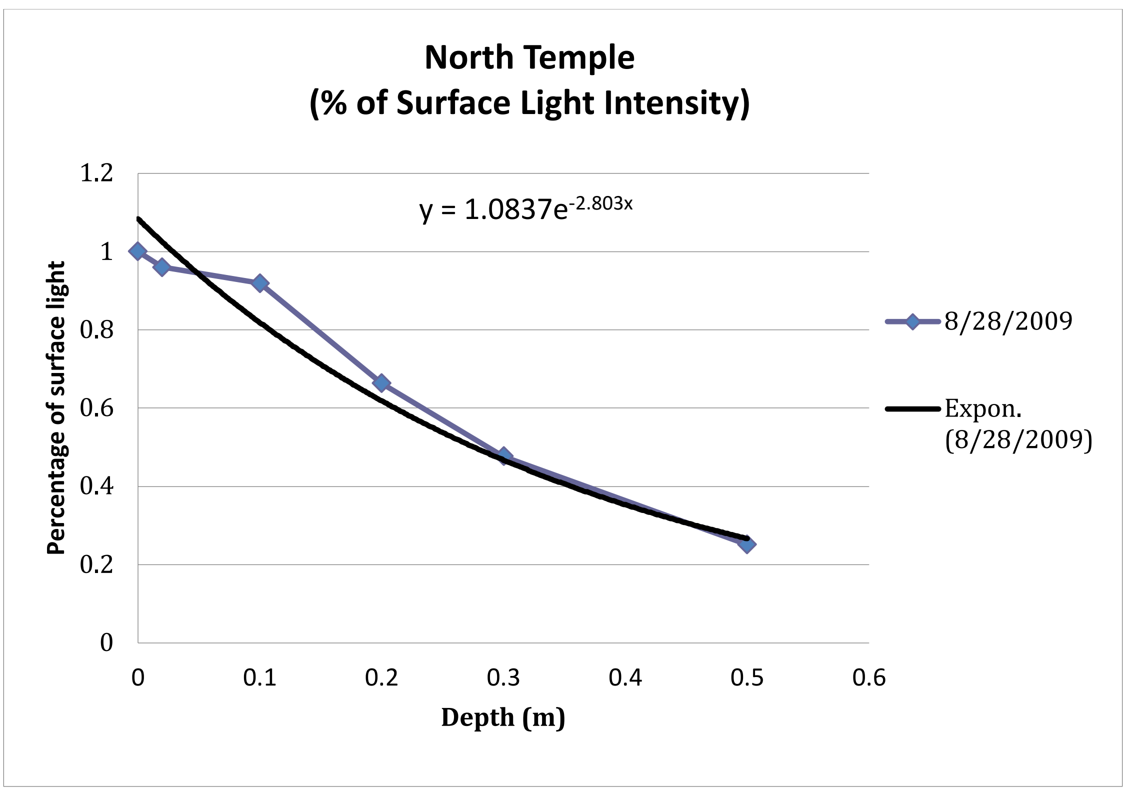

1700 S
(Light Intensity)
1400
1200
1000
800
600
400
200
0
Irradiance (umoles m-2 s-1)
0
0.2
0.4
0.6
0.8
1
Depth (m)
8/11/2009
8/28/2009

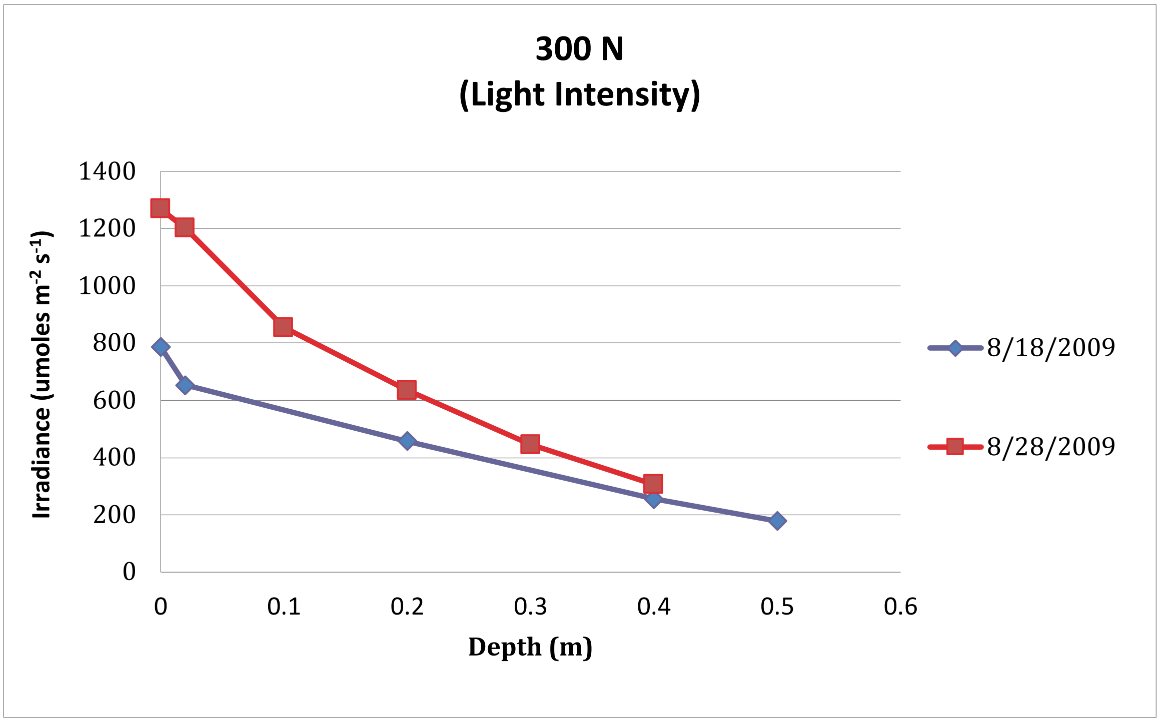

1700S
(% of Surface Light Intensity)
1.2
1
0.8
0.6
0.4
0.2
0
Percentage of surface light
y = 0.9349e-2.714x
0
0.2
0.4
0.6
0.8
1
Depth (m)
8/11/2009
8/28/2009
Expon.
(8/28/2009)


900 S
(Light Intensity)
Irradiance (umoles m-2 s-1)
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
y = 1445.8e-2.612x
7/14/2009
7/23/2009
7/29/2009
8/11/2009
8/18/2009
8/28/2009
Expon. (8/11/2009)

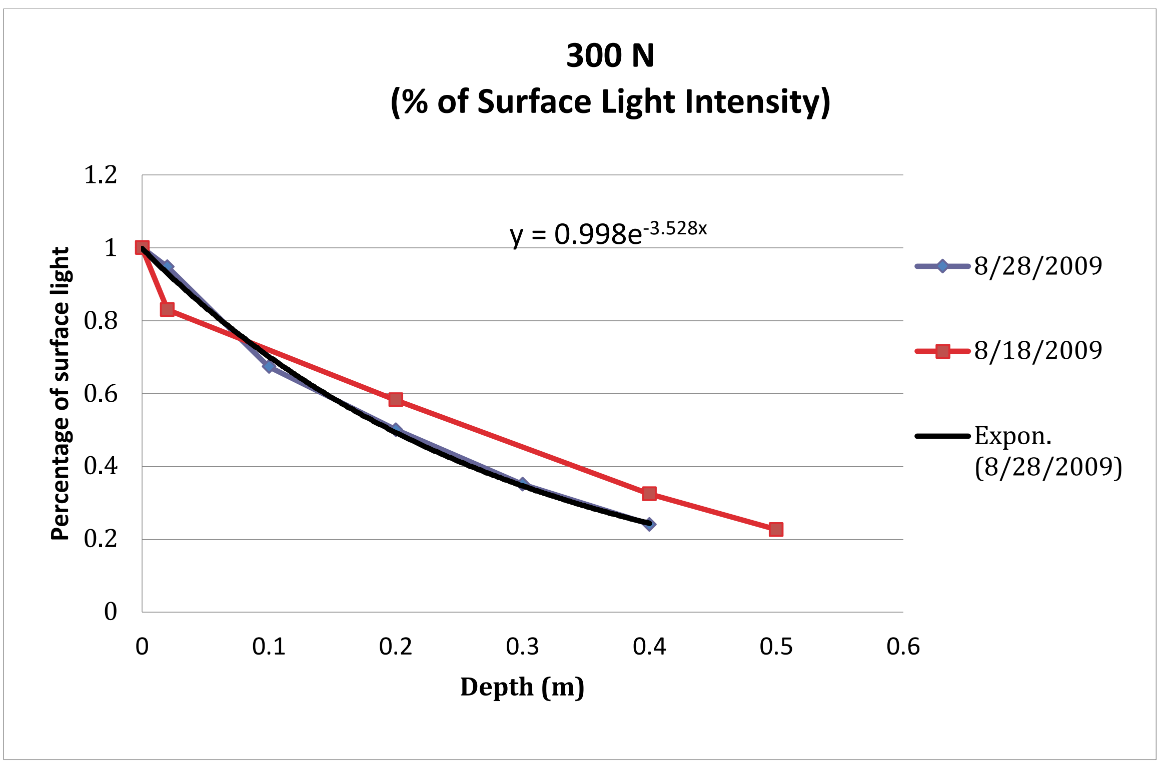

900 S
(% of Surface Light Intensity)
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
y = 1.0098e-2.612x
7/14/2009
7/23/2009
7/29/2009
8/11/2009
8/18/2009
8/28/2009
Expon. (8/11/2009)


North Temple
(Light Intensity)
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Irradiance (umoles m-2 s-1)
Depth (m)
y = 1212.3e-2.803x
8/28/2009
Expon. (8/28/2009)

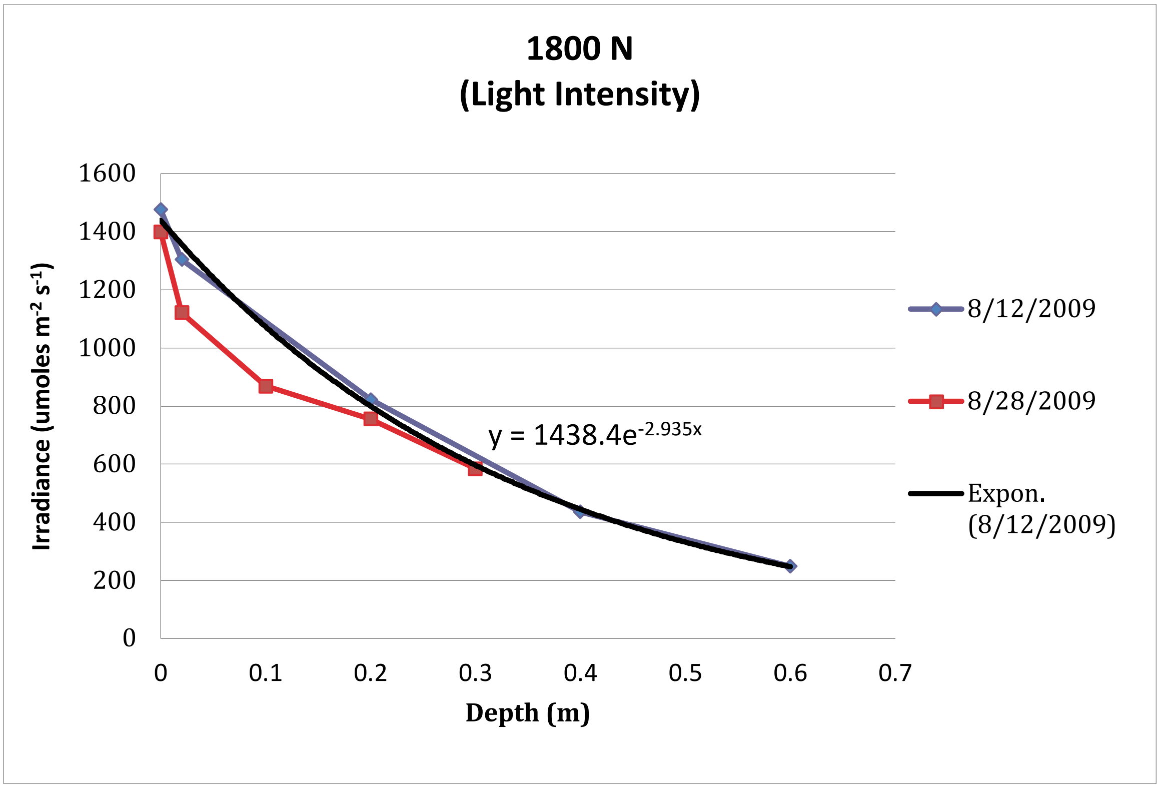

North Temple
(% of Surface Light Intensity)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Percentage of surface light
Depth (m)
y = 1.0837e-2.803x
8/28/2009
Expon. (8/28/2009)

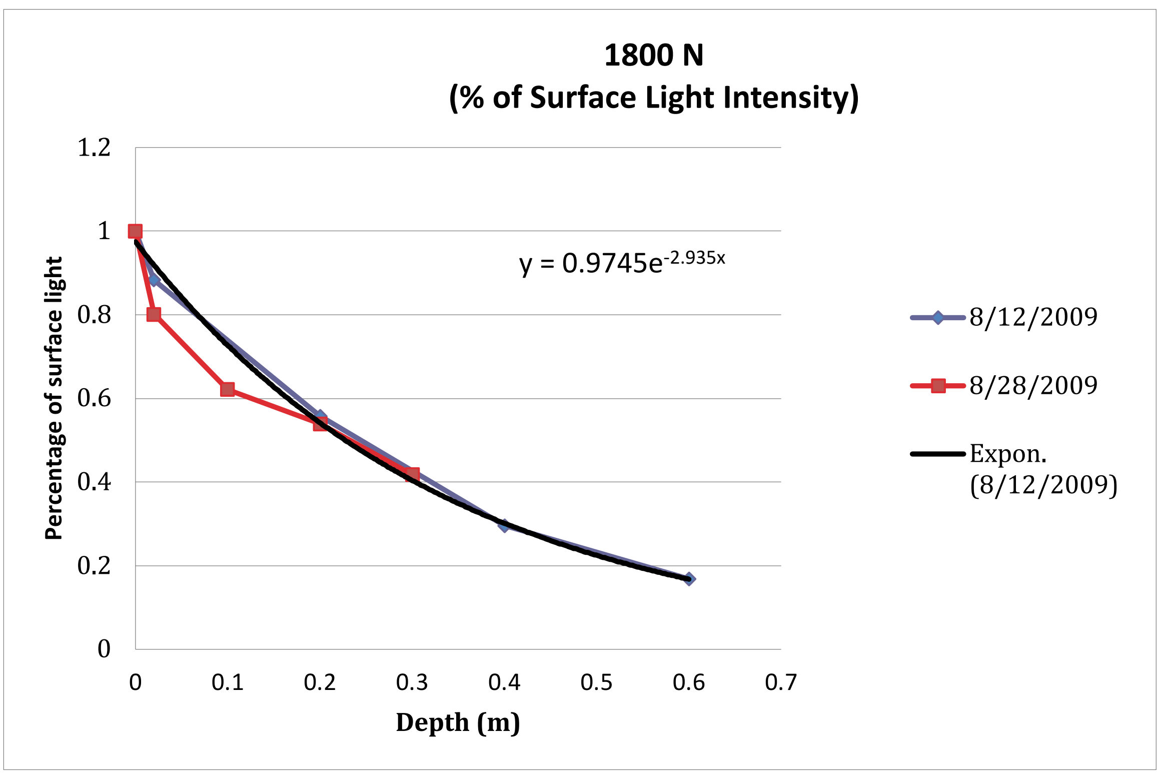


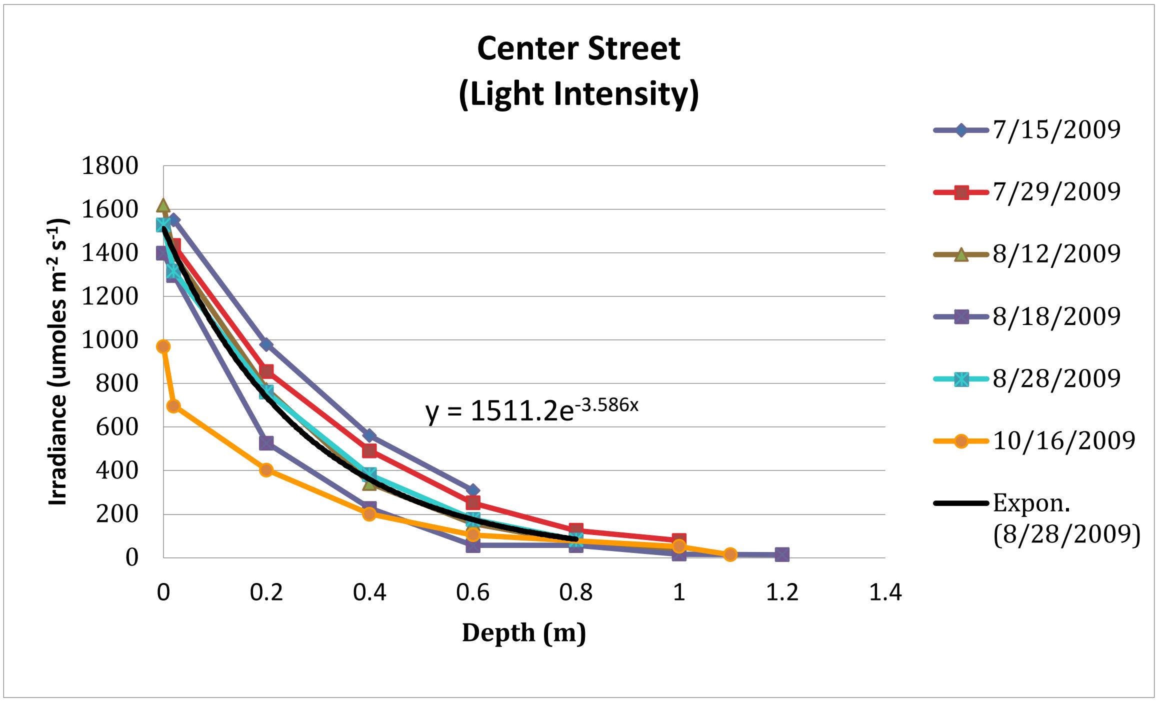
300 N
(Light Intensity)
Irradiance (umoles m-2 s-1)
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depth (m)
8/18/2009
8/28/2009



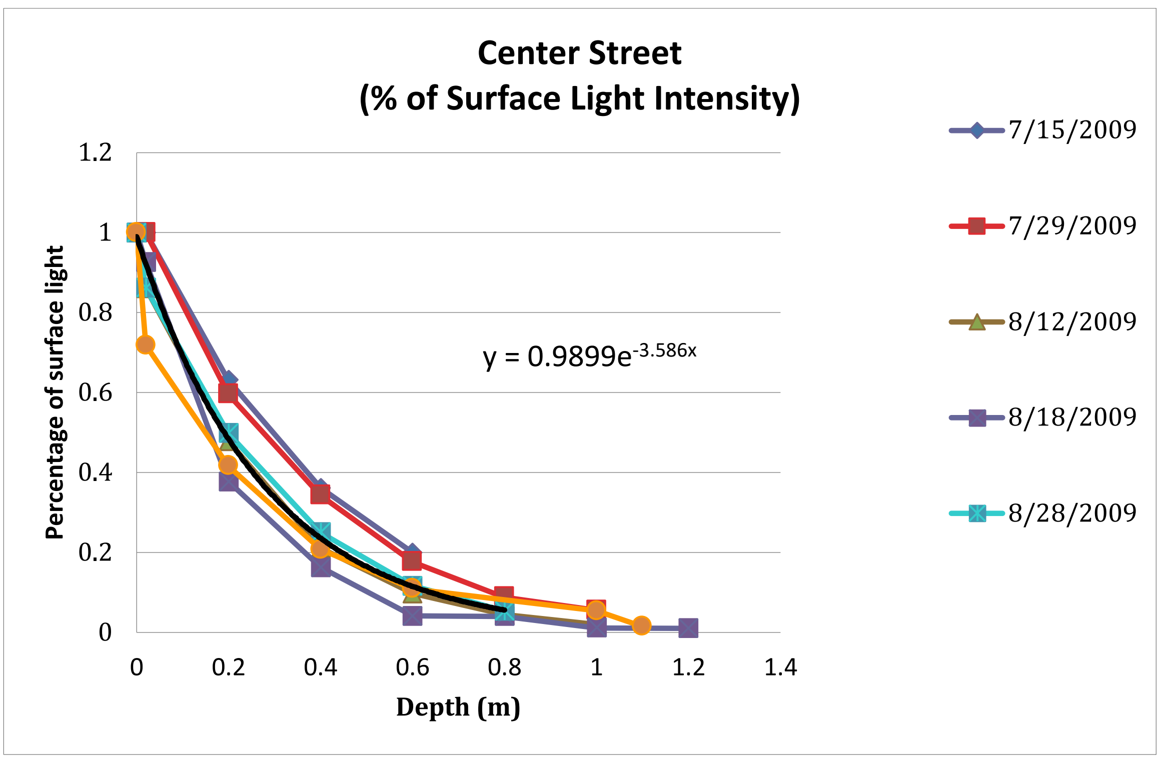
300 N
(% of Surface Light Intensity)
y = 0.998e-3.528x
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depth (m)
8/28/2009
8/18/2009
Expon.
(8/28/2009)


1800 N
(Light Intensity)
Irradiance (umoles m-2 s-1)
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Depth (m)
y = 1438.4e-2.935x
8/12/2009
8/28/2009
Expon. (8/12/2009)

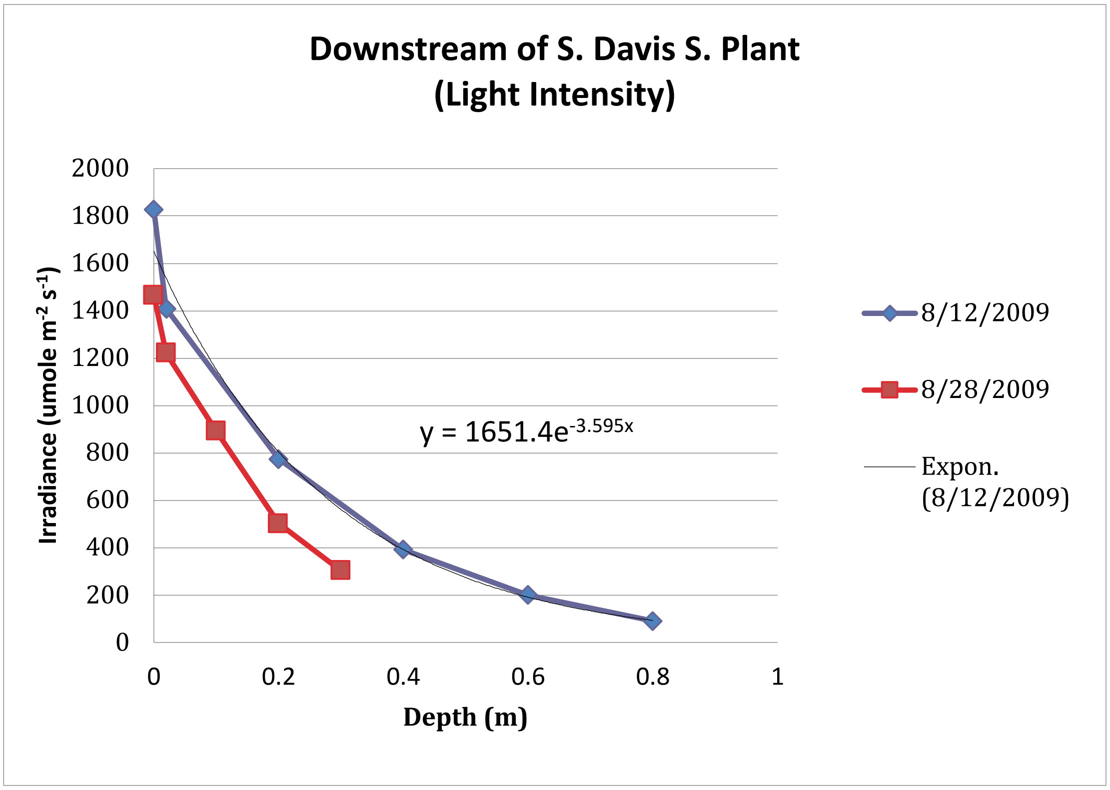

1800 N
(% of Surface Light Intensity)
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Depth (m)
y = 0.9745e-2.935x
8/12/2009
8/28/2009
Expon. (8/12/2009)

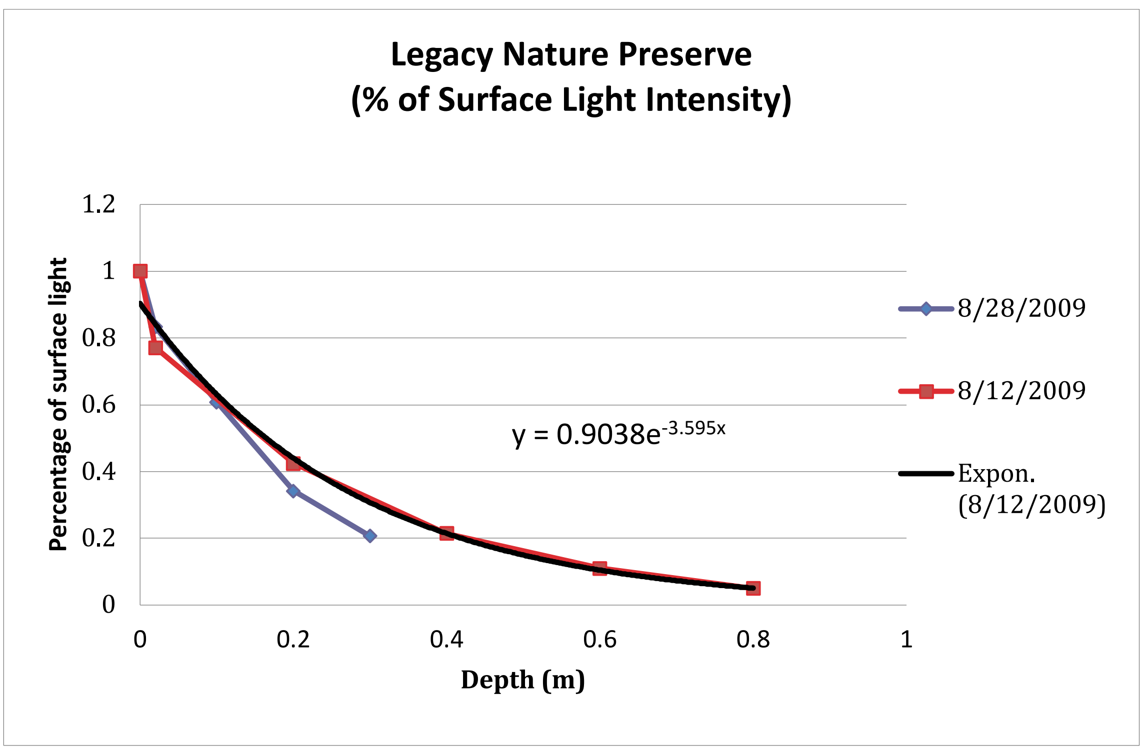


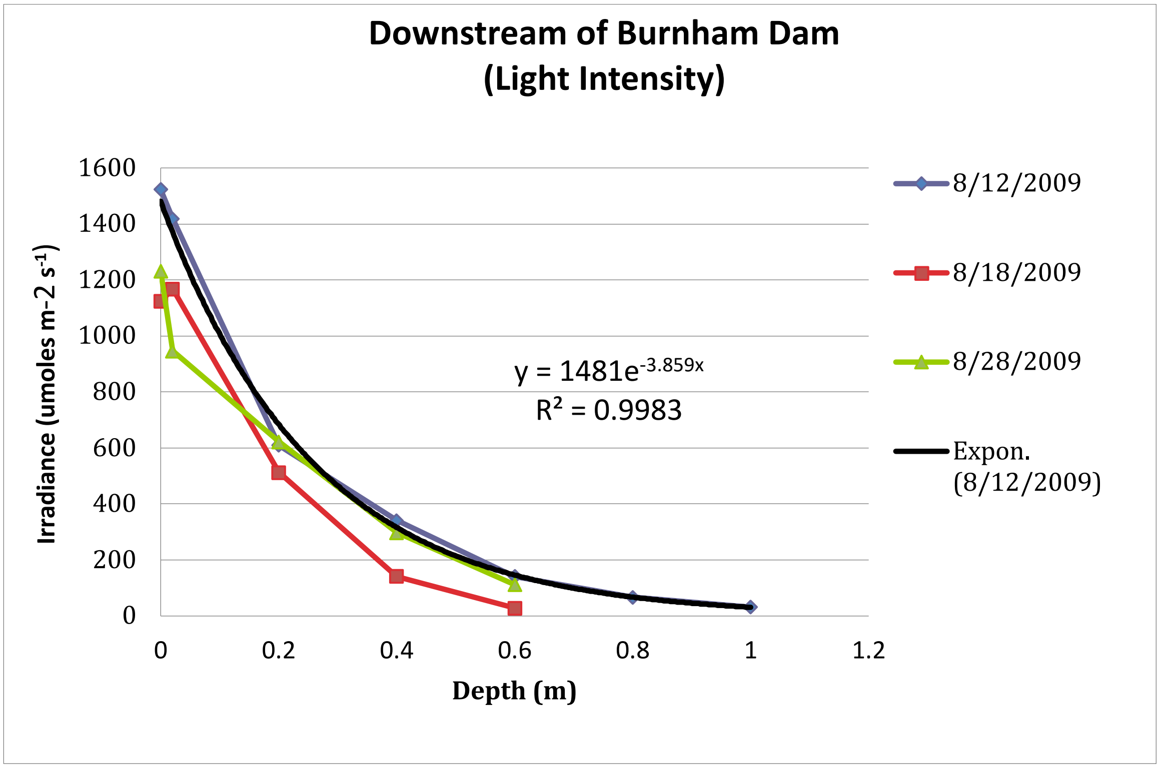
Center Street
(Light Intensity)
Irradiance (umoles m-2 s-1)
Depth (m)
y = 1511.2e-3.586x
7/15/2009
7/29/2009
8/12/2009
8/18/2009
8/28/2009
10/16/2009
Expon. (8/28/2009)

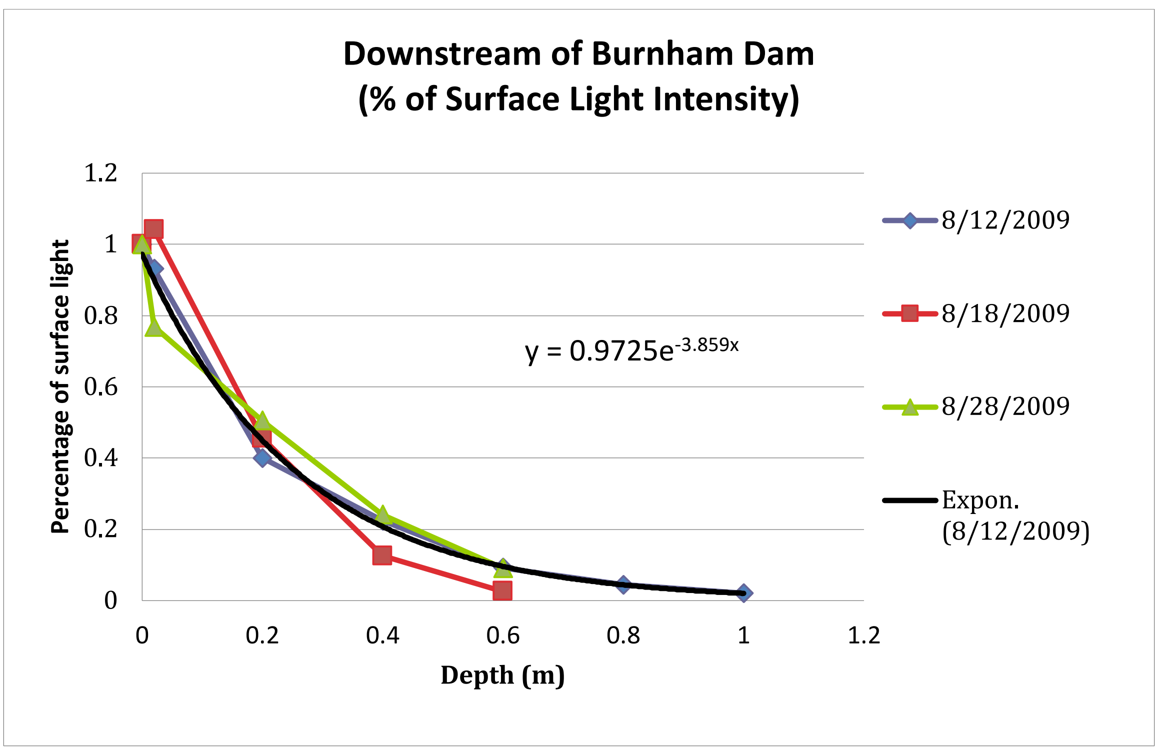


Center Street
(% of Surface Light Intensity)
Percentage of surface light
Depth (m)
y = 0.9899e-3.586x
7/15/2009
7/29/2009
8/12/2009
8/18/2009
8/28/2009


Downstream of S. Davis S. Plant
(Light Intensity)
Irradiance (umole m-2 s-1)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
Depth (m)
y = 1651.4e-3.595x
8/12/2009
8/28/2009
Expon. (8/12/2009)


Legacy Nature Preserve
(% of Surface Light Intensity)
Percentage of surface light
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Depth (m)
y = 0.9038e-3.595x
8/28/2009
8/12/2009
Expon. (8/12/2009)


Downstream of Burnham Dam
(Light Intensity)
1600
1400
1200
1000
800
600
400
200
0
Irradiance (umoles m-2 s-1)
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
y = 1481e-3.859x
R² = 0.9983
8/12/2009
8/18/2009
8/28/2009
Expon. (8/12/2009)


Downstream of Burnham Dam
(% of Surface Light Intensity)
1.2
1
0.8
0.6
0.4
0.2
0
Percentage of surface light
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
y = 0.9725e-3.859x
8/12/2009
8/18/2009
8/28/2009
Expon. (8/12/2009)