Dworshak Reservoir: Rationale for Nutrient Supplementation for Fisheries Enhancement

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SECTION 1.0 BACKGROUND

A request for proposal (RFP) was received in August 2005 from the Walla Walla District, Corps of Engineers, requesting collation of past/present limnological information required to prepare a report on the current trophic position and productive state of Dworshak Reservoir as it relates to the current depressed state fish stocks. Rationale was requested for the efficacy of nutrient supplementation to restore reservoir fisheries potentials. A site visit of Dworshak Reservoir was conducted in October 2004, and a presentation was given to Idaho Fish and Game and Corps biologists and local political representatives on the cost effectiveness of over 25 years of lake fertilization for restoration of sockeye salmon stocks in British Columbia (BC) sockeye nursery lakes. Ensuing discussions with staff identified several potential problems (bottlenecks) facing lake rearing kokanee fry populations, with declining reservoir forage production or 'oligotrophication' as the primary cause and elevated mortality from entrainment as a secondary cause.

SECTION 2.0 WORK OBJECTIVES AND DELIVERABLES

The primary work objective was to assemble data to enable assessment of the current trophic status of Dworshak Reservoir, and examine Nitrogen:Phosphorus ratio, determine where and when imbalances occur and prepare a prescription of nutrient supplementation to restore a proper N and P balance through the growing season so Carbon flows are restored to kokanee populations. More specifically, the deliverables were:

1. Review existing limnological information on Dworshak Reservoir and comment on state of the ecosystem and quality of the database.
2. Examine relevant nutrient data and summarize present balance or imbalance in NO_3:TDP ratio on production of edible/inedible phytoplankton as forage base and its impact on the productive (trophic) state of the reservoir and its fisheries.
3. Calculate the current annual areal total phosphorus (TP) loads - TP/m^2, using existing limnological and hydrological data, and compare, if possible, with historic loads.
4. Write the Prescription for the proper addition of nitrogen (N) and phosphorus (P) at appropriate frequencies with concentrations of N and P to restore a balanced N:P ratio to selected regions of the reservoir to promote a higher level of primary and secondary (forage) production. List anticipated water quality changes with nutrient supplementation.
5. Recommend appropriate suppliers of high quality liquid fertilizer of correct N:P formulations and list equipment required for application.
6. Develop a cost-effective 'state of the art' limnological monitoring program that is based on assessment of 'key' variables (i.e., those considered to be the most sensitive for the detection of major shifts in the reservoir's physio-chemical and biological systems).

2.1 Limitations of Database

Much of the past limnological work on Dworshak Reservoir was done either by Idaho Fish & Game fisheries staff, by private consultants to the U.S. Army Corps of Engineers (USACE), or by graduate students and university or government researchers, whose scope was often specific to either fisheries or limnology but seldom both in comprehensive detail. There is a paucity of good water quality data, and inconsistency of nutrient chemistry results which confounds meaningful comparisons among years. There are few extant data on seasonal distribution and abundance of phytoplankton, and an absence of data on populations of free-living bacteria and

pico-cyanobacteria. Further, there are no coherent long-term databases that were specifically designed to assess water quality and system productive capacity changes since impoundment. The best limnological databases are from a progress report (Juul and Funk 1996) and from fisheries investigations of adult kokanee returns, smolt abundance and distribution and seasonal changes in zooplankton populations. The majority of the existing studies were *not* designed for external, peer-review for possible journal publication, but rather for a client-based internal review process (i.e., gray literature). Generally speaking, this 'gray literature' is not as rigorous with its statistical treatment of the database or with the precision of sample collection and analytical chemical and biological analysis. For example, some of the early water chemistry data are not comparable to recent data because of methods used for analyses (i.e., detection levels were markedly different among labs utilized). Therefore, this report will by necessity be brief and rely largely on recent monitoring data (e.g., 1990-present).

Caveat: In the absence of a reliable TP and Total Dissolved Phosphorus (TDP) nutrient database I have had to rely on recent (May 1, 2005) analyses to write the supplementation prescription. I consider most of the earlier TP and TDP values too high for a number of reasons, the prime one being laboratory detection levels, the second being the high concentrations of colloidal and particulate debris and detritus from constantly eroding shorelines. Microscopic examination at 1560X magnification of 2005 phytoplankton samples revealed an inordinate amount detritus and debris, some clearly inorganic (silt, rock flour, etc.) but the majority in large clumps with what appeared to be large, colloidal, gelatinous debris clusters with large numbers of attached bacteria, dead algal cells (mostly benthic or riverine in origin), some phytoplankton, ciliates, and flagellates entrapped in the debris field. My feeling is that it comes from early success ional stages of biofilm developing on the eroded shorelines and washed into the pelagic by wind, and current from an ever eroding and fluctuating littoral slope/shoreline. Because of this omnipresent debris field in the reservoir, my surmise is that it leads to erroneously high values of TP, mostly unavailable for pelagic phytoplankton. Therefore I have used a 4-8µg/L TDP and 8-16µg/L TP range as a most realistic average seasonal TP and TDP concentration gradient for Dworshak. I have used a broader 10-20µg/L TP range in computation of annual TP loads and in summary figures in this report (Vollenweider 1976), hoping to capture within the range boundaries the present trophic position.

SECTION 3.0 OVERVIEW OF RESERVOIRS AND IMPOUNDMENTS

The building of dams on rivers or on lake outflows increases water retention and concurrently rates of bio-degradation and sedimentation of particulate organic and inorganic matter within the newly created impoundment; hence new reservoirs usually become effective nitrogen (N) and phosphorus (P) sinks. New reservoirs typically undergo a 'boom' and bust' production cycle following impoundment (Ney 1996, Stockner et al. 2000). The 'boom' or 'high' production phase results from the release of soluble reactive nutrients from eroding soils and from decomposing flooded vegetation. However, this nutrient source is only temporary, usually sustained for a few (4-7 yrs) growing seasons following inundation, but within 10 yrs ambient nutrient levels decline sharply to levels in balance with nutrient inputs from the drainage basin in which the reservoir is located. In the case of Dworshak reservoir the base geology results in very low nutrient delivery to the system. This 'bust' or low production phase is caused by a combination of factors, the most important being increased sediment N & P retention and P losses from discharge (P export). Another factor hastening the decline in carbon total (C) production or '*oligotrophication'* of impoundments is the loss of C production from an unstable and disrupted littoral zone. The primary cause of littoral zone dysfunction is abnormally large and irregular water level fluctuations (i.e., draw down). Draw down in winter can be particularly severe as ice-abrasion erodes, denudes and exposes the littoral zone to cold temperatures and periods of desiccation. This annual loss of littoral zone production further exacerbates the loss of P by sedimentation and alters the nutrient dynamics of regulated reservoir ecosystems, sometimes severely limiting their production potentials. Dworshak Reservoir has exhibited a response consistent with "boom and bust" production cycle as was reported by Falter (1979, 1982).

3.1 How New Reservoirs Age

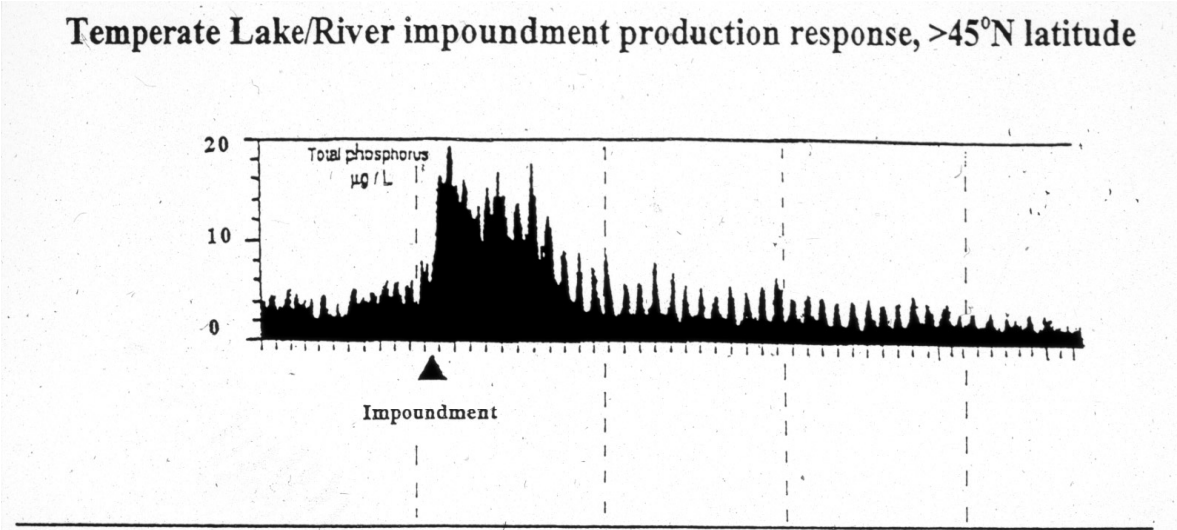
There are basically two types of reservoirs: those that are created by damming rivers, termed '**river reservoirs,'** (e.g., Kinbasket and Revelstoke reservoirs), and those that increase the level of existing lakes by damming the lake's outflow, called '**lake reservoirs,'** (e.g., Arrow lakes Upper Columbia Basin, Kootenay Lake). The river reservoir becomes a 'new' lake and the extent of flooded land and the associated environmental impact is usually large (see Fig. 1). The new lake starts recording change the day the water level stabilizes behind the dam, but there is no background data (it is a *new* lacustrine ecosystem!) with which to assess rate of change of new

river reservoirs. But in old lake basin reservoirs (e.g., Arrow Lakes) the land area flooded is often smaller and environmental impact less severe than in river impoundments. It is also easier to assess changes by using paleolimnological techniques or by examining pre-regulation data on water chemistry, fish or aquatic biotic. Despite differences in formation and environmental impact, both types of reservoirs seem to age in a similar manner after intervention with typical 'boom' and 'bust' cycles (Ney 1996, Stockner et al. 2000). After about 10-15 years, depending on latitude and water temperature, there follows a post-intervention period when the biota of reservoirs reach a new equilibrium that is sustained by more predictable nutrient supplies and balanced production levels. From a fisheries perspective it is unfortunate that this post-impoundment stable condition occurs about 20 years *after* impoundment, is irreversible in areas with minimal anthropogenic inputs (except by fertilization) and usually stabilizes at a *lower* C production level than occurred in the pre-intervention system. Of course, in a 'river' reservoir there is no previous lake system with which to compare post-production levels.

3.1.1 Summary of Reservoir Aging

Reservoir aging or 'oligotrophication' is linked to substantial nutrient losses once the 'boom' cycle subsides. Losses occur by:

- Reduced nutrient inputs (loads) from upstream impoundments (e.g., Kinbasket, Revelstoke reservoirs),
- Increased sedimentation rates with concomitant sediment adsorption (i.e., N & P retention),
- Deep-water (hypolimnetic) penstock discharge (nutrient bleeding), and
- Chronic littoral zone impairment.



Phase	*Pre-*	*'Boom'*	*Transition*	*'Bust'*	*Post-*
Year		1-5	5-8	8-15	perpetuity
Production ($gC \cdot m^{-2} y^{-1}$)	50-70	100-120	80-100	40-60	30-50
Total P	2-4	10-14	6-8	2-4	1-3
Trophic state	oligotrophic	mesotrophic	oligotrophic	ultra-oligotrophic	ultra-oligotrophic
Fish prod.	low	moderate	low	very low	very low
Transparency	high	low	moderate	high	very high

Fig. 1 A schematic primary production time series for a north temperate reservoir following impoundment (from Stockner et al. 2000)

SECTION 4.0 PHYSIO/CHEMICAL CHARACTERISTICS

Dworshak Reservoir is located on the North Fork Clearwater River. The North Fork Clearwater River drains into the Clearwater River 2.4 kilometers downstream from the dam face. The dam construction started in 1966, was completed in 1971, and the reservoir reached full pool by the spring of 1973.

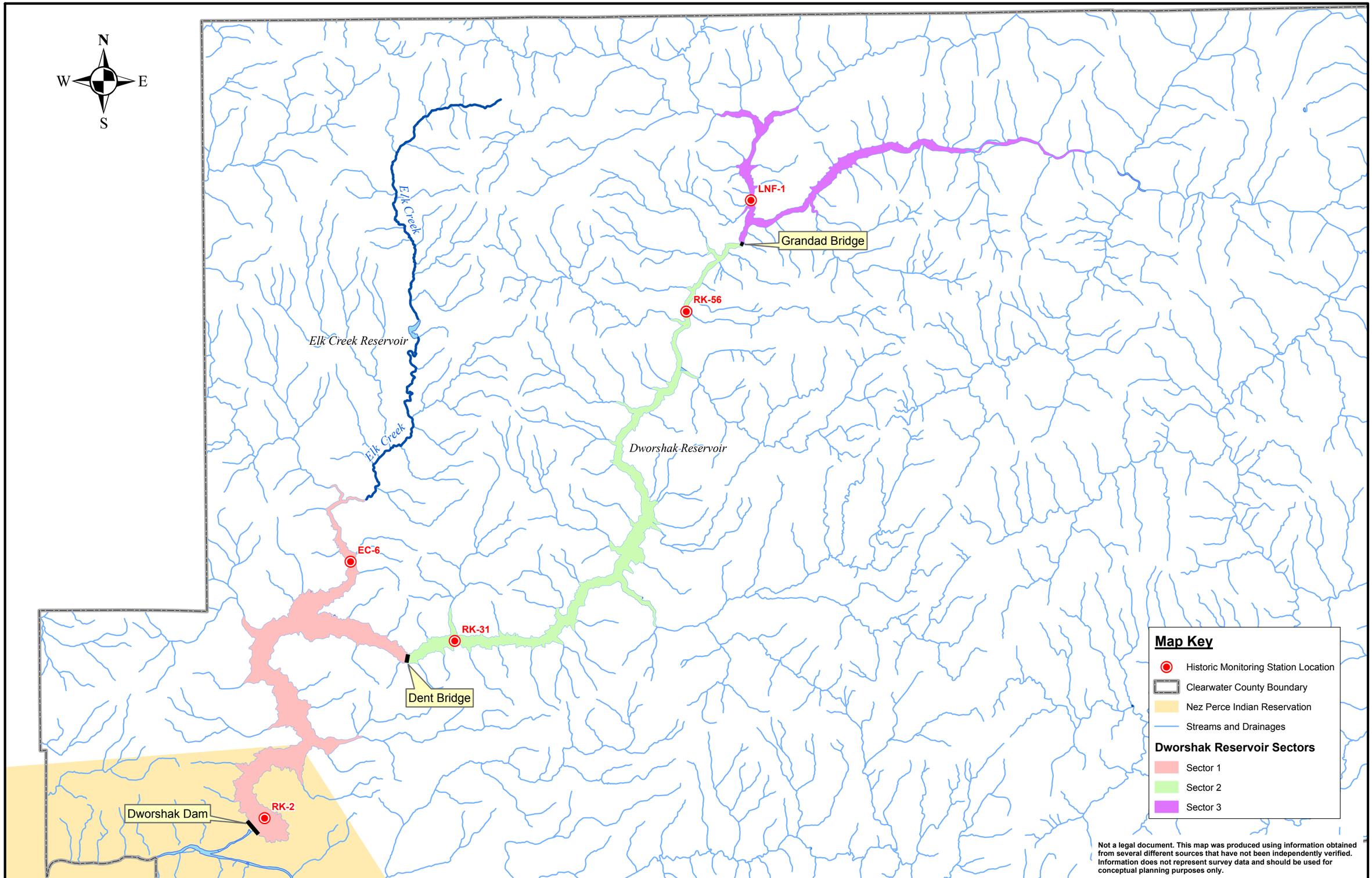
The dam is a concrete structure rising 218 meters above the riverbed. At normal full pool, the water depth at the dam is 193 meters, and the reservoir has a storage capacity of 4.26 cubic kilometers, of which 2.47 cubic kilometers are usable for flood control and power generation. When full, the water elevation is 488 meters and impounds the river for 86.3 kilometers and creates 282 kilometers of shoreline. The resulting surface area is 6,645 hectares. Additional physical characteristics of the reservoir can be found in Table 1.

Table 1 Physical characteristics of the Dworshak Reservoir Project.

Characteristic	Value
Drainage Area (Hectares)	632,000
Effective Hydraulic Height (M)	193
Water Elevation at Full Pool (M)	488
Stream Flow (m^3/s)	
Minimum on Record	7.1
Mean Annual	162
Storage Capacity (Km^3)	
Gross	4.26
Usable	2.47
Surface Area (Hectares)	
At 488 Meters	6,645
At 440 Meters	3,660
Mean Water Residence Time (Months)	10

The reservoir is operated by the U.S. Army Corps of Engineers, Walla Walla District. The lower 9.5 kilometers of the reservoir is located on the Nez Perce Indian Reservation and the entire project is in Clearwater County, Idaho (Fig. 2).

The project does not have any fish passage facilities. To mitigate for the loss of the anadromous fish migrations a fish hatchery was built near the base of the dam. The dam is equipped with selector gates to allow water from varying depths to be discharged thereby giving some control over the water temperature and dissolved oxygen content being released from the dam and promote optimal conditions for fish propagation in the hatchery.



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File	05_Dworshak / dworshak	Requestor	D. Brandt
Print Date	December 7, 2005	Project Manager	D. Brandt
Project Number	05085	Cartographer	B. Bailey

Project Name: Dworshak Limnology Analysis

2 1 0 2 4 Kilometers

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Dworshak Reservoir and Vicinity

The North Fork of the Clearwater River drains 632,000 hectares of montane forest. The primary geology of the area is Columbia River Basalt and exposed metamorphosed sediments with granitic intrusions. The base geology results in relatively low values of nitrogen and phosphorus in the runoff water. The area consists of steep slopes (40-70%) with shallow surface soils (0.50 to 1.25 M).

Peak flow occurs in mid-May and with discharges in the range of 300 to 560 m^3/s. Typical mean annual stream discharge is between 100 and 225 m^3/s. During low stable base flow the mean stream discharge is approximately 50-60 m^3/s. The reservoir operations have resulted in lower peak flows in the spring and early summer and slightly higher stream flows in the late summer and fall (Fig. 3). The reservoir reaches full pool in June and by July water is being released from the reservoir to provide a cold water supply to reduce water temperatures in the Clearwater River. In the years of 2001-2004 Dworshak Reservoir's volume was reduced by 0.6, 0.7 and 0.23 km^3 during the months of July, August, and September. The water discharged from the reservoir in these three months consisted of approximately 61% of the usable storage.

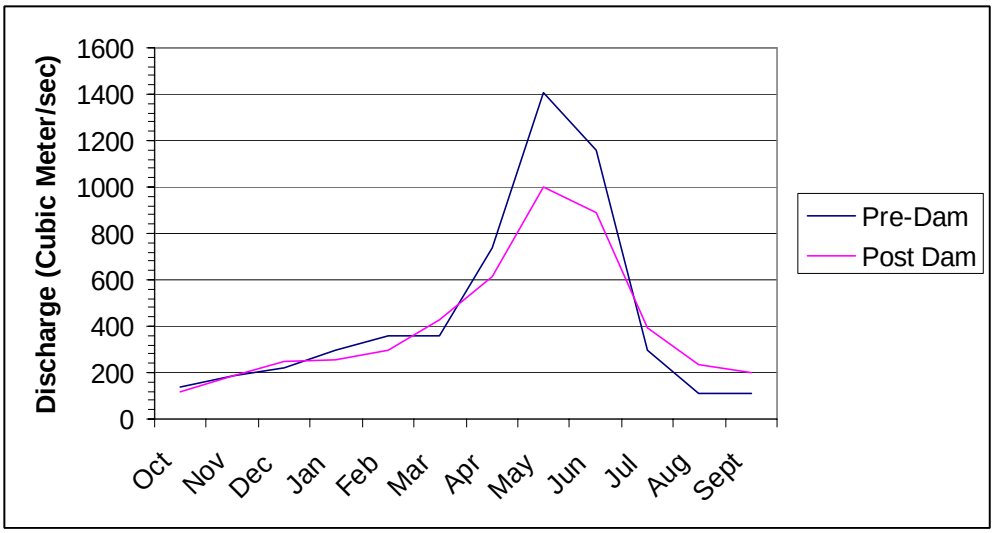


Fig. 3 Mean monthly stream discharge pre vs. post impoundment.

The basin is dominated by maritime air masses and prevailing westerly winds. Prolonged gentle rains, deep snow accumulations at higher elevations with fog, cloudiness, and high humidity characterize the basin in the fall, winter, and spring. Winter temperatures are often 8 to 15 degrees Celsius warmer than continental locations of the same latitude. A seasonal snowpack generally covers the area from November to June. The climate during the summer months is influenced by high-pressure stationary systems. These warm, dry, summer systems result in less than approximately 15% of the annual precipitation.

On rare occasions, mild Pacific air masses meet cold continental air masses producing heavy rainfall combined with rapid snowmelt. This phenomenon is called a rain-on-snow event. These events often occur mid-winter, outside the normal spring snowmelt. They lead to soil saturation, huge amounts of run-off, and can produce large amounts of sediment through erosion and mass wasting. Low to mid elevations, up to about 4,000 feet elevation, are the most susceptible to rain-on-snow in the sub-basin, since above 4,000 feet most of the precipitation still falls as snow. Several major rain-on-snow events have occurred in recent history.

The reservoir is very narrow compared to its length. The width of the reservoir ranges from 0.5 km to 2.5 kms. The reservoir's volume development value is 0.96 indicating that the reservoir is almost a perfect cone and that the side walls maintain a similar slope from the surface to bottom. The hypsographic curve and volume curve for the usable storage area of the reservoir are presented in Fig. 4.

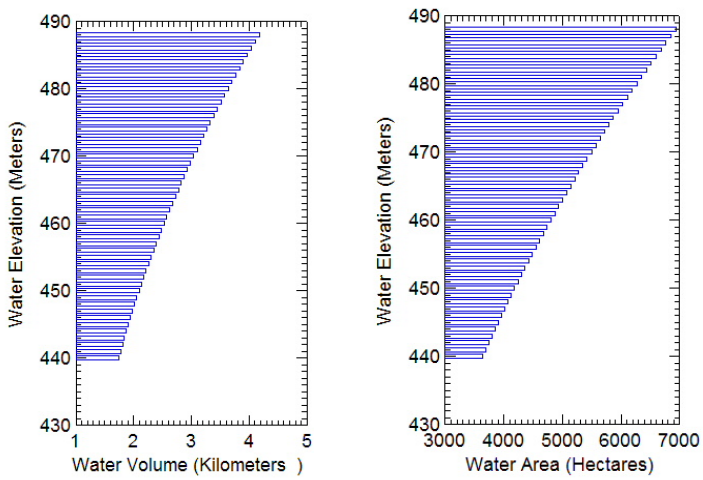


Fig. 4 Hypsographic and volume curve for the upper 48 meters of Dworshak Reservoir.

4.1 Historical Nutrient Information

The data used in the following sections were reported in three separate reports. Shortly after the reservoir filled, the USACE commissioned a limnological survey of the reservoir. This study was conducted by the University of Idaho under the direction of Dr. Mike Falter. This study provides baseline physical, chemical, and biological conditions within the reservoir. A second in depth limnological survey was conducted in 1993-1996. This survey was conducted approximately 20 years after the reservoir was filled and was conducted by Steve Juul. In 2004 and 2005 Erik Stark with the Idaho Department of Fish and Game (IDFG) performed a third

limnological survey on the reservoir. This report will be used to indicate current physical and chemical conditions within the system.

4.1.1 Nitrogen

Nitrate was used to indicate nitrogen availability within the reservoir. It was collected in two of the three studies. Juul and Funk collected Nitrite+Nitrate, but due to the transitory nature of nitrite in surface water, we used the Nitrate and Nitrite+Nitrate values interchangeably. Mean epilimnetic (0-12.5 M) values at three mainstem pelagic stations and two pelagic stations in major arms of the reservoir for the three studies are summarized in Table 2a. The concentration for Nitrate has dropped significantly since the 1973 and 1995 studies (Fig. 5). The area submerged by the reservoir consisted of a recently harvested coniferous forest. A considerable amount of biomass was removed but the slash from the activities as well as undecomposed duff were left in place. The higher concentrations earlier in the reservoir's history are likely a result of the large amount of organic matter submerged and its subsequent decay.

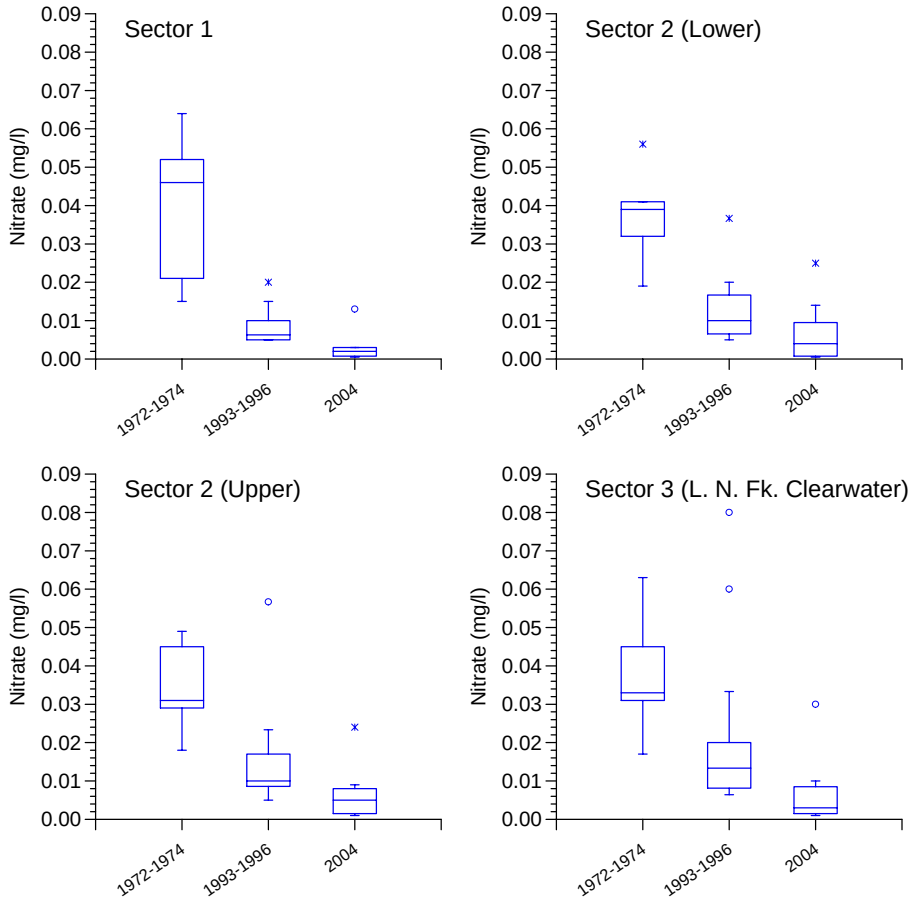


Fig. 5 Epilimnetic nitrate concentrations in four pelagic stations.

4.1.2 Phosphorus

The only species of phosphorus collected consistently in the three studies was Orthophosphate. The equations develop by Vollenweider requires the use of total phosphorus, however due to the lack of total phosphorus in one of the studies we looked at trends in orthophosphate as an indicator of the changes in phosphorus concentration through the history of the reservoir. Mean epilimnetic (0-12.5 M) values at three mainstem pelagic stations and two pelagic stations in major arms of the reservoir for the three studies are summarized in Table 2b.

Table 2a Mean epilimnion nitrite + nitrate concentrations (mg/L).

	Sector 1			Sector 2 (Lower)			Sector 2 (Upper)			Elk Creek			Sector 3 (L. N. Fk. Clearwater)		
	1972-75	1992-1995	2004	1972-75	1992-1995	2004	1972-75	1992-1995	2004	1972-75	1992-1995	2004	1972-75	1992-1995	2004
Maximum	0.0520	0.0200	0.0030	0.0410	0.0367	0.0140	0.0450	0.0567	0.0240	0.0450	0.0200	0.0080	0.0450	0.0800	0.0300
Mean	0.0377	0.0083	0.0018	0.0307	0.0129	0.0049	0.0313	0.0154	0.0078	0.0327	0.0104	0.0034	0.0310	0.0218	0.0084
Minimum	0.0150	0.0050	0.0005	0.0190	0.0050	0.0005	0.0180	0.0050	0.0010	0.0170	0.0050	0.0010	0.0170	0.0064	0.0010
N of cases	3	20	5	3	12	5	3	13	5	3	14	5	3	13	5
Standard Dev	0.0199	0.0042	0.0013	0.0111	0.0091	0.0054	0.0135	0.0136	0.0094	0.0143	0.0060	0.0030	0.0140	0.0230	0.0123

Table 2b Mean epilimnion orthophosphate concentrations (mg/L).

	Sector 1			Sector 2 (Lower)			Sector 2 (Upper)			Elk Creek			Sector 3 (L. N. Fk. Clearwater)		
	1972-1975	1992-1995	2004	1972-1975	1992-1995	2004	1972-1975	1992-1995	2004	1972-1975	1992-1995	2004	1972-1975	1992-1995	2004
Maximum	0.0190	0.0014	0.0130	0.0170	0.0017	0.0100	0.0160	0.0060	0.0050	0.0220	0.0027	0.0070	0.0270	0.0038	0.0070
Mean	0.0157	0.0007	0.0055	0.0127	0.0009	0.0040	0.0127	0.0010	0.0030	0.0177	0.0010	0.0041	0.0177	0.0010	0.0034
Minimum	0.0110	0.0005	0.0025	0.0100	0.0005	0.0025	0.0100	0.0005	0.0025	0.0120	0.0005	0.0025	0.0110	0.0005	0.0025
No. of cases	3	20	5	3	12	5	3	13	5	3	14	5	3	13	5
Standard Dev.	0.0042	0.0003	0.0046	0.0038	0.0005	0.0034	0.0031	0.0015	0.0011	0.0051	0.0007	0.0022	0.0083	0.0010	0.0020

Average epilimnetic (12M) values for May-September.
Values below the reportable limit were halved for calculation of descriptive statistics.
The Nitrate values are Nitrate for the Falter and Stark studies but Nitrite+Nitrate for the Juul and Funk data. We combined them due to the very low percentage of Nitrite in surface waters.
Sector 1 Station is located at RM-3 (Falter), NFC-3 (Juul and Funk), and RK-2 (Stark)
Sector 2 (Lower) Station is located at RM-19 (Falter), NFC-19 (Juul and Funk), and RK 31 (Stark)
Sector 2 (Upper) Station is located at RM-35 (Falter), NFC-35 (Juul and Funk), and RK 56 (Stark)
Elk Creek is a combination of EC-4 (Falter, and Juul and Funk), and EC-6 (Stark)
Sector 3 (L. N. Fk. Clearwater) is a combination of LNF-1 (Falter, and Juul and Funk), and LNF-3 (Stark)
The Falter and Juul and Funk sites were the same locations. The Stark sites were within 1 to 1.5 Kilometers of the other sites.

The orthophosphate concentrations have dropped considerably since the 1973 study (Fig. 6). The data seem to indicate that the orthophosphate concentrations have increased from the 1995 study. We contend that this is due to the inability for laboratories to accurately measure orthophosphate concentrations in the values found in Dworshak Reservoir. We suspect that the current orthophosphate levels are significantly lower than those reported by Stark.

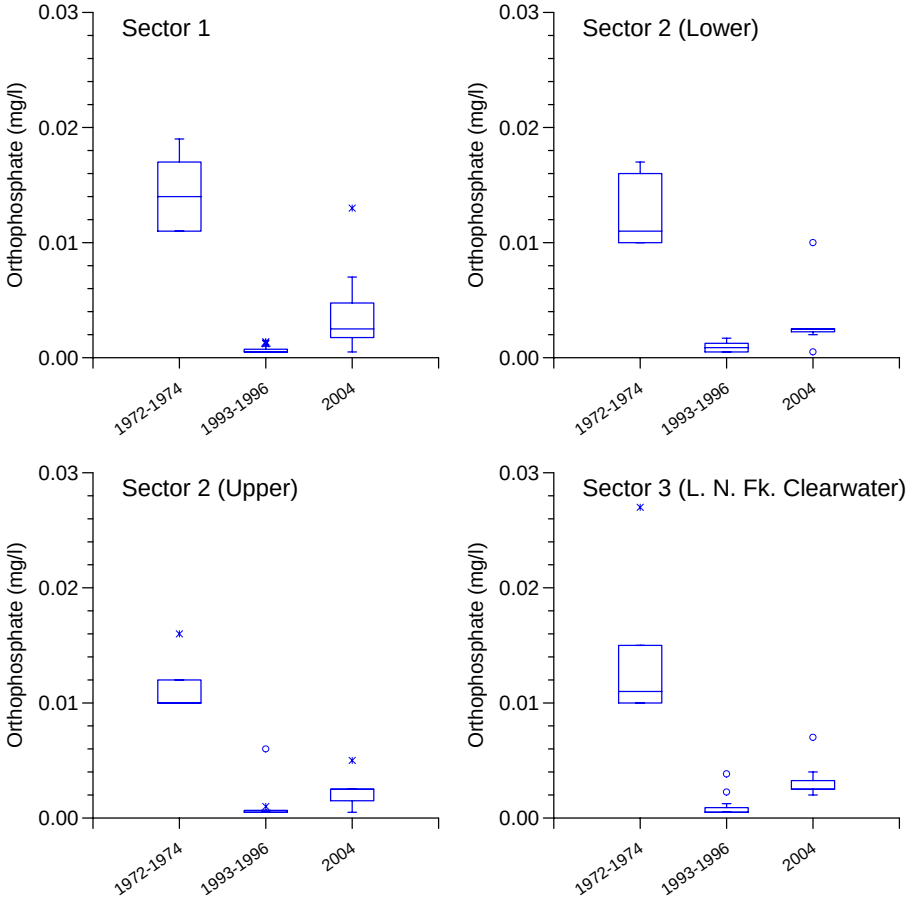


Fig. 6 Epilimnetic orthophosphate concentrations in four pelagic stations.

4.2 Temperature

Dworshak Reservoir starts to thermally stratify in April, with a strong thermocline by June that intensifies until August (Fig. 7). The reservoir is monomictic for the lower 30 kilometers and dimictic as the reservoir becomes shallower and closer to the tributary streams. The lower portion of the reservoir does not become fully mixed until January or February. The upper portion of the reservoir attains homothermy approximately three weeks sooner than the lower portions (Falter et al. 1979).

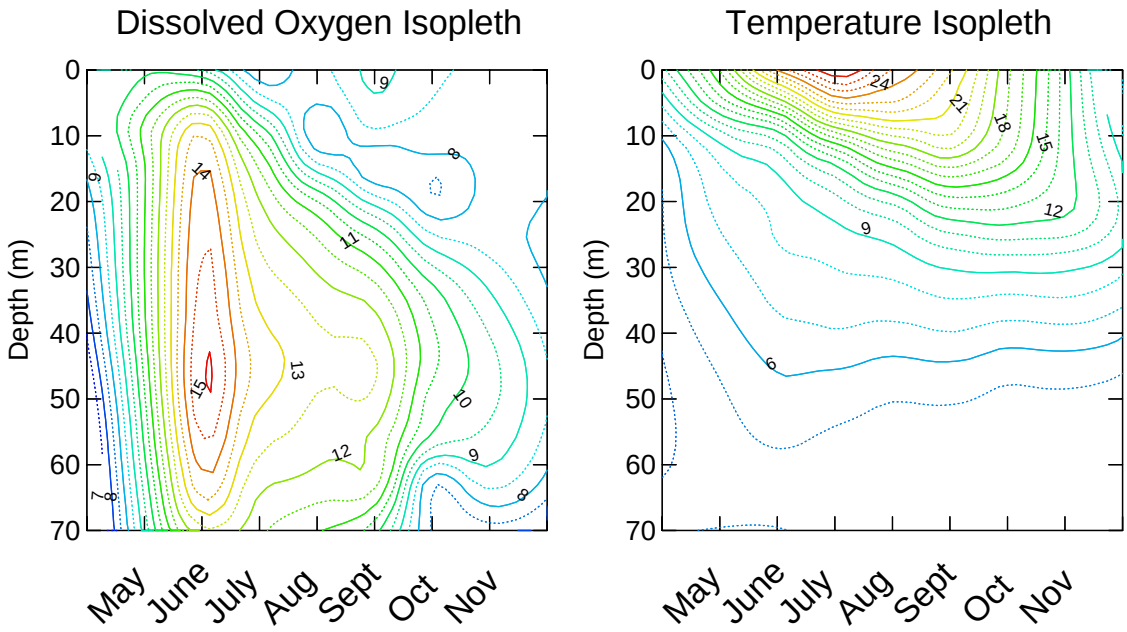


Fig. 7 Dissolved oxygen and temperature isopleths for the Lower Reservoir in 2004.

Mean summer surface temperatures of Dworshak Reservoir can exceed 25°C during the months of July and August. The water temperature remains relatively warm (>20°C) for the upper 6-8 meters during the summer. The epilimnion averages 10 meters to 13 meters below the water surface and constitutes 20% to 22% of the total reservoir volume for the summer months. The hypolimnion makes up a majority (70%) of the water volume in the reservoir. Hypolimnetic temperatures during June, July and August range from 9°C around 20 meters below the water surface to 4.5°C at depths greater than 60 meters (Stark 2005a).

4.3 Dissolved Oxygen

Dissolved oxygen concentrations in lakes and reservoirs are strongly influenced by thermal stratification, the decay of organic material, and oxygen resupply rates. Data from the 1972-1974 Falter study indicate that decay of organic matter in Dworshak Reservoir depleted the oxygen supply in depths greater than 150 meters. Interpretation of the dissolved oxygen isopleths presented in the Falter report indicates that dissolved oxygen concentrations were depleted to 6 mg/L at depths of 75 meters, the level at which one can start to find adverse effects on the aquatic community. In 1995, Juul and Funk collected dissolved oxygen data to depth at the lower reservoir station. The dissolved oxygen profile from 1995 no longer shows a significant depletion in the hypolimnion (Fig. 8). This would suggest that the organic matter submerged

during the creation of the reservoir was no longer a significant factor in creating oxygen depletion in the hypolimnion. The 2004 Dworshak Reservoir dissolved oxygen profile also indicates that there is little oxygen depletion in the hypolimnion (Fig. 7). The data collected in 2004 did not exceed 60 meters in depth so there is no recent data of the deep water dissolved oxygen levels. The 1995 and 2004 dissolved oxygen isopleths are similar for the upper 60 meters and it is likely that current dissolved oxygen conditions in the hypolimnion are similar to those found in 1995. Dissolved oxygen concentrations in Dworshak Reservoir should not be a limiting factor to the aquatic community and there appears to be a large buffer before reductions in dissolved oxygen would be a concern.

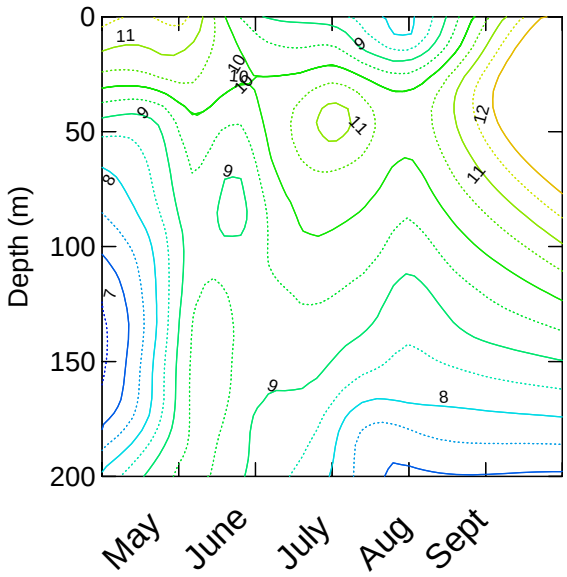


Fig. 8 Dissolved oxygen isopleth for Lower Reservoir from Juul and Funk's 1995 survey.

4.4 Water Clarity

Secchi measurements for Dworshak reservoir from the three studies are presented in Table 3. The Secchi values from the Falter study are estimated from figures presented in the report. This will result in some inaccuracies in these early readings but should still be useful in determining if there have been substantial changes in clarity from the early 1970s to present.

Overall, it appears that there has been little change in reservoir clarity in the past 30 years. Lake means for the months of March through November were approximately 3 meters in 1972-1974, and 1993-1996. In 2004 and 2005, the lake wide mean had increased to just under 4 meters. Minimum Secchi depths of approximately 1 meter were recorded in 1972, 1974, and 1995. The lowest readings in the Falter study were recorded in the lower reservoir. In 1995, the

lowest Secchi reading was taken in the Elk Creek arm and at the mid-reservoir station. The upper reservoir typically has the highest Secchi depths with a maximum of 7.6 m (estimate) recorded in August 1974. The area of the reservoir with the lowest water clarity continues to be the Elk Creek arm.

Table 3 Minimum, maximum, and mean Secchi measurements for 1972-1974, 1993-1996, and 2004-2005.

	1972-1974*		**1993-1996**		**2004-2005**	
	Value	**Date**	**Value**	**Date**	**Value**	**Date**
Minimum (M)	<1	July 1972 May 1974	1	March 1995	2.1	Aug. 2004 April 2005 May 2005
Mean (M)	3		3.2		3.85	
Maximum (M)	7.6	Aug. 1974	7.2	Nov. 1993	6.7	Oct. 2004 Nov. 2005

* Values were estimated from Figure 17. in Falter et al. (1979)

SECTION 5.0 ECOLOGY OF THE SYSTEM

5.1 Chlorophyll a

Chlorophyll a data are available for the work done in the mid 1990s and in 2004 and 2005. The Falter study did not report chlorophyll a values so we do not know what the values were in the early history of the reservoir. The mean for the three mainstem and two tributary stations indicate that chlorophyll a concentrations were similar for 1993-1996 and 2004 (Table 4).

Table 4 Mean study chlorophyll a concentrations for select stations in µg/l.

	Sector 1			Sector 2 (Lower)			Sector 2 (Upper)		
	1993-1995	2004	2005	1993-1995	2004	2005	1994-1995	2004	2005
Maximum	5.07	5	2.35	6.68	5	1.97	4.12	2	2.86
Mean	2.41	2.79	1.94	2.44	2.71	1.635	2.33	1.57	1.98
Minimum	0.54	0.5	1.37	0.25	2	1.16	0.41	1	1.09
No. of cases	40	7	7	22	7	4	13	7	5
Standard Dev	1.07	1.47	0.4	1.63	1.11	0.34588	1.19	0.53	0.79

Table 4, cont. Mean study chlorophyll a concentrations for select stations in ug/l.

	Elk Creek			Sector 3 (L. N. Fk. Clearwater)		
	1993-1995	2004	2005	1994-1995	2004	2005
Maximum	10.52	7	3.81	5.61	6	3.08
Mean	3.56	3.71	2.47	2.85	2.86	2.25
Minimum	0.5	1	1.65	0.27	2	1.12
No. of cases	21	7	7	13	7	5
Standard Dev	2.68	2.29	0.7	1.45	1.46	0.95

Chlorophyll a station means for 2005 were lower than those seen in previous studies (Fig. 9). This may have been due to the atypical spring runoff pattern in the spring of 2005.

There does not seem to be a longitudinal shift in chlorophyll a concentrations as one progresses up the reservoir (Fig. 10). The mean, maximum and minimum chlorophyll a concentrations were similar in all sections of the reservoir.

In all cases the chlorophyll a concentrations were extremely low for the moderate TP values reported for each of the studies. This is indicative of a system with a large amount of unavailable particulate or colloidal P present.

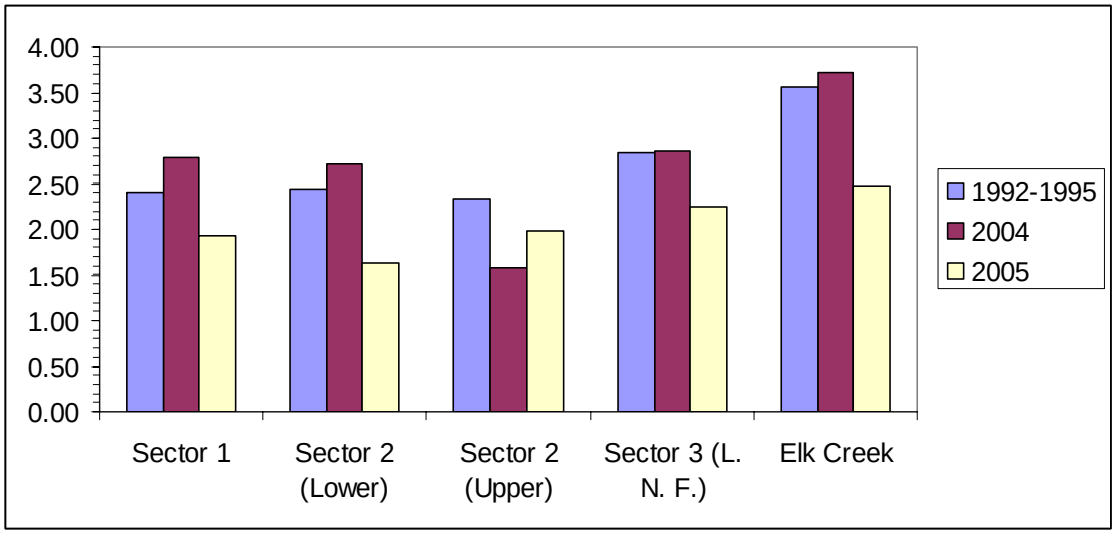


Fig. 9 Mean chlorophyll a concentration by year for select stations in µg/l.

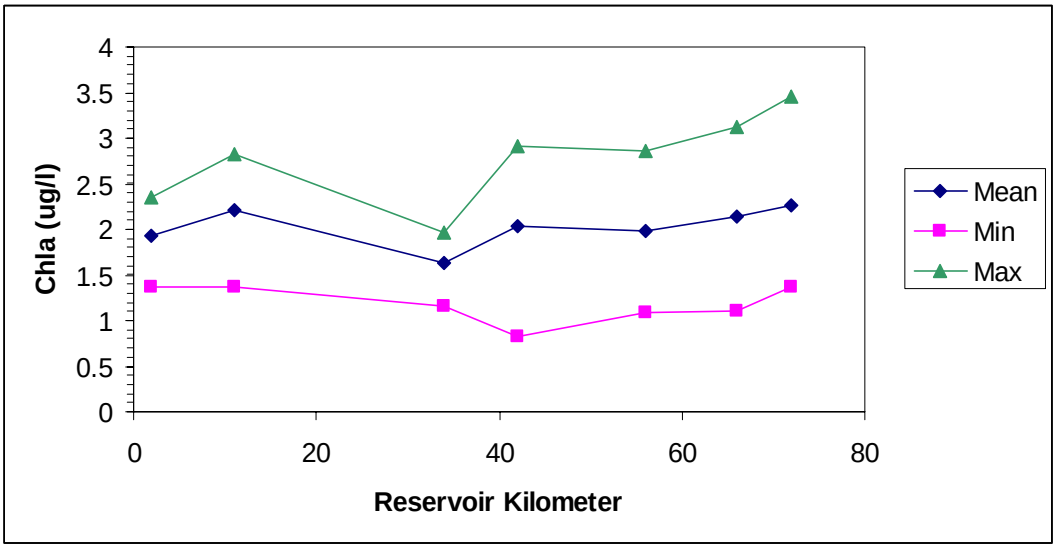


Fig. 10 Longitudinal chlorophyll a concentrations in µg/L for 2005.

5.2 Phytoplankton

5.2.1 Biomass and abundance

Phytoplankton counts from 2005 samples from selected stations in each major sector of the reservoir showed a diverse assemblage of colonial diatoms (e.g., *Fragilaria crotonensis*, *F. delicatissima*, *F. acus*, *Asterionella formosa*), flagellates (*Dinobryon*, *Chromulina*, *Chrysochromulina*), small but very abundant pico-phytoplankters (*Synechococcus* and *Synechocystis*), and in summer a moderate density of N_2 – fixing blue-green algae (*Anabaena* spp. and *Microcystis* spp.). Both the colonial diatoms and blue-green algae were, by virtue of

their morphology, gelatinous matrix or toxicity, inedible to zooplankton, and as such represented a **significant** carbon sink within the reservoir in summer and early fall. The epilimnetic species composition was similar among stations with prominent abundance peaks in August and September at most stations (see Appendix A, Figs. 1 & 2), with about a 10 - fold higher total abundance of phytoplankton in the epilimnion than in deeper meta-hypolimnetic waters. Phytoplankton biovolume, like chlorophyll, provides a good estimate of photosynthetic (autotrophic) plankton biomass, and not surprisingly, the largest peaks were concomitant with peaks of inedible blue-greens and colonial diatoms. The phytoplankton species composition, abundance and biovolume were within the normal range of values seen in large, interior BC and Yukon Territory lakes.

The phytoplankton assemblages of Dworshak are characteristic of assemblages common in summer in nitrogen limited lakes and reservoirs (Pieters et al. 2000, Bloomqvist 1999), with filamentous N_2 - fixing cyanobacteria common, e.g. *Anabaena, Microcystis*, along with inedible colonial diatoms, e.g. *Fragilaria crotonensis, F. delicatissima, Asterionella formosa*. The prevalence of these inedible species is common in summer in Kootenay Lake and Arrow Lakes Reservoir whose epilimnion loses NO_3-N by late July or early August. Owing to the size and weight of colonial diatom's silica frustules, it is common to see large portions of the population in the meta- or hypolimnion, removed from the epilimnion by sinking, i.e. average sinking rate 1 – 2 m/day (Jackson et al. 1989). Not surprisingly, in 2005 Dworshak hypolimnetic samples were loaded with colonial diatoms by August and September.

The dam Forebay station RK-2 had the lowest phytoplankton abundance and biovolume with RK -11 showing the highest biomass but not abundance. With the exception of EC-6 station there was a clear N-S gradient in phytoplankton biomass/abundance up-reservoir with lowest values near the Forebay and highest at RK-66 at the junction of Little North Fork and North Fork Arms (Table 5).

Table 5 Seasonal average phytoplankton abundance and biovolume for selected Dworshak Reservoir stations in 2005.

2005 Stations	Abundance (cells/mL)	Biovolume (mm^3/L)
RK-2	1,987	0.31
RK-11	2,957	0.531
EC-6	2,317	0.359
RK-31	2,258	0.419
RK-42	3,121	0.445
RK-56	2,490	0.456
RK-66	3,192	0.498
Seasonal Average	**2,624**	**0.426**

5.2.2 Comparisons with large interior BC lakes/reservoirs

If one compares the average seasonal phytoplankton abundance and biovolume estimates from Dworshak in 2005 with similar values from large BC lakes/reservoirs, it is evident that Dworshak average abundance is most comparable to Kinbasket Reservoir on the upper Columbia Basin, a very low production ecosystem. In terms of biomass Dworshak is more similar to Okanagan Lake, of oligo-mesotrophic N_2 – limited lake with moderate populations of N_2 - fixing blue-green algae (Table 6). Dworshak is well below the most productive system - Kootenay Lake, where values of both abundance and biomass or phytoplankton were 2-fold higher. Both Kootenay and Arrow Reservoir have been receiving annual nutrient supplementation since the early 90's, so it is not surprising that both systems exhibit higher standing stocks of phytoplankton and are also likely much more productive than Dworshak.

Table 6 Comparison of phytoplankton abundance and biomass in Dworshak Reservoir with BC lakes and reservoirs in 2005.

Reservoir or Lake	Abundance (cells/mL)	Biovolume (mm^3/L)
Dworshak Reservoir	**2,624**	**0.43**
Williston Reservoir	4,571[1]	0.24[1]
Arrow Reservoir	4,183[2]	0.63
Revelstoke Reservoir	3,285[3]	0.20[2]
Kinbasket Reservoir	2,625	0.28
Okanagan Lake	2,651[2]	0.54
Kootenay Lake	5,645	1.01

[1] Data from 2000, [2] Data from 2004, [3] Data from 2003

5.3 Bacteria and Pico-cyanobacteria

5.3.1 Abundance

The average density of free-living bacteria populations in Dworshak Reservoir was about 600,000 cells/mL. These values are close to estimates from several fertilized and untreated BC *coastal* lakes, where average population densities ranged from 500 – 600,000 cells/mL (MacIsaac et al. 1981), densities well within the oligotrophic range for Canadian Boreal lakes (Bird and Kalff 1986). The higher values seen in Dworshak in spring suggest that ambient turbidity from inflow streams and eroding shorelines impart a moderate concentration of dissolved organic and particulate inorganic matter to the deeper epilimnion that elevate both free-living and attached bacterial numbers above those found in late summer and fall during strong stratification periods(Weisse 1991).

In 2005 pico-cyanobacteria populations in Dworshak averaged 68,500 cells/mL, a value similar to those seen in large, oligo-mesotrophic 'interior' BC lakes (e.g., Shuswap Lake, Fraser Lake, and lakes within the Yukon River Basin) (Stockner and Shortreed 1991, Stockner et al. 1999). The highest pico-cyanobacteria populations in Dworshak were at mid-reservoir stations RK-31 and 42 where populations exceeded 131,000 cells/mL in September. The seasonal pattern of pico-cyanobacterial density in Dworshak in 2004 was typical of what has been noted in many large 'interior' BC lakes/reservoirs where a short spring burst is followed by mid-summer lows that sometimes, but not always, build to autumn density peak (Figure 11). The other exception was that September abundances were approximately 2-fold lower than normally seen in 'interior' lakes (e.g., Shuswap, Quesnel, Chilko, etc.), and doubtless related to low DIN:TDP ratios and possibly to light, turbidity or both factors (Stockner and MacIsaac 1996).

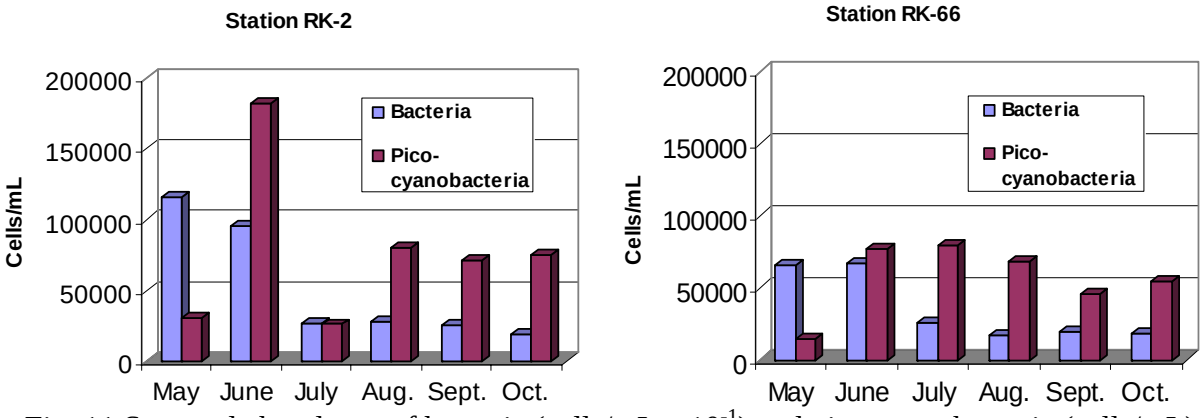


Fig. 11 Seasonal abundance of bacteria (cells/mL x 10^{-1}) and pico-cyanobacteria (cells/mL) at stations RK-2 (Dam Forebay, Section 1) and RK-66 (confluence of Little N. Fork and N. Fork, Section 3), Dworshak Reservoir, 2005.

5.3.2 Species composition

Pico-cyanobacteria belonging to the Class Cyanobacteracae were the largest component of the Dworshak picoplankton community, and these were composed largely of 2 single-celled coccoid species - *Synechococcus* and *Synechocystis* spp. (see Photo 1). There were also small *Chlorella*-like green algae in the reservoir, albeit at very low population densities (< 2-3000 cells/mL), but by virtue of their small size (< 2 μ) they are also a component of the picoplankton community.

It is of interest to compare densities of bacteria and pico-cyanobacteria in Dworshak in 2005 with values from Kinbasket Reservoir, Upper Columbia River Basin, and an ultra-oligotrophic system with seasonal average TDP values of 2-3 μg/L, contrasted to 4-8 μg/L in Dworshak (Stockner, unpublished data). Dworshak had nearly twice the average number of pico-cyanobacteria as Kinbasket, but only moderately higher densities of free-living bacteria (Fig. 12).

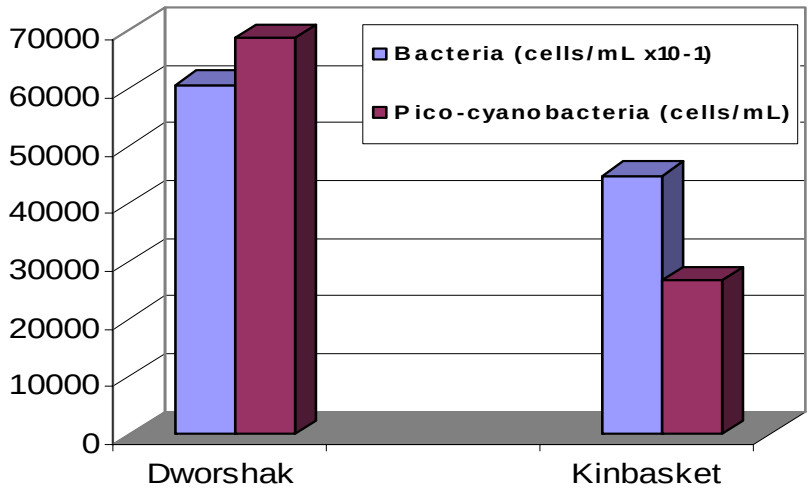
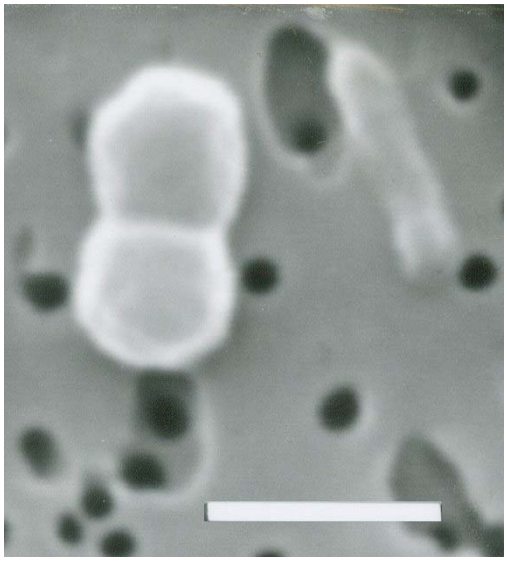


Fig. 12 Seasonal average density of bacteria and pico-cyanobacteria in Dworshak and Kinbasket reservoirs in 2005.

A.



B.

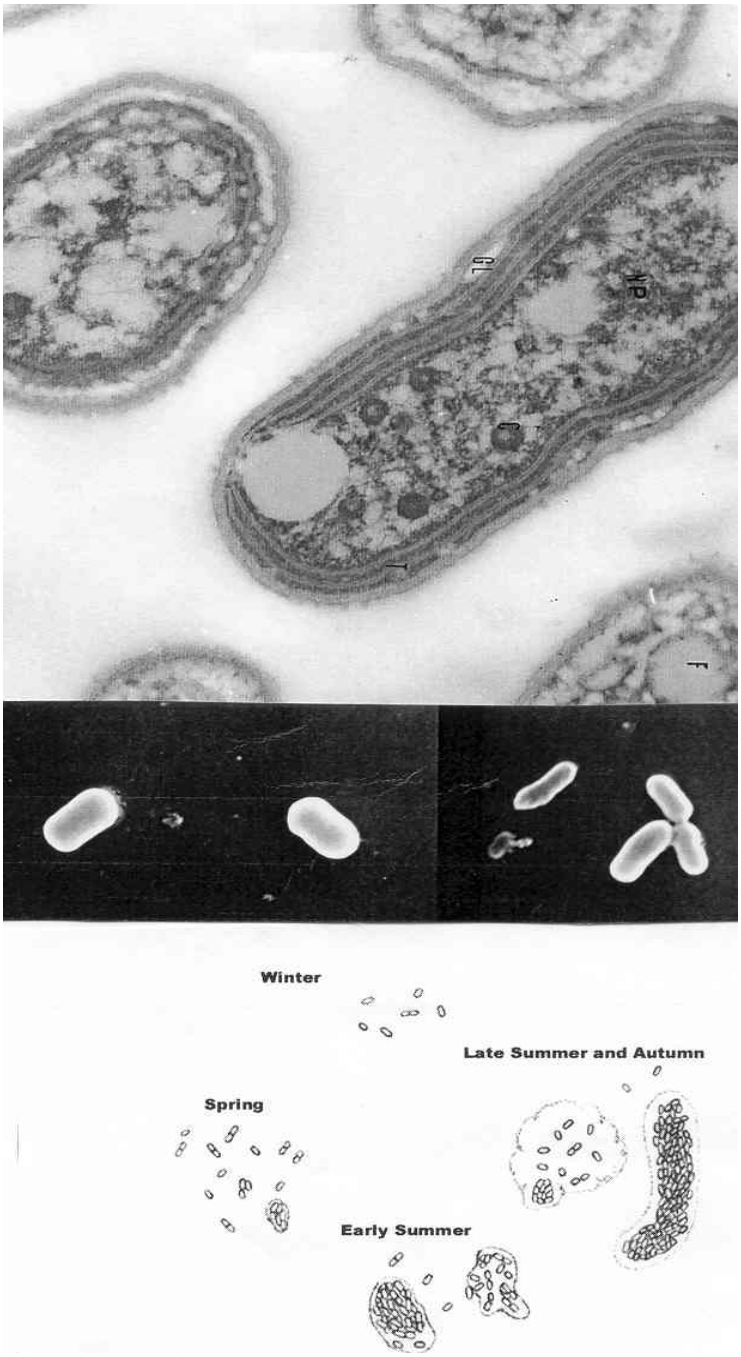


Photo 1. **A**. *Synechococcus* spp. cell in process of division and a rod-shaped free-living bacteria (on right). Bar is 1µ. **B**. Electron micrograph of *Synechococcus* (top), free-living bacteria (center), seasonal morphs picoplankers (bottom).
Photo M. Klut & J. Stockner, UBC, Vancouver, BC.

The high densities of heterotrophic (bacteria) and autotrophic (pico-cyanobacteria) biomass strongly suggest the predominance of microbial communities (e.g., ciliates, flagellates, and micro-zooplankton in the euphotic zone) that can process moderate amounts of organic carbon through complex and multilevel food chains but far less efficiently than conventional pelagic food-webs, consuming large amounts of CO_2 and passing smaller amounts of carbon to higher trophic levels, (e.g., zooplankton and fish) (see Fig. 13). The presence of inedible phytoplankton in mid-summer early fall coupled with the predominance of microbial food webs in early spring signals the prevalence of inefficient carbon flows in spring, of large C sinks in summer and fall, and translates into low carbon production throughout the growing season in the reservoir.

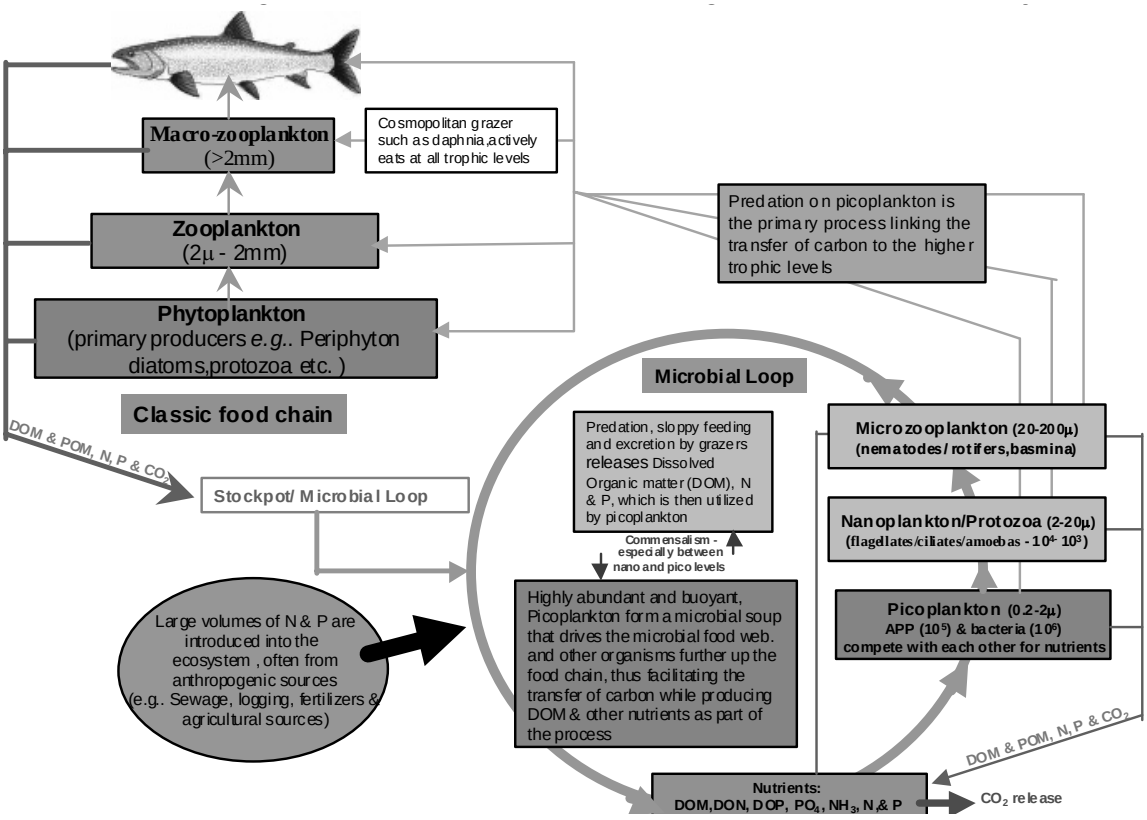


Fig. 13 Schematic diagram of the microbial loop of an Oligotrophic reservoir ecosystem.

5.4 Zooplankton

Comparison of zooplankton data between studies proved difficult due to differences in methods and reported data. The Falter et al. 1972-1974 study used a horizontally towed zooplankton net at depths of 1 and 10 meters. Stark's samples were taken in the euphotic zone; therefore, the late summer tows were considerably longer than the spring tows. We did not have

data from the mid 1990s study by Juul and Funk, so the data collected by IDFG in 1988 has been used to portray the reservoir conditions 15 years after its creation. The methods used to collect the data in 1988 consisted of a vertical tow from 12.2 meters to the surface. Table 7 summarizes the data from the three studies.

Table 7 Zooplankton individuals/liter and percent Cladocerans for selected stations in Dworshak Reservoir.

Station	Individuals/Liter			Percent Cladoceran		
	1972-1974	1988*	2004	1972-1974	1988*	2004
Sector 1	39.8	12.7	16.5	60%	35%	44%
Sector 2 (Lower)	17	10.6	17.7	73%	42%	45%
Sector 2 (Upper)	11.3	8.6	14.4	72%	52%	50%
Sector 3 (L. N. Fk. Clearwater)	8.8	11.7	17.8	81%	56%	48%
Elk Creek	25.1	12.4	25.6	77%	48%	32%
Reservoir Mean	18.9	11.2	18.4	78%	46%	44%

* Mean summer values from Table 4. Mauser et al. (1989).

The total zooplankton densities for the mainstem of the reservoir declined between the Falter et al. study conducted in 1972-1974 and the Mauser et al. study in 1988 (Fig. 14). The zooplankton data collected in 2004 suggest that zooplankton densities have increased since 1988 and may be approaching levels found in 1974. Due to the variability of factors that affect zooplankton populations (precipitation, hydrograph, summer temperature, and reservoir operations) and the differences in sampling methods, it is difficult to conclusively determine if the increase in the zooplankton population from 1988 to 2004 is due to a change in long term reservoir conditions or due to typical population dynamics. A more complete investigation of all zooplankton data collected from 1998 to 2004 may determine the significance of this difference. The largest increase in zooplankton densities since 1988 occurred in the Little North Fork Clearwater River arm. The larger increase in zooplankton density in this arm may be a result of timing or amount of runoff in the spring of 2004, or of activities within the drainage basins feeding this arm of the reservoir.

The Little North Fork arm of the reservoir has several drainages with elevated sediment and nutrient levels compared to a ‘natural’ watershed. The levels of nutrients and sediment were not impairing the beneficial uses of these watersheds, with the exception of Long Meadow Creek, but the increases in sediment erosion and associated nutrients could account for the zooplankton densities in these sections of the reservoir.

The percent of cladocerans making up the zooplankton community within the reservoir has shifted since 1974 (Fig. 15). The percent cladocerans have declined since the early life of the reservoir. The reservoir mean percent of cladocerans fell from 78% in 1973-1975 to 46% in 1988 and 44% in 2004. There seems to be little change in the percent of cladocerans in the zooplankton community since 1988 with the exception of the Little North Fork Clearwater arm where the percent cladocerans have continued to decline to present. The reduction in percent cladocerans may indicate that the cladoceran population is being suppressed by selective grazing of zooplanktivorous fish species.

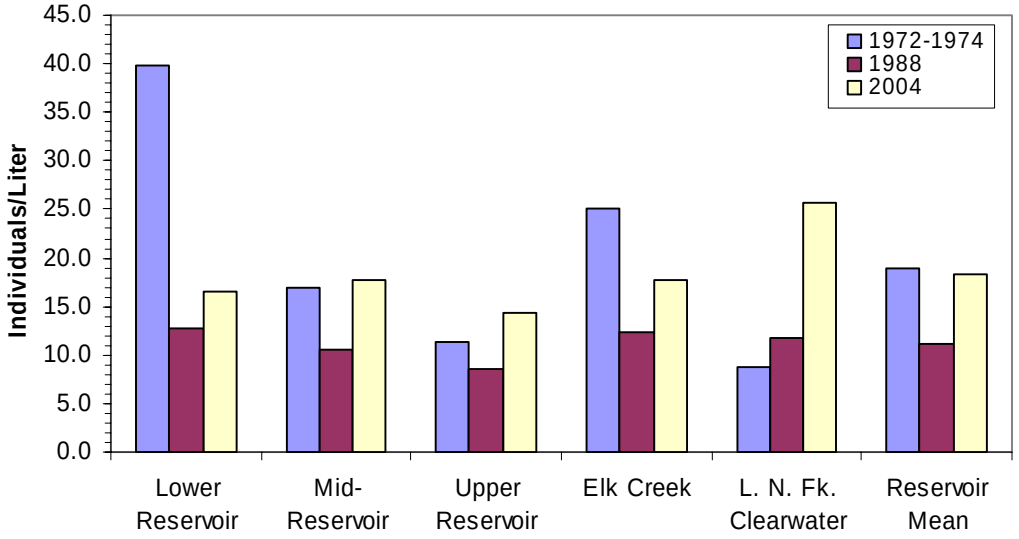


Fig. 14 Number of zooplankton individuals/liter in selected stations of Dworshak Reservoir over time.

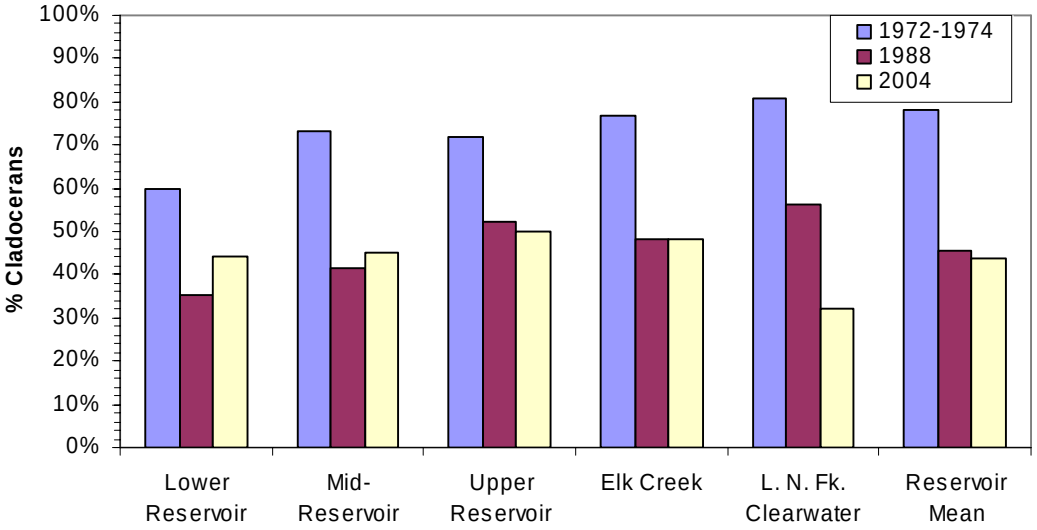


Fig. 15 Percent cladocerans in select stations of Dworshak Reservoir over time.

5.5 Kokanee Fisheries - Population Status 2005

5.5.1 Abundance

Hydroacoustic surveys estimated a total of 3,889,832 kokanee (90% CI +/- 15.2%) in Dworshak Reservoir, July 2005; 2,757,559 age-0 (90% CI +/- 15.9%), 993,470 age-1 (90% CI+/- 16.0%), and 138,803 age-2 (90% CI +/- 15.2%). Aging of angler-caught kokanee revealed fish from two age classes: age 1 and age 2; and again there was no age-3+ kokanee present in the catch. Age-1 kokanee ranged from 100 to 250 mm TL (3.9 – 9.8 in), and age-2+ kokanee ranged from 250 to 333 mm TL (9.8 – 13.1 in). Therefore, most if not all age 1+ kokanee are recruited to the fishery (Stark 2005b).

The total population abundance has decreased since 2004 although both age 1 and age 2 abundances and therefore densities are greater than last year. However, the density of adult catchable sized (age 2) fish was below management goals of 30-50 fish/ha (Table 8), as it was last year as well (Stark 2005b).

Table 8 Estimated abundance of kokanee (thousands) in Dworshak Reservoir, Idaho, 1994-2005.

Year	Sampling Technique	Age Classes				Total	Density of age-2 & -3 (fish/ha)
		0+	1+	2+	3+		
2005	Hydroacoustic	2,757,559	993,470	138,803	0	3,889,832	21
2004	Trawling	3,136,892	692,348	90,715	0	4,298,868	14
2003	Hydroacoustic	439,580	434,586	276,055	0	1,150,222	42
2002	Hydroacoustic	1,129,917	1,071,044	231,891	0	2,432,852	24
2001	Hydroacoustic	1,962,000	781,000	405,000	0	3,150,000	75
2000	Hydroacoustic	1,894,857	303,680	199,155	0	2,397,692	37
1999	Hydroacoustic	1,143,634	363,250	38,464	0	1,545,348	7
1998	Hydroacoustic	537,000	73,000	39,000	0	649,000	7
1997	Trawling	65,000	0	0	0	65,000	0
1996	Hydroacoustic	231,000	43,000	29,000	0	303,000	5
1995	Hydroacoustic	1,630,000	1,300,000	595,000	0	3,539,000	110

5.5.2 Age and Growth

Monthly trawl sampling was not conducted in 2005 due to funding constraints. Therefore, no estimates of mean monthly growth for each age class throughout the summer were obtained. However, there is evidence to suggest kokanee growth was substantially slower in 2005 than in 2004. Since kokanee exhibit density-dependent growth it is reasonable to expect reduced growth rates for both age 0 (fry) and age 1 kokanee based upon very high abundances in July, 2004. In addition, zooplankton densities in 2005 appear to be approximately one half to one third of last

year's 2004 estimates. Such a low forage base would be expected to further reduce kokanee growth in 2005 (Stark 2005b).

5.5.3 Spawner Count

We counted a total of 12,742 spawning kokanee in our three index streams (Table 9). Dead spawned-out kokanee available for measuring varied in length from 180 to 320 mm, and averaged 248 mm (Stark 2005b).

Table 9 Tributary and total adult spawner abundance, September 24th and 25th, 2005.

Tributary	Adult Spawner Count
Isabella Creek	6,890
Skull Creek	3,715
Quartz Creek	2,127
Total	**12,742**

Kokanee spawner counts in 2005 were slightly larger than 2004 counts. The abundance of spawners appears to closely match what we expected for the index tributaries based upon the 2005 acoustic population estimate (Table 9). This 2005 data closely fit the normal relationship between spawner counts and reservoir adult abundance (Stark 2005b).

The most surprising finding was the presence of age 1 sexually mature kokanee in large numbers in spawning tributaries. The variability in total length of spawned-out adults was surprisingly broad, with several fish as small as 180 mm and one large fish at 320 mm, yet the majority of fish were between 230 and 280 mm in total length. Despite outliers at either end of the frequency distribution, the mean spawner length was 60 mm smaller in 2005 than in 2004. These data suggest that the smaller spawners may actually be age 1 fish which for some reason have matured early and are at least attempting, if not actually, successfully spawning. Although speculative, it is possible that food resources were scarce enough during this summer to induce early maturation, but we do not have data to support this hypothesis. More importantly though, this could have an appreciable impact on next year's kokanee fishing since a large proportion of age 1 fish have presumably spawned and died and will not be available as catchable age 2 fish next year (Stark 2005b).

SECTION 6.0 CURRENT STATE OF DWORSHAK RESERVOIR

6.1 Nutrients and Trophic State

One of the key elements of analysis missing in the database and in past assessments of Dworshak as well are those related to P and N loading and annual rates of carbon production/accrual, data that would allow estimates to be made to strengthen predictions of changing reservoir trophic conditions. We have attempted to assess the current state of the reservoir using the most reliable, recent nutrient data. Because of inconsistencies of laboratory analysis and high variance imparted by moderate colloidal/particulate loads, we have chosen what we consider to be realistic ranges of Dworshak mean total phosphorus concentrations (10-20 mg/m^3) and plotted these against a range of Dworshak average chlorophyll values (2-5 mg/m^3) in 2 graphic loading presentations that predict the present trophic status or the reservoir. The 'true' TP loading value doubtless falls within the box demarcated by TP and Chl. ranges used in the computations, and both graphic representations suggest that the reservoir's current condition is on the border between oligo- and mesotrophic states (Fig. 16). Values from other large lakes/reservoirs in BC, (e.g., Kootenay and Shuswap lakes, Williston Reservoir) also lie within Dworshak chlorophyll ranges, but not TP, providing further empirical evidence for some commonality among phytoplankton biomass in these large interior, fast-flushing reservoirs. Using the empirical based equations of Vollenweider (1976) it was possible to provide a first estimate of the range of annual TP loadings to Dworshak Reservoir - **1325 to 1988 mgTP/m^2/y**.

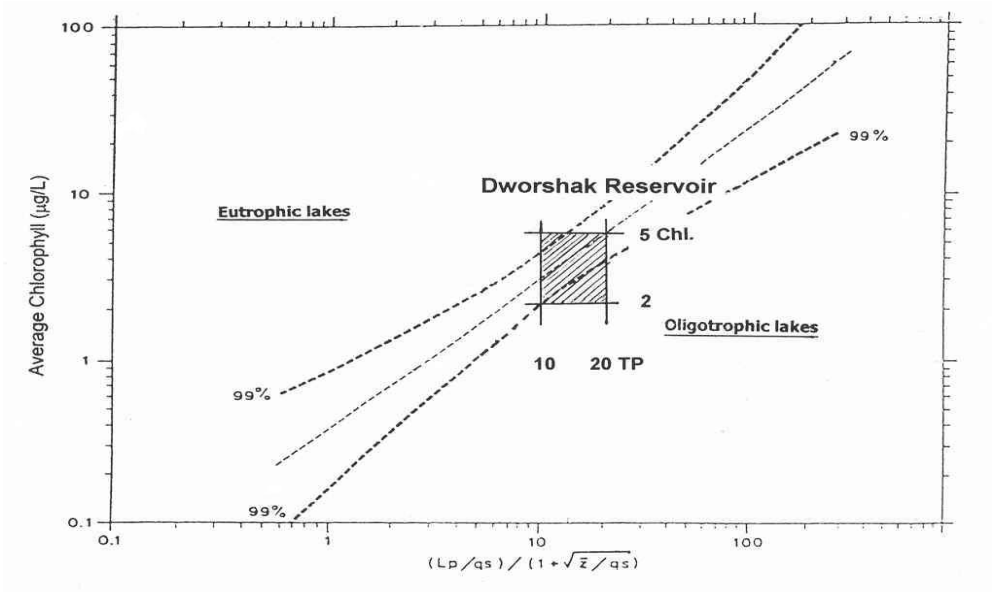


Fig. 16 Dworshak Reservoir range of TP vs. range of average chlorophyll concentration in 2005, and predicted trophic state.

6.2 Food Webs and Community Structure

It is somewhat surprising that Dworshak Reservoir's spring and early summer phytoplankton communities and associated food web structure so closely resembles those described for fast-flushing, ultra-oligotrophic, BC lakes/reservoirs, ecosystems that are microbial dominated and composed largely of small pico-cyanobacteria, μ-flagellates, ciliates, and small dinoflagellates with a paucity of large diatoms (Stockner 1981,1987; Stockner and Shortreed 1988; Stockner and MacIsaac 1996). These 'microbial' populations create a community that possesses a relatively high mean abundance, but low biomass owing to the small-size of most organisms. These 'microbial' communities are well adapted to low ambient nutrient conditions and heavily reliant upon 'recycled' nutrient supplies (Weisse & Stockner 1993), so their ubiquity in turn serves to question the 'true' nutrient status of the system at spring overturn. These microbial communities are characterized by multiple transfers of carbon that results in high respiratory costs (CO_2 loss) and low pelagic fish production (Fig. 17).

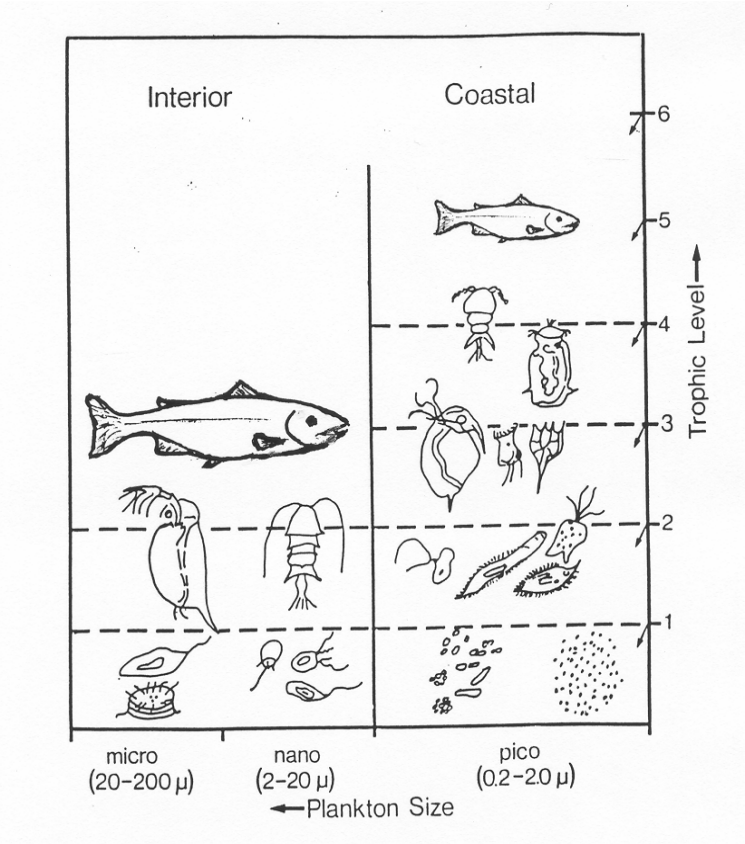


Fig. 17 Schematic of the pelagic food webs of interior and coastal BC lakes (after Stockner and Porter 1988).

By late July, Dworshak becomes a N_2 depleted ecosystem and the 'drivers' or C template of the spring microbial community bacteria and pico-cyanobacteria decline and are replaced by large inedible blue-green algae and colonial, chain-forming diatoms, a well known carbon sink, further exacerbating the flow of carbon to pelagic zooplankton and kokanee. In more productive 'interior' BC kokanee lakes and reservoirs that do not support large stocks of inedible blue-greens and diatoms and possess more typical 'classic' food webs that deliver carbon more directly to pelagic fishes (Stockner and Porter 1988, Stockner 1997, Stockner and Shortreed 1994, Stockner and MacIsaac 1996) (see Fig. 17).

SECTION 7.0 CONCLUSIONS

The prediction of the present state of Dworshak Reservoir is in many respects a conundrum. The pelagic communities of early spring with a predominance of a picoplankton (*Synechococcus* + free-living bacteria) is clear and unambiguous evidence of the oligotrophic condition of the reservoir, while by mid-summer the communities of largely inedible micro-phytoplankton present the characteristics of the high oligotrophic to mesotrophic state, created to some extent by epilimnetic N depletion. The potential to move carbon to pelagic fishes from these two very different communities is minimal and may in part be one of the more compelling reasons for low fish production in current years. A high N nutrient supplementation prescription is therefore likely to greatly improve the flow of pelagic carbon throughout the growing season by enhancement of edible forms of plankton (pico-, nano- and small microplankters) and removal of inedible blue-green algae, and likely to greatly reduce the abundance of large colonial diatoms. The efficacy of enhancing the pico- and nano-plankton based food webs of spring and early summer to the entire growing season has been repeatedly demonstrated over 2-3 decades of fertilization of oligotrophic BC lakes (Stockner and MacIsaac 1996, Stockner and Ashley 2003), and there are no reasons to suggest that the technique could not be successfully applied to specific sectors or embayments within Dworshak Reservoir.

The present phytoplankton communities of Dworshak suggest that carbon flows are being short-circuited by inedible C sinks throughout the summer and fall, and the paucity of zooplankton forage together with the small size and age-distribution of spawning kokanee support this contention. The high N nutrient prescription has its risks, namely those associated with the uncertainty of really knowing how much of the TP will be ‘available’ to support further production once the N:P ratio is balanced by supplementation. A nitrogen only nutrient supplementation was used effectively in the south basin of Kootenay Lake in 2005 without major sinks or nuisance algal growth, but data are not yet available on zooplankton or pelagic kokanee responses to the elevated production and diminishment of cyanobacteria that were prevalent, like Dworshak, in summer in previous years. Clearly Dworshak will have to be monitored very closely during the first year of supplementation and may require in season adjustments to the amounts of N and P added.

SECTION 8.0 APPLICATION

The application of the treatment (nutrients) is dependent upon the equipment available and therefore not conducive to an equipment list or a prescriptive methodology at this time. Because the material being added to the water is rapidly diluted and taken-up by the biota in the system and will have no long-term adverse impacts the application methodology can be fairly flexible and forgiving of minor deviations.

There are only a few basic rules that should be followed. They include:

- The concentrated nutrients are corrosive so all equipment should be resistant to corrosion by the solutions, i.e. stainless steel, polyethylene.
- The 10-34-0 and 32-0-0 solutions can be mixed in the tank for each sector, mixed in the distribution line prior to discharge or discharged separately.
- It is preferable that the 10-34-0 solution contain long chain polyphosphate.
- The ammonium polyphosphate solution should have the lowest available concentrations of trace metals. The ones of greatest concerns for water quality concerns are Arsenic, Zinc, and Cadmium. The Cadmium criteria is the lowest of these metals and will be the most difficult to meet. When selecting a fertilizer supplier the request should require an analysis of the concentrations of these metals and these concentrations should be considered in the selection of a vendor.
- The more evenly you can disburse the nutrients in the pelagic zone the better the response.
    - For the Dworshak Reservoir, we recommend that you apply the treatment in two passes for each sector.
    - That the solutions are applied in the prop wash to assist with dispersal.
    - The nutrients should be applied at or just below the surface to insure absorption by biota in the euphotic zone.
- Adjust the mixture to reflect changes in the prescription between sectors.
- Adjust the mixture to reflect changes in the prescription between events.
- Adjust the prescription based on reservoir surface area.

- The sectors and application days are examples only. The USACE can modify the application events as long as the weekly schedule is maintained, i.e. two day application event versus a three day.
- The USACE will need to develop a spill prevention and containment plan.

Any application methodology or equipment that allows one to meet these conditions is acceptable. Additional guidance for application can be found in Ashley and Stockner (2003). Appendix D. includes some photos of the Quinault Nation's nutrient supplementation apparatus to aid in designing the system for Dworshak. The Quinault system is for a smaller project than that proposed for Dworshak so the set-up is not directly transferable.

SECTION 9.0 PRESCRIPTION

The prescription was developed using the area/volume/elevation curves and dosages added are most sensitive to large elevational changes that in turn affect volume and epilimnetic nutrient concentrations. We used the 2004 elevation curve to compute the volumes to be treated in each of the 3 reservoir sectors. The weekly additions to each sector of the 2 types of fertilizer are presented in the spreadsheets (Appendix B), and given the length of the reservoir it is suggested that a day may be required for application to each sector, e.g. starting with Sector 3 on a Tuesday, Sector 2 on Wednesday and completing the weekly application on Thursday in Sector 1. The application days are flexible and can be modified to meet the logistical requirements of the USACE. As application days approach, it is advisable to vessel operators to check on present reservoir elevation and confirm that the spreadsheet recommended dose is adequate for the elevation/volume prescribed. If disjunction between elevations occurs the daily dose can be quickly recalculated from the spreadsheet and more/less fertilizer can be applied to fit the prescription and N:P ratio balance.

We received estimates for fertilizer from an Idaho based company that has the required formulations in stock and available for shipment to Orofino, ID. Based on this estimate, the fertilizer costs for doing the 3 sectors is estimated as follows – Sector 1 $34,837, Sector 2 $19,576, and Sector 3 $7838, for a total of: $62,250. There will also be application costs which we have not estimated but will need to include items such as storage tanks, hoses, pumps, etc.

SECTION 10.0 ANTICIPATED RESULTS

The information presented in this and other reports indicate that the Dworshak Reservoir has been losing nutrients since it creation and that current conditions are not adequate for the maintenance of a reasonable fishery. The goal of the fertilization project is to increase primary production in the system so that there is an increased forage base for the aquatic organism within the system. Each lake and reservoir system is unique, however this process has been used on over 20 lakes and reservoirs in British Columbia and to a lesser extent the northwest United States. In 1987, Stockner and MacIsaac published a paper that included a summary table of key limnological variables before and after treatment (Table 10). In the studies looked at for this table, the increase in all categories was appreciable but not extreme. There have been several additional projects since the publication of this paper and in all cases the results have resulted in an increased fishery with little degradation to water clarity or quality. Pieters et al. (2000) reported on the results of fertilization efforts in Arrow Reservoir in British Columbia. The techniques used and the conditions with in Arrow Reservoir are highly analogous to the situation within Dworshak Reservoir. The expectation is that the Dworshak project will have results similar to those reported by Stockner (1987) and Pieters et al.(2000).

Table 10 Community responses to fertilization of coastal British Columbia nursery lakes. Values are average August and September epilimnetic values, and exclude glacial lakes; number of observations in parentheses* (Adapted from Stockner and MacIsaac, 1996).

Variable	Before Treatment	After Treatment	% Change
Bacteria (10^6 ml^{-1})	0·70 (29)	1·41 (91)	100
APP† ($No.ml^{-1}$)	30-40000	59-66000	50-60
CHL*(μgl^{-1})	1·23 (28)	2·15 (105)	65
Phytoplankton volume* (mm^3 m^{-3})	555 (25)	1195 (85)	115
Primary production* (mgC m^{-2} day^{-1})	68	167	146
Zooplankton biomass* ($mgAFDWm^{-3}$)	5·0 (38)	18 (87)	260
Fish smolt weight‡ (g)	2·12 (16)	3·5 (25)	68

* Stockner, 1987
† Stockner and Shortreed, 1991
‡ Hyatt and Stockner, 1985

SECTION 11.0 SOME RECOMMENDATIONS FOR RESERVOIR MONITORING

11.1 Pelagic zone monitor - Dworshak Reservoir

The monitoring program has been divided into 2 phases: initial pilot and routine monitor. The key or sentinel components are given in Table 11, while detailed procedural methods for each of the various components of the monitoring program are provided in Appendix C entitled: Reservoir Monitoring Manual (RMM).

11.1.1 Background

Because pelagic zone carbon (C) production by phytoplankton and bacteria dominates total lake/reservoir annual C production, the monitoring of the physico-chemical features and biological communities of the pelagic provides valuable information needed to understand the ecosystem's response to supplementation. Such information forms a valuable database for assessments of C flow within food chains and nutrient dynamics within the euphotic zone of the ecosystem. Unless there are **major** perturbations that have occurred within the drainage basin, e.g. clear-cut logging, landslides, floods, earthquakes, etc., the rates of pelagic C production/flow within communities and values of TP and chlorophyll should remain relatively stable, showing some inter-annual variability, but this is usually not large and well within established ranges of the trophic state of the lake/reservoir. The following monitor of the pelagic of Dworshak Reservoir has been designed to focus mainly on the key '***sentinel***' variables that have proven to be reliable indicators of change in the production cycles of lakes and reservoirs (Stockner 1981, 1987; Stockner & Shortreed 1985). The specifics of the monitor are given in Table 11. It is important to emphasize that this initial monitor should have <u>at minimum</u> 3 year duration that commences in year 1 with the onset of supplementation. At the end of year 3 a professional 'peer' review of current conditions should be initiated to determine whether the magnitude of system response warrants further detailed monitoring or that the ecosystem has stabilized and a new higher productive state has been achieved, requiring less detailed monitoring, (i.e., a **routine** monitor for years 4 and 5 of the pilot program) (see below).

11.1.2 Monitored variables: Initial 'pilot' - 3 yrs (1st, 2nd & 3rd yrs) of nutrient supplementation

- ***Stations.***
  - Use currently established stations for monitoring the effectiveness of the treatment. The stations with the most complete limnological records are RK-2, RK-31, RK-56, EC-6 and LNF-1.
  - Two additional monitoring stations should be established for the first year as well. One of these stations should be in the upper North Fork Clearwater River arm of the reservoir and the second one should be located in the pelagic region of one of the major bays within the reservoir.
- ***Timing.***
  - The collection of the chemical and biological samples should take place 3-4 days after the fertilizer application.
  - In the first year these key stations should be sampled every 2 weeks during the treatment period to allow for careful assessment of the first responses to nutrient addition, and then monthly into November.
  - **Rapid analysis of the monitoring data is essential.** The most time critical parameters are Chlorophyll a and phytoplankton. These should be analyzed within a day or two after collection. The zooplankton response is not as rapid as the phytoplankton community so a delay of a couple of weeks is acceptable but not longer than 3 weeks if avoidable. Water chemistry should also be analyzed within two weeks of collection. The rapid analysis of these parameters will allow for responsive changes to the prescription if needed.
  - If no major changes need to be made to the prescription the 2nd and 3rd year monitoring frequency can be dropped to monthly, with the samples taken 3-4 days after one of the supplementation events.
- ***Light, Temperature & O_2.***
  - Vertical profiles of temperature and O_2 from surface to 1m above sediment surface should be taken with a probe.
  - Light attenuation of photosynthetic available radiation (PAR) from surface to 1% light level should be measured with an underwater light sensor.
  - Secchi depths should also be determined through the season.

Comment: These data will aid in calculations of euphotic depth (volumes), epilimnetic depths (volumes), light compensation depths, C loads to the sediments and presence of hypolimnetic O_2 deficits.

- ***Nutrient concentrations.***
  - Measurements through the growing season (February-October) of TP, TDP, TN and NO_3, analyzed using low-level detection methods (TP, TDP reportable limit of 0.5 ug/L, and Nitrite+Nitrate reportable limit of 1 ug/L).
  - One depth integrated sample (0-10 m)
  - One sample taken 2-3 m below the metalimnetic lower boundary.

  Comment: Limnologists recognize three basic factors that regulate lake production: nutrient supply, lake basin morphometry, and climate, of the 3 factors, nutrient supply rates are deemed the most important. Once we have confidence in reported nutrient values and can look for consistency between stations and among years, then greater reliance can be placed on annual loading calculations and ecosystem mass-balance TP, TC and TN estimates.

- ***Bacteria, Phyto- and zooplankton communities, abundance and biomass***.
  - The bacterioplankton and phytoplankton samples should be a 0-10 m depth integrated sample. A tube sampler is one accepted method for collecting this sample.
  - Quantitative measurements of bacterioplankton and phytoplankton abundance (cells/mL) and biovolume (mm^3/L) should be done from direct microscopic counts.
  - Depth integrated Chlorophyll(µg/L) samples should be taken from the epilimnion (0-10 m) throughout the growing season.
  - Estimates of both micro- and macrozooplankton biomass/species composition should be made by direct counts from 0-35 or 50 m vertical hauls with Wisconsin-type net (80 um mesh diameter) with removable cup.

  Comment: This information will chronicle changes in abundance and biomass of major plankton components. Shifts in abundance of species and/or assemblages will signal changes in production, carbon flows and food-webs (see below).

- ***C^{14} primary production, size-fractionated.***
  - Measure rate of total pelagic C production the samples after incubation *in situ* for 3-4 hrs with ^{14}C will be size-fractionated into 3 major components - small picoplankton (0.2-2 um), nano-phytoplankton (2-20 um), and micro-phytoplankton (20-200 um).
  - The pelagic station should be established in conjunction with one of the sentinel stations.

  Comment: Minute plankton assemblages dominate pelagic production cycles in pacific northwest coastal and mountain oligotrophic ecosystems (Stockner 1987, Stockner & Porter 1988, Stockner & Shortreed 1991), and it is important to determine where the majority of the carbon is being produced and whether it is within edible fractions for herbivorous zooplankton.
- ***Hydroacoustic/trawl survey.***
  - A detailed late summer or early autumn, dual-beam hydroacoustic and trawl survey to provide information on pelagic fish population distribution, abundance, and species composition.

  Comment: This is the most cost effective means of determining abundance of pelagic fishes, (e.g., kokanee, stickleback, whitefish, etc.).

11.1.3 Monitored variables: routine - 2 yrs (4th & 5th yrs) of nutrient supplementation

- ***Stations.***
  - RK-2, RK-31, RK-56, EC-6, and LNF-1.
- ***Timing.***
  - 3-4 days after treatment
  - Sample monthly from March to November
- ***Physical/Chemical Monitoring.***
  - Same as years 1-3 except for primary production. Primary production measurements do not need to occur in year 4 or 5.

Table 11 Some key 'Sentinel' components of an initial Dworshak monitor for supplementation.

Key Variable	How Measured/ Monitored	What does it tell us?
Nutrients (TP, TDP, TN, NO_3)	• Sampled monthly from fixed pelagic zone stations • Monthly throughout Phase 1 and 2.	• Allows annual computation of nutrient loads (above) and values can be related to changes in phytoplankton biomass and production.
Carbon[14] assessment of photosynthetic carbon production	• 6 estimates/y pelagic • Baseline (if possible) in summer 2006 • For 2-3 years annually. Every 3rd year as part of a routine monitor.	• Defensible estimates of lake productivity and how it varies through seasons and from year to year. • Allows Dworshak to be compared with other interior lake lake/reservoir systems. • Captures production processes (provides rate information), not static, snapshots, e.g. chlorophyll
Pelagic plankton community	• Monthly samples of phyto, zooplankton, bacteria and picoplankton from Mar. to Nov.	• Provides needed abundance and depth distribution data to supplement C^{14} prod. Estimates. • Captures forage production in relation to grazing pressure (top-down) and food limitation (phyto, nutrients). • Provides community data vital to understanding carbon flows in Dworshak Reservoir.
Periphyton biomass and production (optional)	• Sampled monthly from artificial substrata along selected littoral transects	• Permits assessment of magnitude of littoral zone production.
Fish Biomass and abundance	• Gill netting • Hydroacoustic/trawl survey • Creel census	• Present state of resident fish stocks, including adult kokanee, their abundance, composition (rough vs. sport fish), and distribution. • State of juvenile kokanee and other pelagic stocks, their size, density, condition factor, etc., and estimate of size of adult kokanee escapement in the system. • Indicates whether fish are associated within pelagic or littoral habitats/communities and provides a first look at the degree of interactions, (i.e., competition).

11.2 River Monitoring- North Fork Clearwater

The North Fork Clearwater River downstream of the reservoir serves as a drinking water supply for the town of Ashahka, and for the USACE fish hatchery. The Idaho Department of Environmental Quality (IDEQ) has expressed concern over the impact the project may have on the water quality for these two facilities. To ensure that there isn't any adverse effect of the fertilization activities on the water quality downstream of the reservoir IDEQ has requested that a monitoring station be established immediately upstream of the water intake of the facilities. In addition to the drinking water concerns, monitoring of the river needs to occur to insure that there are no adverse impacts to any of the endangered species within the Clearwater River downstream of the reservoir.

Because of these concerns we are proposing that the North Fork Clearwater River be monitored at the same frequency as the reservoir pelagic monitoring. This means that for the first year there will be 16 samples taken and 9 samples taken in subsequent years. The analytes that will be analyzed include the full suite of low level detection of nutrients, as well as Chla. We also recommend that the physical parameters of temperature, and dissolved oxygen be collected. The cost for this effort can be found in Table 14.

11.3 Monitoring Costs

Based on the proposed monitoring plan we have developed estimated costs for each of the components (Tables 12-15). The costs are only estimates based on readily available laboratory costs and labor costs. The actual cost of the monitoring program may be higher or lower depending upon the actual costs.

Table 12 Lake limnology

Project Year	N. of Stations	N. of Sampling Events	Analysis cost/station[1]	Total Analysis cost/year	Labor & Equip Costs[2]	Yearly Total
1	7	16	$680	$76,160	$55,000	$131,160
2	4	9	$680	$24,480	$25,000	$49,480
3	4	9	$680	$24,480	$25,000	$49,480
4	4	9	$680	$24,480	$25,000	$49,480
5	4	9	$680	$24,480	$25,000	$49,480

1 - Includes epilimnion and hypolimnion samples of nutrients, phytoplankton, and zooplankton as well as epilimnetic samples of Chla and pico-cyanobacteria and bacteria.
2- Two person crews working for 2 10 hour days/event with 4 hours of prep time as well as equipment maintenance and costs.

Table 13 Primary productivity

Project Year	N. of Stations	N. of Sampling Events	Analysis cost/station[1]	Total Analysis cost/year	Labor & Equip Costs	Yearly Total
1	1	6	$400	$2,400	$16,520	$18,920
2	1	6	$400	$2,400	$16,520	$18,920
3	1	6	$400	$2,400	$16,520	$18,920
6	1	6	$400	$2,400	$16,520	$18,920
9	1	6	$400	$2,400	$16,520	$18,920

Table 14 North Fork Clearwater River monitoring below Reservoir

Project Year	**N. of Stations**	**N. of Sampling Events**	**Analysis cost/station[3]**	**Total Analysis cost/year**	**Labor & Equip Costs[2]**	**Yearly Total**
1	1	16	$185	$2,960	$5,760	$8,720
2	1	9	$185	$1,665	$3,240	$4,905
3	1	9	$185	$1,665	$3,240	$4,905
4	1	9	$185	$1,665	$3,240	$4,905
5	1	9	$185	$1,665	$3,240	$4,905

3- Full Nutrient suite and Chla

Table 15 Total yearly cost of Monitoring Program

Project Year	Yearly Total[4]
1	$158,800
2	$73,005
3	$73,005
4	$54,385
5	$54,385
5 Year Total	$433,380

4- Year 4 and 5 do not have primary productivity monitoring.

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Appendix A

Phytoplankton Figures

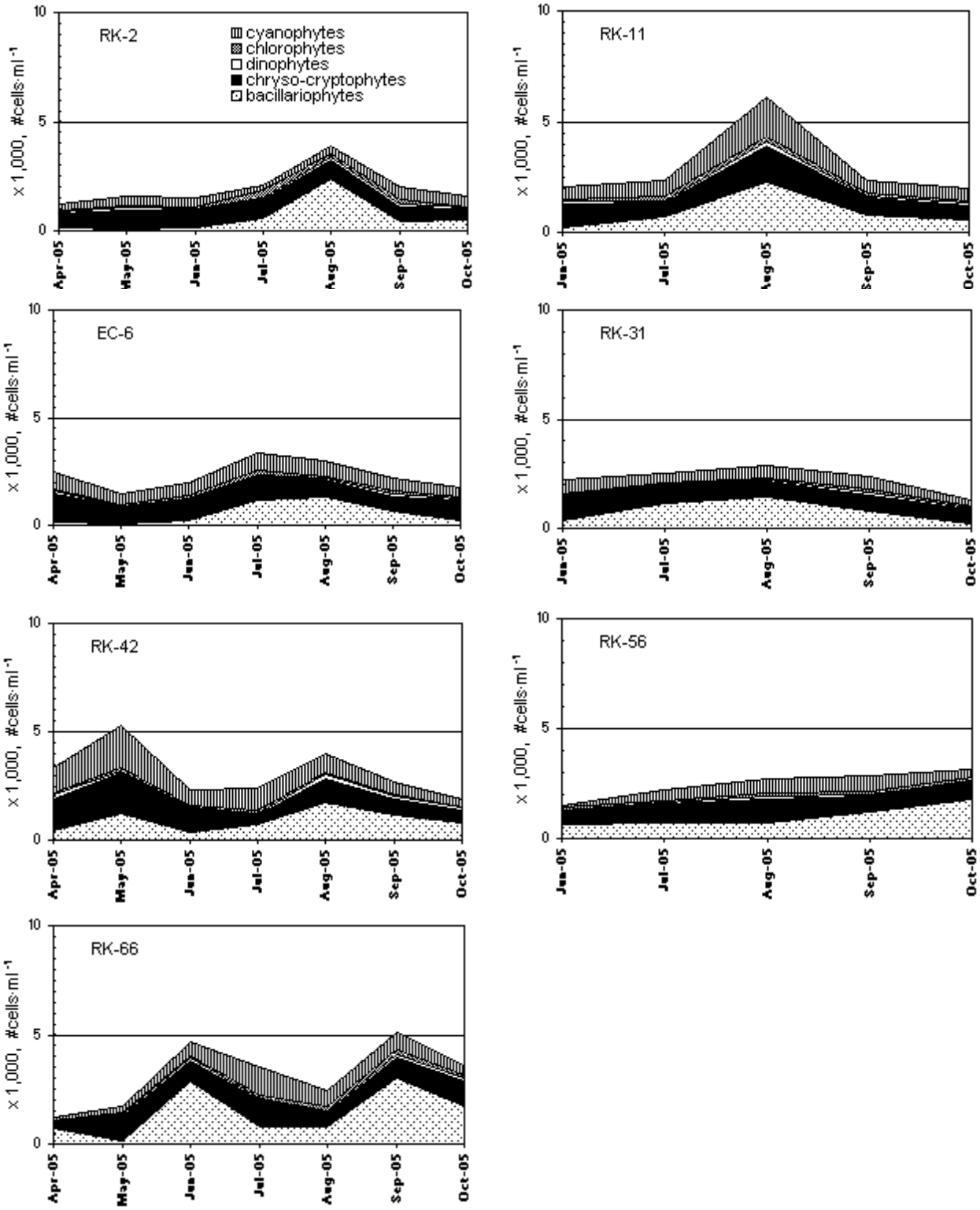


Fig. 1 Seasonal phytoplankton abundance by class for selected stations in Dworshak Reservoir, Idaho, 2005.

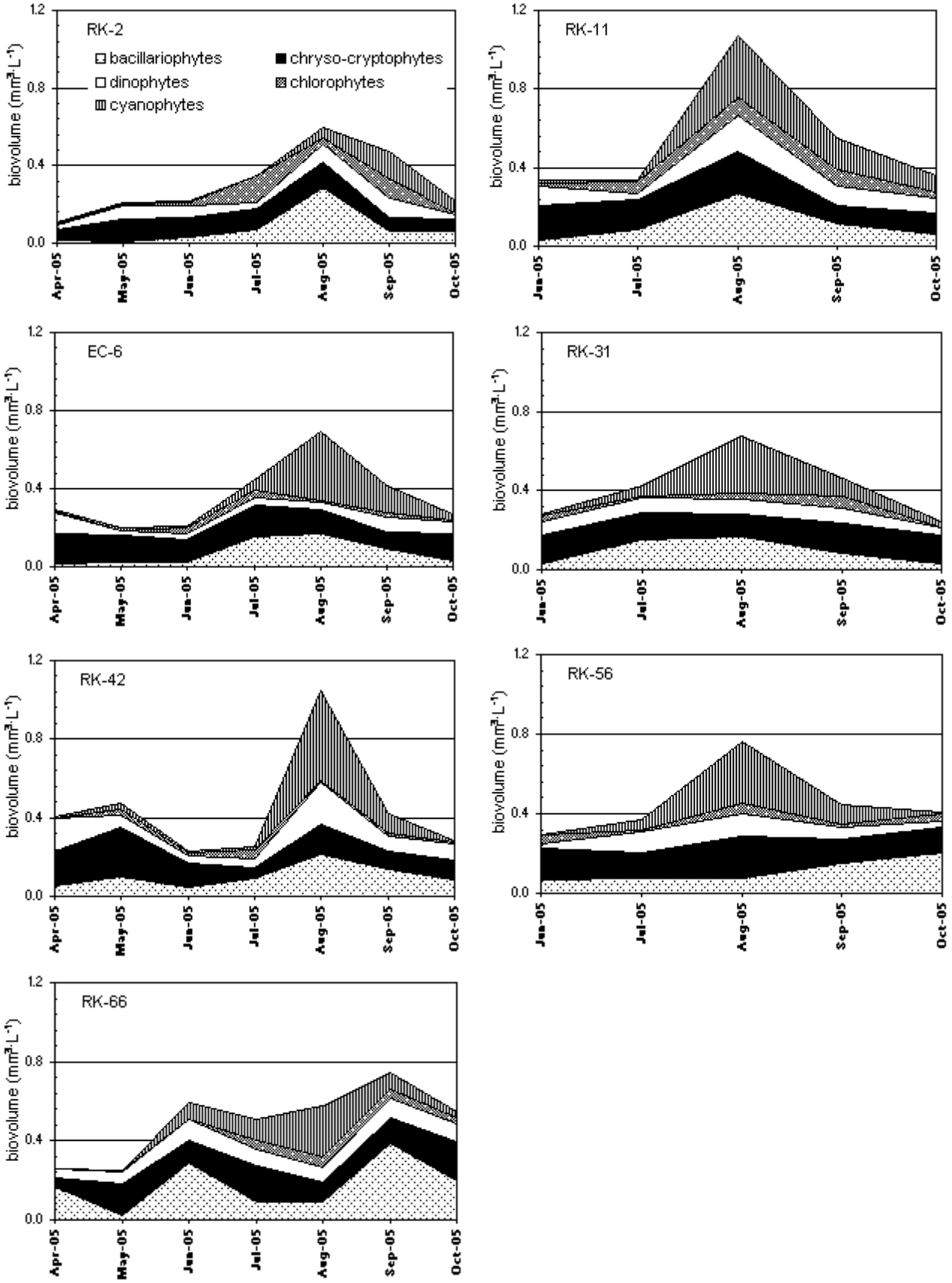


Fig. 2 Seasonal phytoplankton biovolume by class for selected stations in Dworshak Reservoir, Idaho, 2005.

Appendix B

Dworshak Reservoir Fertilization Schedule and Application Rate

Sector 1 Prescription Tables

Dworshak Reservoir Fertilization Schedule Area 1 - March 30 to Sept 28, 2006. K. Ashley, Dec 12, 2005

Year 1 of 5 **2006 Schedule - Area 1 applications on Thursday**

Week	Date	M. tons 10-34-0	% of 10-34-0 in total	% of 10-34-0 in blend	litres 10-34-0	M. Tons 32-0-0	% of 32-0-0 in total	% of 32-0-0 in blend	litres 32-0-0	Total M. Tons	Blend (%) N-P2O5-K2O	N:P ratio wt:wt	Application rate litres/min for 60 minutes
1	March 30	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
2	April 6	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
3	April 13	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
4	April 20	0.23	7.6	2.6	164	2.78	92.4	30.3	2,106	3.0	30.3 - 2.6 - 0	26.7	38
5	April 27	0.23	7.3	2.5	164	2.92	92.7	30.4	2,212	3.2	30.4 - 2.5 - 0	28.0	40
6	May 4	0.24	7.2	2.5	171	3.08	92.8	30.4	2,333	3.3	30.4 - 2.5 - 0	28.3	42
7	May 11	0.24	6.9	2.4	171	3.22	93.1	30.5	2,439	3.5	30.5 - 2.4 - 0	29.6	44
8	May 18	0.24	6.7	2.3	171	3.36	93.3	30.5	2,545	3.6	30.5 - 2.3 - 0	30.8	45
9	May 25	0.24	6.4	2.2	171	3.50	93.6	30.6	2,652	3.7	30.6 - 2.2 - 0	32.1	47
10	June 1	0.25	6.4	2.2	179	3.66	93.6	30.6	2,773	3.9	30.6 - 2.2 - 0	32.2	49
11	June 8	0.25	6.2	2.1	179	3.80	93.8	30.6	2,879	4.1	30.6 - 2.1 - 0	33.4	51
12	June 15	0.25	6.0	2.0	179	3.94	94.0	30.7	2,985	4.2	30.7 - 2.0 - 0	34.6	53
13	June 22	0.25	5.8	2.0	179	4.08	94.2	30.7	3,091	4.3	30.7 - 2.0 - 0	35.8	54
14	June 29	0.25	5.6	1.9	179	4.22	94.4	30.8	3,197	4.5	30.8 - 1.9 - 0	37.0	56
15	July 6	0.24	5.2	1.8	171	4.34	94.8	30.8	3,288	4.6	30.8 - 1.8 - 0	39.6	58
16	July 13	0.37	7.6	2.6	264	4.48	92.4	30.3	3,394	4.9	30.3 - 2.6 - 0	26.8	61
17	July 20	0.37	7.4	2.5	264	4.61	92.6	30.4	3,492	5.0	30.4 - 2.5 - 0	27.5	63
18	July 27	0.37	7.2	2.5	264	4.75	92.8	30.4	3,598	5.1	30.4 - 2.5 - 0	28.3	64

19	Aug 3	0.43	8.2	2.8	307	4.84	91.8	30.2	3,667	5.3	30.2 - 2.8 - 0	24.9	66
20	Aug 10	0.43	7.9	2.7	307	4.98	92.1	30.3	3,773	5.4	30.3 - 2.7 - 0	25.6	68
21	Aug 17	0.43	7.7	2.6	307	5.12	92.3	30.3	3,879	5.6	30.3 - 2.6 - 0	26.3	70
22	Aug 24	0.43	7.6	2.6	307	5.25	92.4	30.3	3,977	5.7	30.3 - 2.6 - 0	27.0	71
23	Aug 31	0.50	8.5	2.9	357	5.39	91.5	30.1	4,083	5.9	30.1 - 2.9 - 0	23.9	74
24	Sept 7	0.50	8.3	2.8	357	5.50	91.7	30.2	4,167	6.0	30.2 - 2.8 - 0	24.4	75
25	Sept 14	0.50	8.1	2.8	357	5.64	91.9	30.2	4,273	6.1	30.2 - 2.8 - 0	25.0	77
26	Sept 21	0.50	8.0	2.7	357	5.78	92.0	30.2	4,379	6.3	30.2 - 2.7 - 0	25.6	79
27	Sept 28	0.50	7.8	2.7	357	5.91	92.2	30.3	4,477	6.4	30.3 - 2.7 - 0	26.1	81
MT of	**10-34-0**	8.2			**MT of 32-0-0**	105.2				113.4	**Total MT of 10-34-0 and 32-0-0**		
	MT of P	1.2											
					MT of N in 32-0-0	33.6							
					MT of N in 10-34-0	0.8							
Litres 10-34-0	5,888												
					Total MT of N	34.5							
Litres 32-0-0	79,659												
Total litres	85,547		**N:P blend calculation (red) is built into spreadsheet, but manual entry into Blend (%) column is required.**										

The application rate is based on 60 minutes of pumping time along the centre line of the pelagic zone of Dworshak Reservoir Area 1.

Note: Density of 10-34-0 is 1.4 kg/L, 32-0-0 is 1.32 kg/L at 15 deg. C

Timing, fertilizer load and N:P ratios for Dworshak Reservoir Area 1 - K. Ashley, December 12, 2005
Fertilizer: blend of 10-34-0 (ammonium polyphosphate) and 32-0-0 (urea-ammonium nitrate)
Density of 10-34-0 is 1.415 kg/L, and 32-0-0 is 1.32 kg/L @ 15 C

Year 1 of 5 - 2006 for Dworshak Reservoir Area 1

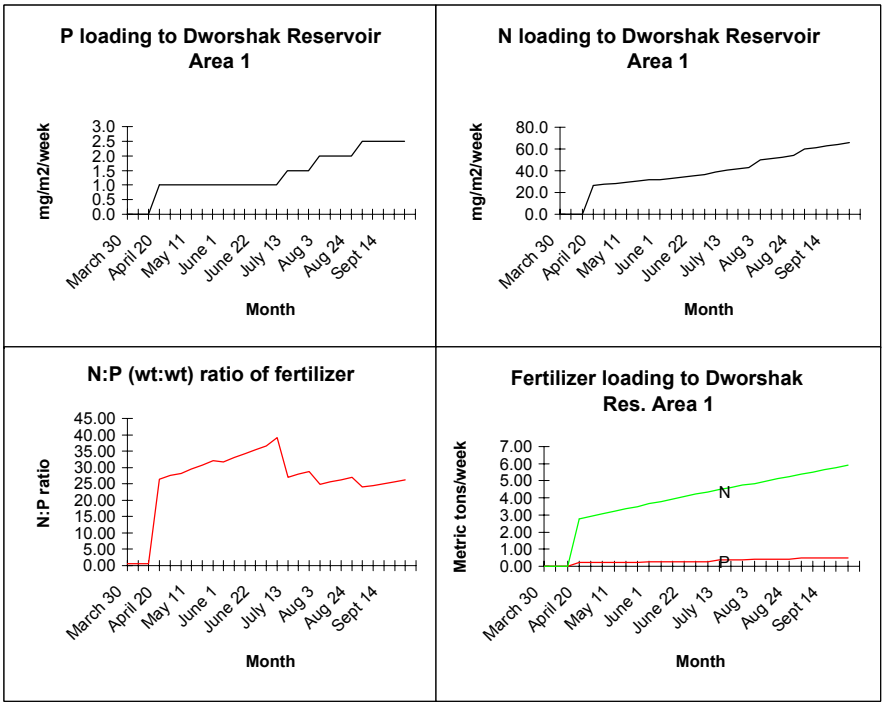
Notes:
a. N:P ratios are increased during application period
b. Surface area is adjusted monthly
c. Surface area derived from Area 1 linear regression of elevation vs. surface area
d. kgs N ratioed by Area 1/Area 2

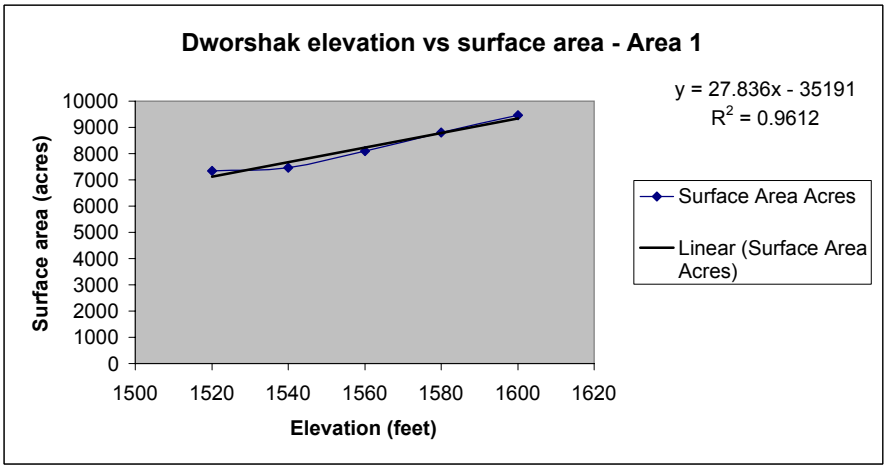
Reservoir area varies monthly
Costs in $US

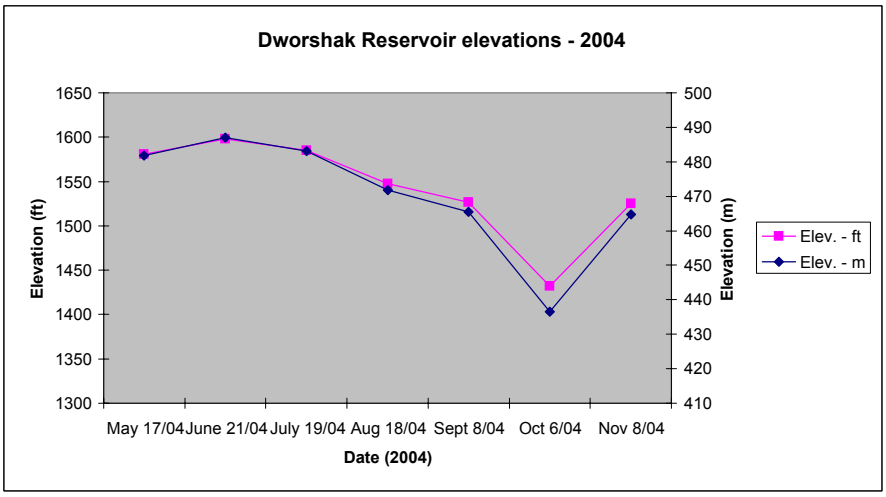
2004 data			Area	Area
Date	Elev. ft	Elev. m	(acres)	(m2)
March x/04	1561.7	476.0	8,279.39	33,506,691
April x/04	1571.5	479.0	8,553.36	34,615,460
May 17/04	1581.0	481.9	8,818.20	35,687,270
June 21/04	1598.1	487.1	9,293.09	37,609,136
July 19/04	1585.0	483.1	8,927.79	36,130,778
Aug 18/04	1547.9	471.8	7,895.83	31,954,415
Sept 8/04	1526.9	465.4	7,311.35	29,589,041
Oct 6/04	1432.4	436.6	4,681.21	18,944,860
Nov 8/04	1524.9	464.8	7,256.56	29,367,287

Week Dates	Nutrient P or N	N / P Loading mg/m2/wk	Amount N or P kg	Amount Fert (mt)	Form of fertilizer	N:P ratio wt:wt	Expected P (ug/L)	Expected Chlor a
March 30	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 6	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 13	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 20	P	1.0	35	0.23	10-34-0	26.38	1.0	0.7
	N	0.7	23		10-34-0			
	N	25.7	890	2.78	**32-0-0**			
April 27	P	1.0	35	0.23	10-34-0	27.67	1.0	0.7
	N	0.7	23		10-34-0			
	N	27.0	935	2.92	**32-0-0**			
May 4	P	1.0	36	0.24	10-34-0	28.26	1.0	0.7
	N	0.7	24		10-34-0			
	N	27.6	985	3.08	**32-0-0**			
May 11	P	1.0	36	0.24	10-34-0	29.51	1.1	0.7
	N	0.7	24		10-34-0			
	N	28.8	1,029	3.22	**32-0-0**			
May 18	P	1.0	36	0.24	10-34-0	30.77	1.1	0.8
	N	0.7	24		10-34-0			
	N	30.1	1,074	3.36	**32-0-0**			
May 25	P	1.0	36	0.24	10-34-0	32.02	1.1	0.8
	N	0.7	24		10-34-0			
	N	31.3	1,119	3.50	**32-0-0**			
June 1	P	1.0	38	0.25	10-34-0	31.78	1.1	0.8
	N	0.7	25		10-34-0			
	N	31.1	1,170	3.66	**32-0-0**			
June 8	P	1.0	38	0.25	10-34-0	32.98	1.1	0.8
	N	0.7	25		10-34-0			
	N	32.3	1,215	3.80	**32-0-0**			
June 15	P	1.0	38	0.25	10-34-0	34.18	1.2	0.8
	N	0.7	25		10-34-0			
	N	33.5	1,260	3.94	**32-0-0**			
June 22	P	1.0	38	0.25	10-34-0	35.37	1.2	0.8
	N	0.7	25		10-34-0			
	N	34.7	1,305	4.08	**32-0-0**			
June 29	P	1.0	38	0.25	10-34-0	36.57	1.2	0.8
	N	0.7	25		10-34-0			
	N	35.9	1,350	4.22	**32-0-0**			
July 6	P	1.0	36	0.24	10-34-0	39.07	1.2	0.8
	N	0.7	24		10-34-0			
	N	38.4	1,387	4.34	**32-0-0**			
July 13	P	1.5	54	0.37	10-34-0	27.10	1.2	0.8
	N	1.0	37		10-34-0			
	N	39.6	1,432	4.48	**32-0-0**			
July 20	P	1.5	54	0.37	10-34-0	27.92	1.3	0.8
	N	1.0	37		10-34-0			
	N	40.9	1,477	4.61	**32-0-0**			
July 27	P	1.5	54	0.37	10-34-0	28.75	1.3	0.8
	N	1.0	37		10-34-0			
	N	42.1	1,522	4.75	**32-0-0**			
Aug 3	P	2.0	64	0.43	10-34-0	24.91	1.3	0.8
	N	1.3	43		10-34-0			
	N	48.5	1,549	4.84	**32-0-0**			
Aug 10	P	2.0	64	0.43	10-34-0	25.60	1.4	0.8
	N	1.3	43		10-34-0			
	N	49.9	1,593	4.98	**32-0-0**			
Aug 17	P	2.0	64	0.43	10-34-0	26.29	1.4	0.8
	N	1.3	43		10-34-0			
	N	51.2	1,637	5.12	**32-0-0**			
Aug 24	P	2.0	64	0.43	10-34-0	26.98	1.5	0.8
	N	1.3	43		10-34-0			
	N	52.6	1,682	5.25	**32-0-0**			
Aug 31	P	2.5	74	0.50	10-34-0	24.00	1.5	0.9
	N	1.7	50		10-34-0			
	N	58.3	1,726	5.39	**32-0-0**			
Sept 7	P	2.5	74	0.50	10-34-0	24.47	1.6	0.9
	N	1.7	50		10-34-0			
	N	59.5	1,760	5.50	**32-0-0**			
Sept 14	P	2.5	74	0.50	10-34-0	25.06	1.6	0.9
	N	1.7	50		10-34-0			
	N	61.0	1,804	5.64	**32-0-0**			
Sept 21	P	2.5	74	0.50	10-34-0	25.66	1.7	0.9
	N	1.7	50		10-34-0			
	N	62.5	1,848	5.78	**32-0-0**			
Sept 28	P	2.5	74	0.50	10-34-0	26.25	1.7	0.9
	N	1.7	50		10-34-0			
	N	63.9	1,892	5.91	**32-0-0**			

	Total P	37.0	1.2	8.3	$3,301			
	load	mg/m2	metric ton	metric ton	Cost of P			
		in 24 weeks	of P	of 10-34-0	@$400/mt	(estimated cost)		
	Total N	1,031.4	34.5	105.1	$31,536			
	load	mg/m2	metric ton	metric ton	Cost of N			
		in 24 weeks	of N	of 32-0-0	@$300/mt	(estimated cost)		
Total	weight	113.4		Total cost	$34,837			
	of N and P	metric tons		of fertilizer				
	fertilizer							
			Summary					
		Phosphorus			**Nitrogen**			
	Load	**Amount**	**10-34-0**	**Load**	**Amount**	**32-0-0**	**N:P Ratio**	**No.**
	mg/m2	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**		
March 30	0.0	0	0.00	0.0	0	0.0	0.67	1
April 6	0.0	0	0.00	0.0	0	0.0	0.67	2
April 13	0.0	0	0.00	0.0	0	0.0	0.67	3
April 20	1.0	35	0.23	26.4	913	2.78	26.38	4
April 27	1.0	35	0.23	27.7	958	2.92	27.67	5
May 4	1.0	36	0.24	28.3	1,009	3.08	28.26	6
May 11	1.0	36	0.24	29.5	1,053	3.22	29.51	7
May 18	1.0	36	0.24	30.8	1,098	3.36	30.77	8
May 25	1.0	36	0.24	32.0	1,143	3.50	32.02	9
June 1	1.0	38	0.25	31.8	1,195	3.66	31.78	10
June 8	1.0	38	0.25	33.0	1,240	3.80	32.98	11
June 15	1.0	38	0.25	34.2	1,285	3.94	34.18	12
June 22	1.0	38	0.25	35.4	1,330	4.08	35.37	13
June 29	1.0	38	0.25	36.6	1,375	4.22	36.57	14
July 6	1.0	36	0.24	39.1	1,412	4.34	39.07	15
July 13	1.5	54	0.37	40.6	1,469	4.48	27.10	16
July 20	1.5	54	0.37	41.9	1,513	4.61	27.92	17
July 27	1.5	54	0.37	43.1	1,558	4.75	28.75	18
Aug 3	2.0	64	0.43	49.8	1,592	4.84	24.91	19
Aug 10	2.0	64	0.43	51.2	1,636	4.98	25.60	20
Aug 17	2.0	64	0.43	52.6	1,680	5.12	26.29	21
Aug 24	2.0	64	0.43	54.0	1,725	5.25	26.98	22
Aug 31	2.5	74	0.50	60.0	1,776	5.39	24.00	23
Sept 7	2.5	74	0.50	61.2	1,810	5.50	24.47	24
Sept 14	2.5	74	0.50	62.7	1,854	5.64	25.06	25
Sept 21	2.5	74	0.50	64.1	1,898	5.78	25.66	26
Sept 28	2.5	74	0.50	65.6	1,942	5.91	26.25	27
		Phosphorus			**Nitrogen**			
	Load	**Amount**	**10-34-0**	**Load**	**Amount**	**32-0-0**	**N:P Ratio**	**No.**
	mg/m2	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**		
	37.0	1.2	8.3	1,031.4	34.5	105.1		
	mg/m2	P	10-34-0	mg/m2	N	32-0-0		
	in 24 weeks	metric ton	metric ton	in 24 week	metric ton	metric ton		


P loading to Dworshak Reservoir
Area 1
mg/m2/week
3.0
2.5
2.0
1.5
1.0
0.5
0.0
March 30
April 20
May 11
June 1
June 22
July 13
Aug 3
Aug 24
Sept 14
Month
N loading to Dworshak Reservoir
Area 1
mg/m2/week
80.0
60.0
40.0
20.0
0.0
Month
N:P (wt:wt) ratio of fertilizer
N:P ratio
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Month
Fertilizer loading to Dworshak
Res. Area 1
Metric tons/week
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
N
P
Month


Dworshak elevation vs surface area - Area 1
y = 27.836x - 35191
R2 = 0.9612
Surface area (acres)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1500
1520
1540
1560
1580
1600
1620
Elevation (feet)
Surface Area Acres
Linear (Surface Area Acres)


Dworshak Reservoir elevations - 2004
Elevation (ft)
1650
1600
1550
1500
1450
1400
1350
1300
Elevation (m)
500
490
480
470
460
450
440
430
420
410
May 17/04
June 21/04
July 19/04
Aug 18/04
Sept 8/04
Oct 6/04
Nov 8/04
Date (2004)
Elev. - ft
Elev. - m

Sector 2 Prescription Tables

Dworshak Reservoir Fertilization Schedule Area 2 - March 29 to Sept 27, 2006. K. Ashley, Dec 12, 2005

Year 1 of 5

2006 Schedule - Area 2 applications on Wednesday

Week	Date	M. tons 10-34-0	% of 10-34-0 in total	% of 10-34-0 in blend	litres 10-34-0	M. Tons 32-0-0	% of 32-0-0 in total	% of 32-0-0 in blend	litres 32-0-0	Total M. Tons	Blend (%) N-P2O5-K2O	N:P ratio wt:wt	Application rate litres/min for 60 minutes
1	March 29	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
2	April 5	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
3	April 12	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
4	April 19	0.13	7.5	2.6	93	1.60	92.5	30.3	1,212	1.7	30.3 - 2.6 - 0	27.2	22
5	April 26	0.13	7.3	2.5	93	1.64	92.7	30.4	1,242	1.8	30.4 - 2.5 - 0	27.9	22
6	May 3	0.13	7.0	2.4	93	1.72	93.0	30.5	1,303	1.9	30.5 - 2.4 - 0	29.2	23
7	May 10	0.13	6.7	2.3	93	1.80	93.3	30.5	1,364	1.9	30.5 - 2.3 - 0	30.5	24
8	May 17	0.13	6.5	2.2	93	1.88	93.5	30.6	1,424	2.0	30.6 - 2.2 - 0	31.8	25
9	May 24	0.13	6.3	2.1	93	1.95	93.8	30.6	1,477	2.1	30.6 - 2.1 - 0	33.0	26
10	May 31	0.14	6.5	2.2	100	2.03	93.5	30.6	1,538	2.2	30.6 - 2.2 - 0	31.9	27
11	June 7	0.14	6.2	2.1	100	2.11	93.8	30.6	1,598	2.3	30.6 - 2.1 - 0	33.2	28
12	June 14	0.14	6.0	2.0	100	2.19	94.0	30.7	1,659	2.3	30.7 - 2.0 - 0	34.4	29
13	June 21	0.14	5.8	2.0	100	2.27	94.2	30.7	1,720	2.4	30.7 - 2.0 - 0	35.6	30
14	June 28	0.14	5.6	1.9	100	2.34	94.4	30.8	1,773	2.5	30.8 - 1.9 - 0	36.7	31
15	July 5	0.14	5.5	1.9	100	2.42	94.5	30.8	1,833	2.6	30.8 - 1.9 - 0	37.9	32
16	July 12	0.20	7.4	2.5	143	2.50	92.6	30.4	1,894	2.7	30.4 - 2.5 - 0	27.6	34
17	July 19	0.20	7.2	2.4	143	2.58	92.8	30.4	1,955	2.8	30.4 - 2.4 - 0	28.5	35
18	July 26	0.20	7.0	2.4	143	2.66	93.0	30.5	2,015	2.9	30.5 - 2.4 - 0	29.3	36

19	Aug 2	0.24	8.1	2.7	171	2.73	91.9	30.2	2,068	3.0	30.2 - 2.7 - 0	25.2	37
20	Aug 9	0.24	7.9	2.7	171	2.81	92.1	30.3	2,129	3.1	30.3 - 2.7 - 0	25.9	38
21	Aug 16	0.24	7.7	2.6	171	2.89	92.3	30.3	2,189	3.1	30.3 - 2.7 - 0	26.6	39
22	Aug 23	0.24	7.5	2.5	171	2.97	92.5	30.4	2,250	3.2	30.4 - 2.5 - 0	27.3	40
23	Aug 30	0.28	8.4	2.9	200	3.05	91.6	30.2	2,311	3.3	30.2 - 2.9 - 0	24.1	42
24	Sept 6	0.28	8.2	2.8	200	3.13	91.8	30.2	2,371	3.4	30.2 - 2.8 - 0	24.8	43
25	Sept 13	0.28	8.0	2.7	200	3.20	92.0	30.2	2,424	3.5	30.2 - 2.7 - 0	25.3	44
26	Sept 20	0.28	7.9	2.7	200	3.28	92.1	30.3	2,485	3.6	30.3 - 2.7 - 0	25.9	45
27	Sept 27	0.28	7.7	2.6	200	3.36	92.3	30.3	2,545	3.6	30.3 - 2.6 - 0	26.5	46
MT of	**10-34-0**	4.6			**MT of 32-0-0**	59.1				63.7	**Total MT of 10-34-0 and 32-0-0**		
	MT of P	0.7											
					MT of N in 32-0-0	18.9							
Litres 10-34-0	3,274				**MT of N in 10-34-0**	0.5							
Litres 32-0-0	44,780				**Total MT of N**	19.4							
Total litres	48,054		**N:P blend calculation (red) is built into spreadsheet, but manual entry into Blend (%) column is required.**										

The application rate is based on 60 minutes of pumping time along the centre line of the pelagic zone of Dworshak Reservoir Area 2.

Note: Density of 10-34-0 is 1.4 kg/L, 32-0-0 is 1.32 kg/L at 15 deg. C

Timing, fertilizer load and N:P ratios for Dworshak Reservoir Area 2 - K. Ashley, December 11, 2005
Fertilizer: blend of 10-34-0 (ammonium polyphosphate) and 32-0-0 (urea-ammonium nitrate)
Density of 10-34-0 is 1.415 kg/L, and 32-0-0 is 1.32 kg/L @ 15 C

Year 1 of 5 - 2006 for Dworshak Reservoir Area 2

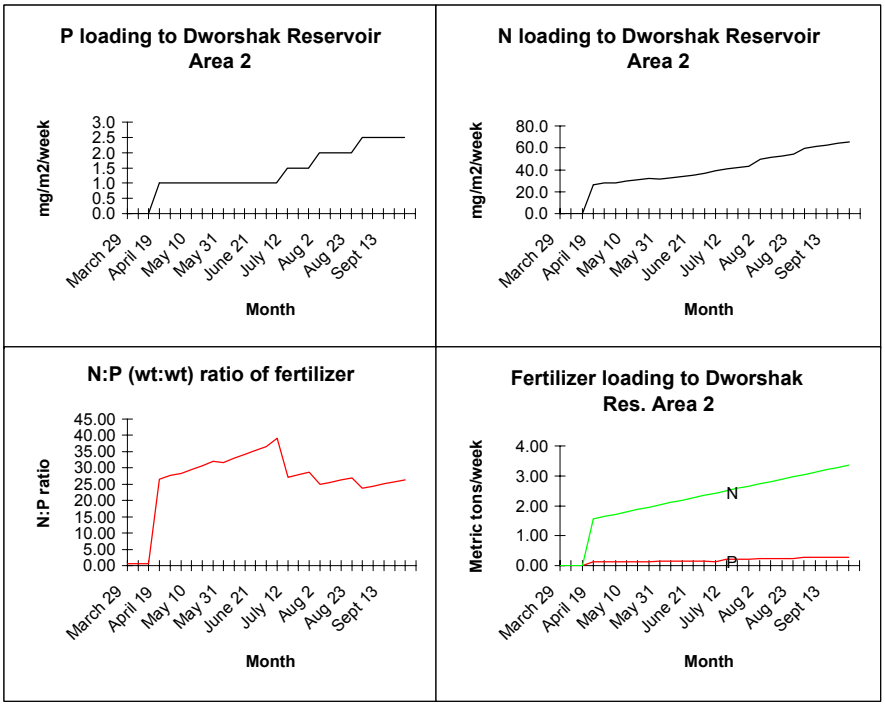
Notes:
a. N:P ratios are increased during application period
b. Surface area is adjusted monthly
c. Surface area derived from Area 2 linear regression of elevation vs. surface area

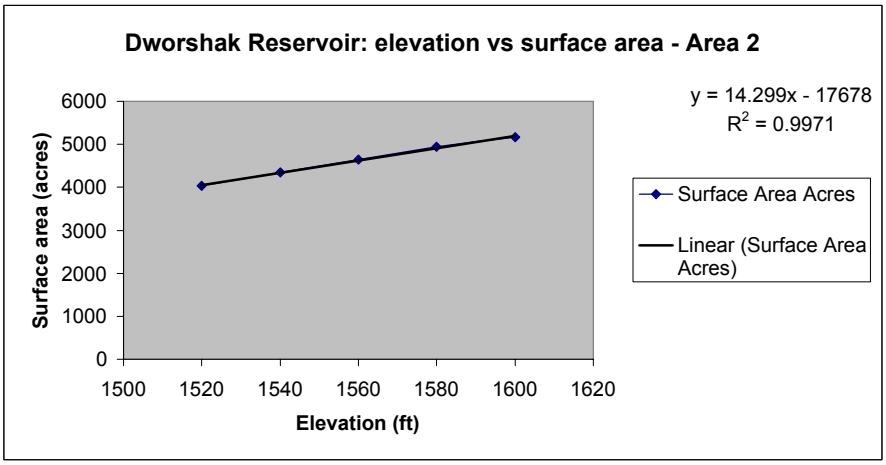
Reservoir area varies monthly
Costs in $US

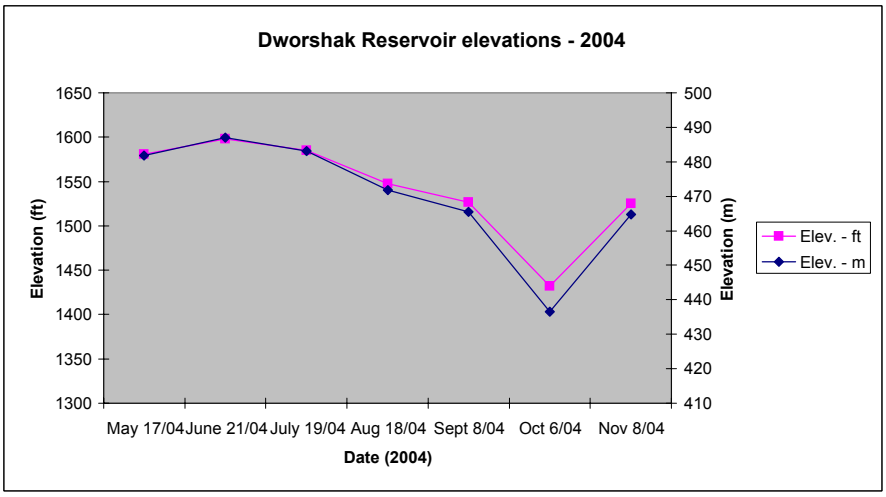
	2004 data			Area	Area
	Date	Elev. ft	Elev. m	(acres)	(m2)
	March x/04	1561.7	476.0	4,652.19	18,827,404
	April x/04	1571.5	479.0	4,792.92	19,396,964
	May 17/04	1581.0	481.9	4,928.97	19,947,540
	June 21/04	1598.1	487.1	5,172.91	20,934,778
	July 19/04	1585.0	483.1	4,985.26	20,175,364
	Aug 18/04	1547.9	471.8	4,455.16	18,030,019
	Sept 8/04	1526.9	465.4	4,154.92	16,814,957
	Oct 6/04	1432.4	436.6	2,803.85	11,347,176
	Nov 8/04	1524.9	464.8	4,126.77	16,701,045

Week Dates	Nutrient P or N	N / P Loading mg/m2/wk	Amount N or P kg	Amount Fert (mt)	Form of fertilizer	N:P ratio wt:wt	Expected P (ug/L)	Expected Chlor a
March 29	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 5	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 12	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 19	P	1.0	19	0.13	10-34-0	26.45	1.0	0.7
	N	0.7	13		10-34-0			
	N	25.8	500	1.56	**32-0-0**			
April 26	P	1.0	19	0.13	10-34-0	27.74	1.0	0.7
	N	0.7	13		10-34-0			
	N	27.1	525	1.64	**32-0-0**			
May 3	P	1.0	20	0.13	10-34-0	28.25	1.0	0.7
	N	0.7	13		10-34-0			
	N	27.6	550	1.72	**32-0-0**			
May 10	P	1.0	20	0.13	10-34-0	29.50	1.1	0.7
	N	0.7	13		10-34-0			
	N	28.8	575	1.80	**32-0-0**			
May 17	P	1.0	20	0.13	10-34-0	30.75	1.1	0.8
	N	0.7	13		10-34-0			
	N	30.1	600	1.88	**32-0-0**			
May 24	P	1.0	20	0.13	10-34-0	32.01	1.1	0.8
	N	0.7	13		10-34-0			
	N	31.3	625	1.95	**32-0-0**			
May 31	P	1.0	21	0.14	10-34-0	31.72	1.1	0.8
	N	0.7	14		10-34-0			
	N	31.0	650	2.03	**32-0-0**			
June 7	P	1.0	21	0.14	10-34-0	32.92	1.1	0.8
	N	0.7	14		10-34-0			
	N	32.2	675	2.11	**32-0-0**			
June 14	P	1.0	21	0.14	10-34-0	34.11	1.2	0.8
	N	0.7	14		10-34-0			
	N	33.4	700	2.19	**32-0-0**			
June 21	P	1.0	21	0.14	10-34-0	35.30	1.2	0.8
	N	0.7	14		10-34-0			
	N	34.6	725	2.27	**32-0-0**			
June 28	P	1.0	21	0.14	10-34-0	36.50	1.2	0.8
	N	0.7	14		10-34-0			
	N	35.8	750	2.34	**32-0-0**			
July 5	P	1.0	20	0.14	10-34-0	39.09	1.2	0.8
	N	0.7	14		10-34-0			
	N	38.4	775	2.42	**32-0-0**			
July 12	P	1.5	30	0.20	10-34-0	27.11	1.2	0.8
	N	1.0	20		10-34-0			
	N	39.7	800	2.50	**32-0-0**			
July 19	P	1.5	30	0.20	10-34-0	27.93	1.3	0.8
	N	1.0	20		10-34-0			
	N	40.9	825	2.58	**32-0-0**			
July 26	P	1.5	30	0.20	10-34-0	28.76	1.3	0.8
	N	1.0	20		10-34-0			
	N	42.1	850	2.66	**32-0-0**			
Aug 2	P	2.0	36	0.24	10-34-0	24.94	1.3	0.8
	N	1.3	24		10-34-0			
	N	48.5	875	2.73	**32-0-0**			
Aug 9	P	2.0	36	0.24	10-34-0	25.63	1.4	0.8
	N	1.3	24		10-34-0			
	N	49.9	900	2.81	**32-0-0**			
Aug 16	P	2.0	36	0.24	10-34-0	26.33	1.4	0.8
	N	1.3	24		10-34-0			
	N	51.3	925	2.89	**32-0-0**			
Aug 23	P	2.0	36	0.24	10-34-0	27.02	1.5	0.8
	N	1.3	24		10-34-0			
	N	52.7	950	2.97	**32-0-0**			
Aug 30	P	2.5	42	0.28	10-34-0	23.87	1.5	0.9
	N	1.7	28		10-34-0			
	N	58.0	975	3.05	**32-0-0**			
Sept 6	P	2.5	42	0.28	10-34-0	24.46	1.6	0.9
	N	1.7	28		10-34-0			
	N	59.5	1,000	3.13	**32-0-0**			
Sept 13	P	2.5	42	0.28	10-34-0	25.06	1.6	0.9
	N	1.7	28		10-34-0			
	N	61.0	1,025	3.20	**32-0-0**			
Sept 20	P	2.5	42	0.28	10-34-0	25.65	1.7	0.9
	N	1.7	28		10-34-0			
	N	62.4	1,050	3.28	**32-0-0**			
Sept 27	P	2.5	42	0.28	10-34-0	26.25	1.7	0.9
	N	1.7	28		10-34-0			
	N	63.9	1,075	3.36	**32-0-0**			

	Total P	37.0	0.7	4.6	$1,857			
	load	mg/m2	metric ton	metric ton	Cost of P			
		in 24 weeks	of P	of 10-34-0	@$400/mt	(estimated cost)		
	Total N	1,031.1	19.4	59.1	$17,719			
	load	mg/m2	metric ton	metric ton	Cost of N			
		in 24 weeks	of N	of 32-0-0	@$300/mt	(estimated cost)		
Total	weight	63.7		Total cost	$19,576			
	of N and P	metric tons		of fertilizer				
	fertilizer							
			Summary					
		Phosphorus			**Nitrogen**			
	Load	**Amount**	**10-34-0**	**Load**	**Amount**	**32-0-0**	**N:P Ratio**	**No.**
	mg/m2	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**		
March 29	0.0	0	0.00	0.0	0	0.0	0.67	1
April 5	0.0	0	0.00	0.0	0	0.0	0.67	2
April 12	0.0	0	0.00	0.0	0	0.0	0.67	3
April 19	1.0	19	0.13	26.5	513	1.6	26.45	4
April 26	1.0	19	0.13	27.7	538	1.64	27.74	5
May 3	1.0	20	0.13	28.2	563	1.72	28.25	6
May 10	1.0	20	0.13	29.5	588	1.80	29.50	7
May 17	1.0	20	0.13	30.8	613	1.88	30.75	8
May 24	1.0	20	0.13	32.0	638	1.95	32.01	9
May 31	1.0	21	0.14	31.7	664	2.03	31.72	10
June 7	1.0	21	0.14	32.9	689	2.11	32.92	11
June 14	1.0	21	0.14	34.1	714	2.19	34.11	12
June 21	1.0	21	0.14	35.3	739	2.27	35.30	13
June 28	1.0	21	0.14	36.5	764	2.34	36.50	14
July 5	1.0	20	0.14	39.1	789	2.42	39.09	15
July 12	1.5	30	0.20	40.7	820	2.50	27.11	16
July 19	1.5	30	0.20	41.9	845	2.58	27.93	17
July 26	1.5	30	0.20	43.1	870	2.66	28.76	18
Aug 2	2.0	36	0.24	49.9	899	2.73	24.94	19
Aug 9	2.0	36	0.24	51.3	924	2.81	25.63	20
Aug 16	2.0	36	0.24	52.7	949	2.89	26.33	21
Aug 23	2.0	36	0.24	54.0	974	2.97	27.02	22
Aug 30	2.5	42	0.28	59.7	1,003	3.05	23.87	23
Sept 6	2.5	42	0.28	61.2	1,028	3.13	24.46	24
Sept 13	2.5	42	0.28	62.6	1,053	3.20	25.06	25
Sept 20	2.5	42	0.28	64.1	1,078	3.28	25.65	26
Sept 27	2.5	42	0.28	65.6	1,103	3.36	26.25	27
		Phosphorus			**Nitrogen**			
	Load	**Amount**	**10-34-0**	**Load**	**Amount**	**32-0-0**	**N:P Ratio**	**No.**
	mg/m2	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**		
	37.0	0.7	4.6	1,031.1	19.4	59.1		
	mg/m2	P	10-34-0	mg/m2	N	32-0-0		
	in 24 weeks	metric ton	metric ton	in 24 week	metric ton	metric ton		


P loading to Dworshak Reservoir
Area 2
mg/m2/week
3.0
2.5
2.0
1.5
1.0
0.5
0.0
March 29
April 19
May 10
May 31
June 21
July 12
Aug 2
Aug 23
Sept 13
Month
N loading to Dworshak Reservoir
Area 2
mg/m2/week
80.0
60.0
40.0
20.0
0.0
Month
N:P (wt:wt) ratio of fertilizer
N:P ratio
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Month
Fertilizer loading to Dworshak
Res. Area 2
Metric tons/week
4.00
3.00
2.00
1.00
0.00
N
P
Month


Dworshak Reservoir: elevation vs surface area - Area 2
y = 14.299x - 17678
R2 = 0.9971
Surface area (acres)
6000
5000
4000
3000
2000
1000
0
1500
1520
1540
1560
1580
1600
1620
Elevation (ft)
Surface Area Acres
Linear (Surface Area Acres)


Dworshak Reservoir elevations - 2004
Elevation (ft)
1650
1600
1550
1500
1450
1400
1350
1300
Elevation (m)
500
490
480
470
460
450
440
430
420
410
May 17/04
June 21/04
July 19/04
Aug 18/04
Sept 8/04
Oct 6/04
Nov 8/04
Date (2004)
Elev. - ft
Elev. - m

Sector 3 Prescription Tables

Dworshak Reservoir Fertilization Schedule Area 3 - March 28 to Sept 26, 2006. K. Ashley, Dec 12, 2005

Year 1 of 5

2006 Schedule - Area 3 applications on Tuesday

Week	Date	M. tons 10-34-0	% of 10-34-0 in total	% of 10-34-0 in blend	litres 10-34-0	M. Tons 32-0-0	% of 32-0-0 in total	% of 32-0-0 in blend	litres 32-0-0	Total M. Tons	Blend (%) N-P2O5-K2O	N:P ratio wt:wt	Application rate litres/min for 60 minutes
1	March 28	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
2	April 4	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
3	April 11	0.00	100.0	34.0	1	0.00	0.0	10.0	0	0.0	10.0 - 34.0 - 0	0.7	0
4	April 18	0.06	8.3	2.8	43	0.66	91.7	30.2	500	0.7	30.2 - 2.8 - 0	24.4	9
5	April 25	0.06	8.0	2.7	43	0.69	92.0	30.2	523	0.8	30.2 - 2.7 - 0	25.5	9
6	May 2	0.06	7.3	2.5	43	0.76	92.7	30.4	576	0.8	30.4 - 2.5 - 0	28.0	10
7	May 9	0.06	7.1	2.4	43	0.79	92.9	30.4	598	0.9	30.4 - 2.4 - 0	29.0	11
8	May 16	0.06	6.7	2.3	43	0.83	93.3	30.5	629	0.9	30.5 - 2.3 - 0	30.5	11
9	May 23	0.06	6.5	2.2	43	0.86	93.5	30.6	652	0.9	30.6 - 2.2 - 0	31.6	12
10	May 30	0.07	7.3	2.5	50	0.89	92.7	30.4	674	1.0	30.4 - 2.5 - 0	28.1	12
11	June 6	0.07	6.5	2.2	50	1.01	93.5	30.6	765	1.1	30.6 - 2.2 - 0	31.8	14
12	June 13	0.07	6.3	2.1	50	1.05	93.8	30.6	795	1.1	30.6 - 2.1 - 0	33.0	14
13	June 20	0.07	6.0	2.1	50	1.09	94.0	30.7	826	1.2	30.7 - 2.1 - 0	34.2	15
14	June 27	0.07	5.8	2.0	50	1.13	94.2	30.7	856	1.2	30.7 - 2.0 - 0	35.5	15
15	July 4	0.06	5.2	1.8	43	1.09	94.8	30.9	826	1.2	30.9 - 1.8 - 0	39.8	14
16	July 11	0.09	7.4	2.5	64	1.13	92.6	30.4	856	1.2	30.4 - 2.5 - 0	27.7	15
17	July 18	0.09	7.2	2.4	64	1.16	92.8	30.4	879	1.3	30.4 - 2.4 - 0	28.4	16
18	July 25	0.09	7.0	2.4	64	1.20	93.0	30.5	909	1.3	30.5 - 2.4 - 0	29.4	16

19	Aug 1	0.09	8.2	2.8	64	1.01	91.8	30.2	765	1.1	30.2 - 2.8 - 0	24.9	14
20	Aug 8	0.09	8.0	2.7	64	1.04	92.0	30.2	788	1.1	30.2 - 2.7 - 0	25.6	14
21	Aug 15	0.09	7.8	2.6	64	1.07	92.2	30.3	811	1.2	30.3 - 2.6 - 0	26.3	15
22	Aug 22	0.09	7.6	2.6	64	1.10	92.4	30.3	833	1.2	30.3 - 2.6 - 0	27.0	15
23	Aug 29	0.09	7.4	2.5	64	1.13	92.6	30.4	856	1.2	30.4 - 2.5 - 0	27.7	15
24	Sept 5	0.09	8.5	2.9	64	0.97	91.5	30.1	735	1.1	30.1 - 2.9 - 0	23.9	13
25	Sept 17	0.09	8.3	2.8	64	0.99	91.7	30.2	750	1.1	30.2 - 2.8 - 0	24.4	14
26	Sept 19	0.09	8.1	2.8	64	1.02	91.9	30.2	773	1.1	30.2 - 2.8 - 0	25.1	14
27	Sept 26	0.09	8.0	2.7	64	1.04	92.0	30.2	788	1.1	30.2 - 2.7 - 0	25.6	14
MT of	**10-34-0**	1.9			**MT of 32-0-0**	23.7				25.6	**Total MT of 10-34-0 and 32-0-0**		
	MT of P	0.3											
					MT of N in 32-0-0	7.6							
Litres 10-34-0	1,324				**MT of N in 10-34-0**	0.2							
Litres 32-0-0	17,962				**Total MT of N**	7.8							
Total litres	19,286		**N:P blend calculation (red) is built into spreadsheet, but manual entry into Blend (%) column is required.**										

The application rate is based on 60 minutes of pumping time along the centre line of the pelagic zone of Dworshak Reservoir Area 3.

Note: Density of 10-34-0 is 1.4 kg/L, 32-0-0 is 1.32 kg/L at 15 deg. C

Timing, fertilizer load and N:P ratios for Dworshak Reservoir Area 3 - K. Ashley, December 12, 2005
Fertilizer: blend of 10-34-0 (ammonium polyphosphate) and 32-0-0 (urea-ammonium nitrate)
Density of 10-34-0 is 1.415 kg/L, and 32-0-0 is 1.32 kg/L @ 15 C

Year 1 of 5 - 2006 for Dworshak Reservoir Area 3

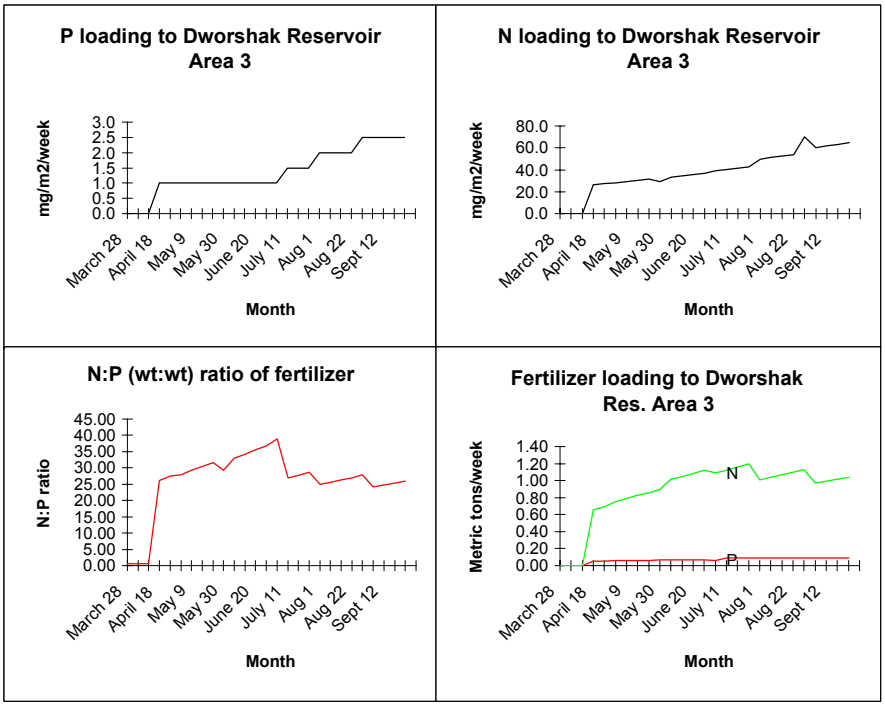
Notes:
a. N:P ratios are increased during application period
b. Surface area is adjusted monthly
c. Surface area derived from Area 3 linear regression of elevation vs. surface area
d. kgs N ratioed by Area 3/Area 2

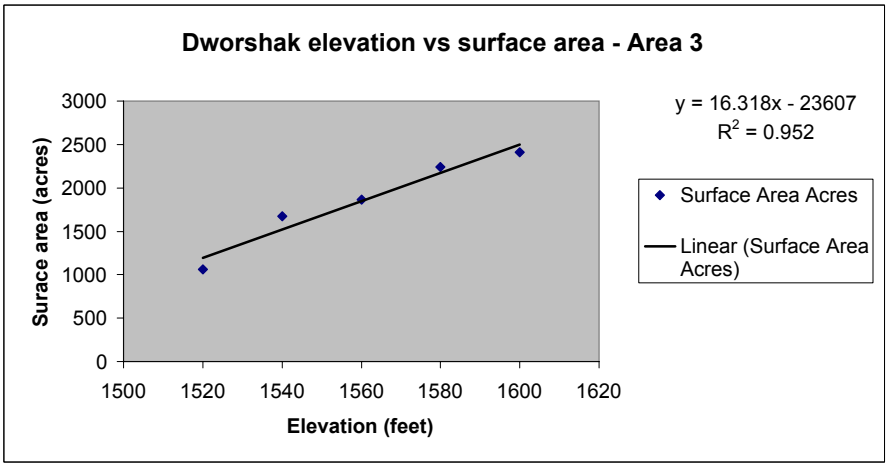
Reservoir area varies monthly
Costs in $US

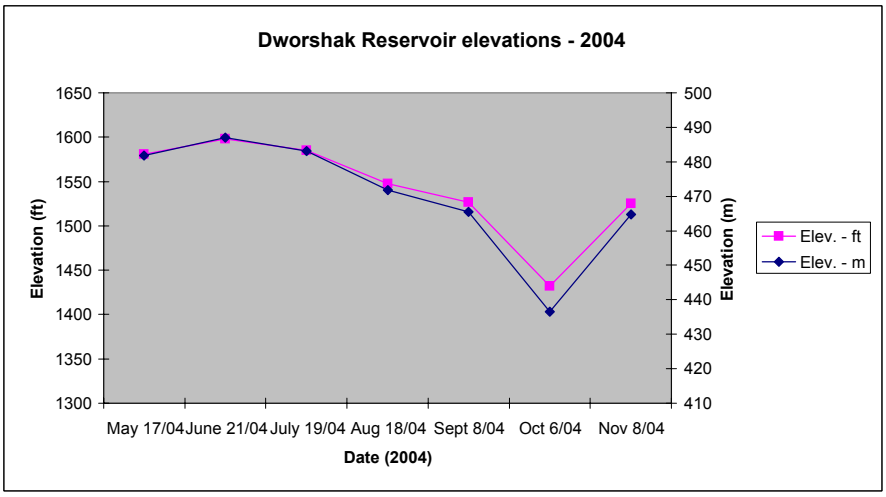
2004 data Date	Elev. ft	Elev. m	Area (acres)	Area (m2)
March x/04	1561.7	476.0	1,876.18	7,592,904
April x/04	1571.5	479.0	2,036.79	8,242,886
May 17/04	1581.0	481.9	2,192.04	8,871,202
June 21/04	1598.1	487.1	2,470.43	9,997,837
July 19/04	1585.0	483.1	2,256.29	9,131,194
Aug 18/04	1547.9	471.8	1,651.33	6,682,930
Sept 8/04	1526.9	465.4	1,308.70	5,296,302
Oct 6/04	1521.0	463.6	1,212.33	4,906,313
Nov 8/04	1524.9	464.8	1,276.58	5,166,306

Week Dates	Nutrient P or N	N / P Loading mg/m2/wk	Amount N or P kg	Amount Fert (mt)	Form of fertilizer	N:P ratio wt:wt	Expected P (ug/L)	Expected Chlor a
March 28	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 4	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 11	P	0.0	0	0.00	10-34-0	0.67	1.0	0.7
	N	0.0	0		10-34-0			
	N	0.0	0	0.00	**32-0-0**			
April 18	P	1.0	8	0.06	10-34-0	26.15	1.0	0.7
	N	0.7	6		10-34-0			
	N	25.5	210	0.66	**32-0-0**			
April 25	P	1.0	8	0.06	10-34-0	27.42	1.0	0.7
	N	0.7	6		10-34-0			
	N	26.8	221	0.69	**32-0-0**			
May 2	P	1.0	9	0.06	10-34-0	27.95	1.0	0.7
	N	0.7	6		10-34-0			
	N	27.3	242	0.76	**32-0-0**			
May 9	P	1.0	9	0.06	10-34-0	29.19	1.1	0.7
	N	0.7	6		10-34-0			
	N	28.5	253	0.79	**32-0-0**			
May 16	P	1.0	9	0.06	10-34-0	30.43	1.1	0.8
	N	0.7	6		10-34-0			
	N	29.8	264	0.83	**32-0-0**			
May 23	P	1.0	9	0.06	10-34-0	31.67	1.1	0.8
	N	0.7	6		10-34-0			
	N	31.0	275	0.86	**32-0-0**			
May 30	P	1.0	10	0.07	10-34-0	29.28	1.1	0.8
	N	0.7	7		10-34-0			
	N	28.6	286	0.89	**32-0-0**			
June 6	P	1.0	10	0.07	10-34-0	33.08	1.1	0.8
	N	0.7	7		10-34-0			
	N	32.4	324	1.01	**32-0-0**			
June 13	P	1.0	10	0.07	10-34-0	34.28	1.2	0.8
	N	0.7	7		10-34-0			
	N	33.6	336	1.05	**32-0-0**			
June 20	P	1.0	10	0.07	10-34-0	35.48	1.2	0.8
	N	0.7	7		10-34-0			
	N	34.8	348	1.09	**32-0-0**			
June 27	P	1.0	10	0.07	10-34-0	36.68	1.2	0.8
	N	0.7	7		10-34-0			
	N	36.0	360	1.13	**32-0-0**			
July 4	P	1.0	9	0.06	10-34-0	38.87	1.2	0.8
	N	0.7	6		10-34-0			
	N	38.2	349	1.09	**32-0-0**			
July 11	P	1.5	14	0.09	10-34-0	26.96	1.2	0.8
	N	1.0	9		10-34-0			
	N	39.4	360	1.13	**32-0-0**			
July 18	P	1.5	14	0.09	10-34-0	27.78	1.3	0.8
	N	1.0	9		10-34-0			
	N	40.7	371	1.16	**32-0-0**			
July 25	P	1.5	14	0.09	10-34-0	28.60	1.3	0.8
	N	1.0	9		10-34-0			
	N	41.9	383	1.20	**32-0-0**			
Aug 1	P	2.0	13	0.09	10-34-0	24.90	1.3	0.8
	N	1.3	9		10-34-0			
	N	48.4	324	1.01	**32-0-0**			
Aug 8	P	2.0	13	0.09	10-34-0	25.59	1.4	0.8
	N	1.3	9		10-34-0			
	N	49.8	333	1.04	**32-0-0**			
Aug 15	P	2.0	13	0.09	10-34-0	26.28	1.4	0.8
	N	1.3	9		10-34-0			
	N	51.2	342	1.07	**32-0-0**			
Aug 22	P	2.0	13	0.09	10-34-0	26.97	1.5	0.8
	N	1.3	9		10-34-0			
	N	52.6	352	1.10	**32-0-0**			
Aug 29	P	2.5	13	0.09	10-34-0	27.92	1.5	0.9
	N	1.7	9		10-34-0			
	N	68.1	361	1.13	**32-0-0**			
Sept 5	P	2.5	13	0.09	10-34-0	24.09	1.6	0.9
	N	1.7	9		10-34-0			
	N	58.5	310	0.97	**32-0-0**			
Sept 12	P	2.5	13	0.09	10-34-0	24.67	1.6	0.9
	N	1.7	9		10-34-0			
	N	60.0	318	0.99	**32-0-0**			
Sept 19	P	2.5	13	0.09	10-34-0	25.26	1.7	0.9
	N	1.7	9		10-34-0			
	N	61.5	326	1.02	**32-0-0**			
Sept 26	P	2.5	13	0.09	10-34-0	25.84	1.7	0.9
	N	1.7	9		10-34-0			
	N	62.9	333	1.04	**32-0-0**			

	Total P	37.0	0.3	1.8	$733			
	load	mg/m2	metric ton	metric ton	Cost of P			
		in 24 weeks	of P	of 10-34-0	@$400/mt	(estimated cost)		
	Total N	1,032.4	7.8	23.7	$7,105			
	load	mg/m2	metric ton	metric ton	Cost of N			
		in 24 weeks	of N	of 32-0-0	@$300/mt	(estimated cost)		
Total	weight	25.5		Total cost	$7,838			
	of N and P	metric tons		of fertilizer				
	fertilizer							
			Summary					
		Phosphorus			**Nitrogen**			
	Load	**Amount**	**10-34-0**	**Load**	**Amount**	**32-0-0**	**N:P Ratio**	**No.**
	mg/m2	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**		
March 28	0.0	0	0.00	0.0	0	0.0	0.67	1
April 4	0.0	0	0.00	0.0	0	0.0	0.67	2
April 11	0.0	0	0.00	0.0	0	0.0	0.67	3
April 18	1.0	8	0.06	26.2	216	0.66	26.15	4
April 25	1.0	8	0.06	27.4	226	0.69	27.42	5
May 2	1.0	9	0.06	28.0	248	0.76	27.95	6
May 9	1.0	9	0.06	29.2	259	0.79	29.19	7
May 16	1.0	9	0.06	30.4	270	0.83	30.43	8
May 23	1.0	9	0.06	31.7	281	0.86	31.67	9
May 30	1.0	10	0.07	29.3	293	0.89	29.28	10
June 6	1.0	10	0.07	33.1	331	1.01	33.08	11
June 13	1.0	10	0.07	34.3	343	1.05	34.28	12
June 20	1.0	10	0.07	35.5	355	1.09	35.48	13
June 27	1.0	10	0.07	36.7	367	1.13	36.68	14
July 4	1.0	9	0.06	38.9	355	1.09	38.87	15
July 11	1.5	14	0.09	40.4	369	1.13	26.96	16
July 18	1.5	14	0.09	41.7	380	1.16	27.78	17
July 25	1.5	14	0.09	42.9	392	1.20	28.60	18
Aug 1	2.0	13	0.09	49.8	333	1.01	24.90	19
Aug 8	2.0	13	0.09	51.2	342	1.04	25.59	20
Aug 15	2.0	13	0.09	52.6	351	1.07	26.28	21
Aug 22	2.0	13	0.09	53.9	361	1.10	26.97	22
Aug 29	2.5	13	0.09	69.8	370	1.13	27.92	23
Sept 5	2.5	13	0.09	60.2	319	0.97	24.09	24
Sept 12	2.5	13	0.09	61.7	327	0.99	24.67	25
Sept 19	2.5	13	0.09	63.1	334	1.02	25.26	26
Sept 26	2.5	13	0.09	64.6	342	1.04	25.84	27
		Phosphorus			**Nitrogen**			
	Load	**Amount**	**10-34-0**	**Load**	**Amount**	**32-0-0**	**N:P Ratio**	**No.**
	mg/m2	**kgs**	**M. Tons**	**mg/m2**	**kgs**	**M. Tons**		
	37.0	0.3	1.8	1,032.4	7.8	23.7		
	mg/m2	P	10-34-0	mg/m2	N	32-0-0		
	in 24 weeks	metric ton	metric ton	in 24 week	metric ton	metric ton		


P loading to Dworshak Reservoir
Area 3
mg/m2/week
3.0
2.5
2.0
1.5
1.0
0.5
0.0
March 28
April 18
May 9
May 30
June 20
July 11
Aug 1
Aug 22
Sept 12
Month
N loading to Dworshak Reservoir
Area 3
mg/m2/week
80.0
60.0
40.0
20.0
0.0
Month
N:P (wt:wt) ratio of fertilizer
N:P ratio
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Month
Fertilizer loading to Dworshak
Res. Area 3
Metric tons/week
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
N
P
Month


Dworshak elevation vs surface area - Area 3
Surace area (acres)
3000
2500
2000
1500
1000
500
0
1500
1520
1540
1560
1580
1600
1620
Elevation (feet)
y = 16.318x - 23607
R2 = 0.952
Surface Area Acres
Linear (Surface Area Acres)


Dworshak Reservoir elevations - 2004
Elevation (ft)
1650
1600
1550
1500
1450
1400
1350
1300
Elevation (m)
500
490
480
470
460
450
440
430
420
410
May 17/04
June 21/04
July 19/04
Aug 18/04
Sept 8/04
Oct 6/04
Nov 8/04
Date (2004)
Elev. - ft
Elev. - m

Appendix C

Reservoir Monitoring Manual (RMM)

RESERVOIR MONITORING MANUAL (RMM)
Dworshak Reservoir

PREPARED FOR:

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PREPARED BY:

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December 2005

RESERVOIR LIMNOLOGY MONITORING METHODS

Introduction

A Stave Reservoir monitoring program was designed for USACE in May 1999 to assess the reservoir's pelagic and littoral community response to proposed operating changes to reduce water level fluctuation, i.e. stabilization. One of the high priority recommendations of the monitor program was:
"USACE should prepare and publish a **R**eservoir **M**onitoring **M**anual (**RMM**) containing state-of-the-art sampling protocols and methods of analysis for limnological and fisheries monitoring in USACE reservoirs."
The manual would serve as a first step toward the standardization of procedures to be used when conducting limnological monitors of reservoirs operated by USACE. The Manual would include methods deemed appropriate for tracking changes in both littoral and pelagic communities. The incorporation of standard sampling and laboratory procedures on all USACE reservoirs would begin to build a reliable limnological database on reservoir water quality and productive state, and would eliminate some uncertainty regarding the quality and comparability of past water quality information presented in older synoptic survey reports.

Scope

When writing this RMM I have attempted to include descriptions of field and laboratory methods for sampling the basic or **'key'** variables, i.e. those variables that have a high probability, if monitored annually, of detecting ecosystem change. I also present some **'optional'** methods that deal with system processes, and, if incorporated in a reservoir monitor program would heighten our understanding of ecosystem function. But they are labeled 'optional' because I realize they are more technical in nature, expensive, and usually difficult to sample in the field without special training, e.g. PN/PC, size-fractionated production. Some methods are excluded from the manual because they either require special equipment at high cost to deploy or specific licenses to operate, i.e. deployment of current meters or thermistor strings, isotopic determination of bacterial production. This Manual was not intended to provide details of analytical *chemical methods* used for nutrient analyses, chlorophyll, etc, but its usefulness relies on the assumption that samples collected 'cleanly' and competently in the field will later be analyzed at a reputable chemistry laboratory specializing in low level detection limits for nutrients and chlorophyll. As well, because of time and dollar constraints, I have not touched either methods of fish capture and sampling or fish population assessment. Hopefully this will be added to the manual in the very near future. It is my hope that this RMM will serve to guide future monitoring of USACE reservoirs, and that it will evolve and expand as it is edited and updated by USACE field staff and consultants involved in reservoir monitoring. Finally, I think it is important that USACE recognize the value of developing, managing and maintaining a high quality limnological/fisheries database on monitored USACE reservoirs. Access to such a database in future will assist managers and stakeholders with the development of water use plans and assessment of changes in reservoir operations.

FIELD SAMPLING

Pelagic Zone *Station locations –*

Each reservoir should have at minimum 1 pelagic zone station in each major basin, or 2 in each very large (>20 km) single basin. Stations should be located by their GPS coordinates and should be appropriately labeled as *permanent* limnological sampling stations.

Before you leave -

Carefully go through equipment lists making sure that all equipment is calibrated and in proper working order e.g. temperature/O_2 probe, Van Dorn bottles, zooplankton nets, light meters, etc). Ensure that all batteries have been checked, replaced or recharged and spares are carried.

If you are doing Primary Production (PP) measurements, get boxes ready - check that all bottles are present (2 light + 1dark/depth), pack Eppendorf pipette and spare tips, waste bag, gloves, ^{14}C, mixing inoculation vial, alkalinity bottles (500 mL), spare PR bottles, holders, lines and floats.

Before you begin sampling –

Sterilize the Van Dorn bottle with ethanol at the start of each day. If using a power winch system, zero the meter block (0 m should be at the middle of the Van Dorn bottle). If using a rope, make sure you have a weight (e.g., 2 kg max) on the end of the rope to keep the Van Dorn bottle vertical. When letting it down, make sure it is vertical when you get to the sampling depth e.g, as you approach the sampling depth, slow down the rate of descent to ensure that the Van Dorn enters the sampling zone vertically. Rinse all carboys, funnels, bottles, tubes and caps before using them. Avoid finger contact with critical areas on the Van Dorn, funnel, carboys, bottles and tubes and make sure you hold sample bottles by the side or bottom, not the neck.

When filled, all 1L bottles should be kept in coolers for transportation to the field laboratory. Fill out field sheets completely. Double-check field notes as you leave the station. It is difficult and at times impossible to correctly process the data when field notes are illegible and/or missing.

When you finish –

If time permits, do the next day's labeling the afternoon or evening before next morning's trip. Do all labeling clearly and neatly. Use only a ball point pen for writing all labels with the exception of zooplankton labels. Use a pencil for zooplankton labels and for field notes (use waterproof paper). Use fractions (i.e. ½), not decimals (0.5) on labels and dates should be written as YYMMDD and time as HHMM PST (24 hr clock - 0100-2400).

When a week's survey is completed, refuel and clean the vessel so it is ready for the next trip. After each monthly monitor, soak primary production (PP) bottles, ^{14}C inoculum vials, alkalinity bottles, and 1- and 2-L bottles in dilute sulphuric acid (1%). Prior to the next scheduled field trip, rinse bottles thoroughly with distilled water (DW), and acid rinse and wash the Van Dorn bottle.

Some precautions to take –

Do not try to sample when the weather is too rough. Data are useless if rope/cables are going out at large angles and sensitive equipment is bouncing around because of heavy waves. Remember it is easy to get hurt when trying to handle heavy equipment in a heaving boat. Do not make any alterations to the methods or field schedule without getting prior approval of person responsible for monitoring program. It is important that data from all stations are consistent and are obtained on every survey. Because of poor weather or other extenuating circumstances, this may mean extending the length of surveys on some occasions, but in the long-term it will be well worth the wait.

Incubations for PP are to be put in between 0900 and 1000 (PST) for 2.0 hr incubations. Never put sets in before 0800. If it is absolutely unavoidable, an incubation could go in as late as 1100 (PST), but this is not desirable. If PP cannot be done in the recommended time on a particular day, reschedule it for a day when it can be done properly. Once a PP set is pulled from the water, it immediately begins to deteriorate, so at the end of the incubation period head directly back to the field lab to commence filtration. Filtration must start within 2hr (preferably much less) of removal from the reservoir or the data are not usable.

VARIABLES TO SAMPLE

A.) TEMPERATURE/O_2

The temperature/O_2 probe is used to profile temperature and oxygen concentration as a function of depth. These data should be gathered first so you will know the surface temperature, the depth of the metalimnion or thermocline and epilimnetic depths and the temperatures and O_2 concentrations in the hypolimnion and just off the sediment surface.

Before placing the probe in the water make sure that the probe is calibrated and attached securely to the cable and the instrument housing. One person can quickly lower it and record the data. Attach a messenger or lead weight (maximum 1 kg) to the end of the cable to reduce on-line angle if moderate winds prevail when sampling, then slowly lower it, recording temperature/O_2 at appropriate depths i.e. 1-2 m intervals to the thermocline, and 5-10 m intervals in hypolimnion to sediment surface.

B.) LIGHT

Underwater irradiance.

The compensation depths and light extinction coefficients (k_e) can be calculated at each station by using a 'LiCor (or similar model) light meter (LiCor Model 185A with the 400-700um, Model LI-192S underwater quantum sensor is highly recommended. It is most important that the sensor be vertical (no line angle), and that the boat does not cast a shadow over the sensor while it is being lowered. Before lowering the sensor, first take a deck reading (dry sensor) then take a 0 m reading (have a film of water on the surface of the sensor), then take readings at every meter until you get to the depth where Ln % of surface irradiance = -2. If the water is clear or slightly turbid you may have to adjust sampling depths accordingly, i.e. sample 1,2 m and then every second or third meter in clear water; sample every ½ meter in turbid water. Take a 0 m reading again when you get back to the surface. Use the mean of the two 0 m readings in your calculations.

Field Calculation of Compensation Depth:

Plot Ln (100 x I_D/I_s) vs. depth:

Where: I_D= light at depth
I_S= light at 0 m

Draw a straight line of best fit. Ignore surface readings when drawing the line. The compensation depth is the depth where light intensity is 1% of the light intensity at 0m.

Secchi disk (water transparency).

Lower the Secchi disk (a round, white 22cm weighted disk) over the shaded side of boat until it just disappears from sight, then raise it until it just reappears. Record this depth to one decimal place, e.g. 3.4 m or 6.2 m, etc..

C.) ZOOPLANKTON

Wisconsin vertical hauls.

Ensure that the net is in good shape with no holes in net or in collecting cup (cod-end) mesh. Make sure the net is hanging vertically in the water and that the cod-end is not tangled in the harness or tow rope, and that an appropriate weight is attached (1-2 kg) to keep the need vertical during the ascent. On all reservoirs, use the 158 um mesh Wisconsin net and lower to 30 m. If the water depth does not permit this, lower to a shallower depth (but remember, it must be the same depth for every survey at that station). Haul the net up at 0.5 $m \cdot sec^{-1}$, and do not stop once you have begun the haul. Make sure the sample is properly collected in the cod-end by lifting the net in and out of the water several times and then rinsing the lower portion of the net with a wash bottle. Carefully pour the sample into the plastic zooplankton bottle, rinse the cod-end several more times, and fill the bottle to the neck. The sample is best preserved in a borax-buffered sucrose/formalin solution (Haney and Hall 1973), which can be added to the jar prior to sampling. The sample jar should contain sufficient preservative to make a 4% formalin solution when the jar is filled with sample. Write reservoir name, station no., date, time, tow depth, sample volume on the label that goes in the jar with the sample and also record the information in the field book.

Schindler Trap (optional)

If your vessel has a winch and cable system, zero the meter block with the middle of the Schindler trap at the water surface. Lower the trap to the selected depth. Lowering speed must be fast enough to keep both doors open but slow enough so the trap descends vertically. When the trap is at your selected depth, carefully retrieve and haul it from the water, draining the water through the cod-end. Once the sample has been rinsed into the cod-end, process it as for Wisconsin net hauls except add fresh soda water to the sample prior to pouring it into the plastic zooplankton bottle containing the sucrose/formalin solution. This narcotizes the sample before it is combined with the formalin.

D.) CHLOROPHYLL

Total chlorophyll.

At each station no more than 500 mL (maximum volume) or less than 250 mL (minimum volume) water samples are to be collected for total chlorophyll determinations. Filtering should always be done in reduced light. Set up clean filtering units with the appropriate filters, 47-mm diameter, 0.45-um Millipore HA. Using a clean plastic graduated cylinders, measure out and filter either 500 or 250 mL of sample. If 500 mL is too large a volume and the filters are becoming plugged, then stop the filtration and discard the sample, and start again and reduce the volume filtered to 250 mL. Do not attempt to filter water through plugged filters by increasing vacuum pressure to above 20cm Hg. Make sure volumes filtered are recorded in the field notebook and on data sheet sent with samples to the chemistry lab. Watch all filtering units carefully and turn off the vacuum as soon as the filter becomes dry. When removing a filter, turn vacuum back on and fold the filter in half, making sure it is free of water and as dry as possible. Place the folded filter in an appropriate receptacle (round aluminum dishes are preferred, but you can also use a large, clean Whatman GF/F or /C filter that is folded in half). When you have finished filtering for a station, place the filters together in an appropriate envelope or jar, making sure it is well labelled with date, station No. depths, volume filtered, etc. and place in a freezer.

[***Remember*** - Don't 'cheat' in the lab. For example, if one replicate chlorophyll filters much faster than another, you know that there was a problem with the filter. Throw that sample out and do another. If you happen to spill some sample while pouring into a filtering unit, do not guess at how much to make up. Throw that out as well and do another. Measure out water carefully.]

Size-fractionation.

If size fractionation of sample is to be done then and 0.2 Nuclepore filter is to used for the pico-plankton (0.2-2.0um) franction, a 2.0-um Nuclepore should used for the nano-plankton (2.0-20.0um) fraction and a 20-um mesh Nitex cloth for the the micro-phytoplankton (20.0-200.0um). The same filtration procedures and precautions as described for total chlorophyll (above) are to be followed.

E.) NUTRIENTS

Total Phosphorus.

Rinse TP tubes and caps, then fill to the shoulder (no more, no less) with sample water, place in a cooler and refrigerate until analyzed. Since total phosphorus analysis is extremely sensitive do not touch the tube mouth or inside of cap. Once/field trip, prepare 2 TP tubes for blanks, i.e. unfiltered double distilled water (DDW).

Dissolved P, N, Si.

For Field Filtration of nutrient samples it is best to use a 47 mm filtering manifold, e.g. Swinnex type, that can be used for *"Nutrients"* only, also keep a clean 60 cc syringe reserved for nutrients only. Using a blunt-nosed forceps, place an ashed 47 mm GF/F filter on the base of the filtering manifold and carefully replace the top. Rinse each filter with 3 full syringes of DDW. If the water runs through with little or no resistance, the filter was probably torn when the Swinnex was assembled. Put in a new filter if this is the case. After the DDW rinse, rinse with 3 full syringes of epilimnetic water and discard filtrate. At each depth, filter one full syringe of sample water into the appropriate plastic bottles. Put caps on bottles, shake, and discard the rinse water. Then proceed to fill bottles to the shoulder with filtered sample water. Put lids on tightly and make sure all labels are legible. Freeze immediately after filtration. Once per field trip, prepare 2 plastic bottles for blanks (ie. filtered DDW).

[*NOTE*: Freeze all filtered water in plastic bottles. Make sure samples are kept frozen during transport to chemistry laboratory. This is critically important so use as much ice as necessary. Fill out the sample submission sheets for the chemistry lab at the end of each day.]

pH and Alkalinity.

Rinse alkalinity bottles (500 mL) thoroughly, fill them slowly and completely (avoid introducing air bubbles as you fill them), tighten cap securely and place in a cooler.
Always use a well-calibrated pH meter and make sure you record the surface water temperature when measuring '*in situ'* pH.
[NOTE: Accurate alkalinity and pH data are essential in determining primary production rates, so these analyses should be done very carefully.]

Particlate Phosphorus (PP) (Optional).

Since GFF filters can vary in their C-N-P content among batches it is best to write down the batch number from each filter box (see note below). Filter 1 L of sample water using same filtration procedures described above for chlorophyll. Set up clean filtering units with ashed 47 mm GF/F filters. It is imperative that you avoid finger contact with these filters. When removing the filter from the filtering manifold, leave the vacuum on, ensuring that the filter is as dry as possible. Carefully fold it into quarters and place it in the bottom of a small, clean labelled vial, e.g. glass scintillation vials are recommended.

[*NOTE*: Once/trip prepare 2 blank samples for the chemistry lab (i.e. 2 unused GF/F filters in scintillation vials). Try not to use different batches of GF/F filters during one trip. If you must, make sure that all samples and blanks are labelled with the correct batch number.]

Particulate Carbon/Nitrogen (PC, PN) (optional).

Use a clean pair of forceps labelled "PC/PN ONLY" and avoid finger contact with filters. Set up clean PC/PN filtering units with ashed 25 mm GFF filters, and using clean plastic graduated cylinders filter 200 mL of sample water. When the sample has been filtered, make sure filters are dry, fold them in half, and place in the appropriate labelled aluminum dish, making sure the bottoms of the aluminum dishes are clean and dry before you start. When finished filtering a station, cover the stack of samples with an empty, labelled aluminum dish, tape them together loosely, label it properly, seal in a labelled Whirl-pak, and freeze. Once each trip, prepare 2 blank filters (with batch number on the label) for the chem lab.
[*NOTE:* Record Batch Number of GFF filters used on each trip.]

A reminder -Blanks required on each field trip:

1 plastic bottles (filtered DDW)
1 TP tube (unfiltered DDW)
2 Particulate Phosphorus filters (in scintillation vials)
2 PC/PN filters (in aluminum dishes) (optional)

F.) BACTERIA

[*NOTE*: Only a small amount of sample water – 25 mL is needed to determine bacterial biomass.]

Place the sample in a clean scintillation vial that has been rinsed once with ethanol and 3 times with DDW. Fill the vial to the shoulder with sample water (do not fill to the top), and add 2 drops of dilute formaldehyde (4%) and place cap on snugly, and ensure that all sample vials are clearly labelled. At a later date in the laboratory, these samples will be flourochrome stained and enumerated at high power (>1000x) with an epiflourescence microscope (see MacIsaac and Stockner 1981)

G.) PHYTOPLANKTON

[*NOTE*: Only 100-150 mL of sample water are needed for phytoplankton analysis.]

Clearly label each phytoplankton bottle and fill to the neck with sample water. Glass bottles are recommended, not plastic, because plastic reacts with the iodine and hastens cell deterioration, making later enumeration difficult. Add 2 mL of acidic Lugol's iodine solution to each phytoplankton bottle. After Lugol's has been added to the sample the colour should look like 'weak tea' or 'single malt scotch', not any darker, otherwise enumeration delicate celled flagellates is made difficult and less accurate.

Autotrophic Picoplankton (APP)

[*NOTE:* Only 25-30 mL of unfiltered sample water are required.]

Set up a 25 mm glass filtering units with Irgalan-black stained 0.2-um, 25-mm diameter Nuclepore polycarbonate filters. Rinse a clean 20-cc syringe with DDW and then filter 15 mL through the pre-stained Nuclepore filter. When the filter is just dry, carefully place it right side up in a labelled petri dish and cover it immediately. A dry, Whatman GF/C or F filter should be used as a cover. Place the filter inside the Whatman filter and clearly label with lake, station, date, depth, and volume filtered. At a later date in the laboratory, these samples will be rehydrated and enumerated at high power (>1000x) with an epiflourescence microscope (see MacIsaac and Stockner 1991).

H.) PRIMARY PRODUCTION RATE

Samples must be kept in the light-tight box and must not be exposed to direct sunlight. Make sure that BOTH people doing the sampling are aware of the depth order of the bottles in the box (label the inside of the box if necessary, row 1 – 1m, row 2 – 3m, etc.)! Do not start ^{14}C inoculations until all bottles have been filled and you are ready to immediately start the incubation. Wear gloves when carrying out inoculations. Use a 1mL Eppendorf pipette with disposable tips to inoculate the light and dark bottles with ^{14}C. Make sure no air is in the pipette. Discard the first ^{14}C aliquot from a freshly filled tip. Be sure to press and release the trigger on the pipette slowly and smoothly. Make sure you keep the pipette tip in the bottle long enough for all of the inoculate to enter the bottle. Make sure lids are on firmly (but not jammed) and carefully agitate bottles. It is critically important to keep inoculated samples in the dark until the set goes in. Place bottles in plexiglass holders in the approved manner and secure with rubber bands. Keep the bottles in the shade while you attach the Plexiglas holders to the line. Clip holders to rope so that light bottles are at the exact depths sampled.

Incubate samples for 2.0 hr. Retrieve samples keeping them cool and out of direct sunlight in the light-tight box. Immediately transport to the field laboratory and filter, if possible, within 2-3 hrs. Monitor vacuum pressure frequently and ensure that it does not go above 20 cm Hg. This is very important!

The filter must not be exposed to vacuum pressure after it has gone dry. However, if necessary, vacuum can be turned on again for a short time to help in removing the filter. Filters should be handled with clean blunt-nosed forceps. Use separate forceps for ^{14}C filtrations, and keep these forceps in a CLEAN Whirl-Pak when they are not being used.

Incubating PP set at another station (optional)

Use the plot of Ln (100 X I_D/I_S) vs. depth at Stn. A (from light section above) to determine the value for Ln (100 X I_D/I_S) at each incubation depth at Stn. A. At the incubation station (Stn. B) proceed to plot: Ln(100 X I_D/I_S) vs. depth for Stn. B, and using the values obtained from Stn. A, determine the actual incubation depths you should use at Stn. B. If you are in a hurry simply use the Secchi disk to determine similarities in clarity between Stn. A and B, and find the best match possible.

FIELD SAMPLING

Littoral zone

Background.

Since it is extremely difficult to sample uniformly the heterogeneous natural substrata (e.g. sediment surface, macrophytes, rocks, woody debris, etc.) of the littoral zone with suitable replication, the method of choice among investigators has been the placement of artificial substrata (e.g. Plexiglas plates, glass slides, Styrofoam sheets, wooden sticks etc.) for sampling periphyton community growth, biomass and community species composition. These artificial substrates are usually attached to cement blocks placed or dug into the sediment within the littoral zone. These anchoring blocks should be placed along a transect line that extends from the interface or 'splash' zone to at least 1m below the mean compensation depth (1% light level) of the lake (see Fig. 1). More care and attention is required for block placement in the littoral of a reservoir because of fluctuating water levels, and extra blocks may be needed to assure that the deepest block is below the compensation depth. The blocks should be made of concrete and heavy enough (25-30 kg) to withstand pounding and erosion by wave action and currents in the upper few meters and stable enough to keep the plate in a horizontal, upright position. The artificial substrate or plate that will be sampled should always be elevated above the anchor block so as to allow free movement of water on both sides of the plate. Plates can be scored with a diamond pen into 'quadrants' or other suitable demarcations that will permit more accurate quantitative sampling of the periphyton on the substrata once the plate is removed from the

block (see inset, Fig. 1). A 10 x 10 cm quadrant (100 cm^2) usually supplies sufficient periphyton to easily detect temporal change in most oligotrophic lakes or reservoirs (see Shortreed et al. 1984)

Field Procedure

Samples should be obtained on 4-5 week intervals except in winter (November to February) when a 6-8 wk interval will suffice. This sampling protocol using blocks and artificial substrates usually requires a SCUBA diver for retrieval and replacement of plates. Sampling consists of removing the Plexiglas plate from the block, returning to shore or a vessel with the plate, and then scraping the accumulated periphyton biomass from each quadrant into a4 or 5 glass jars (depending on how many sub-samples you intend to analyze) and after cleaning the quadrants, immediately returning the cleaned Plexiglas plate to the block. The most efficient scraper for Plexiglas plates is a clean, glass microscope slide. If Styrofoam is used as a substrate then the procedure is simply to take cores from the Styrofoam using a cork borer, cookie cutter or similar round object that is of known surface area.

VARIABLES TO SAMPLE

A.) CHLOROPHYLL

Place a 47 mm diameter, 0.45um Millipore HA filter on a filtering manifold and pour the contents of one jar (*quadrant 1*, i.e. periphyton from one quadrant of the plate, and rinse twice with DDW. Follow the procedures as outlined for pelagic chlorophyll methods (above) for stacking and storage of filters after filtration and prior to laboratory analyses. If periphyton growth is exceptionally heavy, i.e. a predominance of filamentous green or blue-green algae, then a Whatman GF/C filter should be used instead of a cellulose acetate filter (Millipore, Sartorius, etc), and after filtration, the filter should be macerated in a tissue grinder with 10 ml of 90% acetone. This procedure will enhance chlorophyll extraction from a thick mat and will provide more reliable readings. After maceration, the filtrate can be analyzed for chlorophyll spectro-photometrically and chlorophyll expressed on a per unit area basis, i.e. Chl./ cm^2 or m^2.

B.) DRY WEIGHT (BIOMASS)

The contents of the second sample jar (*quadrant 2*) are filtered onto a pre-ashed and weighed 5.5 cm Whatman GF/F glass fiber filter. After filtration at low vacuum (> 20 cm Hg) filters should be folded in half, placed in aluminum weighing dishes and frozen. Filters are dried in an oven at 105°C to constant weight, weighed, then ashed at 500°C for four hours in a muffle furnace, and weighed again. Periphyton biomass values are expressed as dry weight (DW) and ash-free dry weight (AFDW) organic content /cm^2 or m^2.

C.) ACCRUAL

The rate of accumulation of organic periphyton biomass, i.e. accrual rate, can be calculated by dividing total organic biomass (AFDW) accumulation/sampling interval by the number of days in the interval between sampling. Values are then usually expressed as mg organic C/m^2/day. For purposes of comparison, carbon content of periphyton can be estimated as representing about 50% of organic (AFDW) determinations (Stockner and Armstrong 1971). The accrual rate is a first approximation of periphyton net production, but does not account for sloughing or grazing losses during the growth (immersion) period.

D.) SPECIES COMPOSITION

The algal community.

A few drops of acidic Lugol's acetate preservative should be added to the third jar (*quadrant 3*). The jar should be gently shaken to loosen any clumps and then allowed to settle for about 15-30 seconds which removes some of the heavier sand or silt particles from the sample. A 2 mL sub-sample of the

homogeneous periphyton (use a wide-mouth syringe) should be placed on a clean glass slide or depression slide for microscopic examination at low power (100-400X) magnification. If the periphyton is extremely dense, a 1 mL sub-sample can be placed in a 10 cc settling chamber with 9 mL of DDW added, and then examined using an inverted plankton microscope.

The initial microscopic examination can be either a qualitative scan that provides data on the *relative* abundance of major algal groups, or by using a counting grid or transect, a quantitative estimate of *actual* abundance of major groups. Attached diatoms are often the dominant algal assemblage in the littoral zone of oligotrophic lakes and reservoirs (also in streams), and their density is easily quantified by absolute microscopic counts from permanent Hyrax slide mounts after acid treatment of the silicon frustrules (see Stockner and Armstrong 1972).

Bacteria and Biofilm

Biofilms are mostly microbial (e.g. bacteria, picoplankters, flagellates, ciliates and fungi), and because of their small size and rapid growth rates, they constitute the first successional sere of the periphyton community. A homogeneous 10 mL sample of the periphyton from another jar (e.g. *quadrant 4*) should be taken before any preservative is added to the jar and placed in a clean, glass scintillation vail. A drop or 2 of gluteradehyde or dilute (4%) formaldehyde should be added and the vial labeled and refrigerated. Analyses of abundance of various components of the microbial assemblage should be done first with standard microscopy at low power (200-400X), and then with epilflourescence microscopy after staining a small aliquot with DAPI or an equivalent fluorochrome stain (Klut et al.1989).

E.) INVERTEBRATES

Quantitative assessment of invertebrate abundance is a difficult and sometimes laborious sampling operation, requiring special samplers such as -. corers, dreges, or grabs (see Wetzel and Likens 1991). Cages enclosing small stones, broken tiles, marbles or other substrata can be lowered to depth and sampled for invertebrate colonization, if natural substrata in the littoral is mainly rock and precludes the use of dredge or grab samplers. After retrieval of sediment samples they are sieved and sorted by size and major group, e.g. stoneflies, mayflies, caddisflies, diptera etc. Biomass of major invertebrate groups is expressed as mg AFDW (organic) / m^2.

F.) PRIMARY PRODUCTION (optional)

Diurnal rate of change of dissolved gases (CO_2, O_2) in 250-500 mL glass vials in which fresh periphyton samples are suspended can provide reasonable estimates of net carbon production (gross production if dark bottles are used concurrently). But use of the isotope ^{14}C is the method most commonly used, where ^{14}C can be added to freshly scraped periphyton samples from plates or Styrofoam cores, transferred to small vials and then incubated *in situ*. After a 2-4 hr incubation period, samples are filtered and treated using the same protocol as described for pelagic PP rates (above or see also Stockner and Shortreed 1985, Wetzel and Likens 1991).

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Appendix D

Photographs

Photo	Description
1	Polyethylene Carboy
2	Fertilizer Storage Facility
3	Delivery and Mixing System
4	Metering Fertilizer
5	Polyethylene Tank on Boat
6	Polyethylene Tank on Boat
7	Application Vessel

Photo 1: Polyethylene Carboy

Photo 2: Fertilizer Storage Facility

Photo 3: Delivery and Mixing System

Photo 4: Metering Fertilizer

Photo 5: Polyethylene Tank on Boat

Photo 6: Polyethylene Tank on Boat

Photo 7: Application Vessel