Columbia River Project Water Use Plan

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring

Implementation Year 4

Reference: CLBMON-3

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring – Year 4 (2011) Progress Report

Study Period: 2011

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Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring
Year 4 (2011) Progress Report

Revelstoke Reservoir looking north from confluence with Downie Arm.

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This is a progress report for a long term monitoring program and, as such, contains preliminary data. Conclusions are subject to change and any use or citation of this report or the information herein should note this status.

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Suggested Citation for Individual Reports contained within:

Harris, S. 2013. Primary Productivity in Kinbasket and Revelstoke Reservoirs, 2011. Prepared for BC Hydro, Water Licence Requirements. 21 pp.. Appendix 5 *in* Bray, K.E.. 2013. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 4 (2011). BC Hydro, Environment. Study No. CLBMON-3.

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APPENDICES

List of Tables

1.0 Introduction

This report summarises the Year 4 (2011) implementation of CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring project ("the study"). This report contains preliminary data and conclusions are subject to change. Any citations of this report or the data contained herein must note this status.

The Columbia River Water Use Plan (WUP) (BC Hydro 2007a) was concluded in 2004 following four years of public consultation (BC Hydro 2005). Water Use Plans were developed for each of BC Hydro's facilities to achieve optimal balance among operations and environmental and social values.

A lack of basic ecological data and information on Kinbasket and Revelstoke Reservoirs impeded informed decisions for any operational changes in the upper Columbia River system. The WUP Consultative Committee acknowledged the importance of understanding reservoir limnology and the influence of current operations on ecosystem processes for planning future water management activities. Therefore, a monitoring program was recommended to provide long-term data on reservoir limnology and the productivity of pelagic communities. This study is conducted in conjunction with CLBMON-2 Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring and is scheduled for implementation over twelve years (2008-2019).

1.1 Management Questions

A Terms of Reference (TOR) (BC Hydro 2007b) for this study outlines the rationale, approach, and primary management questions to be addressed. The TOR also provides a framework for implementation. The study is to focus on:

i) Reservoir trophic web mechanisms and dynamics;

ii) Obtaining measurements of aquatic productivity that can be used as parameters for system modeling; and

iii) Determining key indicators of change in pelagic production that would ultimately affect food availability and, thus, growth of kokanee.

The management questions to be addressed by this study are as follows:

i) What are the long-terms trends in nutrient availability and how are lower trophic levels affected by these trends?
ii) What are the interactions between nutrient availability, productivity at lower trophic levels and reservoir operations?
iii) Is pelagic productivity, as measured by primary production, changing significantly over the course of the monitoring period?
iv) If changes in pelagic productivity are detected, are the changes affecting kokanee populations?
v) Is there a link between reservoir operation and pelagic productivity? What are the best predictive tools for forecasting reservoir productivity?
vi) How do pelagic productivity trends in Kinbasket and Revelstoke reservoirs compare with similar large reservoir/lake systems (e.g., Arrow Lakes Reservoir, Kootenay Lake, Okanagan Lake, Williston Reservoir)?
vii) Are there operational changes that could be implemented to improve pelagic productivity in Kinbasket Reservoir?

1.2 Objectives

The study objectives are to conduct reservoir pelagic productivity monitoring and establish long term sampling sites and consistent methodologies and analyses for comparison with other Columbia reservoir monitoring programs (e.g. Arrow Lakes Reservoir, Kootenay Lake).

2.0 Implementation

The study team (Table 1) met on February 2-3, 2011, to discuss progress on the management questions, evaluate the sampling program to date, and set the 2011 (Year 4) work plan. Initial results of the 2011 sampling program were reviewed at a study team meeting on February 7-8, 2012, and used to develop the 2012 (Year 5) work plan.

The monitoring program is being implemented in a phased approach in conjunction with the Kinbasket-Revelstoke Reservoirs Kokanee Population Monitoring program (CLBMON-2). Sampling is planned on a 4-year cycle and reviewed annually, thereby taking advantage of information gained in each sampling period to define the data needs for future years. Each phase will conclude with a synthesis report with an annual progress report prepared in intervening years. The first phase of the study is focussing on the hydrology and nutrient budget and general biological data. Reservoir sampling stations were selected based on previous work, information needs, and logistical considerations. The first synthesis report will cover the 2008 to 2011 study years.

Table 1: Study team members (CLBMON-3 and CLBMON-2), 2011.

Study Team Member	Affiliation
Karen Bray, Project Manager/Biologist	BC Hydro
Dr. Ken Ashley, Principal	Ashley and Associates
Dr. Roger Pieters, Research Associate	University of British Columbia, Dept. of Earth and Ocean Sciences
Dale Sebastian, Ecosystems Biologist	Ministry of Forests, Lands and Natural Resources Operations
Eva Schindler, Limnologist	Ministry of Forests, Lands and Natural Resources Operations
Shannon Harris, Reservoir Restoration Biologist	Ministry of Environment

Implementation of this study continues to follow the approach of using a combination of in house and external resources. Overall project management and field work is conducted using in house BC Hydro resources and external expertise is secured to provide analyses and reporting for specific components.

In Year 4 (2011) regular reservoir monthly sampling began in May and concluded in October (Table 3). Kinbasket regular sampling was disrupted twice: once in June due to a staff injury and once in September due to high water levels and debris. Therefore, only four monthly reservoir sampling sessions were conducted on Kinbasket Reservoir and only three sessions for primary production. The Study Team elected to add three discrete sampling depths between 20m and 60m to the reservoir water chemistry to provide additional data for the metalimnion. All other sampling protocols remained unchanged from the previous year.

This fourth annual report presents a study overview followed by individual progress reports for the physical processes and biological components of the 2011 sampling year as per previous progress reports (Bray 2012; BC Hydro 2011; BC Hydro 2010). More specific information pertaining to individual year monitoring results is contained in these reports. A synthesis report of 2008-2011 results has been prepared separately.

Table 2. Summary of Kinbasket and Revelstoke Reservoirs field sampling program 2011.

Parameter (Analysis)	**Sampling Frequency**	**Method**	**Depths**	**Stations/Location**								
				KIN Forebay	**KIN Canoe**	**KIN Wood Arm**	**KIN Col Reach**	**KIN Mid Pool**	**REV Upper**	**REV Middle**	**REV Forebay**	**Tribs**
Weather Station (temp, ppt, bp, RH, PAR, wind)	Hourly/daily	Fixed Data logger		Mica dam crest							Rev Dam crest	
Profile (DO, temp, cond, chl a, PAR, turbidity) +secchi	**May-Oct** Monthly (4/6) Loss of KIN June and Sept Long profile in June	Seabird	0 to 60m+ (to within 5 m of bottom) Longitudunal profile in spring/fall	√	√	√	√	√	√	√	√	
Water Chem - Reservoir (TP, SRP, TDP, cond, NO2+NO3, alk, pH, turb) (silica) Secchi	**May-Oct** Monthly (4/6) Loss of KIN June and Sept	Bottle, tube	2,5,10,15,20, 25,35,45, 60m and 5m off bottom 0-20m for Si (from chl a sample)	√	√	√	√		√	√	√	
Water Chem - Tributary (TP, SRP, TDP, cond, NO2+NO3, pH, alk, turb, temp)	5 reference tribs once in A/S/O/N and twice in M/J/J	Bucket	Surface grab									√
Temperature	Tidbits, hourly	Reference trib sites**										
Chl a	**May-Oct** Monthly (4/6)	Integrated tube	0-20m	√	√	√	√		√	√	√	
Phytoplankton	**May-Oct** Monthly (4/6)	Bottle	2, 5, 10, 15, 25 m	√	√	√	√		√	√	√	
Bacteria	**May-Oct** Monthly (4/6)	Bottle	Two composites of 2,5,10m and 15,20,25m	√	√	√	√		√	√	√	
Zooplankton	**May-Oct** Monthly (4/6)	Wisconsin net 2 hauls per site	0-30m	√	√	√	√		√	√	√	
Primary Production	**June-Aug/Sep** Monthly (3/4)	3 size fractions	0,1,2,5,10,12,15*	√*						√	√	

*Note that station for PP is farther out towards the main pool than the regular sampling station in the forebay.

3.0 References

BC Hydro. 2011. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 2 (2009). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

BC Hydro. 2010. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 1 (2008). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

BC Hydro. 2007a. Columbia River Projects Water Use Plan. Revised for Acceptance by the Comptroller of Water Rights. BC Hydro. 41 pp + appendix.

BC Hydro. 2007b. CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring Terms of Reference. BC Hydro dated October 24, 2007.

BC Hydro. 2005. Columbia River Project Water Use Plan Consultative Committee Report. Volumes 1 and 2. Prepared on behalf of the Consultative Committee for the Columbia River Water Use Plan. July 2005.

Bray, K. E. 2012. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2010). BC Hydro, Environment. Study No. CLBMON-3.

3.0 References

BC Hydro. 2011. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 2 (2009). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

BC Hydro. 2010. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 1 (2008). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

BC Hydro. 2007a. Columbia River Projects Water Use Plan. Revised for Acceptance by the Comptroller of Water Rights. BC Hydro. 41 pp + appendix.

BC Hydro. 2007b. CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring Terms of Reference. BC Hydro dated October 24, 2007.

BC Hydro. 2005. Columbia River Project Water Use Plan Consultative Committee Report. Volumes 1 and 2. Prepared on behalf of the Consultative Committee for the Columbia River Water Use Plan. July 2005.

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Appendix 1

Hydrology of Kinbasket and Revelstoke Reservoirs, 2011

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Hydrology of Kinbasket and Revelstoke Reservoirs, 2011

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Downie Arm, Revelstoke Reservoir, 12 Sep 2012

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1. Introduction

The hydrology of Kinbasket and Revelstoke Reservoirs is described, focusing on flow in 2011. This report updates Pieters et al (2012) and provides context for the ongoing BC Hydro project entitled “Kinbasket and Revelstoke Ecological Productivity Monitoring (CLBMON-3)”.

The upper Columbia River is defined in Figure 1.1 as the flow of the Columbia River near the Canada-US border, excluding the Pend Oreille River which joins the Columbia just above the border. Also excluded are the Kettle, Okanagan and Similkameen Rivers which join the Columbia in Washington State. The upper Columbia accounts for only 13% of the area of the Columbia River, but contributes 27% of the total flow. Kinbasket and Revelstoke Reservoirs account for 4% of the area of the Columbia, and contribute 11% of the flow, Table 1.1.

Table 1.1 Drainage area, mean flow and yield of selected regions of the Columbia River

	Drainage (km^2)	**Flow (m^3/s)**	**Yield (m)**
Kinbasket and Revelstoke Reservoirs (WSC 08ND011 1955-1986)	26,400	796	0.95
Upper Columbia, Figure 1.1 (WSC 08NE058 minus 08NE010)	89,700	2,047	0.72
Columbia River (Kammerer, 1990)	668,000	7,500	0.35

The headwater of the Columbia River begins in wetlands adjoining Columbia Lake, Figure 1.1. The Columbia River flows north-west through Windermere Lake and into Kinbasket Reservoir. Just before Mica Dam the Columbia River turns almost 180 degrees and flows south, through Mica Dam, through Revelstoke Reservoir, and then into the Arrow Lakes Reservoir.

Basic characteristics of Kinbasket and Revelstoke Reservoirs are compared to other major lakes and reservoirs from the Upper Columbia in Table 1.2. Kinbasket and Revelstoke Reservoirs are shown in greater detail in Figures 1.2 and 1.3, respectively. The approximate length of the reservoirs and their reaches are given in Table 1.3.

2. Annual Water Balance

Kinbasket Reservoir

Kinbasket Reservoir is shown in Figure 1.2. To the southwest, the Columbia River enters the Columbia Reach about 15 km downstream of Donald Station. To the east, the Canoe River enters the Canoe Reach near the town of Valemount. These two long, narrow reaches join near Mica Dam.

Table 1.2 Characteristics of major lakes and reservoirs of the Upper Columbia

	Dam	Dam Completed (year)	Dam Height (m)	Max. Depth (m)	Max. Area (km^2)	Mean Outflow (m^3/s)
Kinbasket	Mica	1973	244	*~185*	425	590
Revelstoke	Revelstoke	1984	175	*~125*	115	750
Arrow	Keenleyside	1968	52	290/190	520	1,080
Koocanusa	Libby	1973	95	107	186	350
Duncan	Duncan	1967	39	147	75	90
Kootenay	Cora Linn	1931	38	154	390	780

	Drawdown (m)	Drawdown Area (km^2)	Drawdown Area (% full)
Kinbasket	47	220	50%
Revelstoke	1.5	2.4	2%
Arrow	20	159	30%
Koocanusa	52		
Duncan	28		
Kootenay	3		

The water balance for Kinbasket Reservoir is given in Table 2.1. Also given is the annual water yield from the drainage. The yield is the average annual outflow divided by the drainage area and represents the average depth of net annual precipitation over the drainage. The local inflow to Kinbasket Reservoir has about twice the yield as the Columbia River above Donald, indicating increased precipitation in the local drainage to Kinbasket Reservoir

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Table 1.3 Length of reservoirs

Reservoir	**Length (km)**
Kinbasket Reservoir	190
Columbia Reach	100
Canoe Reach	90
Revelstoke Reservoir	130
Upper Revelstoke	80
Lower Revelstoke	50
Arrow Lakes Reservoir	210
Revelstoke Reach	40
Upper Arrow	60
Narrows	30
Lower Arrow	80
Kootenay Lake	110

Local inflow to Kinbasket dominates the water balance contributing 66% of the inflow. In contrast, the Canoe River, while having a high yield, contributes only 3% due to its relatively small drainage.

Table 2.1 Annual water balance for Kinbasket Reservoir

		Area (km^2)	Flow (m^3/s)	Yield (m/yr)
Qin	Columbia R. at Donald Station	9,710 (45%)	172 (30%)	0.56
Qin	Canoe River near Valemount	368 (2%)	19* (3%)	1.6*
Qloc	Local Flow into Kinbasket	11,422 (53%)	376 (66%)	1.0
Qout	Columbia River at Nagle Creek (Mica Dam Outflow)	21,500	567	0.83

*Estimated from partial data for 1966-1967.

Prior to Mica Dam, most of Kinbasket Reservoir was river, with the exception of Kinbasket Lake which was approximately 10 km long, located near Kinbasket Creek on the Columbia Reach. Water Survey of Canada (WSC) had gauges at several sites along what would become Kinbasket Reservoir, shown in Figure 1.2 (red squares). The data from these sites (Appendix 1) allow the division of Kinbasket Reservoir into the regions given in Table 2.2. The inflow of the Upper Columbia Reach is particularly large, matching the inflow of the Columbia River at Donald.

Table 2.2 Drainage, flow and yield of regions in Kinbasket Reservoir

	Canoe River	Canoe Reach	Wood Arm	Lower Columbia Reach[1]	Upper Columbia Reach[2]	Columbia River Above Donald
Drainage (km^2)	368	2,922	956	3,250	4,290	9,710
Inflow (m^3/s)	~19	86	40	85	165	172
Yield (m)	~1.6	0.93	1.3	0.82	1.2	0.56
% of outflow	3%	15%	7%	15%	29%	30%

[1] Between Mica Dam and the Columbia River at Surprise Rapids
[2] Between the Columbia River at Surprise Rapids and Columbia River at Donald

Revelstoke Reservoir

Revelstoke Reservoir is shown in Figure 1.3. The entire length was formerly a river and the resulting reservoir is very narrow. The water balance for Revelstoke Reservoir is given in Table 2.3. For Revelstoke, the outflow from Mica Dam is the dominant (71%) inflow to the reservoir. While the local drainage area to Revelstoke Reservoir is relatively small (19%), the higher yield of this drainage means that the local inflow still contributes 29% to the total outflow.

Table 2.3 Annual water balance for Revelstoke Reservoir

	Area (km^2)	Flow (m^3/s)	Yield (m/yr)
Columbia River at Nagle Creek (Mica Dam Outflow)	21,500 (81%)	567 (71%)	0.83
Local Flow into Revelstoke	4,900 (19%)	229 (29%)	1.47
Columbia River above Steamboat Rapids (Revelstoke Outflow)	26,400	796	0.95

Unlike Kinbasket Reservoir, no WSC data were available for the Columbia River along what would become Revelstoke Reservoir. While WSC lists a station "Columbia River above Downie Creek" (08ND010), no data were available at this site. We divide Revelstoke Reservoir just above Downie Creek (Figure 1.3) into upper and lower reaches assuming the same yield to each, see Table 2.4. Note the drainage to the lower Revelstoke reach is relatively small.

Table 2.4 Drainage, flow and yield of regions in Revelstoke Reservoir

	Mica Outflow (Columbia above Nagle)	Upper Revelstoke Reach[1]	Lower Revelstoke Reach
Drainage (km^2)	21,500	*3,300*	*1,600*
Inflow (m^3/s)	567	*155*	*75*
Yield (m)	0.83	*1.5*	*1.5*
Of outflow (%)	71%	*19%*	*9%*

[1] The boundary between upper and lower was chosen above Downie Creek.
Values in italics are approximate.

3. Columbia River at Donald

Data

Daily flow data were available for 1944-2011 from WSC station 08NB005, entitled "Columbia River at Donald". This station is located roughly 20 km upstream of Kinbasket Reservoir.

Results

Figure 3.1a shows the daily flows for 1944-2011. The mean daily hydrograph shown in Figure 3.1b peaks from early June to mid-July at roughly 550 m^3/s, tapering through the summer and fall to a base flow in the winter of approximately 35 m^3/s. The mean annual flow for 1944-2011 was 171 m^3/s.

The daily flows are shown in Figure 3.2 for selected years (1992-1994, 2000-2011) which include the years with hydroacoustic surveys of kokanee abundance (1993, 1994, 2003-2010, Sebastian 2010). Also shown for comparison in each panel is the daily mean flow for 1944-2011. The flows generally followed the mean; exceptions include the following: in late fall of 2003 the flow rose to about 4 times the seasonal average; in 2006 and 2007 the flows in the late spring were above average; in 2004, 2009 and 2010 the summer flows were below average. In late September 2010, around the time of kokanee counts, there was a relatively large peak in flow likely the result of a rainfall event (Figure 3.2.2g). Flow for 2011 generally followed the mean, though the flow was slightly above average from mid-June to early August (Figure 3.2.2h).

4. Columbia River at Mica Dam

Data

Data were available for 1947-1983 from WSC station 08ND007, entitled “Columbia River above Nagle Creek”. This station is located approximately 3 km downstream of Mica Dam. Data for the Mica Dam Outflow were available for 1971-2011 from BC Hydro. The data from “Columbia River above Nagle Creek” were used for 1947-1975 and the BC Hydro data were used for 1976-2011.

Results

Pre- and post-impoundment flows are shown in Figure 4.1a. The change in flow after completion of Mica Dam in 1973 is evident. Before impoundment, the hydrograph shown in Figure 4.1b had a large single peak of roughly 1600 m^3/s from early June to mid-July. The flow gradually declined in the summer and fall until it reached a low base flow in the winter of around 120 m^3/s. After Mica Dam was completed, the spring peak flow was reduced and replaced with a more variable flow throughout the year (Figure 4.1c). After impoundment, flow was retained during snowmelt in the spring, but once the reservoir almost fills, the tail of the freshet results in an increase in flow during the late summer. A second broad peak occurs as water is released during the winter for hydroelectric generation.

The discharge from Mica Dam for selected years (1992-1994, 2000-2011) is shown in Figure 4.2, and these generally followed the mean with the following exceptions: in many years outflow was below average from mid-May to mid-July; in 2004 the outflow was below average from August to October; and in 2008 flow was below average not only in early summer but in August and September as well. In 2009, outflow was slightly below average from mid-July to mid-August. In 2010, very low flow occurred in all of June and July and flow in August and September was below average. In 2011 very low flow occurred again from early May to early July, and flow was below average for the remainder of July.

5. Columbia River at Revelstoke Dam

Data

Daily flow data from two WSC stations were used for the Columbia River near Revelstoke Dam. For 1955-1985, data were available from WSC station 08ND011, entitled "Columbia River above Steamboat Rapids". This station is located roughly 1.5 km downstream of Revelstoke Dam. For 1986-2011, data were available from WSC station 08ND025, entitled "Revelstoke Project Outflow".

Results

The daily discharge for 1955-2011 is shown in Figure 5.1a. The change in flow due to the completion of the upstream Mica Dam in 1973 is evident. There is no obvious change in the flow upon the completion of Revelstoke Dam in 1984 as it is operated run of the river. The mean daily pre-impoundment hydrograph given by the data from the Columbia River above Steamboat Rapids is shown in Figure 5.1b. The post-impoundment hydrograph given by the data from the Revelstoke Project Outflow is shown in Figure 5.1c.

Similar to that seen for the pre-impoundment flow at Mica Dam, the pre-impoundment outflow at Revelstoke showed a dramatic spring peak of about 2800 m^3/s which declined through the summer and fall until it reached a winter base flow of around 300 m^3/s. Post-impoundment outflow is distributed more evenly throughout the year with minor peaks in the summer and winter.

The Revelstoke discharge for selected years (1992-1994, 2000-2011) is shown in Figure 5.2, and generally follows the mean post-impoundment hydrograph. One particular exception was July to September 2010 when outflow was below average.

6. Local Metered Inflow

Data

Of the rivers and streams in the Kinbasket and Revelstoke drainage, few have been gauged by Water Survey Canada. Those that have been gauged are listed in Appendix 1. Beaver River, Gold River, and Goldstream River are all currently gauged and will serve as examples of tributary inputs. Although the Illecillewaet River enters the Columbia River about 10 km downstream of Revelstoke Dam, it is included as an example of a gauged tributary because of its proximity, size, and long record of water quality data.

Results

Daily flow data for the four tributaries are summarized in Table 6.1. Figures 6.1-6.4 show the (a) daily and (b) mean flow for each tributary. The hydrographs for 2008 to 2011 are compared in Figures 6.5 to 6.8, respectively, along with those of the Columbia River at Donald and the Columbia River at Revelstoke. The hydrographs for the gauged tributaries are very similar, and generally resemble the flow of the uncontrolled Columbia River at Donald. Note the peak in flow in late September 2010 occurred at all sites, and, in Gold River, was the largest flow of the whole year.

Table 6.1 Gauged tributaries flowing into the Columbia River

Station #	Station Name	Year	Drainage Area (km^2)	Mean Flow (m^3/s)	Yield (m/yr)
08NB019	Beaver River near the Mouth	1985-2010	1150	41.2	1.13
08NB014	Gold River above Palmer Creek	1973-2010	427	18.1	1.34
08ND012	Goldstream River below Old Camp Creek	1954-2010	938	38.7	1.30
08ND013	Illecillewaet River at Greeley	1963-2010	1170	52.6	1.42

7. Kinbasket Reservoir Water Level

Data

Daily water level data were available for 1974-2011 from WSC station 08ND017, entitled “Kinbasket Lake at Mica Dam”. This station is located in Kinbasket Reservoir near Mica Dam.

Daily water level data were also available for 1980-2011 from WSC station 08NB017, entitled “Kinbasket Lake below Garrett Creek”. This station is located about 55 km southeast of Mica Dam in the Columbia Reach. Since both stations are on Kinbasket Reservoir, the water levels are expected to be comparable. The difference between the two stations was generally less than 0.5 m (standard deviation 0.2 m), except for April 2-30, 2007, when data at Kinbasket Lake at Mica Dam had a large (3 m) offset; these data were replaced with that from Kinbasket Lake below Garrett Creek.

Results

Figure 7.1a shows the daily water level of Kinbasket Reservoir for 1974-2011. Note the change in water level due to the completion of the dam in 1973. Figure 7.1b shows the mean daily post-impoundment water level for 1977-2011.

The water level in Kinbasket Reservoir for selected years (1992-1994, 2000-2011) is shown in Figure 7.2 and generally followed the post-impoundment mean level with a few exceptions: in 1993, 1994, 2001 and 2003 the water level was below average for the entire year; and in 2004, the water level was below average from January to September. In 2011, water levels were close to average; below average inflow was balanced by low outflow.

8. Revelstoke Water Level

Data

Daily water level data were available for 1984-2011 from the BC Hydro station located in the Revelstoke fore bay.

Results

Figure 8.1a shows the water level of Revelstoke Reservoir for 1984-2011. Note the change in water level due to the completion of the dam in 1984. Figure 8.1b shows the mean daily post-impoundment water level averaged from 1988-2011. The water level varies by only a few meters, as the reservoir is operated run of the river.

The water level for selected years (1992-1994, 2000-2011) is shown in Figure 8.2, together with the mean post-impoundment level averaged from 1988-2011. The water levels generally followed the post-impoundment mean levels. The largest change in water level was a decrease of ~ 2m in February 2003.

9. Flow to storage

Data

Storage flow gives the rate of change of the volume of the reservoir; when the storage flow is positive, the water level rises and the volume of the reservoir increases. The volume was determined from the water level at the fore bay using the storage elevation curves provided by BC Hydro (Appendix 3). The storage flow, for day i was computed using centered differences as,

$$Q_{stor}^{i} = \frac{V^{i} + V^{i+1}}{2} - \frac{V^{i-1} + V^{i}}{2} = \frac{V^{i+1} - V^{i-1}}{2}.$$

Note the storage flow is a small difference of large values, and can be noisy.

Results

The storage flow for Kinbasket Reservoir is shown in Figure 9.1a for 1976-2011. The average flow is shown in Figure 9.1b; the average flow is positive during the spring and summer as the reservoir fills, and negative through the remainder of the year as the water level falls. Daily storage flow for selected years (1992-1994, 2000-2011) is shown without smoothing in Figure 9.2. The flow in recent years, 2008 to 2011, generally followed the mean.

Revelstoke Reservoir is operated as run of the river with only small changes in water level (Figures 8.1 and 8.2). As a result, the storage flow for Revelstoke is small and noisy (not shown).

10. Local flow

Data

The local flow is composed of all inflow to the reservoir other than the main inflow. The local flow includes tributaries of all sizes, as well as the net precipitation to the surface of the reservoir. The local inflow was computed for both Kinbasket and Revelstoke Reservoirs using a water balance for inflows and outflows:

$$Q_{in} + Q_{loc} = Q_{stor} + Q_{out},$$

where Q_{in} is the main inflow, Q_{loc} is the local flow, Q_{stor} is the storage flow computed in the previous section, and Q_{out} is the outflow. For Kinbasket Reservoir the Columbia at Donald was used for Q_{in}, and for Revelstoke Reservoir Q_{in} was the outflow from Mica Dam.

Like the storage flow, the local flow is a small difference of large values, is subject to considerable error, and can be very noisy. Large peaks in the data are often followed by a large correcting dip. While negative local inflow is not physical (representing high evaporation or outflow), the negative values shown balance the positive peaks.

Results

Figure 10.1 shows the annual and mean local flow for Kinbasket Reservoir. The mean (Figure 10.1b) follows the shape of the natural hydrograph seen in the Columbia at

Donald (Figure 3.1). The peak in the local flow is about twice that of the Columbia at Donald, consistent with the annual water balance (Table 2.1).

Figure 10.2 shows the annual and mean local flow for Revelstoke Reservoir for 1989-2011. The mean hydrograph is consistent with that of local inflow, though it is noisier because there are fewer years of data than for Kinbasket Reservoir.

The annual local flow for both Kinbasket and Revelstoke Reservoirs is shown in Figure 10.3 for selected years (1992-1994, 2000-2011). The data were lightly filtered with three passes of a 3 point moving average. Note also, that both the Kinbasket and Revelstoke local inflows were scaled by drainage area and yield for comparison to the Columbia at Donald. Also shown for comparison is the average flow of the Columbia at Donald. The Columbia at Donald and the two local flows show similar peaks across the three respective drainage areas. There are also some regional differences; for example in May 2008, the local freshet flow rises sooner in Kinbasket and Revelstoke Reservoirs than in than Columbia at Donald (Figure 10.3.1g).

The local flow to Revelstoke Reservoir is compared to the inflow of the Columbia from Mica Dam in Figure 10.4. From May to mid-July, when Kinbasket Reservoir is filling, and the outflow from Mica Dam is low, the inflow to Revelstoke Reservoir is dominated by local inflow.

11. Summer 2008, 2009, 2010 and 2011

The El-Nino/Southern Oscillation ENSO index (Wolter, 2011) and the size of winter snow packs (BCRFC, 2011) are summarized in Table 11.1 for the study years.

Table 11.1 Summary of meteorological and hydrological conditions during study years

2008	Strong La Nina (Jan-Mar 2008)	
		Columbia Region Snow Basin Index (April 1st), 104%
		Flow slightly below average, sharp onset of freshet in mid-May
		Cool mid-March to mid-May
2009	Weak La Nina (Aug 2007 - Feb 2008)	
		Columbia Region Snow Basin Index (April 1st), 78%
		Flow generally below average
2010	Strong El Nino (Jan-Mar 2010; winter Olympics)	
		Columbia Region Snow Basin Index (April 1st), 84%
		Flow generally below average
2011	Strong La Nina (Jul 2010 - Apr 2011)	
		Columbia Region Snow Basin Index (April 1st), 101%
		Flow average
		Consistently colder than average from late March to early May

The summer, including those of 2008 to 2011, can be divided into two periods. From May to mid-July inflow to Kinbasket Reservoir is stored resulting in a rapid increase in water level (Figure 7.2.2e,f,g,h) and little outflow (Figure 4.2.2e,f,g,h). In 2010, this low outflow period extended to the end of July (Figure 4.2.2g). For Revelstoke Reservoir, downstream of Kinbasket, this means that the major inflow from May to mid-July is freshet inflow from local drainage. Because Revelstoke Reservoir is operated as run of the river (Figure 8.2.2e,f,g,h), the outflow from Revelstoke Reservoir is driven by local freshet inflow during the periods of low Mica outflow. In 2008, a strong freshet peak occurred in mid-May and again in early July (Figure 6.5). In 2009, freshet was more gradual peaking in early and mid-June (Figure 6.6). In 2010, two early and short duration peaks occurred in April and May, followed by a broader peak later in June (Figure 6.7). In 2011, the flow was below average until mid-May (a cold spring) and freshet peaked at the end of June (Figure 6.8).

The second period is mid-July to September, when Kinbasket Reservoir has almost filled and the tail of the freshet is discharged from Mica Dam (Figure 4.2.2e,f,g,h). This increased flow from Kinbasket to Revelstoke makes up for the decline in local freshet inflow to Revelstoke and as a consequence the discharge from Revelstoke is similar in both periods (Figure 5.2.2e,f,g,h; Figure10.4.2e,f,g,h).

Acknowledgements

We gratefully acknowledge funding provided by B.C. Hydro and the assistance of D. Robb, A. Akkerman, J. Bowman and A. Sharp.

References

BCRFC (British Columbia River Forecast Centre). 2011. Snow Survey and Water Supply Bulletin. Accessed at http://bcrfc.env.gov.bc.ca/bulletins/.

Kammerer, J.C. 1990. Largest rivers in the United States. USGS Water Fact Sheet, Open File Report 87-242. http://pubs.usgs.gov/of/1987/ofr87-242/

Pieters, R., L.C. Thompson, L. Vidmanic, S. Harris, J. Stockner, H. Andrusak, M. Young, K. Ashley, B. Lindsay, G. Lawrence, K. Hall, A. Eskooch, D. Sebastian, G. Scholten and P.E. Woodruff. 2003. Arrow Reservoir fertilization experiment, year 2 (2000/2001) report. RD 87, Fisheries Branch, Ministry of Water, Land and Air Protection, Province of British Columbia.

Pieters R. and G. Lawrence. 2012. Hydrology of Kinbasket and Revelstoke Reservoirs, 2010. Prepared for BC Hydro, Water Licence Requirements. 52 pp. Appendix 1 *in* Bray, K.E. 2012. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2010). BC Hydro, Environment. Study No. CLBMON-3.

Sebastian, D. 2010. Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring. Progress Report Year 2 (2009). Prepared for BC Hydro, Water Licence Requirements. Study No. CLBMON-2. 30 pp.

Water Survey Canada. 2009. Hydat National Water Data Archive. Accessed at http://www.wsc.ec.gc.ca/products/hydat/main_e.cfm?cname=archive_e.cfm.

Wolter, K. 2011. Multivariate ENSO Index (MEI) Accessed at http://www.esrl.noaa.gov/psd/enso/mei/.

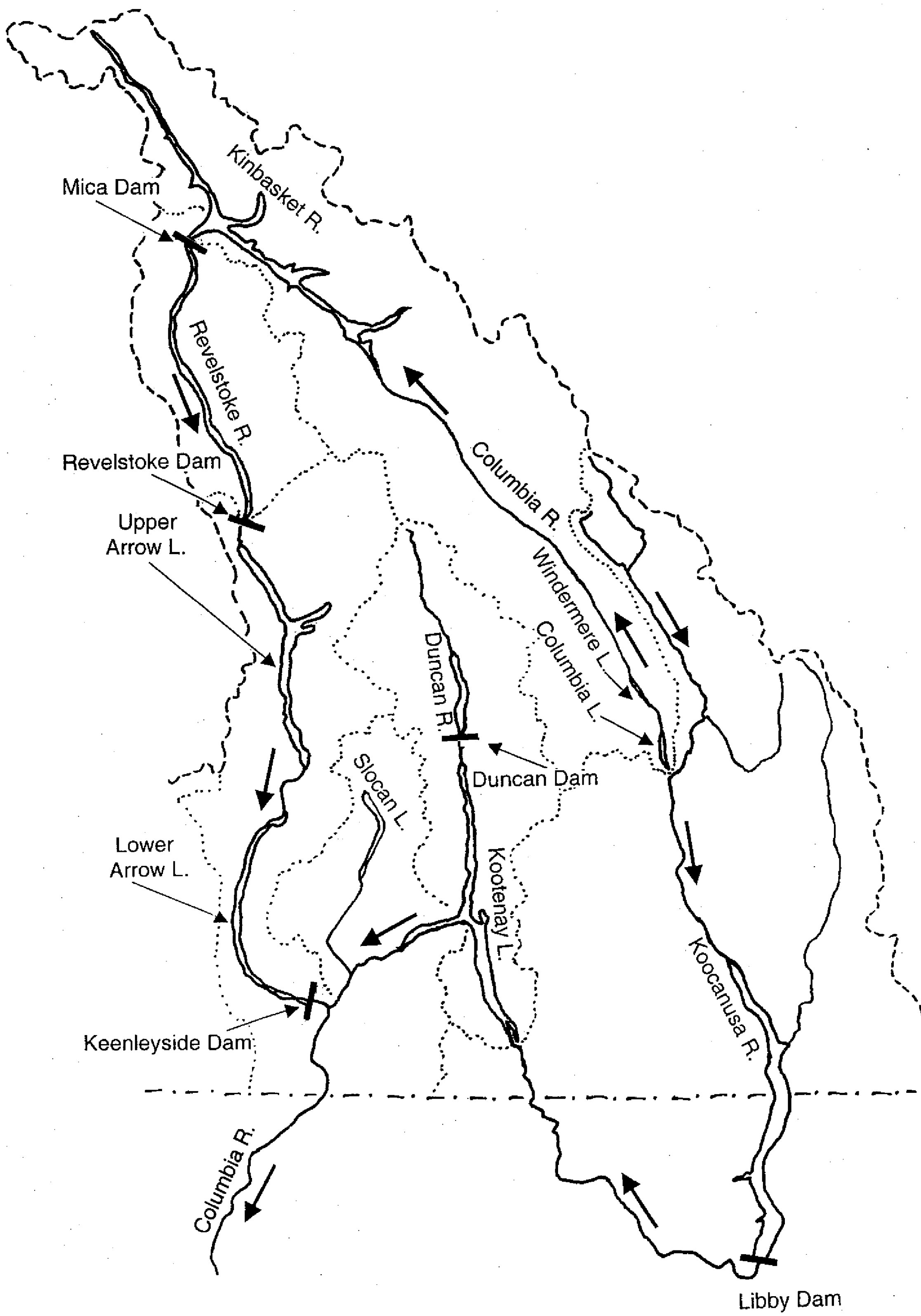


Figure 1.1. Upper Columbia River Basin

Figure 1.2 Kinbasket Reservoir with gauging stations (RED) and sampled tributaries (YELLOW).

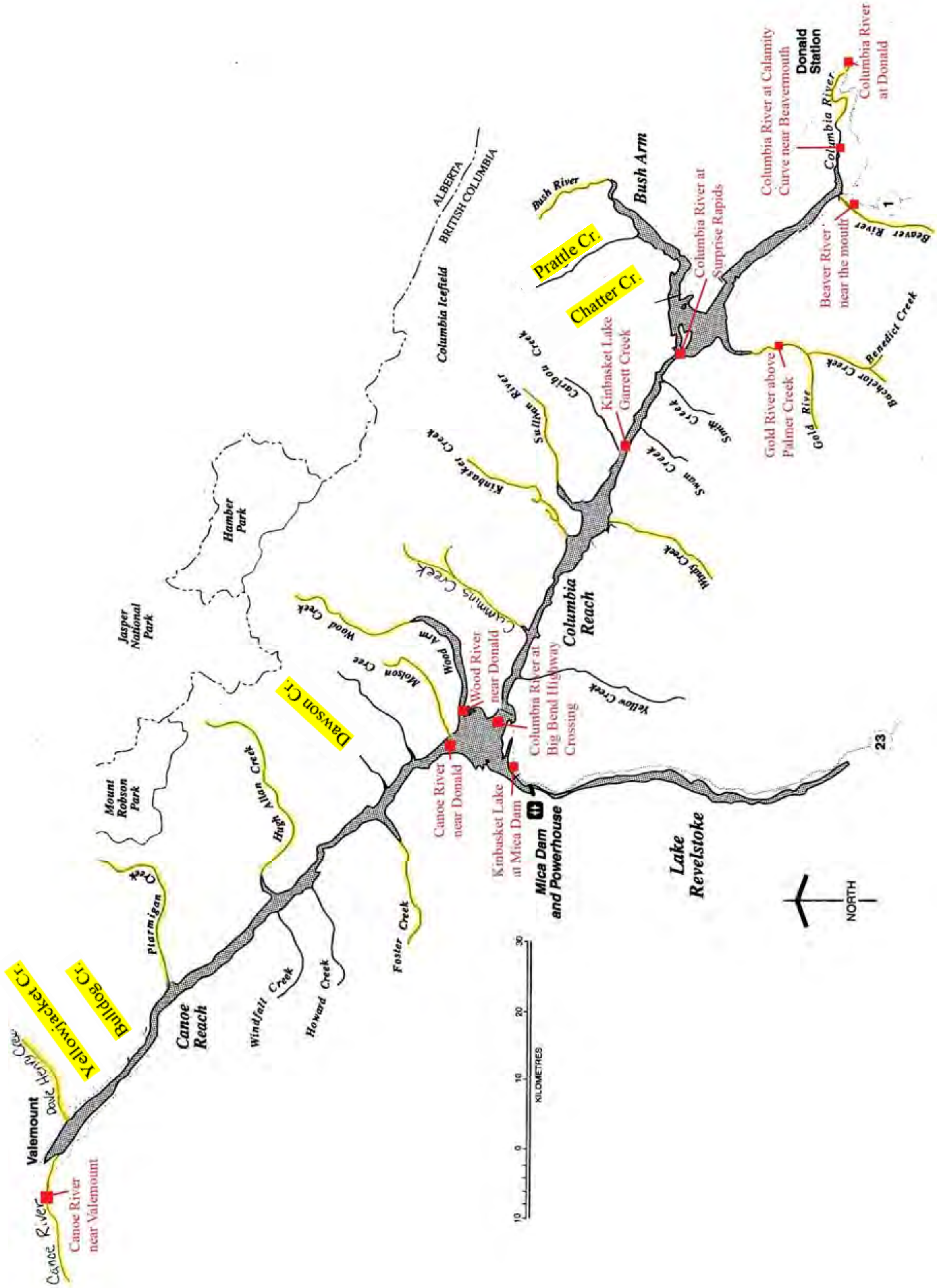
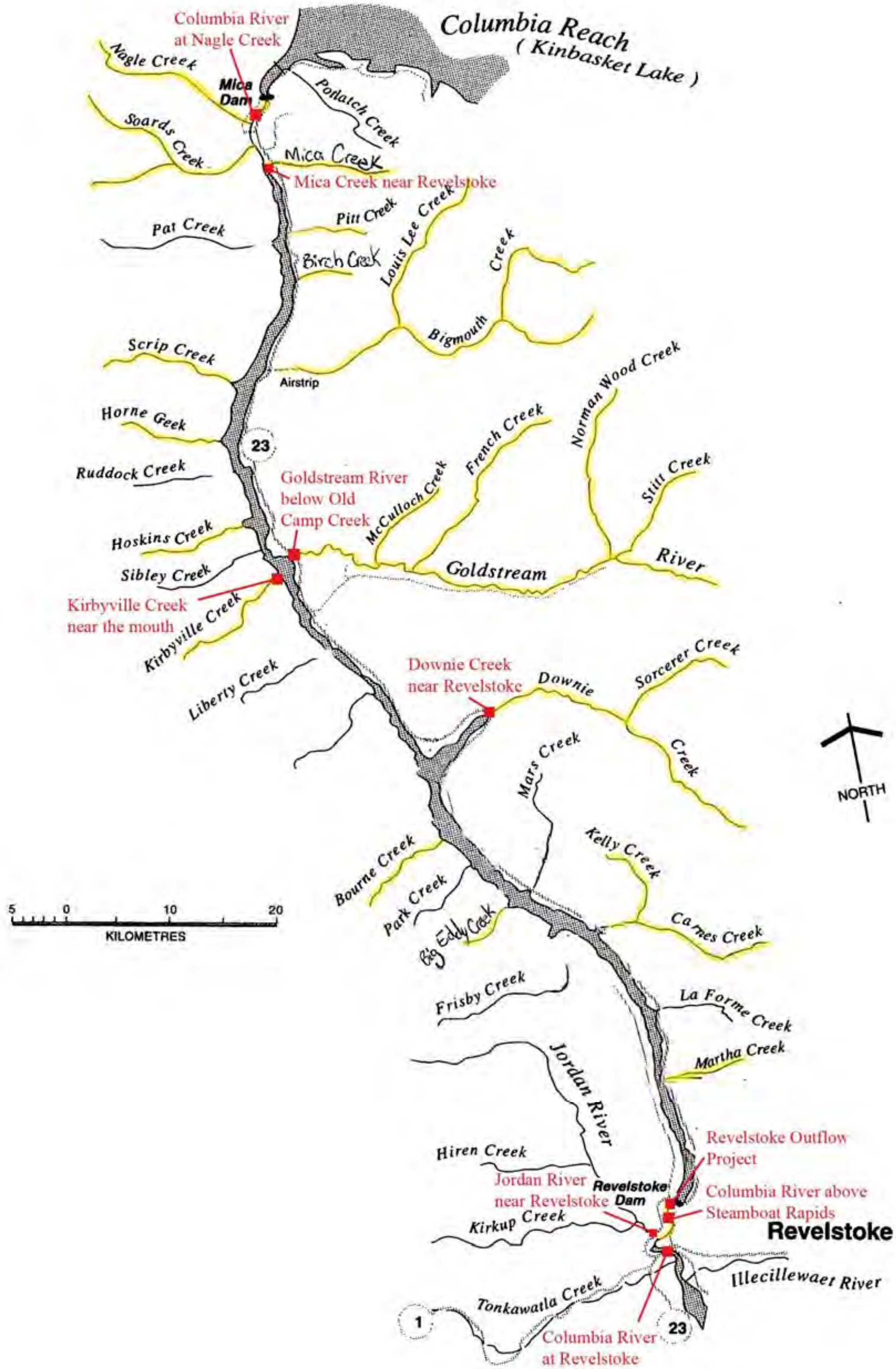


Figure 1.3 Revelstoke Reservoir with gauging stations (RED) and sampled tributaries (YELLOW).



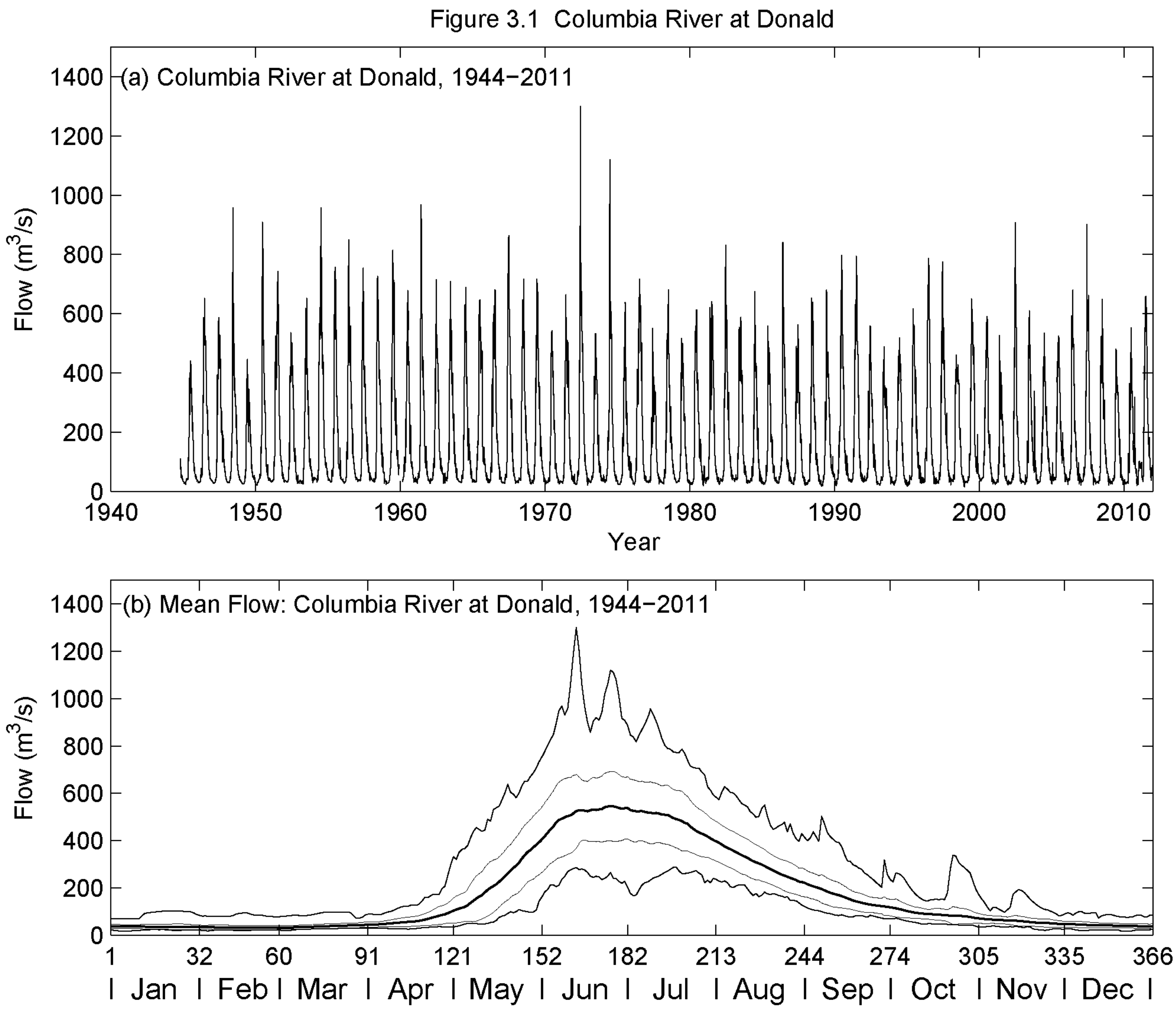


Figure 3.1. (a) WSC station 08NB005, "Columbia River at Donald", 1944-2011. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

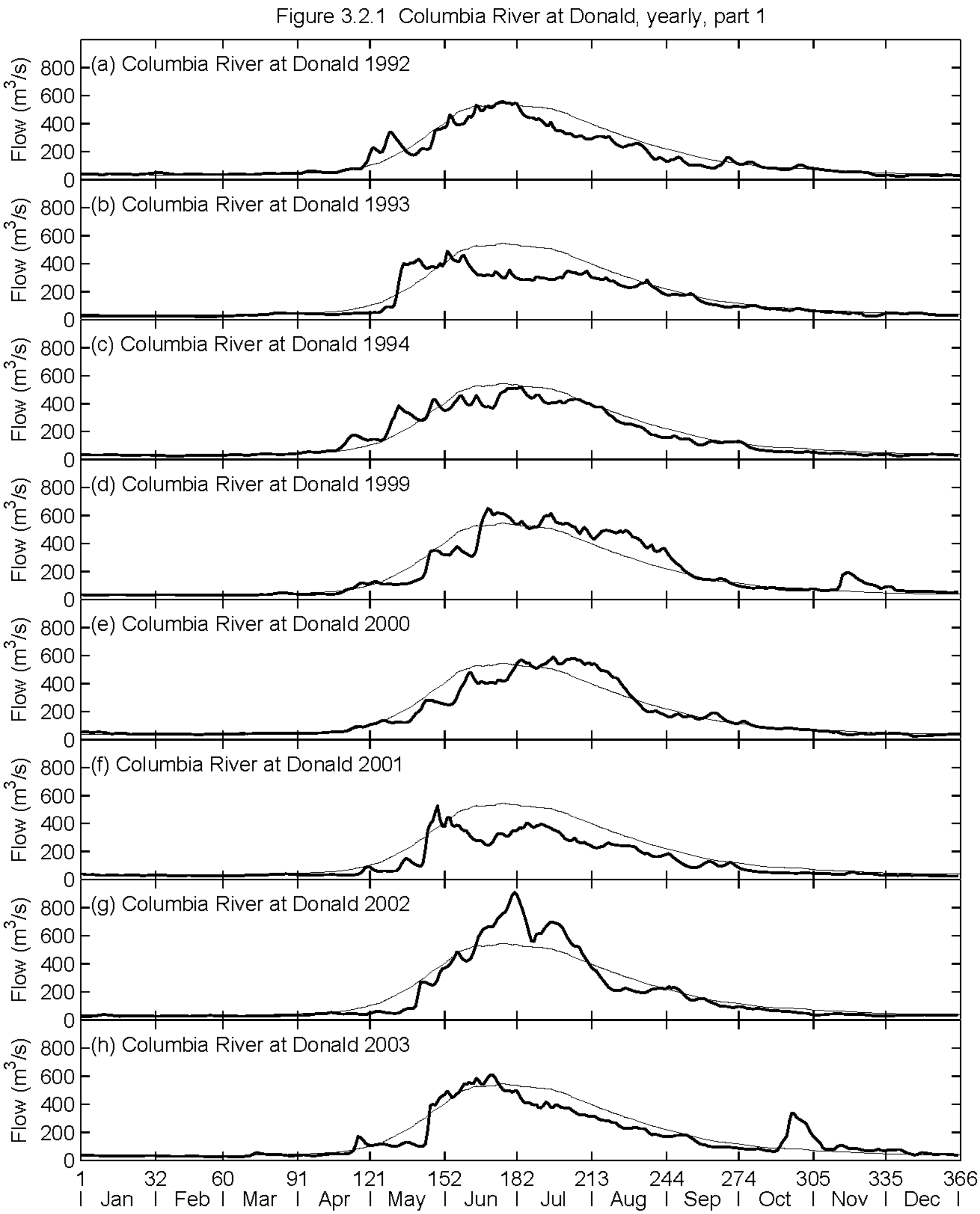


Figure 3.2.1. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2011 (light line) is shown for comparison.

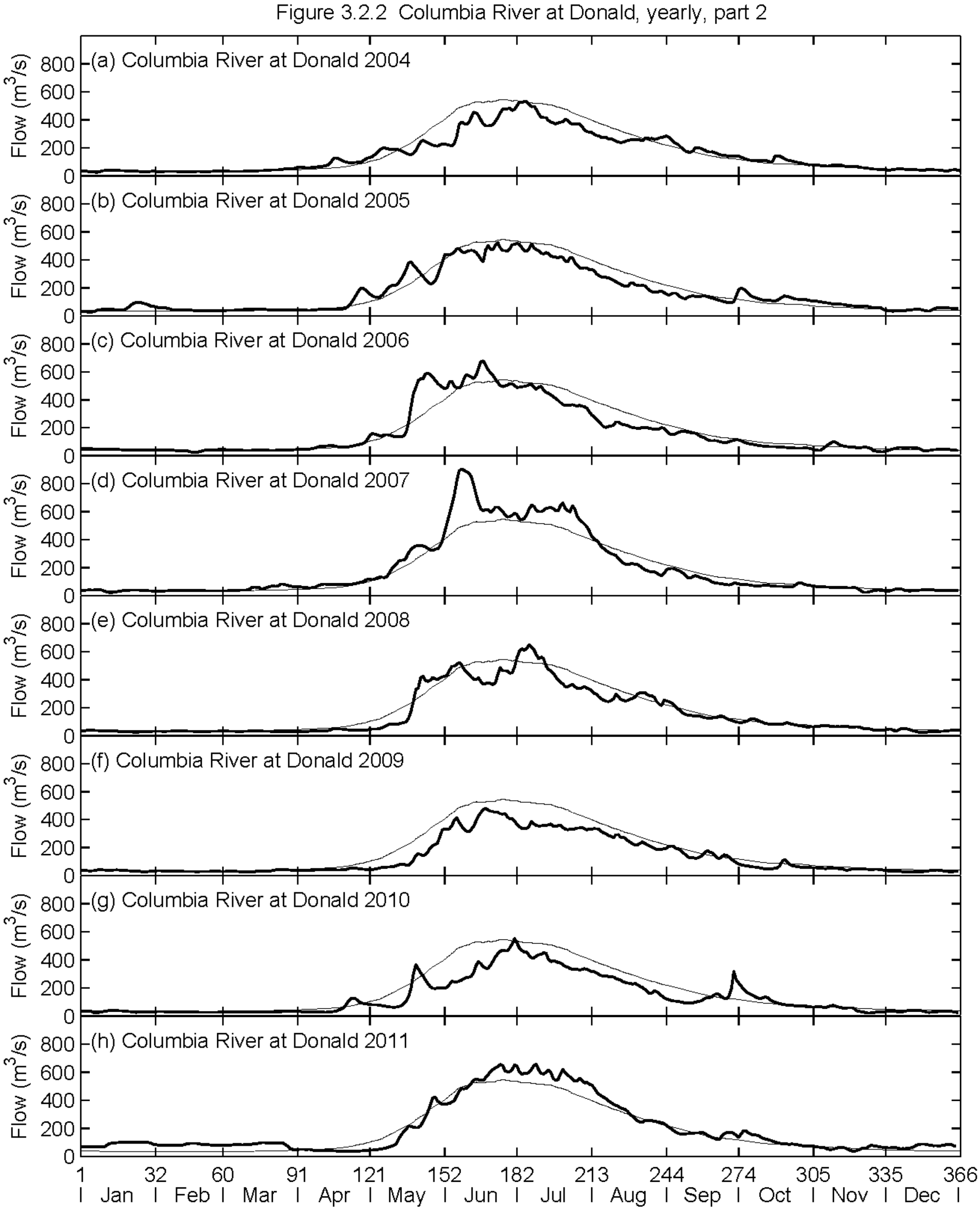


Figure 3.2.2. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2011 (light line) is shown for comparison.

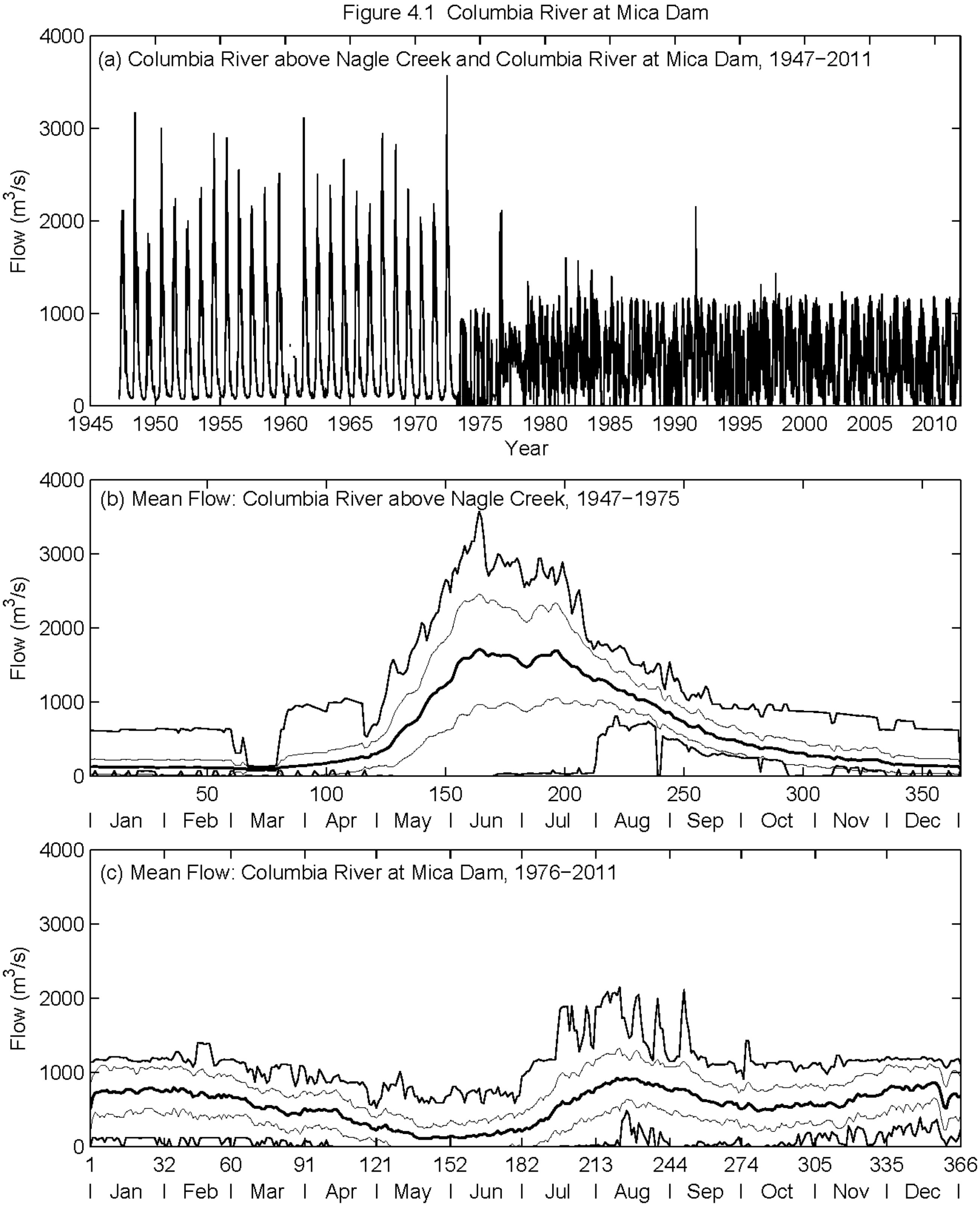


Figure 4.1. (a) WSC station 08ND007, "Columbia River above Nagle Creek", 1947-1975 and BC Hydro station "Columbia River at Mica Dam Outflow", 1976-2011. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

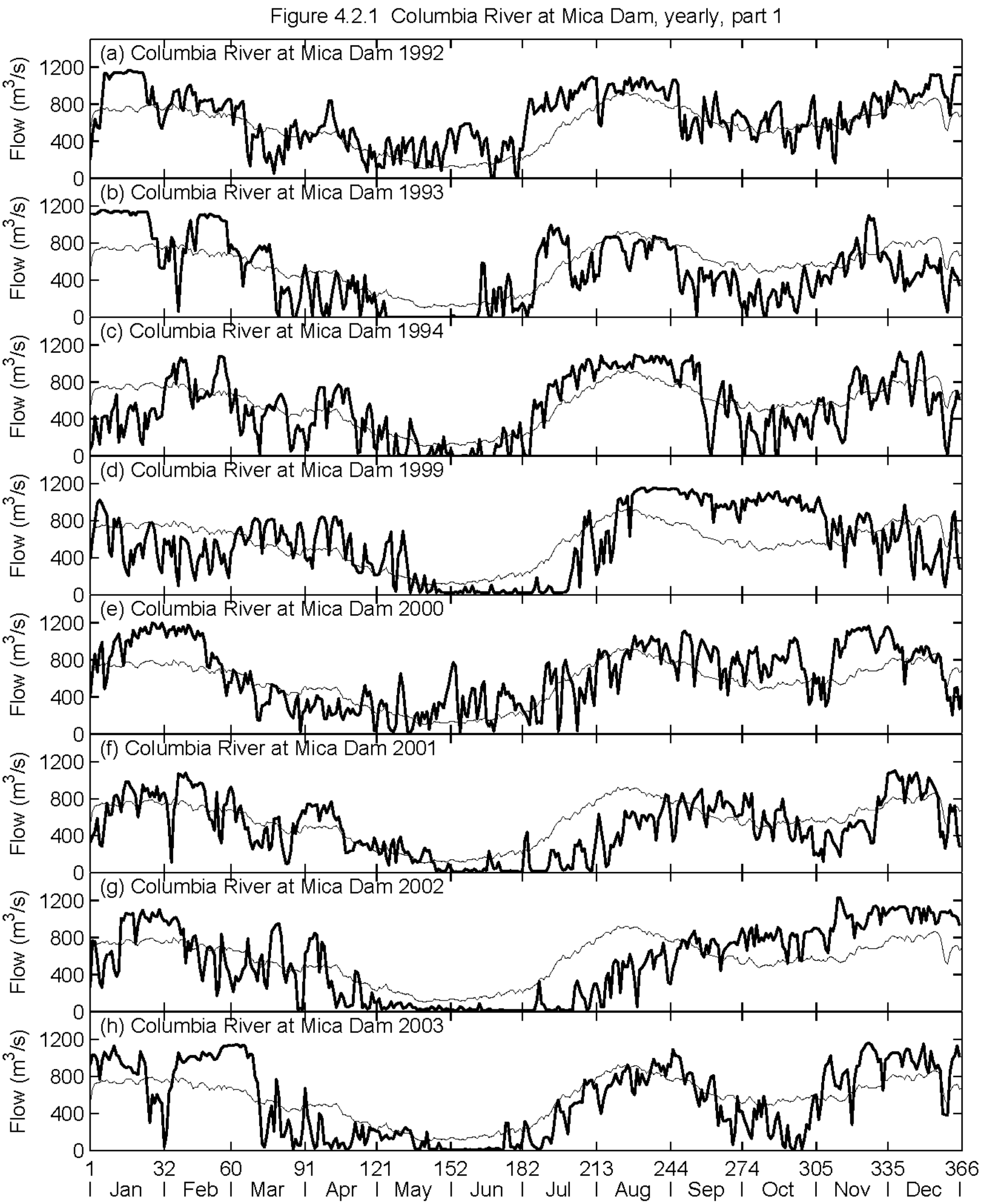


Figure 4.2.1. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2011 (light line) is shown for comparison.

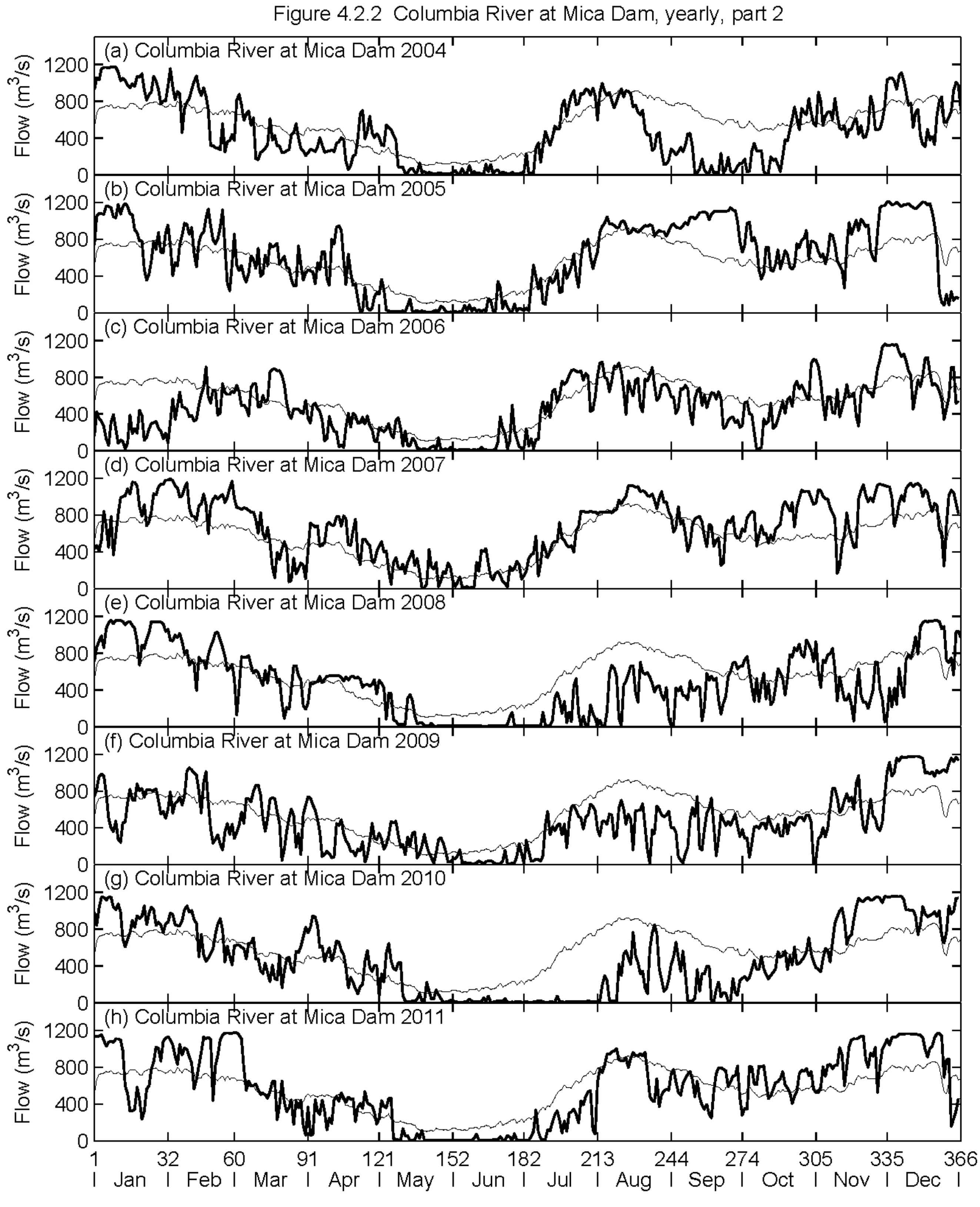


Figure 4.2.2. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2011 (light line) is shown for comparison.

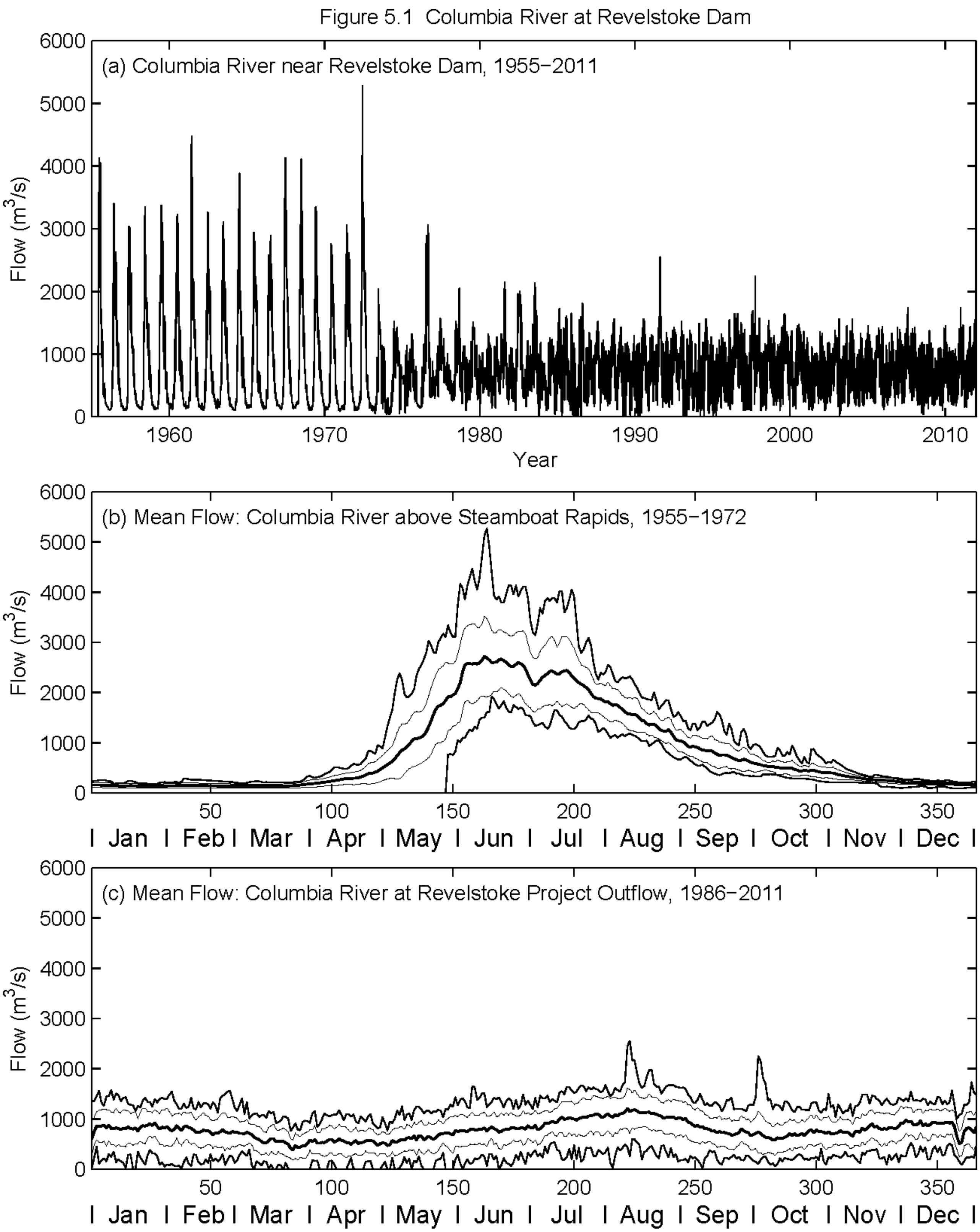


Figure 5.1. (a) WSC station 08ND011, "Columbia River above Steamboat Rapids", 1955-1985 and WSC station 08ND025, "Revelstoke Project Outflow", 1986-2011. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

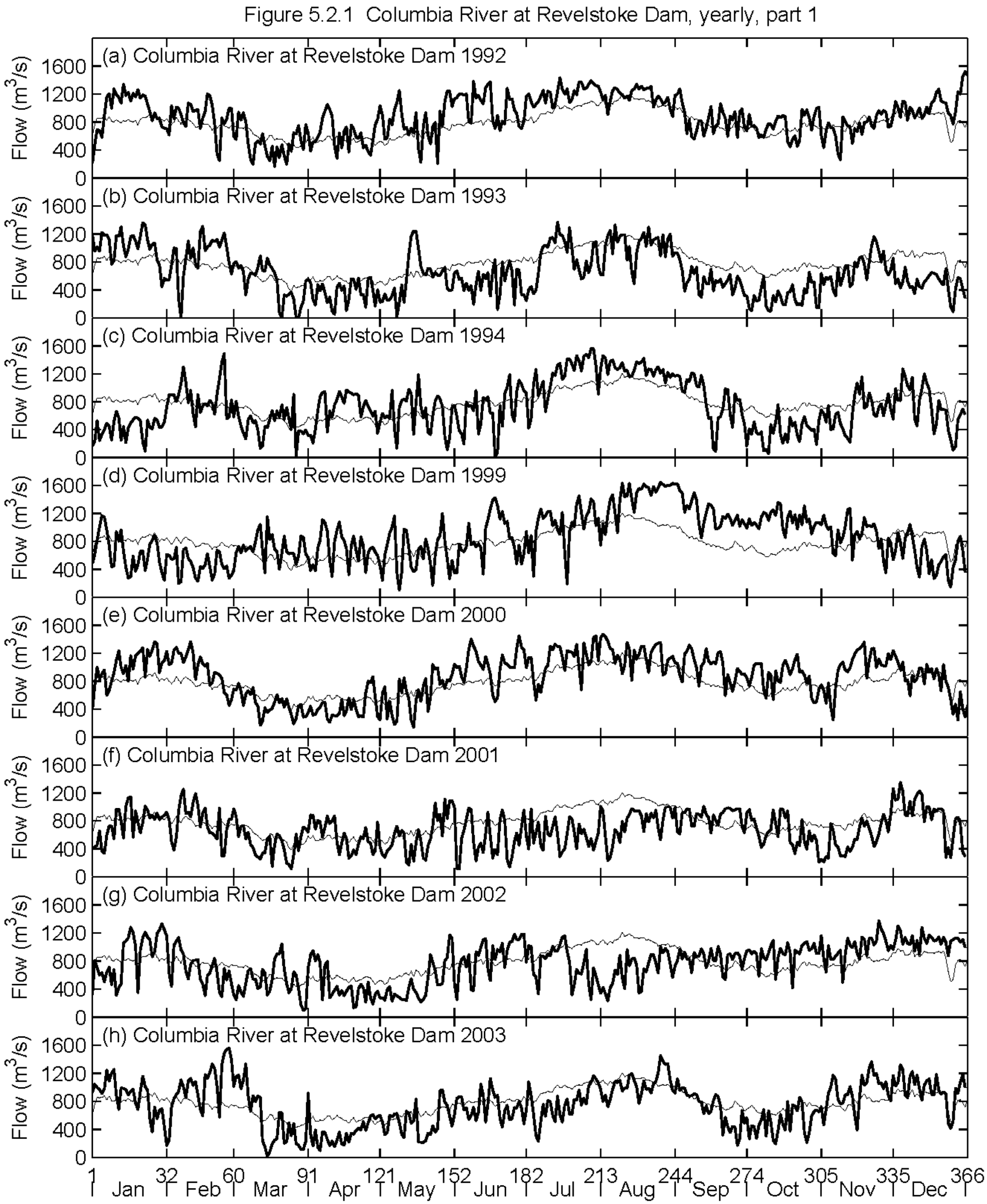


Figure 5.2.1. WSC station 08ND025, "Revelstoke Project Outflow", selected years (heavy line). Mean flow for 1986-2011 (light line) is shown for comparison.

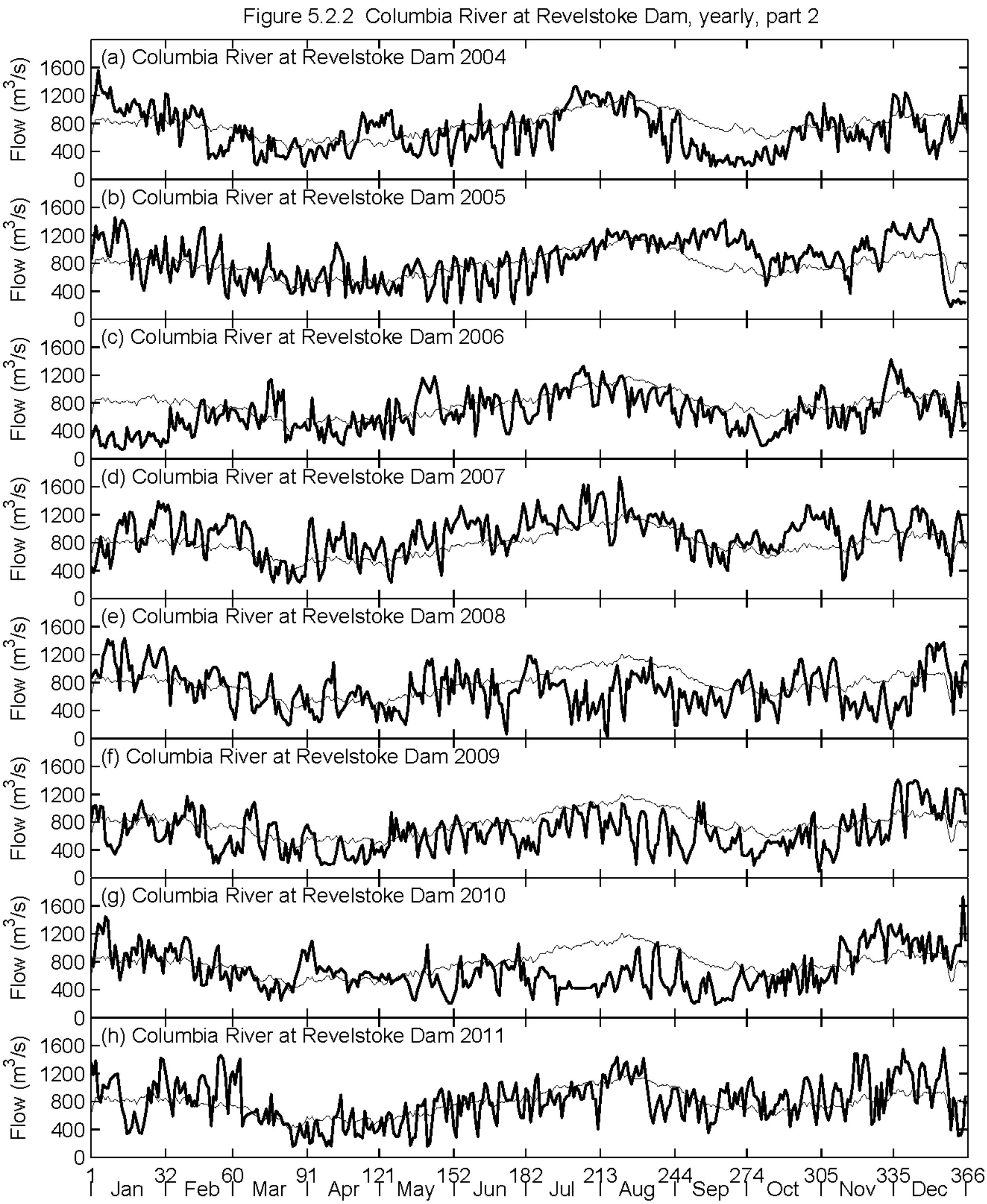


Figure 5.2.2. WSC station 08ND025, "Revelstoke Project Outflow", selected years (heavy line). Mean flow for 1986-2011 (light line) is shown for comparison.

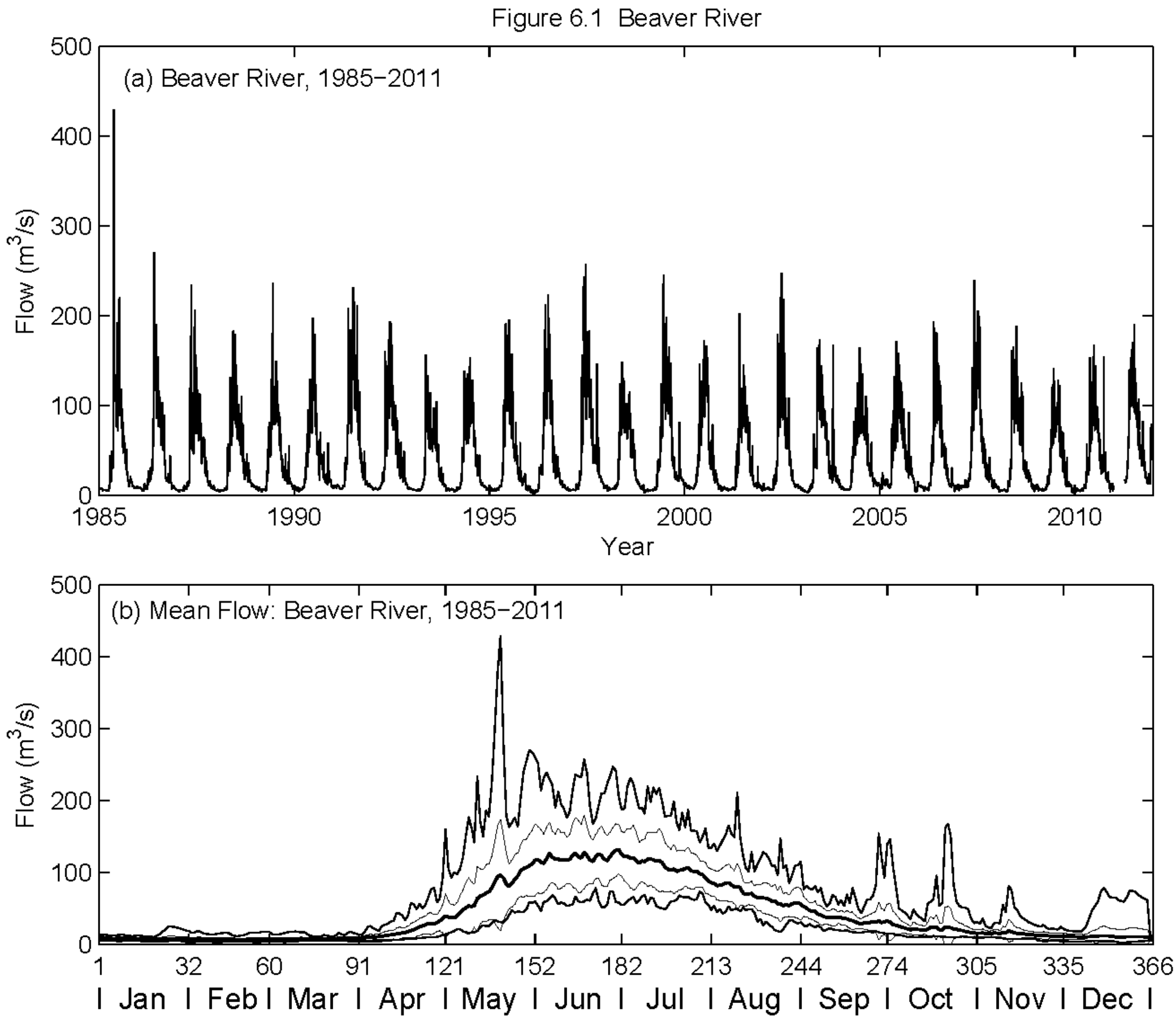


Figure 6.1. **(a)** WSC station 08NB019, "'Beaver River near the Mouth", 1985-2011. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

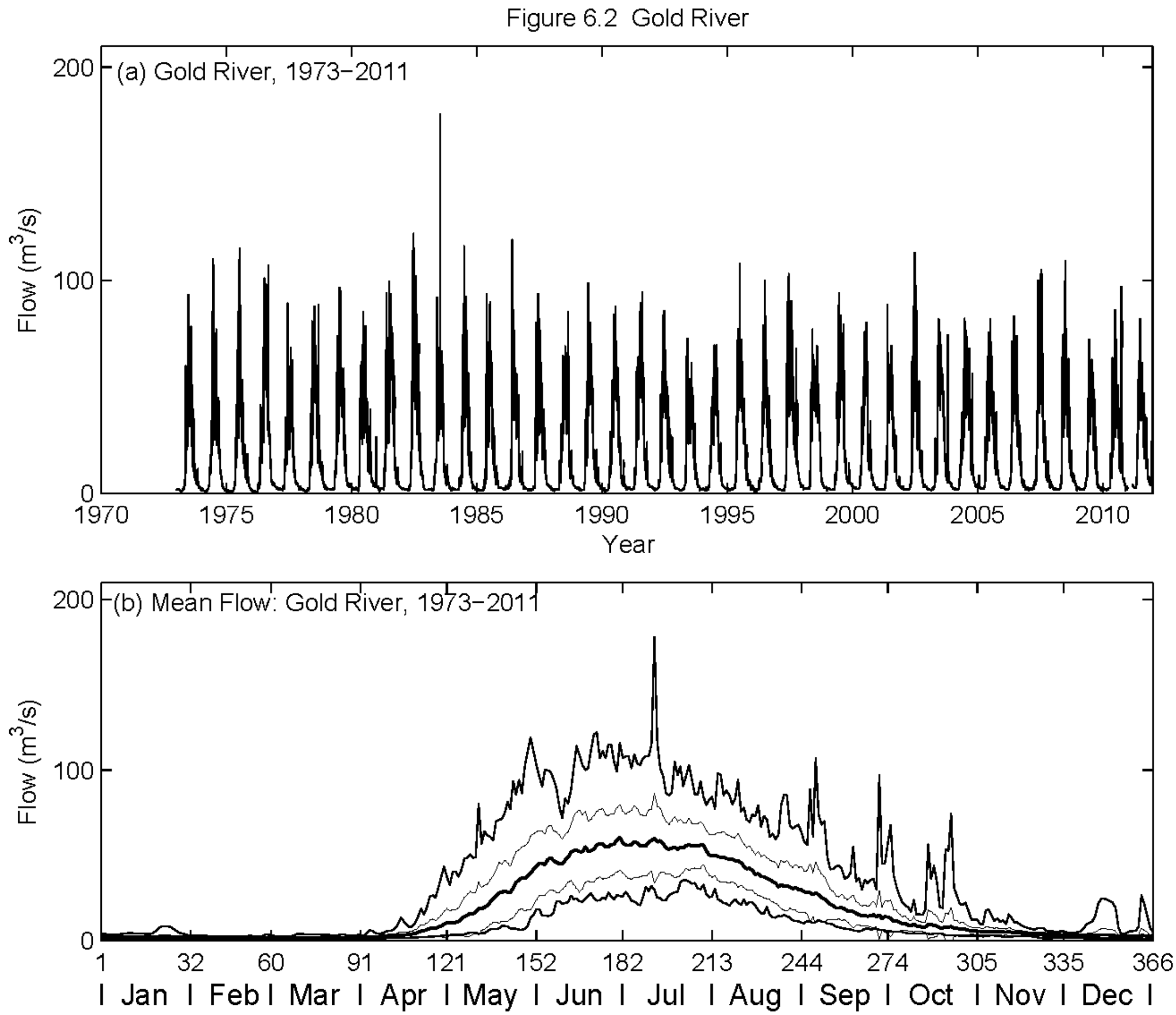


Figure 6.2. (a) WSC station 08NB014, "Gold River above Palmer Creek", 1973-2011. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

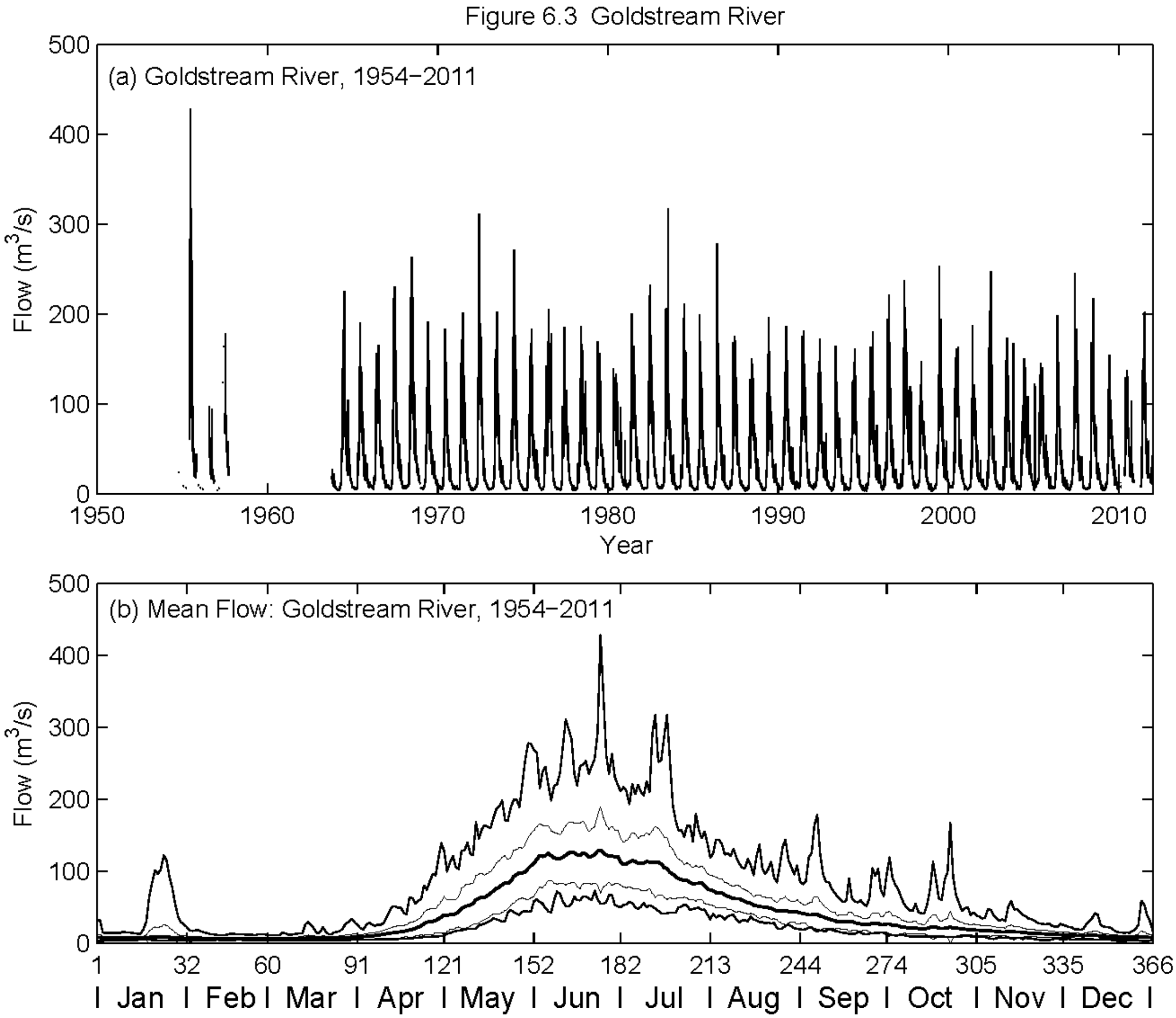


Figure 6.3. **(a)** WSC station 08ND012, "Goldstream River below Old Camp Creek", 1954-2011. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

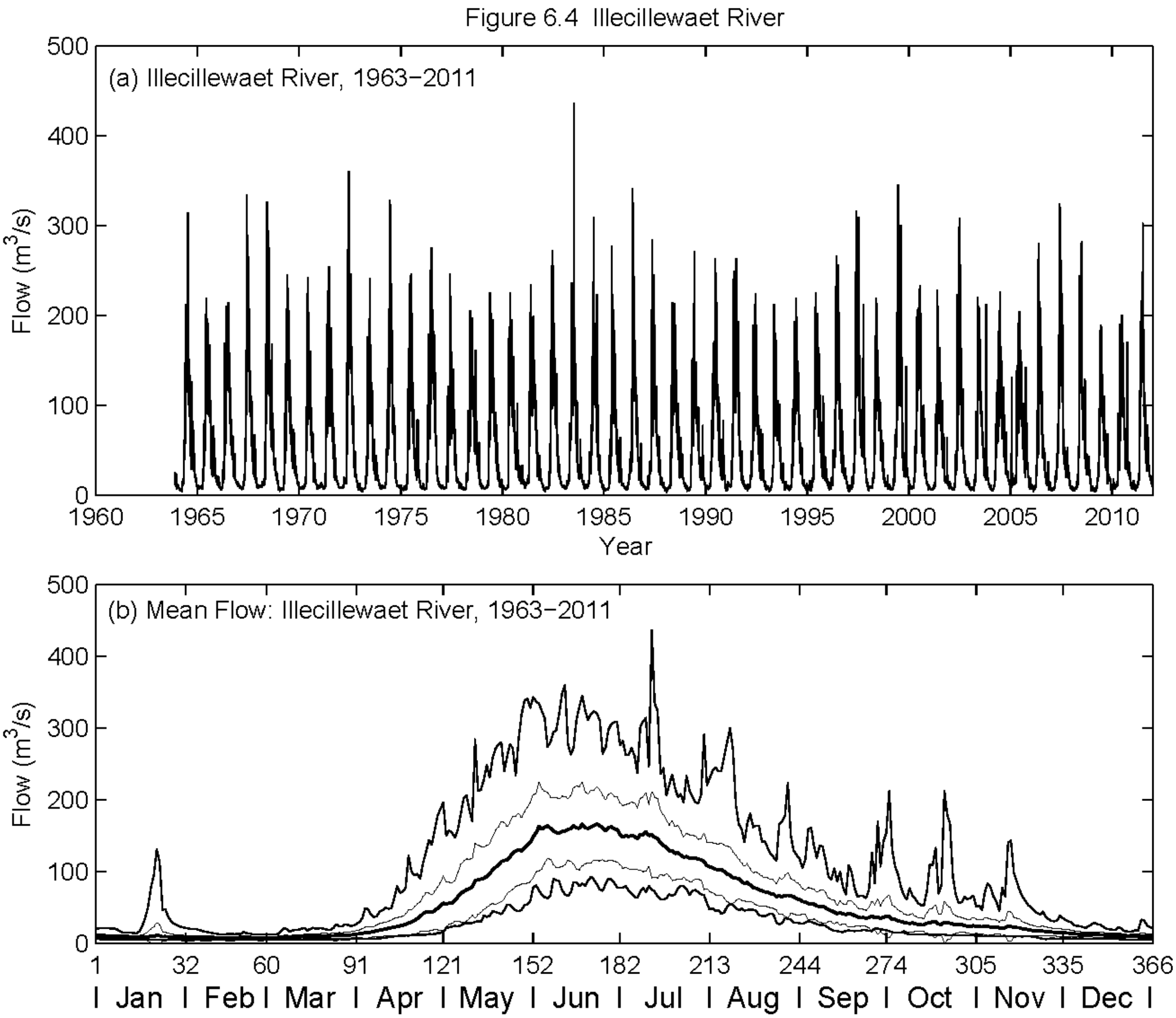


Figure 6.4. (a) WSC station 08ND013, "Illecillewaet River at Greeley", 1963-2011. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

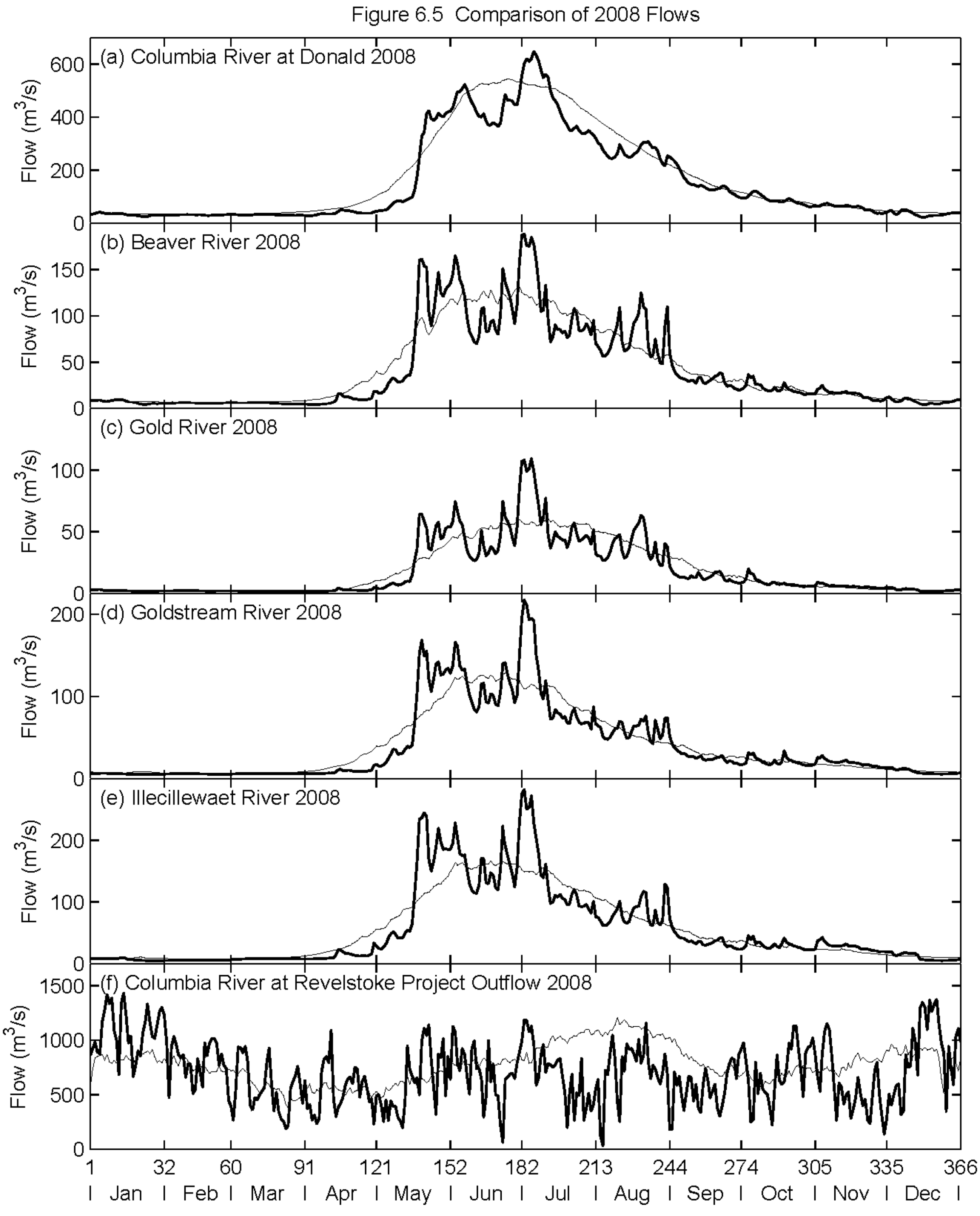


Figure 6.5. Comparison of flows in 2008 for the stations indicated (heavy line). Mean flows for **a)** 1944-2011 **b)** 1985-2011 **c)** 1973-2011 **d)** 1954-2011 **e)** 1963-2011 **f**) 1986-2011 (light line).

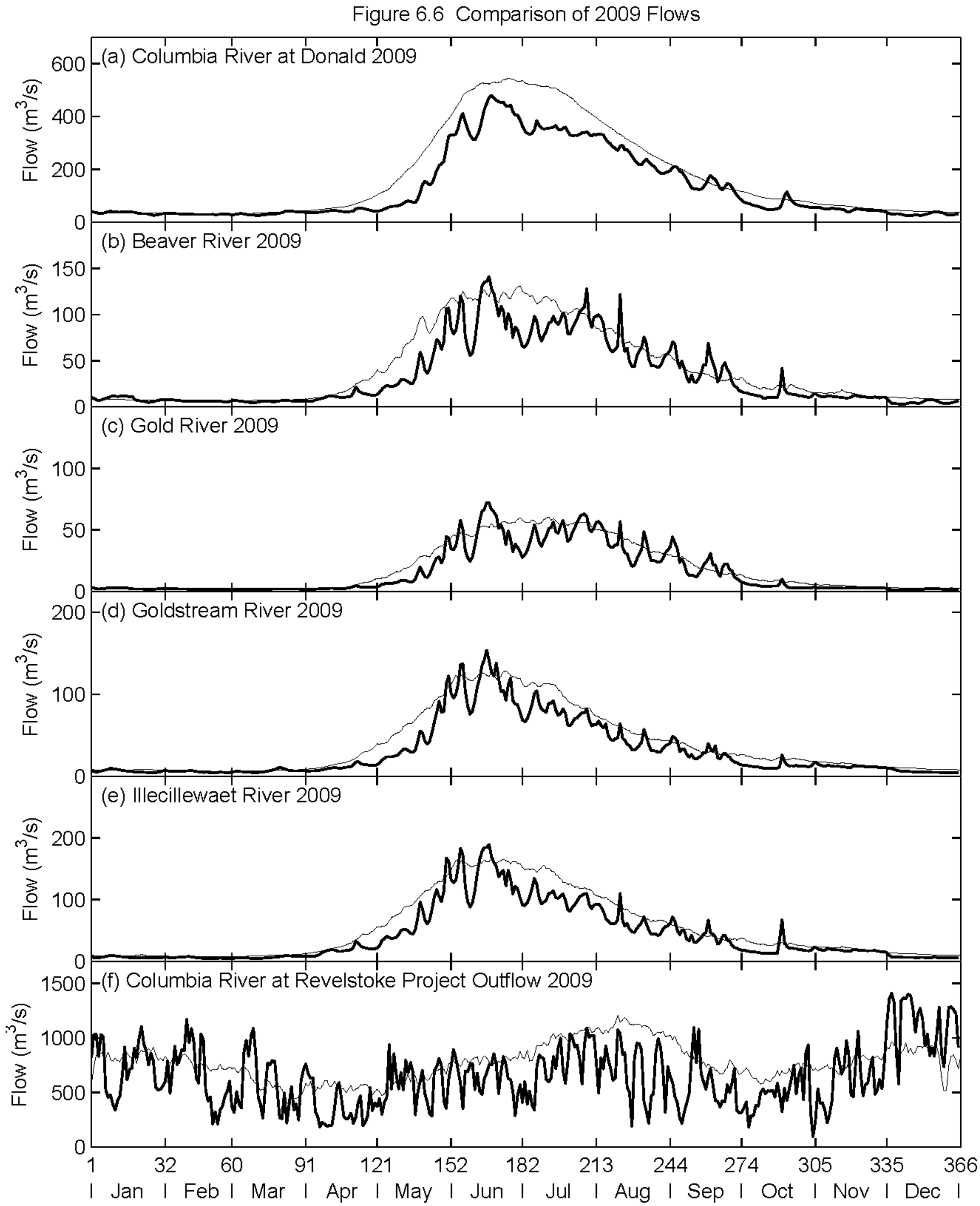


Figure 6.6. Comparison of flows in 2009 for the stations indicated (heavy line). Mean flows for **a)** 1944-2011 **b)** 1985-2011 **c)** 1973-2011 **d)** 1954-2011 **e)** 1963-2011 **f)** 1986-2011 (light line).

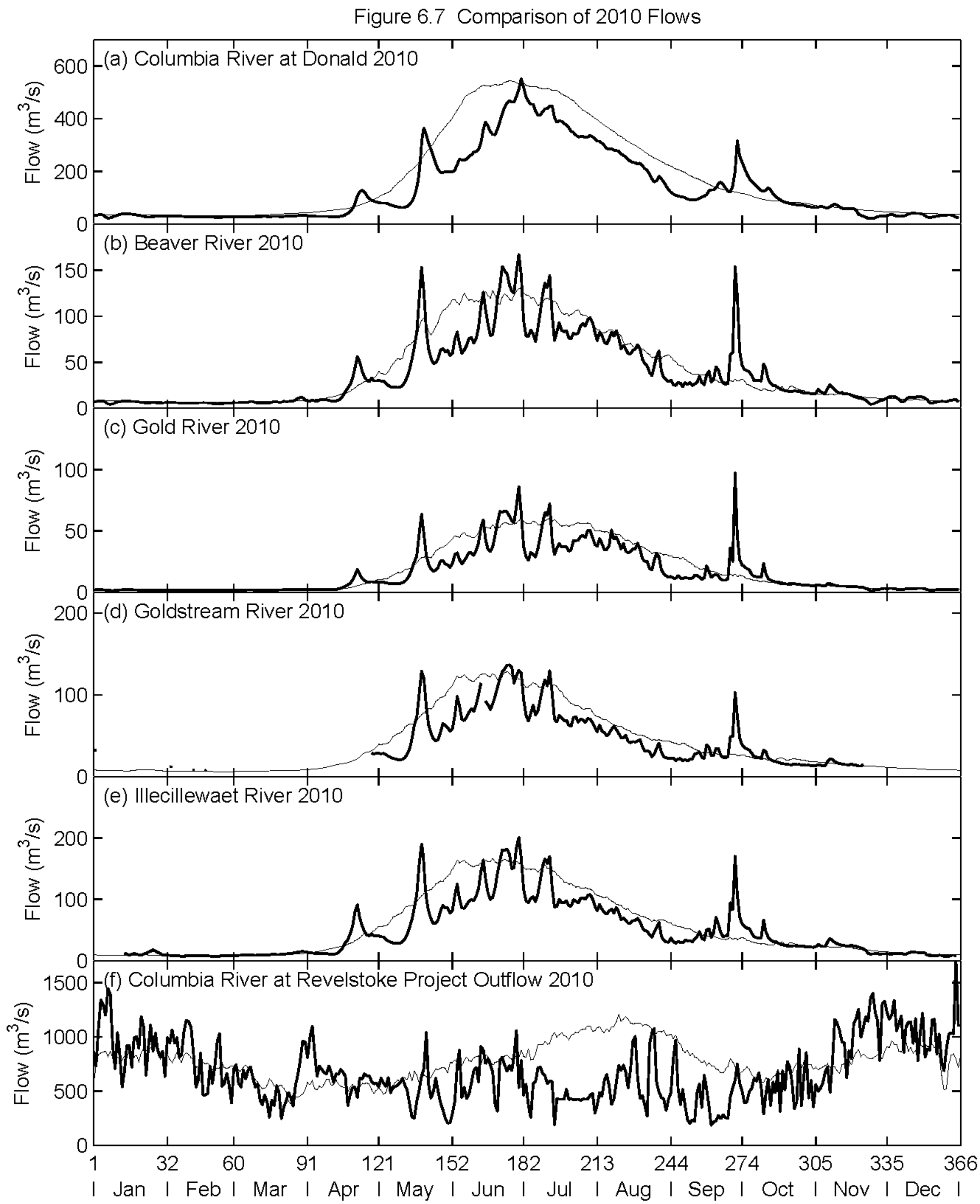


Figure 6.7. Comparison of flows in 2010 for the stations indicated (heavy line). Mean flows for **a)** 1944-2011 **b)** 1985-2011 **c)** 1973-2011 **d)** 1954-2011 **e)** 1963-2011 **f**) 1986-2011 (light line).

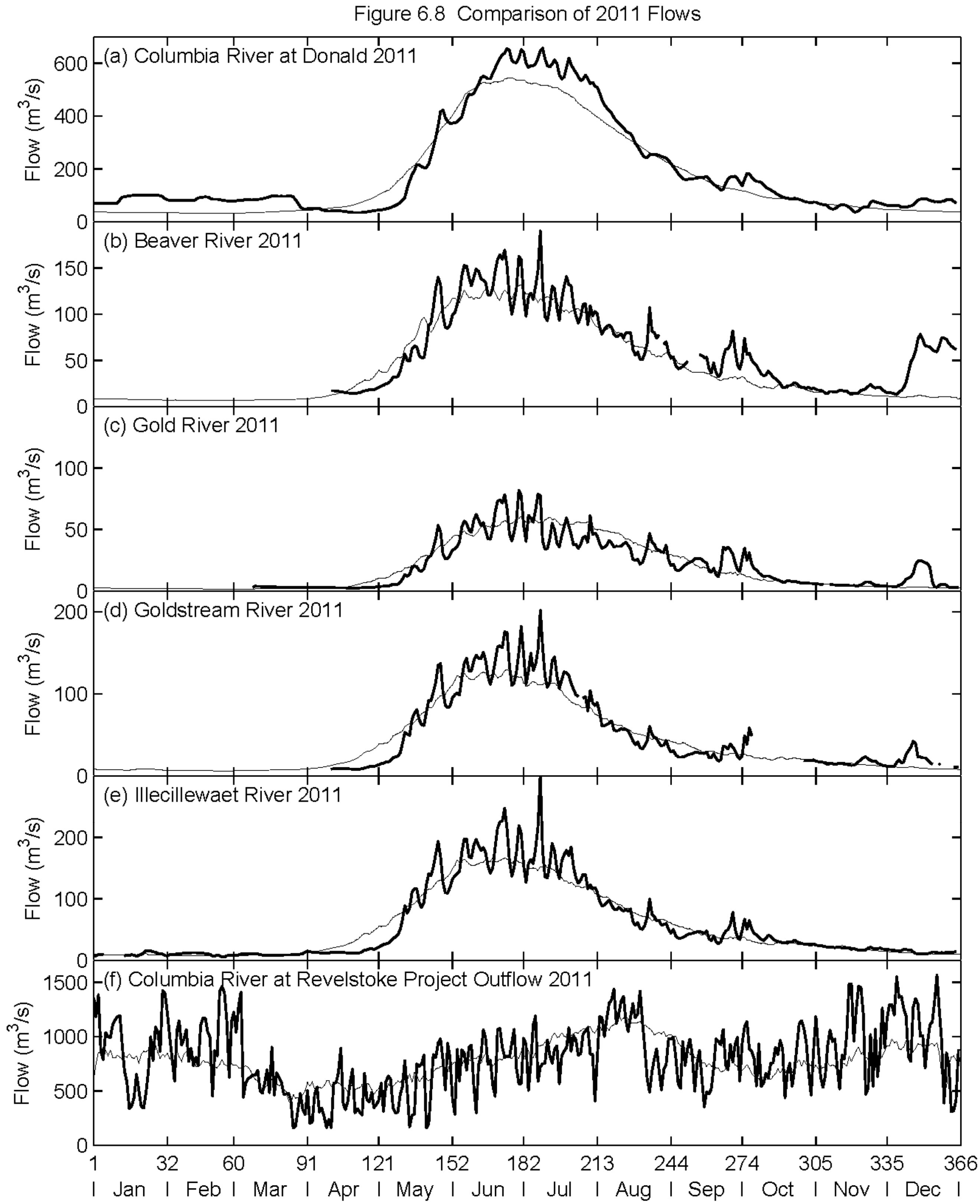


Figure 6.8. Comparison of flows in 2011 for the stations indicated (heavy line). Mean flows for **a)** 1944-2011 **b)** 1985-2011 **c)** 1973-2011 **d)** 1954-2011 **e)** 1963-2011 **f**) 1986-2011 (light line).

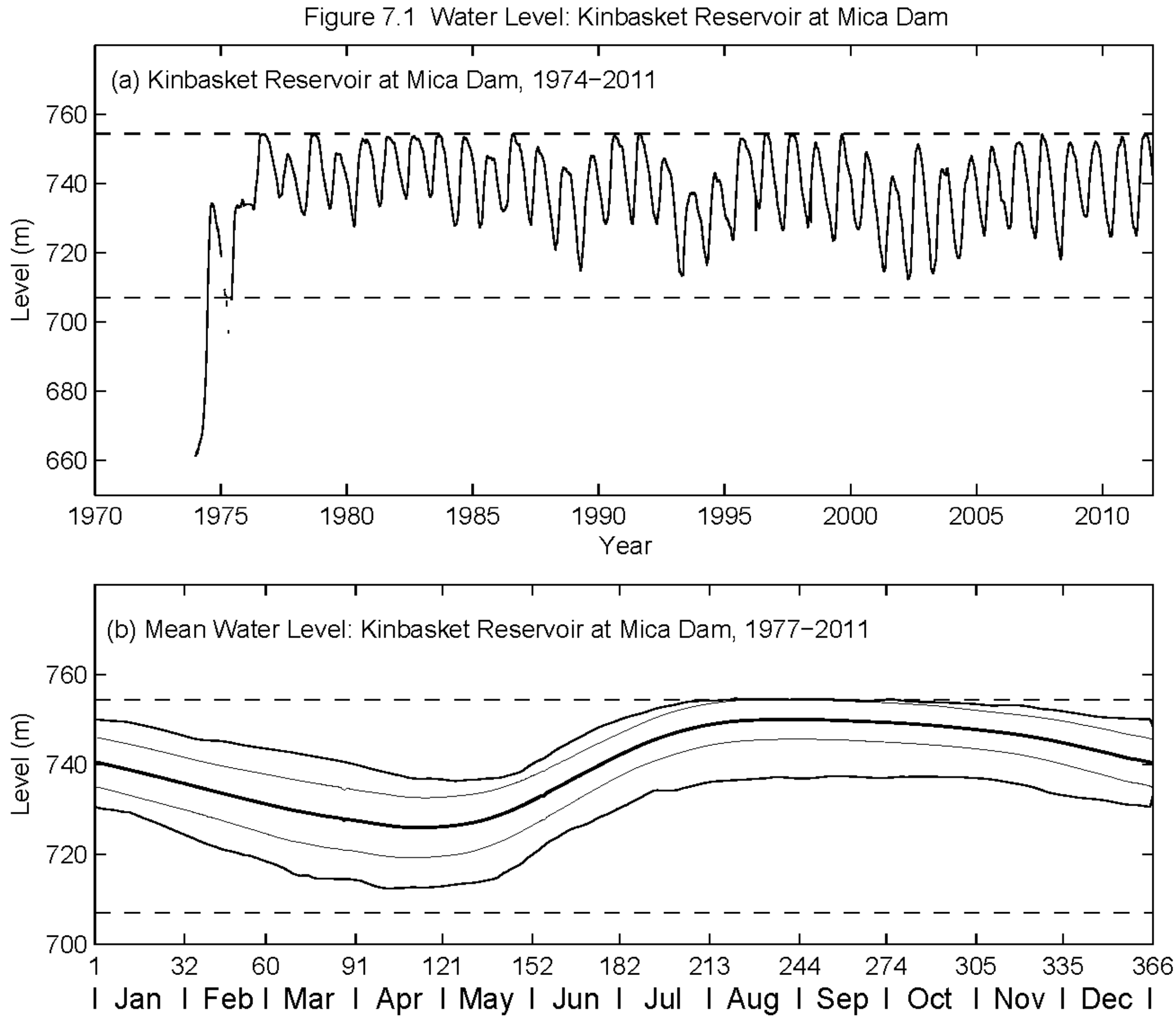


Figure 7.1. **(a)** WSC station 08ND017 "Kinbasket Lake at Mica Dam", 1974-2011. **(b)** Mean daily water level for 1977-2011. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

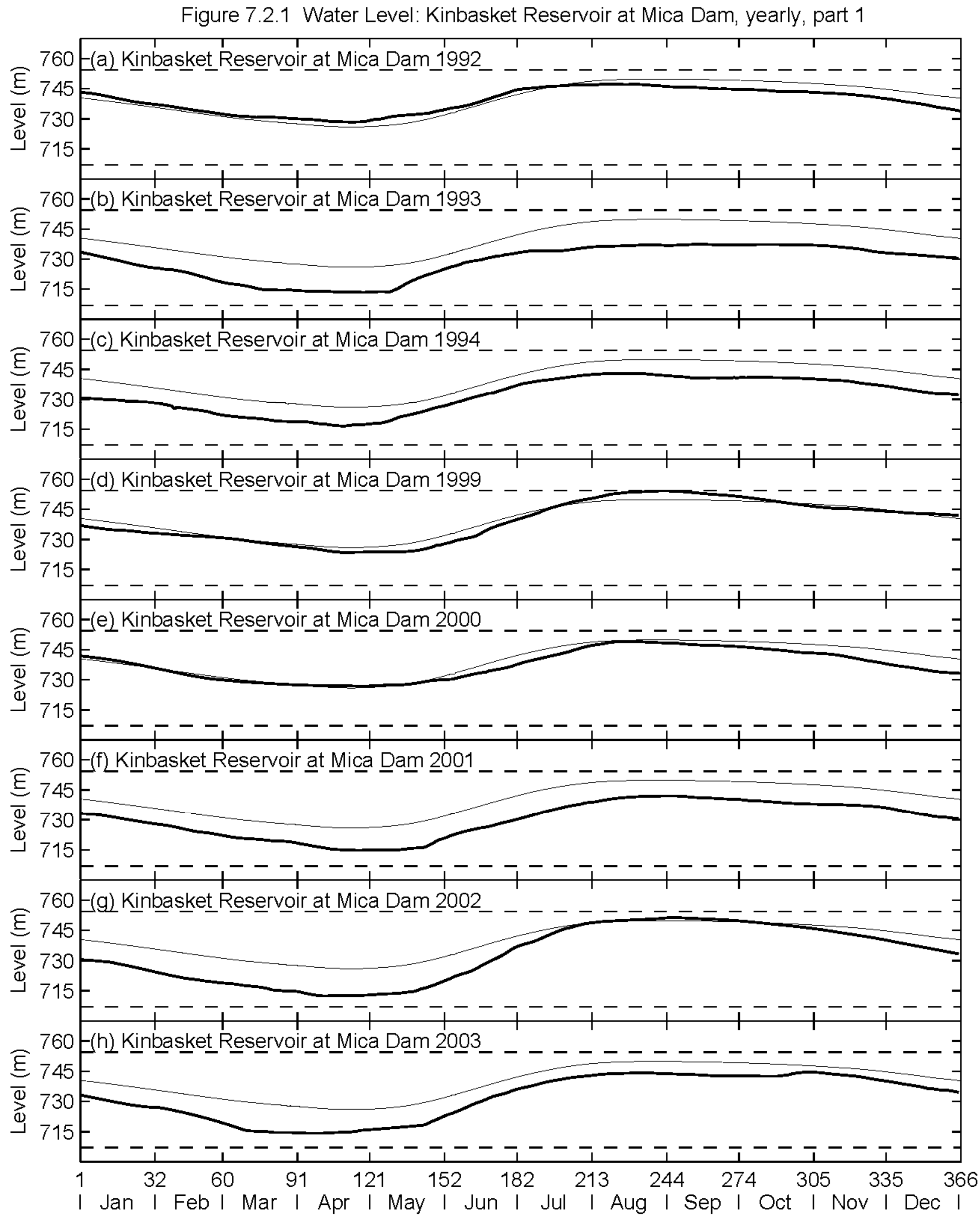


Figure 7.2.1. Water levels for WSC station 08ND017 "Kinbasket Lake at Mica Dam", selected years (heavy line). Mean daily water level for 1977-2011 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

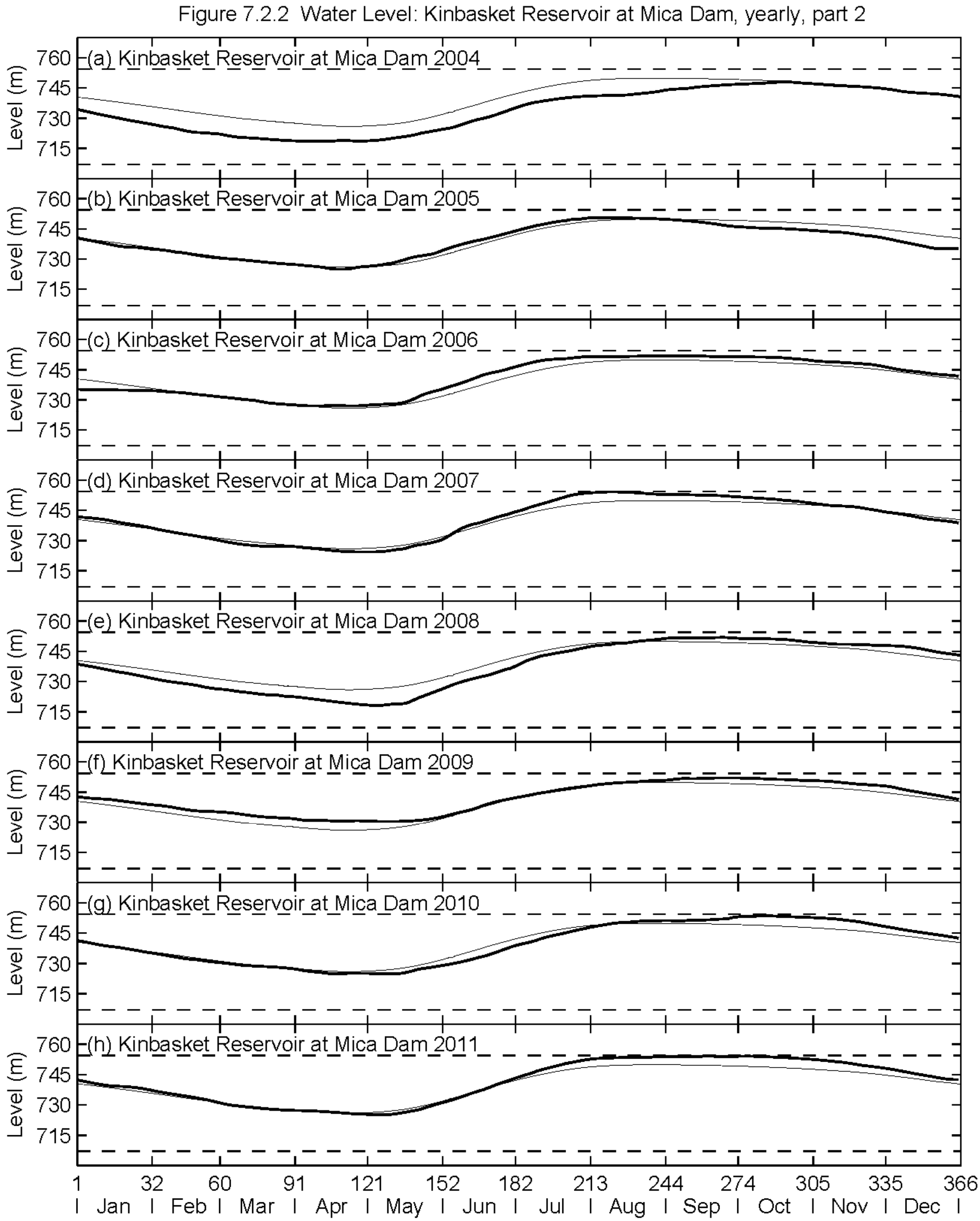


Figure 7.2.2. Water levels for WSC station 08ND017 "Kinbasket Lake at Mica Dam", selected years (heavy line). Mean daily water level for 1977-2011 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

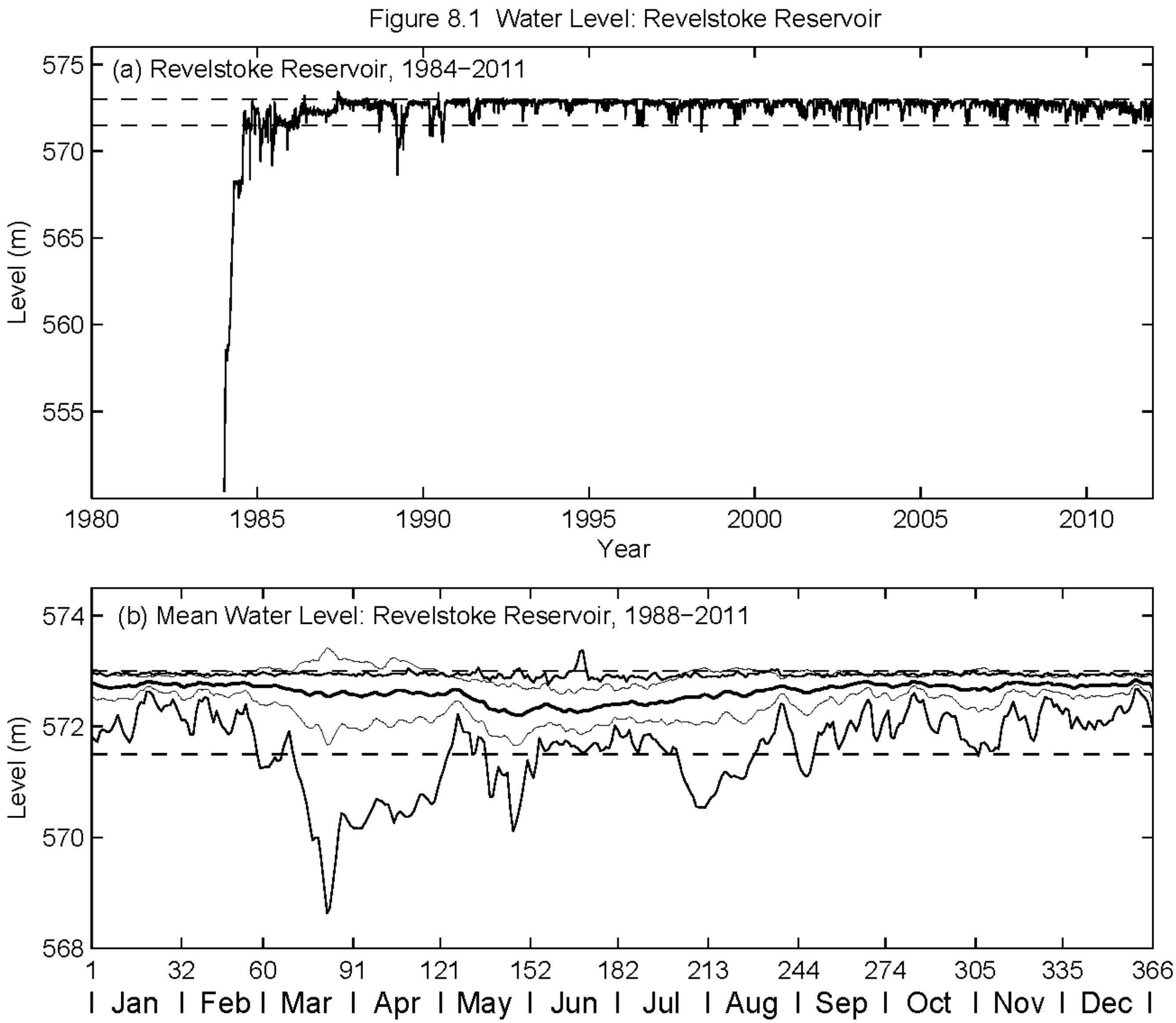


Figure 8.1. (a) BC Hydro station "Revelstoke Lake Forebay", 1984-2011. **(b)** Mean daily water level for 1988-2011. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

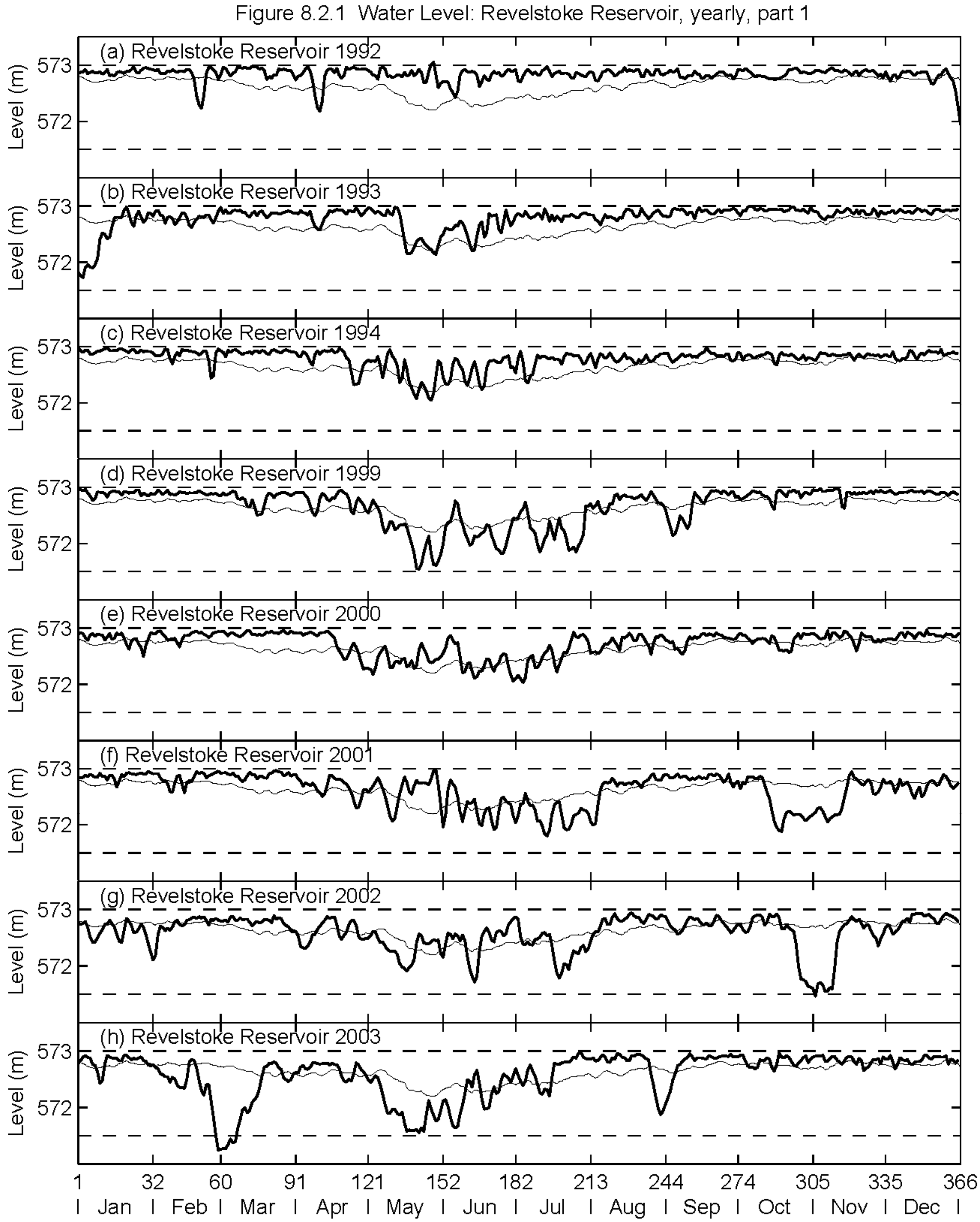


Figure 8.2.1. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2011 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

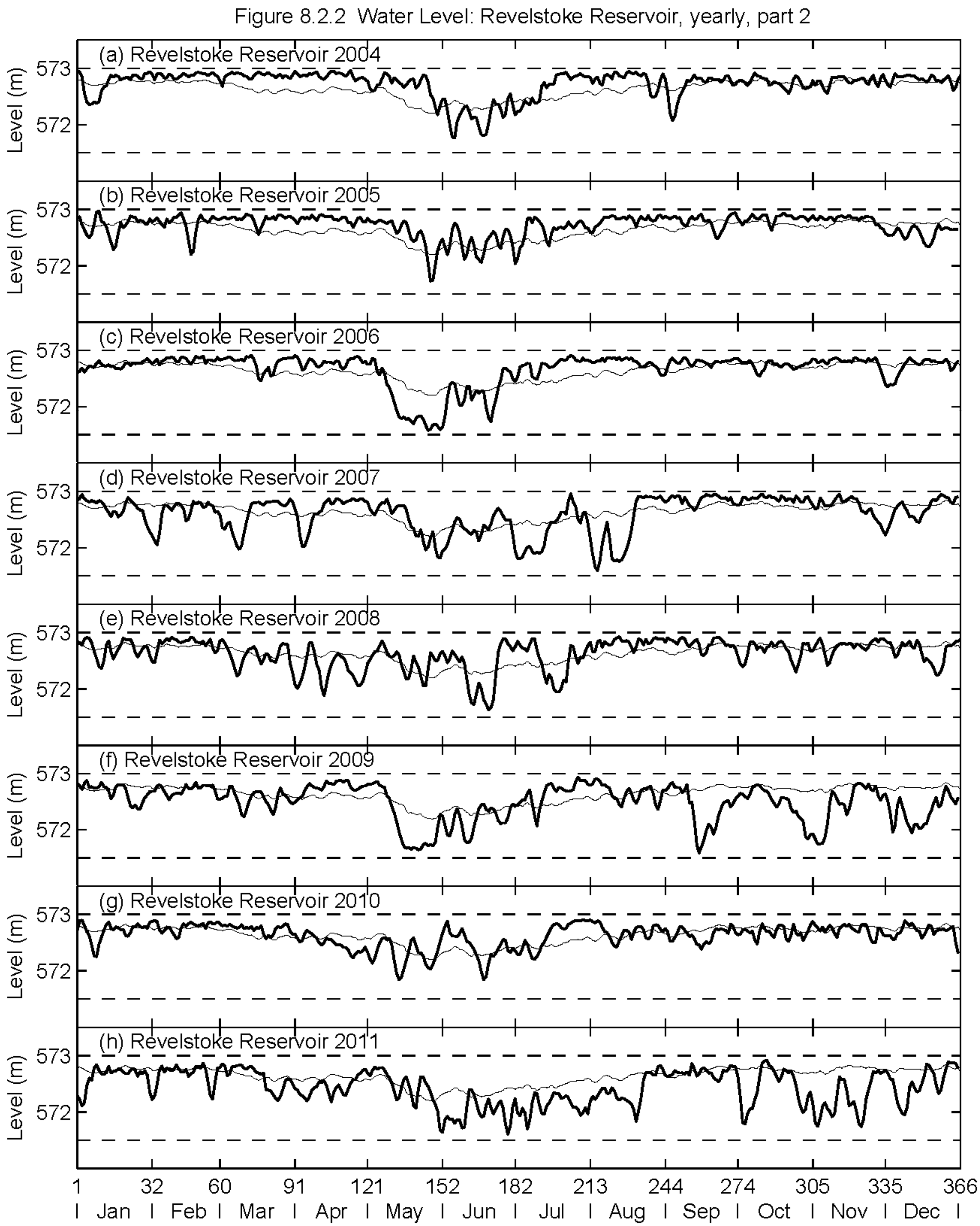


Figure 8.2.2. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2011 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

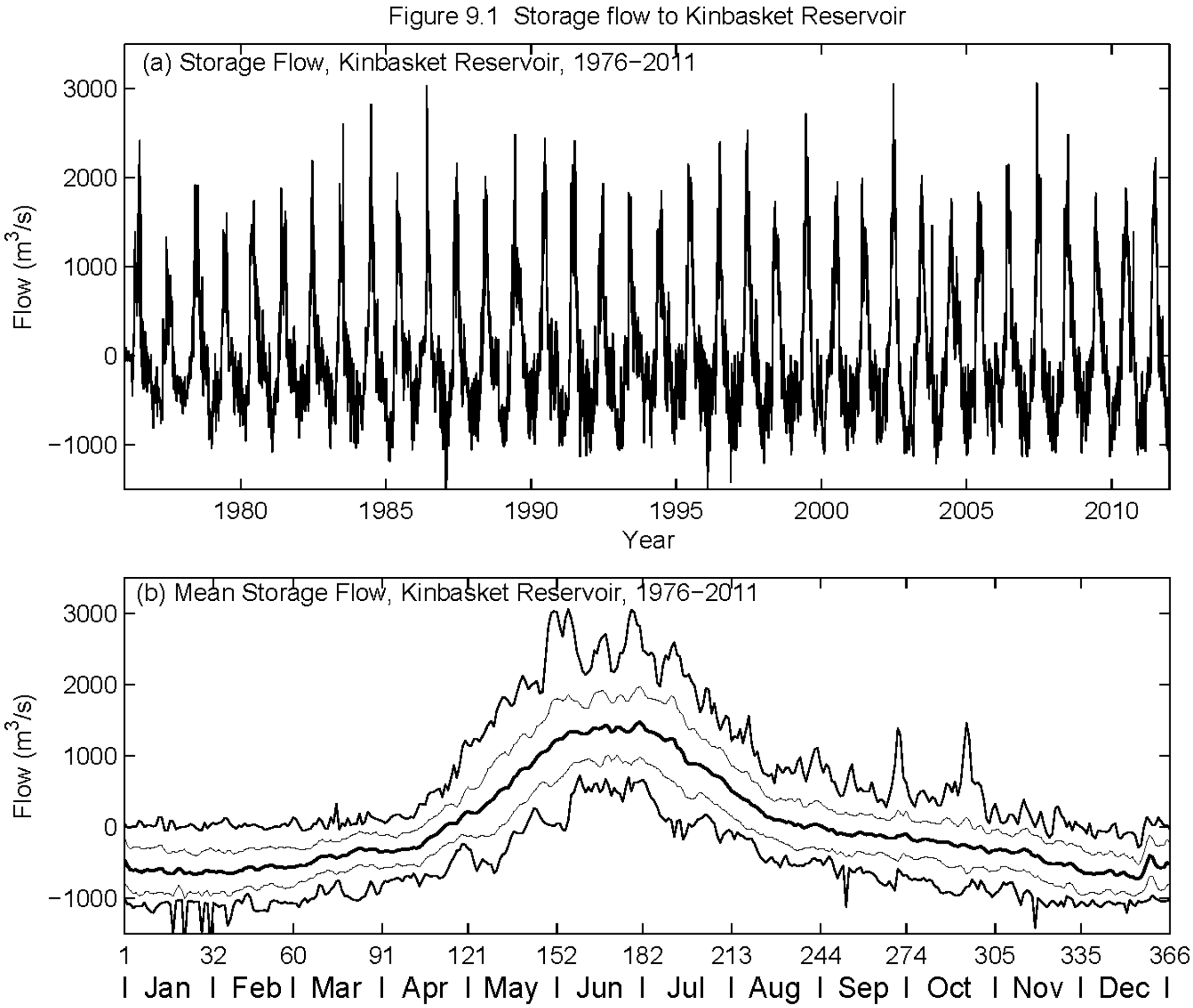


Figure 9.1. **(a)** Storage flow to Kinbasket Reservoir, 1976-2011. **(b)** Mean daily storage flow for 1976-2011. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

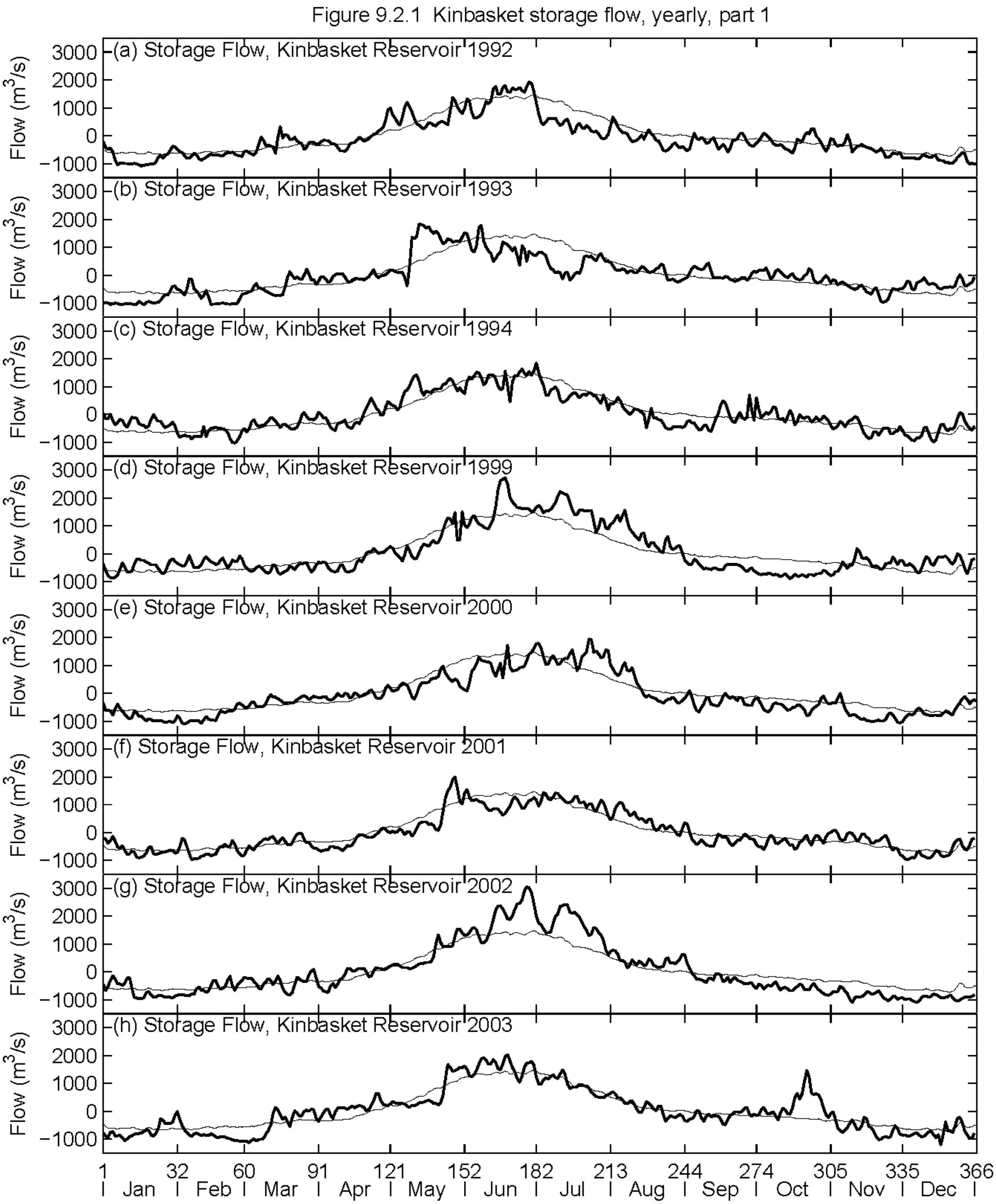


Figure 9.2.1. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2011 (light line) is shown for comparison.

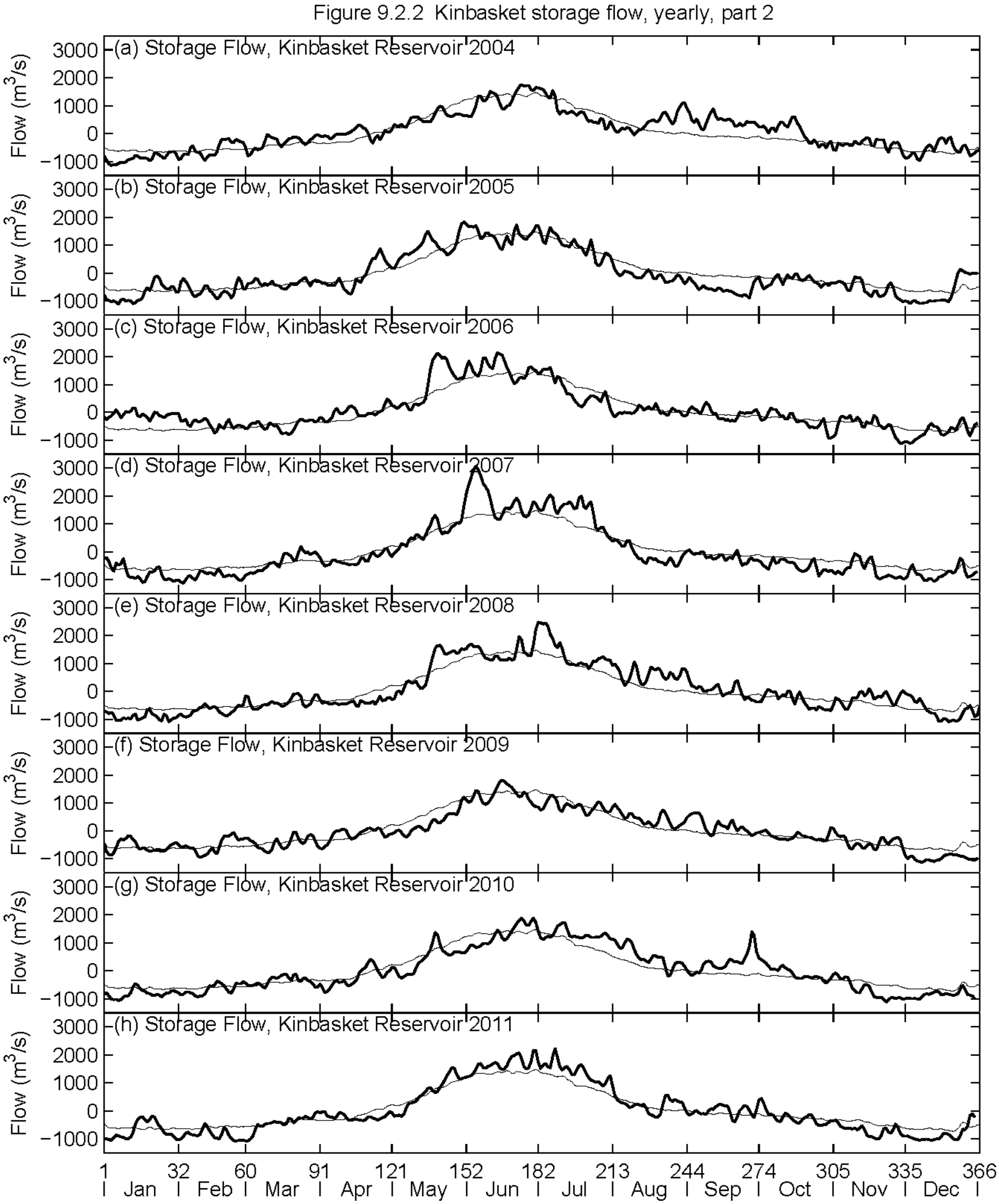


Figure 9.2.2. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2011 (light line) is shown for comparison.

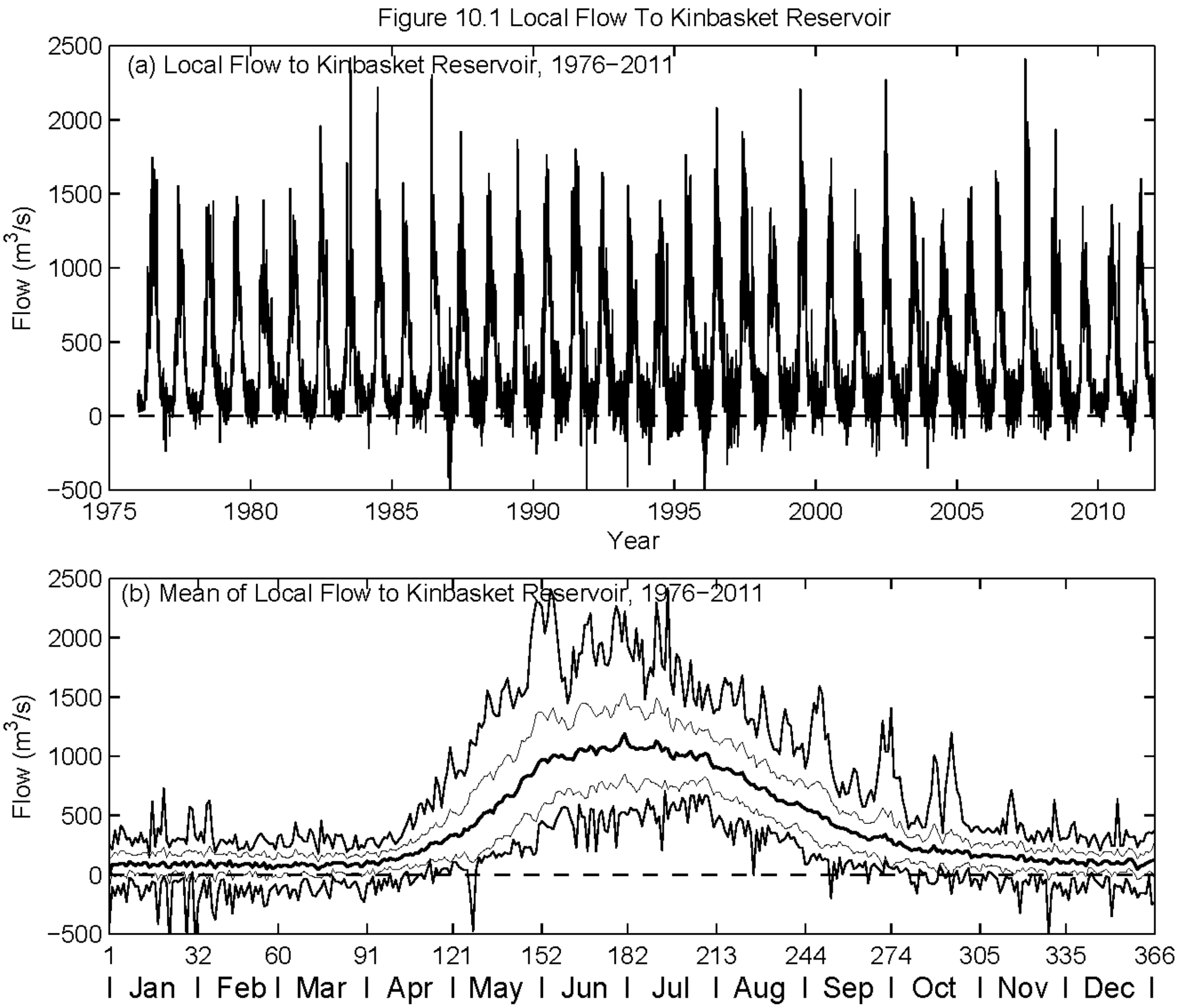


Figure 10.1. (a) Local flow to Kinbasket Reservoir, 1976-2011. **(b)** Mean daily local flow for 1976-2011. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

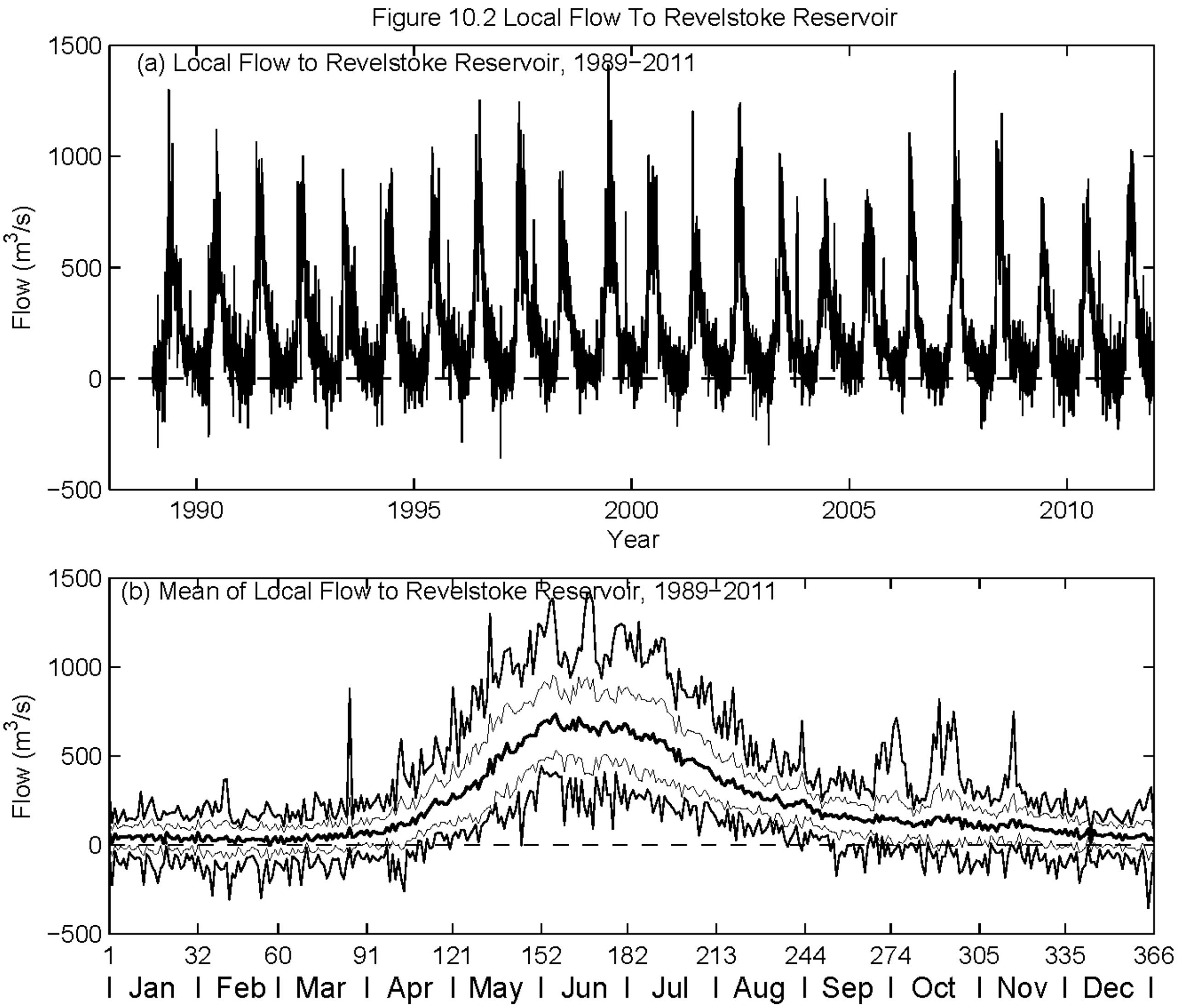


Figure 10.2. **(a)** Local flow to Revelstoke Reservoir, 1976-2011. **(b)** Mean daily local flow for 1976-2011. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

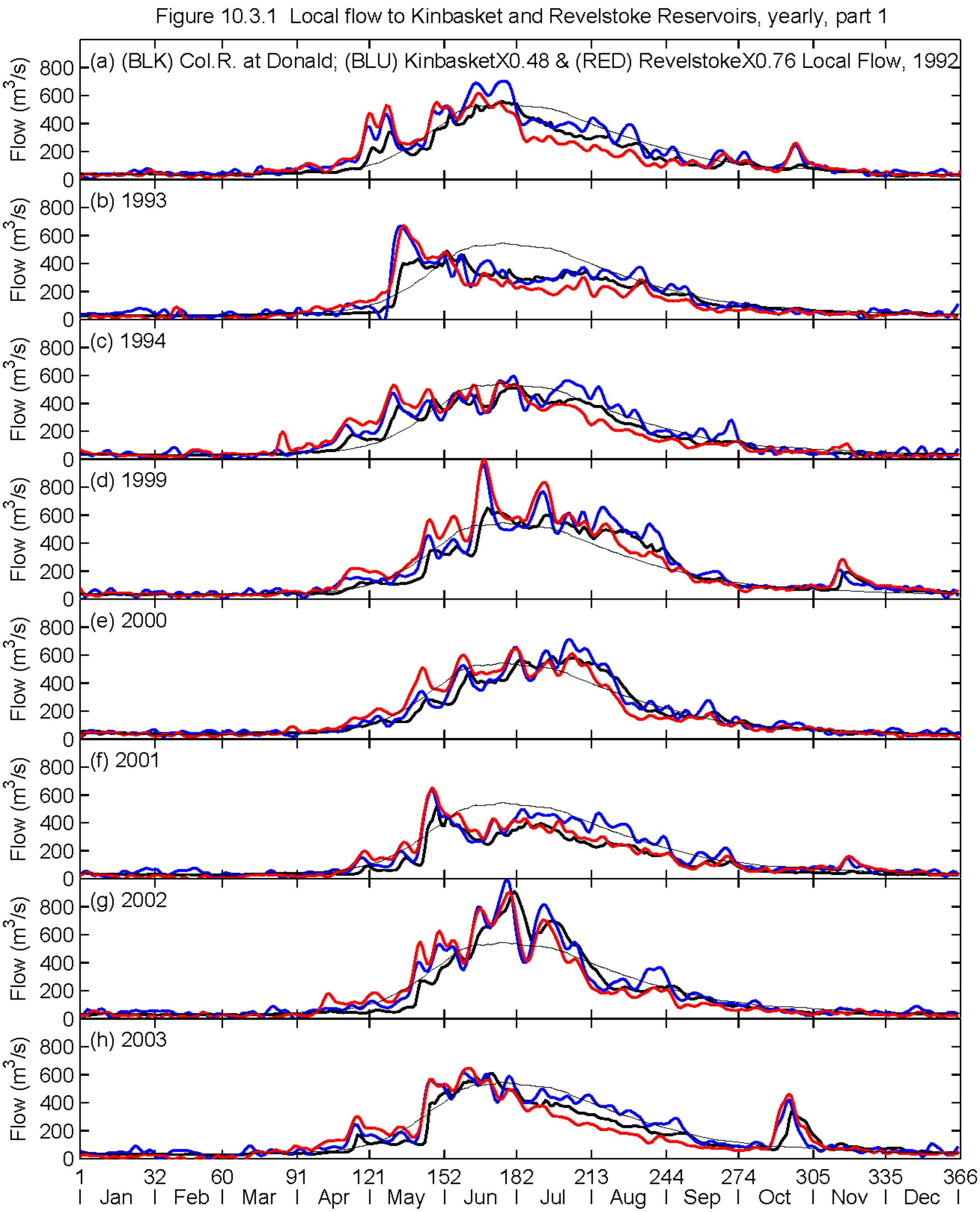


Figure 10.3.1. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2011 (light line) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

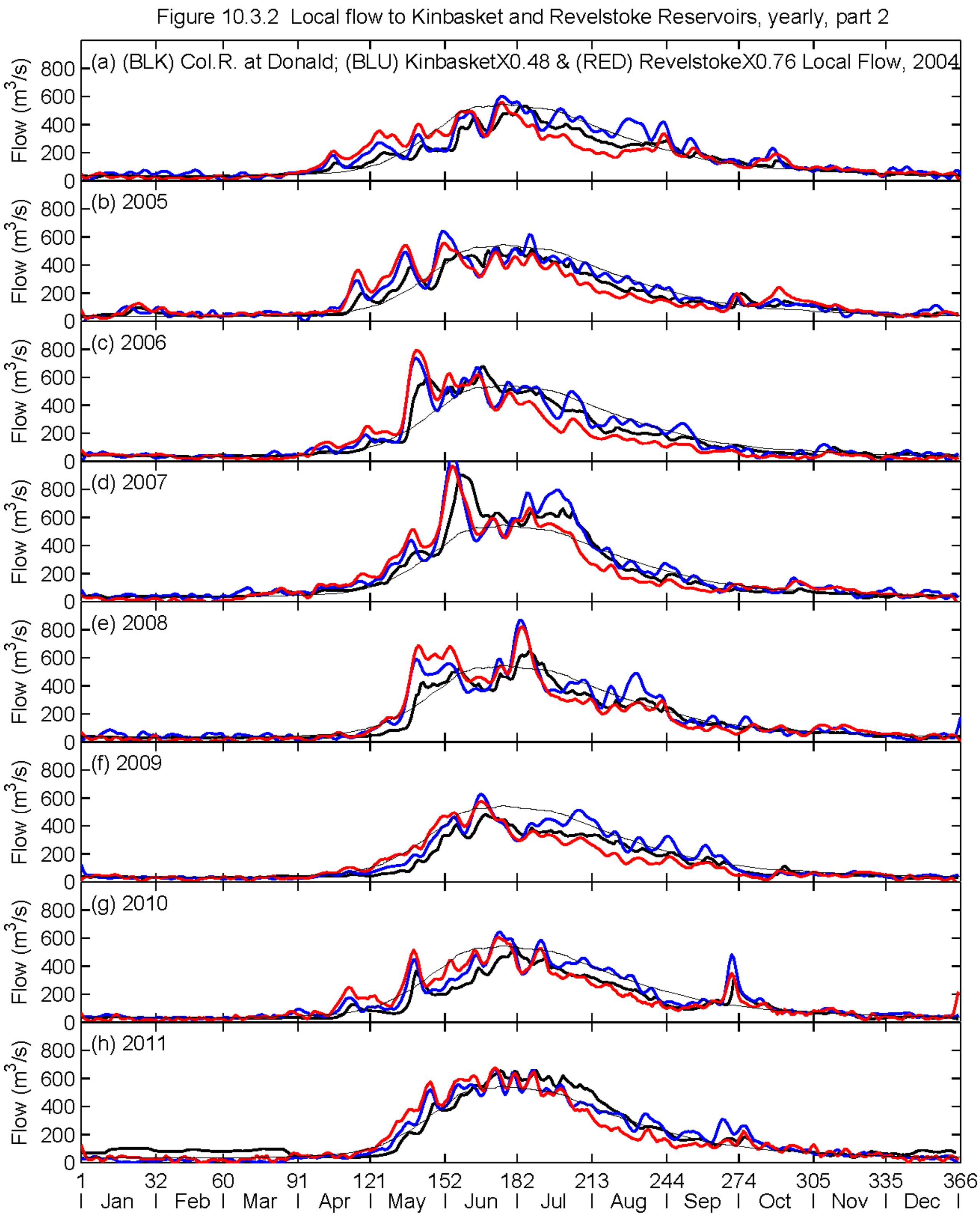


Figure 10.3.2. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2011 (light line) are shown for comparison.

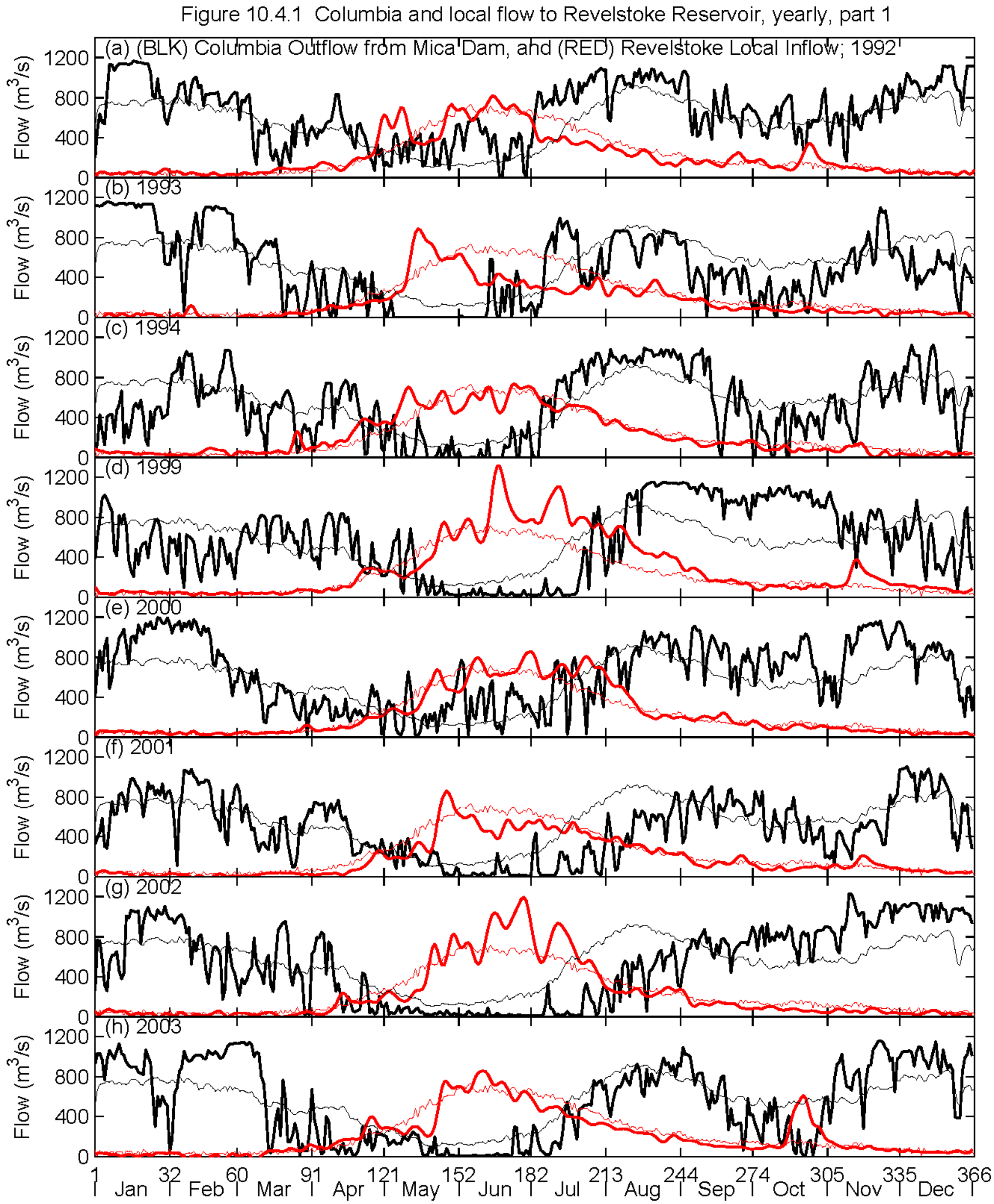


Figure 10.4.1. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison.

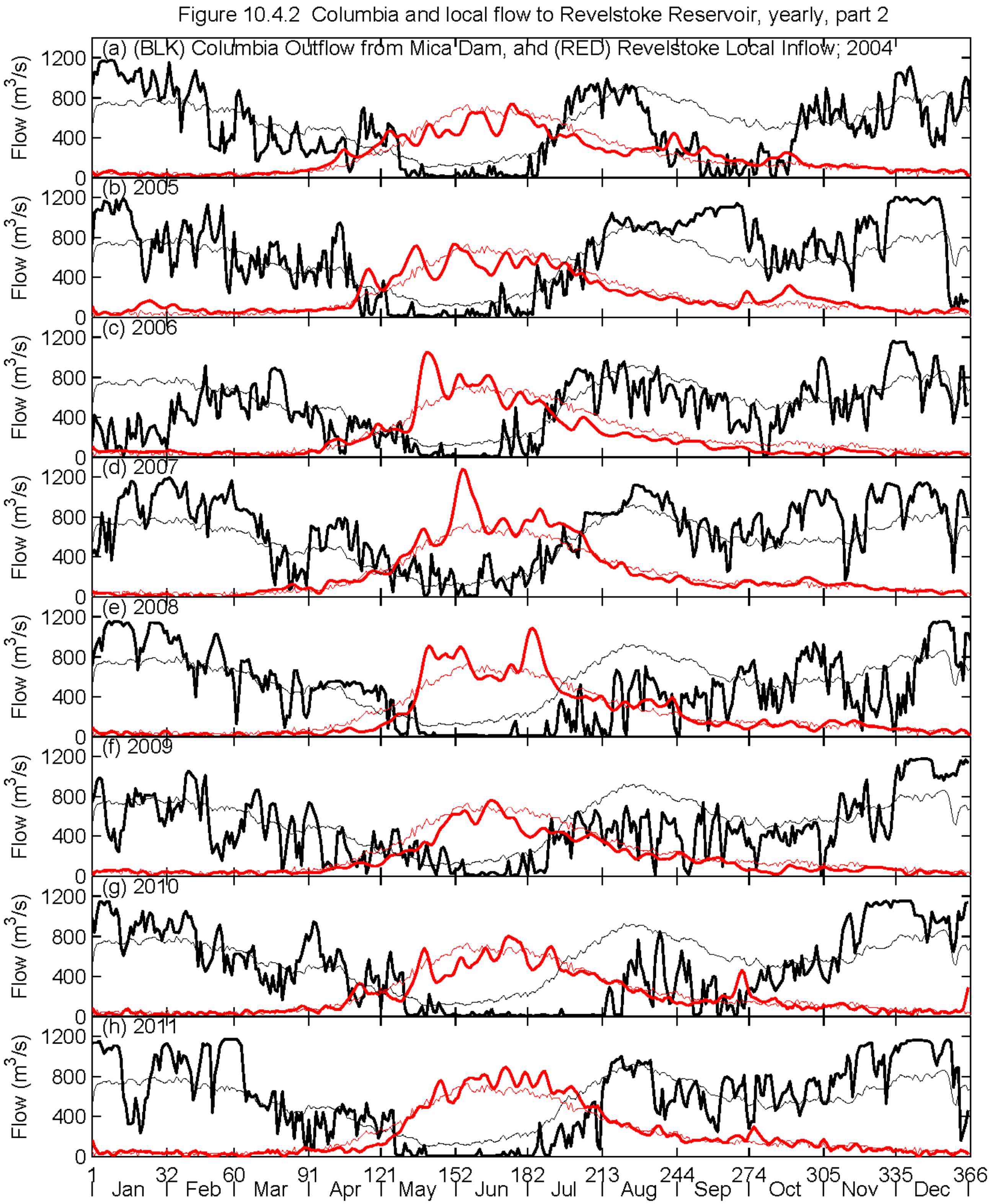


Figure 10.4.2. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

Appendix 1 Gauging Stations in the Kinbasket/ Revelstoke Drainage

Type*	**Station #**	**Abbr**	**Station Name**	**Year**	**Drainage Area[1] (km^2)**	**Mean Flow[1] (m^3/s)**	**Yield (m/yr)**
Columbia River							
Q	08NA045		Columbia River near Fairmont Hot Springs	1944-1996	891	10.4	0.37
WL	08NA004		Columbia River at Athalmer	1944-1984	1340	-	-
ND	08NA027		Columbia River near Athalmer	-	-	-	-
Q	08NA052		Columbia River near Edgwater	1950-1956	3550	58.7	0.52
Q	08NA002		Columbia River at Nicholson	1903-**2008**	6660	107	0.51
Q	08NB005	coldo	Columbia River at Donald	1944-**2008**	9710	172	0.56
ND	08NB008		Columbia River at Calamity Curve near Beavermouth	-	-	-	-
Q	08NB006	colsu	Columbia River at Surprise Rapids	1948-1966	14000	337	0.76
WL	08NB017	lking	Kinbasket Lake below Garrett Creek	1980-**2008**	-	-	-
Q	08NB011	colbb	Columbia River at Big Bend Highway Crossing	1944-1949	16800	472	0.89
WL	08ND017	lkinm	Kinbasket Lake at Mica Dam	1974-**2008**	-	-	-
Q	08ND007	colna	Columbia River above Nagle Creek	1947-1983	21500	567	0.83
ND	08ND010		Columbia River above Downie Creek	-	-	-	-
Q	08ND025	revpo	Revelstoke Project Outflow	1986-**2008**	-	773	-
Q	08ND011	colsr	Columbia River above Steamboat Rapids	1955-1986	26400	796	0.95
Q	08ND002		Columbia River at Revelstoke	1912-1989	26700	854	1.01
WL	-	lreff	Revelstoke Reservoir	1984-**2008**	-	-	-
Local Flow in Kinbasket Lake							
Q	08NB019	beavr	Beaver River near the Mouth	1985-**2008**	1150	41.9	1.15
Q	08NB014	goldr	Gold River above Palmer Creek	1973-**2008**	427	18.3	1.35
Q	08NC001	woodd	Wood River near Donald	1948-1972	956	40.1	1.32
Q	08NC003	canva	Canoe River at Valemont	1966-1967	368	*18.7*	1.60
Q	08NC002	cando	Canoe River near Donald	1947-1967	3290	105	1.01
Local Flow in Revelstoke Lake							
Q	08ND015	micac	Mica Creek near Revelstoke	1964-1965	82.4	*4.0*	1.53
Q	08ND012	golds	Goldstream River below Old Camp Creek	1954-**2008**	938	39.0	1.31
Q	08ND019	kirby	Kirbyville Creek near the Mouth	1973-2005	112	6.14	1.73
Q	08ND009	downi	Downie Creek near Revelstoke	1953-1983	655	30.2	1.45
Other							
Q	08ND013	illgr	Illecillewaet River at Greeley	1963-2008	1170	53.5	1.44

* Q - Flow, WL - Water Level, ND - No Data

[1] From Water Survey of Canada, values in italics were estimated

Appendix 2 Reference Elevations for the Mica and Revelstoke Projects

Kinbasket Reservoir Elevations

Elevation (ft)	**Elevation (m)**	**Storage (Mm^3)**	**Area (km^2)**	**Comments**
2500.0	762.0			Crest of dam
2486.5	757.9	26306.1	446.4	DSI, Dam Safety Incident level when spill gates are open
2484.9	757.4	26083.5	444.2	Expected maximum reservoir level during the PMF inflow event (11,780 m^3/s, 246,000 cfs)
2475.0	754.4	24770.7	431.0	Nmax, Normal maximum operating elevation. WLU, Water License Upper Limit
2319.4	707.0	9875.8	206.9	Nmin, Normal minimum pool level WLL, Calculated water license limit
2275.0	693.4			Sill elevation of 3.0 m W x 5.49 m H (10' W x 18' H) outlet gates (2)
2274.0	693.1			Top of intake conduit
2252.0	686.4			Sill elevation of power intakes (6) (Bottom of intake conduit)

Revelstoke Reservoir Elevations

Elevation (ft)	**Elevation (m)**	**Storage (Mm^3)**	**Area (km^2)**	**Comments**
1894.0	577.6			Crest of dam
1885.0	574.6	5449.4	118.2	DSI, Dam Safety Incident level when spill gates are open. Expected maximum reservoir level during the PMF inflow event (7100 m3/s, 250,000 cfs)
1880.0	573.0	5264.8	116.0	Nmax, Normal maximum operating elevation. WLU, Water License Upper Limit
1875.0	571.5	5089.9	113.6	Nmin, Normal minimum pool level
1830.0	557.8	3692.7	88.7	Minimum pool level (power intake limit)
1820.0	554.7			Minimum pool level (water license storage limit)
1772.6	540.3			Sill elevation of power intakes (6)

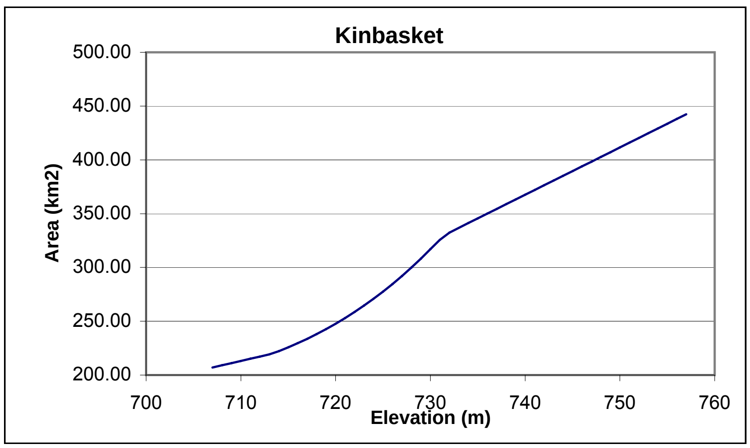
Appendix 3 Storage Elevation Curves

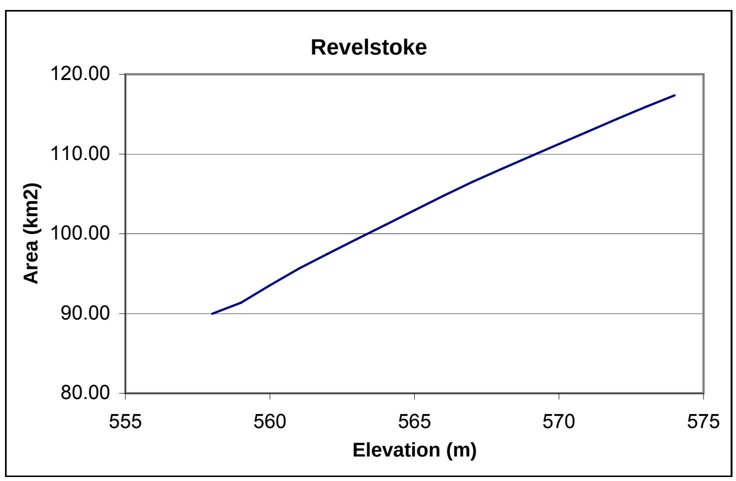
Kinbasket

Elevation (m)	Storage (Mm3)	Area (km2)
706	9.66997E+03	
707	9.87585E+03	206.94
708	1.00838E+04	209.03
709	1.02939E+04	211.09
710	1.05060E+04	213.12
711	1.07201E+04	215.13
712	1.09363E+04	217.11
713	1.11544E+04	219.27
714	1.13748E+04	222.16
715	1.15987E+04	225.73
716	1.18263E+04	229.56
717	1.20578E+04	233.67
718	1.22936E+04	238.05
719	1.25339E+04	242.71
720	1.27790E+04	247.69
721	1.30293E+04	252.97
722	1.32850E+04	258.59
723	1.35464E+04	264.54
724	1.38140E+04	270.85
725	1.40882E+04	277.54
726	1.43691E+04	284.60
727	1.46574E+04	292.06
728	1.49532E+04	299.94
729	1.52572E+04	308.24
730	1.55697E+04	316.98
731	1.58912E+04	325.72
732	1.62212E+04	332.33
733	1.65558E+04	336.89
734	1.68949E+04	341.27
735	1.72384E+04	345.65
736	1.75862E+04	350.04
737	1.79385E+04	354.42
738	1.82951E+04	358.81
739	1.86561E+04	363.20
740	1.90215E+04	367.59
741	1.93913E+04	371.98
742	1.97654E+04	376.38
743	2.01440E+04	380.77
744	2.05270E+04	385.17
745	2.09143E+04	389.57
746	2.13061E+04	393.96
747	2.17023E+04	398.36
748	2.21028E+04	402.77
749	2.25078E+04	407.17
750	2.29172E+04	411.57
751	2.33309E+04	415.98
752	2.37491E+04	420.38
753	2.41717E+04	424.79
754	2.45987E+04	429.20
755	2.50301E+04	433.61
756	2.54659E+04	438.02
757	2.59062E+04	442.43
758	2.63508E+04	

Revelstoke

Elevation (m)	Storage (Mm3)	Area (km2)
557.75	3.68827E+03	
558	3.71048E+03	89.97
559	3.80073E+03	91.35
560	3.89318E+03	93.55
561	3.98783E+03	95.62
562	4.08442E+03	97.50
563	4.18283E+03	99.31
564	4.28305E+03	101.13
565	4.38508E+03	102.94
566	4.48893E+03	104.75
567	4.59458E+03	106.49
568	4.70191E+03	108.11
569	4.81081E+03	109.68
570	4.92127E+03	111.25
571	5.03330E+03	112.81
572	5.14690E+03	114.38
573	5.26206E+03	115.91
574	5.37871E+03	117.36
575	5.49678E+03	





Appendix 2

Tributary Water Quality
Kinbasket and Revelstoke Reservoirs, 2011

Roger Pieters and Greg Lawrence
University of British Columbia

Tributary Water Quality
Kinbasket and Revelstoke Reservoirs, 2011

Roger Pieters[1,2], and Greg Lawrence[2]

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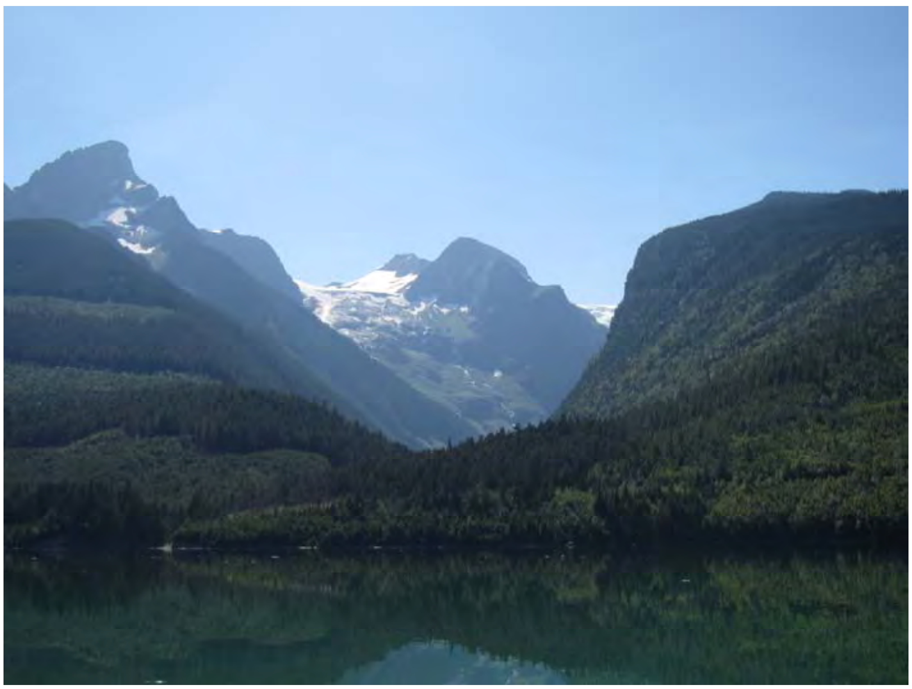

Revelstoke Reservoir, 15 Aug 2012

Prepared for

Karen Bray
Biritsh Columbia Hydro and Power Authority
1200 Powerhouse Road
Revelstoke B.C. V0E 2S0

January 10, 2013

Contents

List of Figures

1. Introduction

We report on water quality data collected from reference tributaries to Kinbasket and Revelstoke Reservoirs in 2011. This is the fourth year of tributary sampling as part of the ongoing B.C. Hydro project entitled "CLBMON-3 Kinbasket and Revelstoke Ecological Productivity Monitoring".*

Two types of tributary samples have been collected in past years: (1) surveys of many streams at the same time, and (2) sampling of reference tributaries from May to November. Surveys were undertaken across both reservoirs in 2008 (Pieters et al, 2010), and 2009 (Pieters et al, 2011), but a survey was not conducted in 2010 (Pieters et al, 2012) or 2011 due to lack of helicopter availability. Here we report on the data from the reference tributaries in 2011.

2. Methods

Four reference tributaries – Columbia River at Donald, Beaver River, Goldstream River, Kinbasket outflow and Revelstoke outflow – were sampled twice monthly in May and June, and once a month from July to October in 2011. Water samples were collected in a bucket and then transferred into sample bottles. Temperature was measured with a handheld thermometer. Filtration was done later the same day. Water samples were either frozen or kept on ice and shipped within 48 hours to the Department of Fisheries and Oceans, Cultus Lake Salmon Research Laboratory, 4222 Columbia Valley Highway Cultus Lake, British Columbia. The samples were analyzed for the water quality parameters listed in Table 1. Laboratory methods are summarized in Appendix 1.

Samples were collected from the point at which the tributary crossed a road. Tributaries entering the east side of Revelstoke Reservoir were sampled at Highway 23. The Columbia River at Donald was sampled near the Highway 1 bridge. Sample locations are given in Appendix 2.

Samples from Beaver River were collected and analyzed by Environment Canada. The Beaver River was sampled at the east gate of Glacier National Park, representing about half of the total drainage of the Beaver River. Note the flow for Beaver River is gauged near the mouth, gauging the entire drainage. Data for all tributaries in 2011 are given in Appendix 3.

* In 2003, eight tributaries to Revelstoke Reservoir were sampled as part of an embayment study (K. Bray, personal communication).

Table 1 Parameters measured

Parameter	Units	Symbol	Detection Limit
pH		pH	
Conductivity, C25	µS/cm	Cond	
Nitrate and Nitrite	µg/L N	NN	1 µg/L
Soluble Reactive Phosphorus	µg/L P	SRP	0.5 µg/L
Total Dissolved Phosphorus	µg/L P	TDP	
Total Phosphorus	µg/L P	TP	0.5 µg/L
Total Phosphorus with color/turbidity correction	µg/L P	TP Turb	
Turbidity	NTU	Turb	
Alkalinity	$mgCaCO_3/L$	Alk	
Water Temperature	^oC	T	

3. Results

Consider first the natural flows: the Columbia River at Donald and the Beaver River which enter Kinbasket Reservoir, and the Goldstream River which enters Revelstoke Reservoir. Data for 2009, 2010 and 2011 are shown in Figures 1 through 3, respectively. River flow is shown in Figures 1-3a, which peaks in mid June (2009) to early July (2010 and 2011). The flow at all three locations is highly correlated in each year.

River temperature is shown in Figures 1-3b. The Columbia at Donald, having wound its way through the Rocky Mountain Trench, was relatively warm, peaking at 15-18 ºC in July each year. In contrast, the Beaver and Goldstream Rivers were cooler, with July temperatures of only 7-12 ºC with the exception of 14 °C in Goldstream on 28 Jul 2009. The conductivity, shown in Figures 1-3c, declined through the freshet to about half by mid-summer. Turbidity (Figures 1-3d) was highly variable while pH remained slightly alkaline (Figures 1-3e).

Even more than conductivity, nitrate and nitrite (NN) concentrations declined by 7 to 10 times from May to mid-summer in 2011 (Figures 3f). For example, on 30 May 2011, the Goldstream River had 390 µg/L NN which declined to 37 µg/L on 26 Jul 2011 (Figure 3f); there were similar declines in previous years (Figure 1f and 2f). Nitrate in the Columbia River at Donald during summer 2011 was particularly low, with several values ranging from 25-46 mg/L (Figure 3f). As in previous years, the concentrations of SRP were low in 2011 (Figure 3g), with concentrations in the Beaver River at or below detection. While TDP was not available for Beaver River, TDP concentrations for the

Columbia at Donald and Goldstream were low (2-11 μg/L) and relatively constant (Figure 3h). TP was highly variable (Figure 3i), likely reflecting phosphorus from particulate minerals typical of glacial fed systems and of low biological availability.

The NN:TDP ratio (by weight) was > 10 through most of the year suggesting tributary nutrients are phosphorus limited. The exception is the Columbia River at Donald in summer, when the decline in tributary nitrate can reduce NN:TDP to < 10 suggesting nitrogen and phosphorus co-limitation; nitrate levels and NN:TDP were particularly low in the summer of 2011 (Figure 3j).

In Figure 4, 5 and 6, the water quality parameters for the Columbia River at Donald are shown again, but this time they are compared to the outflow from Kinbasket Reservoir (Columbia River at Mica) and the outflow from Revelstoke Reservoir (Columbia River above Jordan). As in 2009 and 2010, the outflows were variable in 2011 (Figure 6a), and the outflow temperature was cold (<10 ºC, Figure 6b) as a result of the deep intakes. An exception was the Mica outflow in July and August 2010 when temperatures were warmer; at low flow, the temperature below Mica Dam may have been influenced by Revelstoke Reservoir (Figure 5b). The conductivity below Mica Dam showed some variation, while the conductivity of the outflow from Revelstoke was relatively steady (Figure 6c). The turbidity of the outflow from both Mica and Revelstoke was very low, generally < 2 NTU, with one exception of 7.1 NTU in the Mica outflow on 6 June 2011. Neglecting this exception, the average turbidity in 2011 was 1.2 and 0.8 NTU, respectively, similar to previous years. Like the tributaries, the pH was relatively constant and slightly alkaline (Figure 6e).

While nitrate and nitrite concentrations (NN) dropped from approximately 280 to 120 μg/L in the outflow from Mica, the concentrations did not drop as low as in the reference tributaries. In the outflow from Revelstoke, NN was relatively constant, at approximately 100-165 μg/L (Figure 6f). SRP concentrations were close to the detection limit (Figure 6g) and TDP and TP were low and relatively constant (Figures 6h,i). The NN:TDP ratio for the Mica and Revelstoke outflows was far greater than 10 throughout the year, suggesting nutrients from these sources are phosphorus limited (Figure 6j).

Intensive sampling of the reference tributaries began in 2009. Comparison of the 2009, 2010 and 2011 data are shown for the natural flows in Figure 7 (Columbia River at Donald), Figure 8 (Goldstream River) and Figure 9 (Beaver River). Overall the water quality parameters show similar trends. As additional data were available for Beaver River throughout the year, the entire year is plotted (Figure 9). Of particular interest is nitrate, which first rose as freshet began, dropped dramatically as freshet peaked, and then gradually returned to winter levels by December.

4. Discussion

The reference tributaries provide an indication of seasonal variability. Seasonal variability is also seen in the long record of water quality data available for the Illecillewaet River, which is located just south of the Revelstoke Reservoir. The Illecillewaet is the largest local inflow to the Arrow Reservoir, drains 1170 km^2, and includes flow of glacial origin. Water quality data for 1997 to 2001 are shown in Figure 10. Also shown in grey is the flow from WSC Station 08ND013, Illecillewaet at Greeley. For C25 and NN there is a clear seasonal cycle, with concentrations high during the start of freshet and then decreasing rapidly to lower values during the summer. In late August the values increase again. Also shown for reference are SRP, TDP, TP, pH, NH_3 and water temperature.

Figure 11 compares the seasonal evolution of the flow, C25 and NN for five years, 1997-2001. The onset of freshet occurred between early and mid May. For example, in 1998 a large peak in freshet flow began at the start of May while freshet was delayed toward the end of May in 2001. There is a corresponding variation in the timing of the decline in C25 (Figure 11b). The decline in NN occurs more gradually through May and June to very low values in July and August (Figure 11c). Overall, NN declined from 420-480 μg/L in May to 50-100 μg/L in mid-summer. A similar decline in NN is seen in other tributaries to the Arrow Reservoir (e.g. Pieters et al. 2003).

5. Conclusions

Based on these data, and those of previous years, the tributaries to both Kinbasket and Revelstoke Reservoirs are low in nutrients. Soluble reactive phosphorus (SRP) was very low in both basins, close to the detection limit. Total dissolved phosphorus (TDP) was also low, about 5 μg/L. Total phosphorus (TP) was highly variable, reflecting the glacial origin of many of the tributaries. While correction of TP for colour and turbidity resulted in a modest reduction in TP concentrations, much of the corrected TP is likely of inorganic origin with low biological availability. With glacial inflow, TDP is preferred over TP as a measure of available phosphorus.

In the presence of oxygen, concentrations of nitrate and nitrite (NN) are typically dominated by nitrate. For an N:P ratio > 10 (by weight) phosphorus is expected to limit phytoplankton productivity (Horne and Goldman, 1994). The N:P ratio, based on NN and TDP, is greater than 10 for the reference tributaries which suggests phosphorus limitation, with the notable exception of Columbia River at Donald in summer, when the N:P ratio declined below 10, suggesting phosphorus and nitrogen co-limitation.

Acknowledgements

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References

Horne A. and C. Goldman, 1994. Limnology 2nd Edition. McGraw Hill Inc., New York.

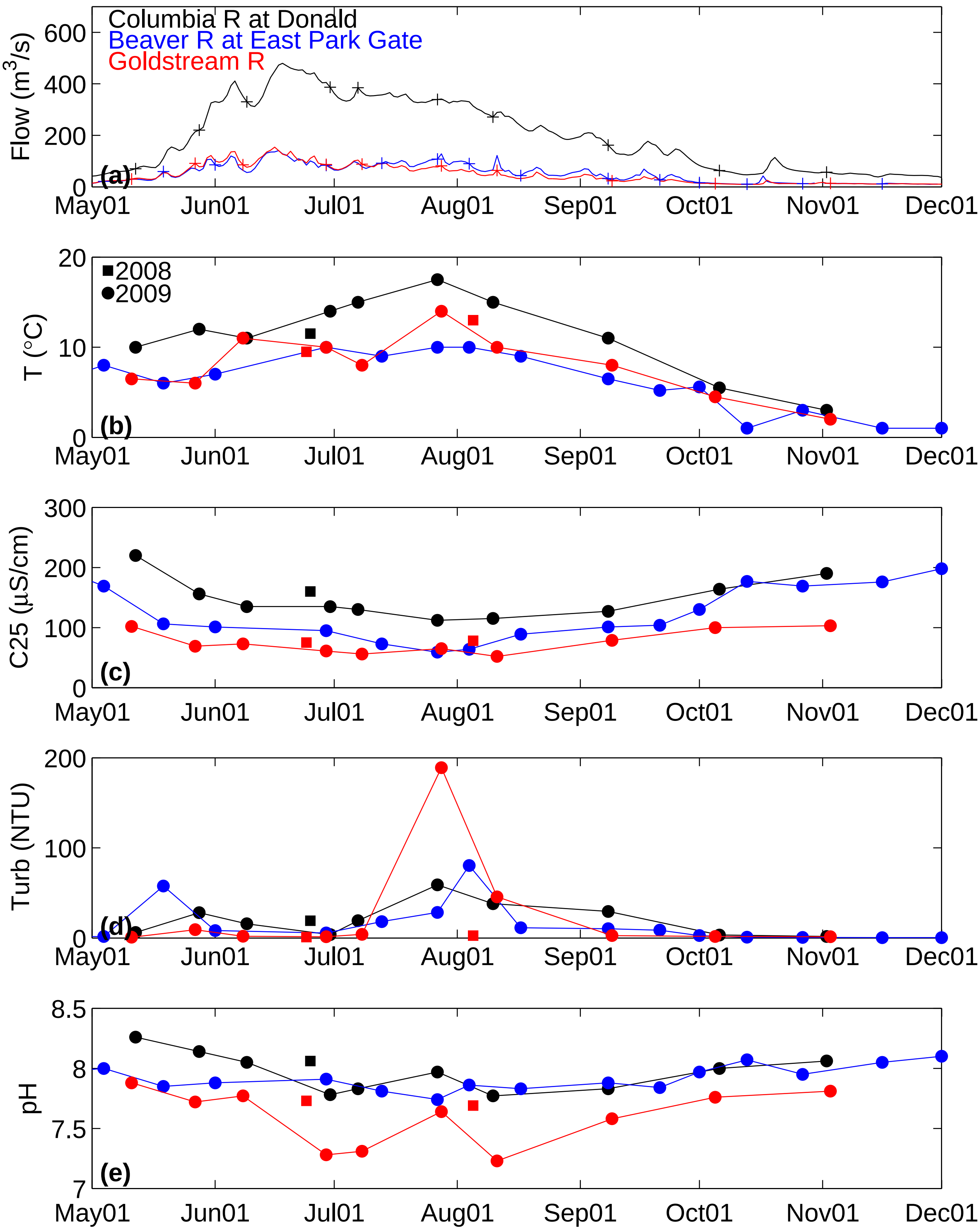
Pieters, R., L. Vidmanic, S. Harris, J. Stockner, H. Andrusak, M. Young, K. Ashley, B. Lindsay, G. Lawrence, K. Hall, A. Eskooch, D. Sebastian, G. Scholten and P.E. Woodruff. 2003. Arrow Reservoir fertilization experiment, year 3 (2001/2002) report. RD 103, Fisheries Branch, Ministry of Water, Land and Air Protection, Province of British Columbia.

Pieters, R., A. Akkerman, and G. Lawrence. 2010. Tributary Water Quality, Kinbasket and Revelstoke Reservoirs, 2008. University of British Columbia. 28 pp. Appendix 2 in BC Hydro. 2010. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 1 (2008). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

Pieters, R., H. Keller and G. Lawrence. 2011. Tributary Water Quality, Kinbasket and Revelstoke Reservoirs, 2009. 52 pp. Appendix 2 in BC Hydro 2011. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 2 (2009). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

Pieters, R. and G. Lawrence. 2012. Tributary Water Quality, Kinbasket and Revelstoke Reservoirs, 2010. 30 pp. Appendix 2 in Bray, K.E. 2012. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2010). BC Hydro, Environment. Study No. CLBMON-3. 4pp. + appendices.

Figure 1 Flow and water quality of reference tributaries, 2009



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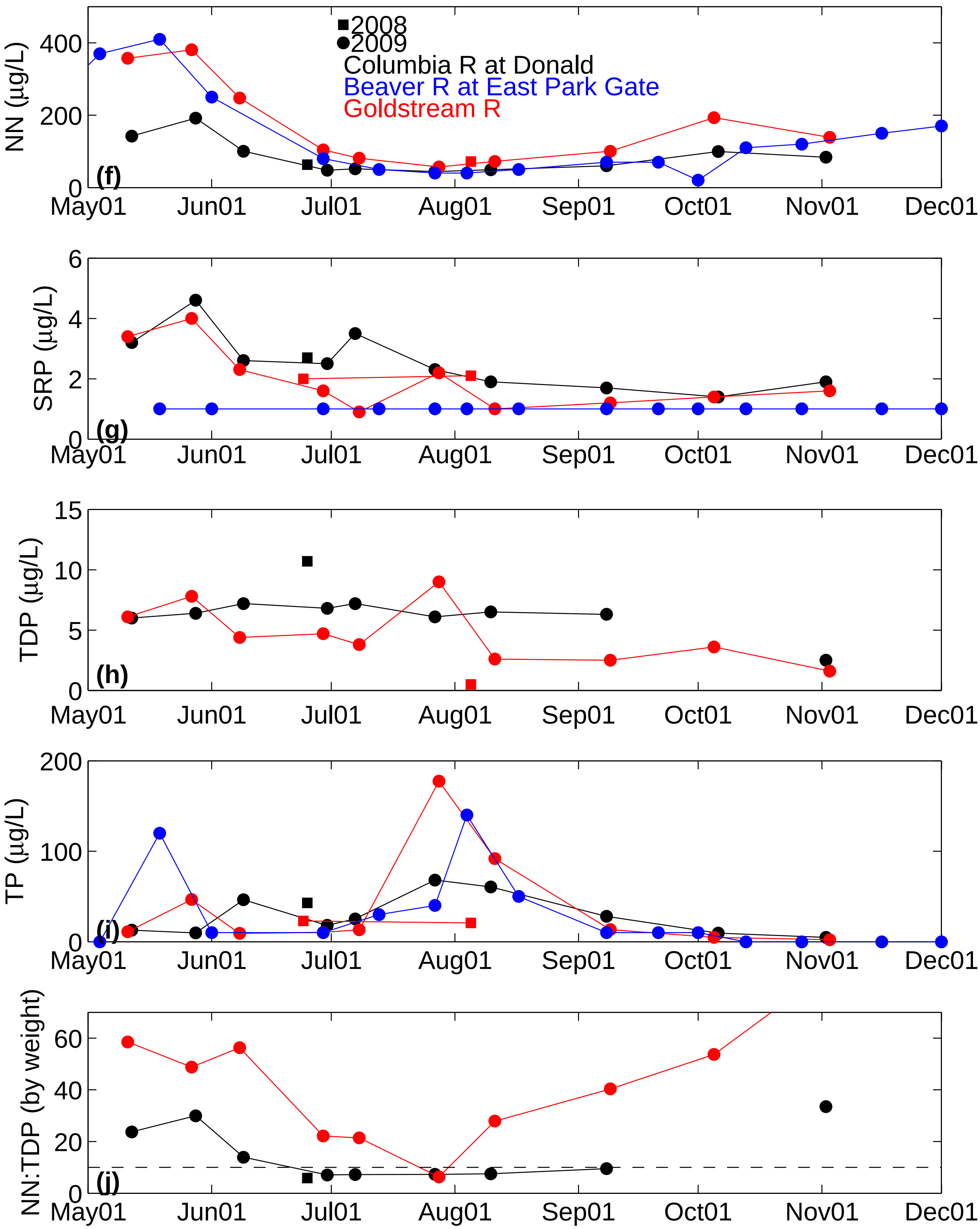

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Figure 2 Flow and water quality of reference tributaries, 2010

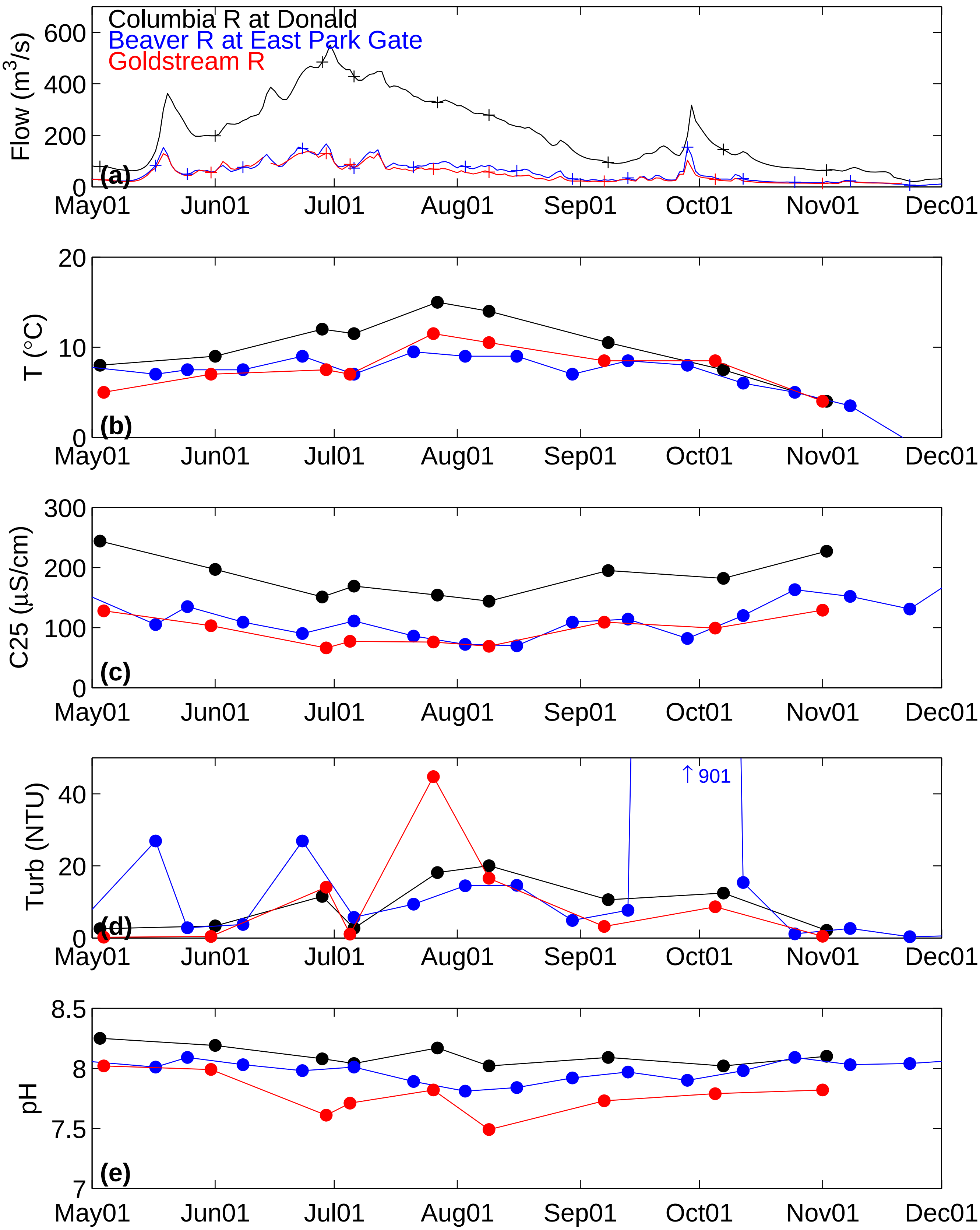

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Figure 2 con't Flow and water quality of reference tributaries, 2010

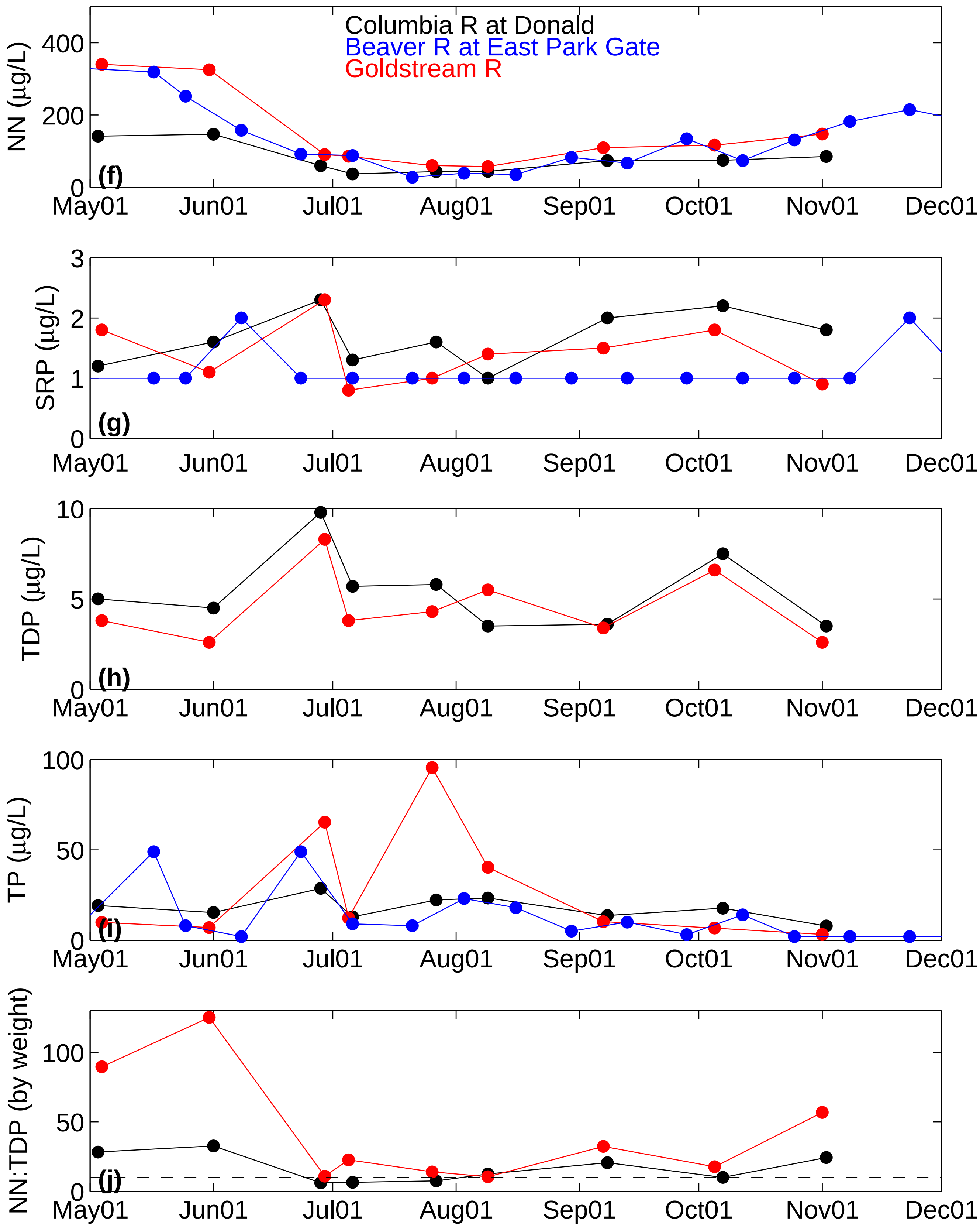

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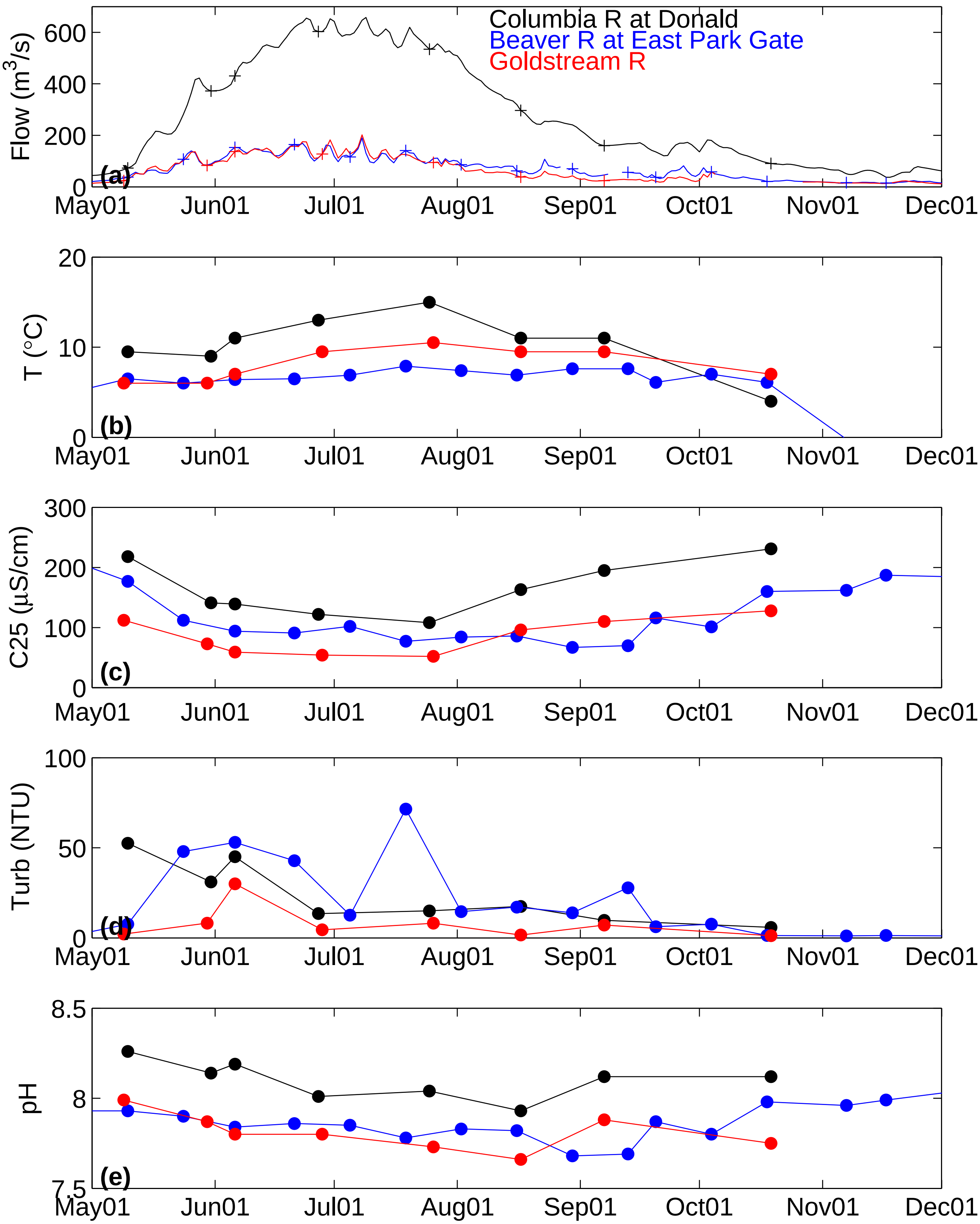
Figure 3 Flow and water quality of reference tributaries, 2011



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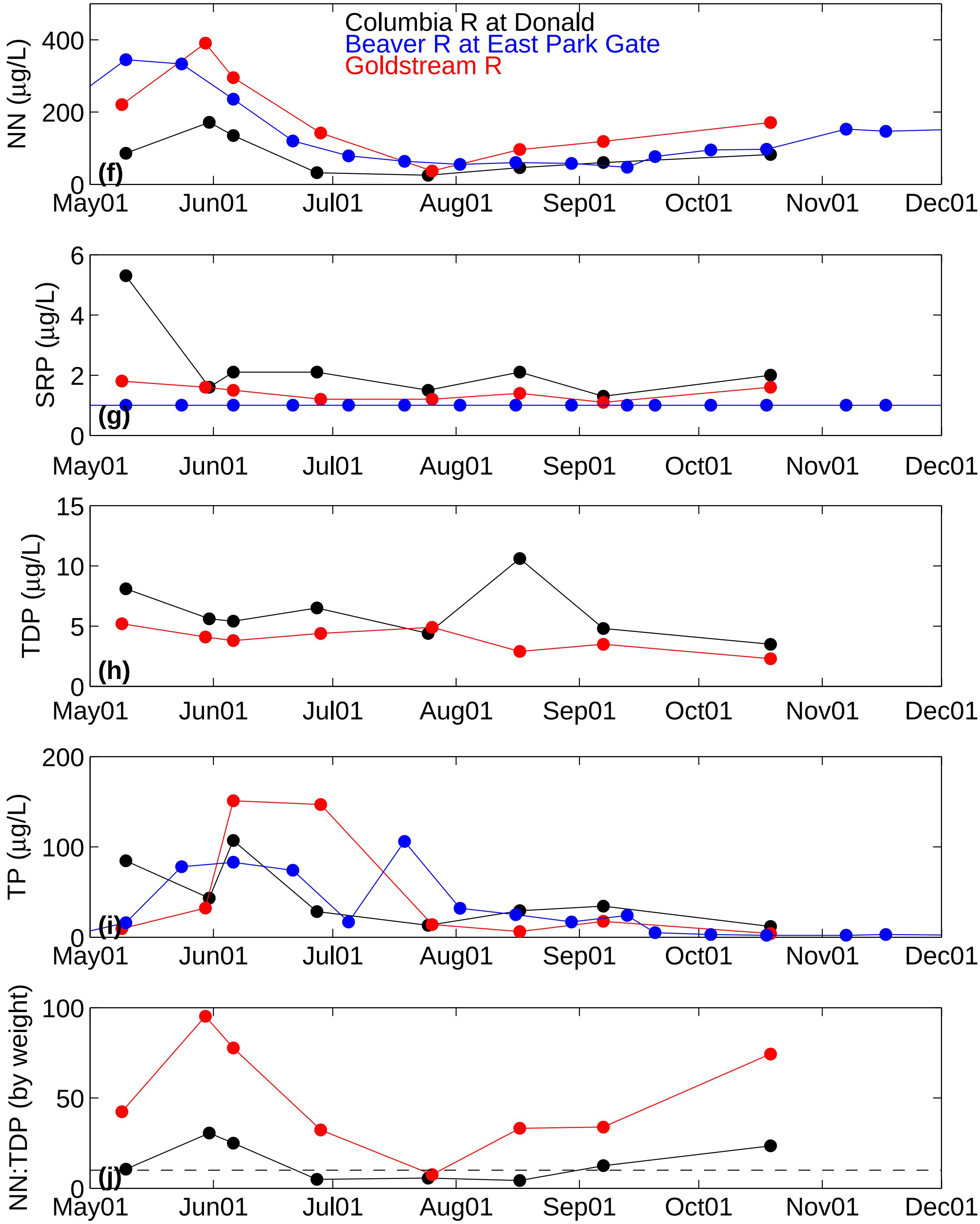

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Figure 4 Flow and water quality of Columbia River, 2009

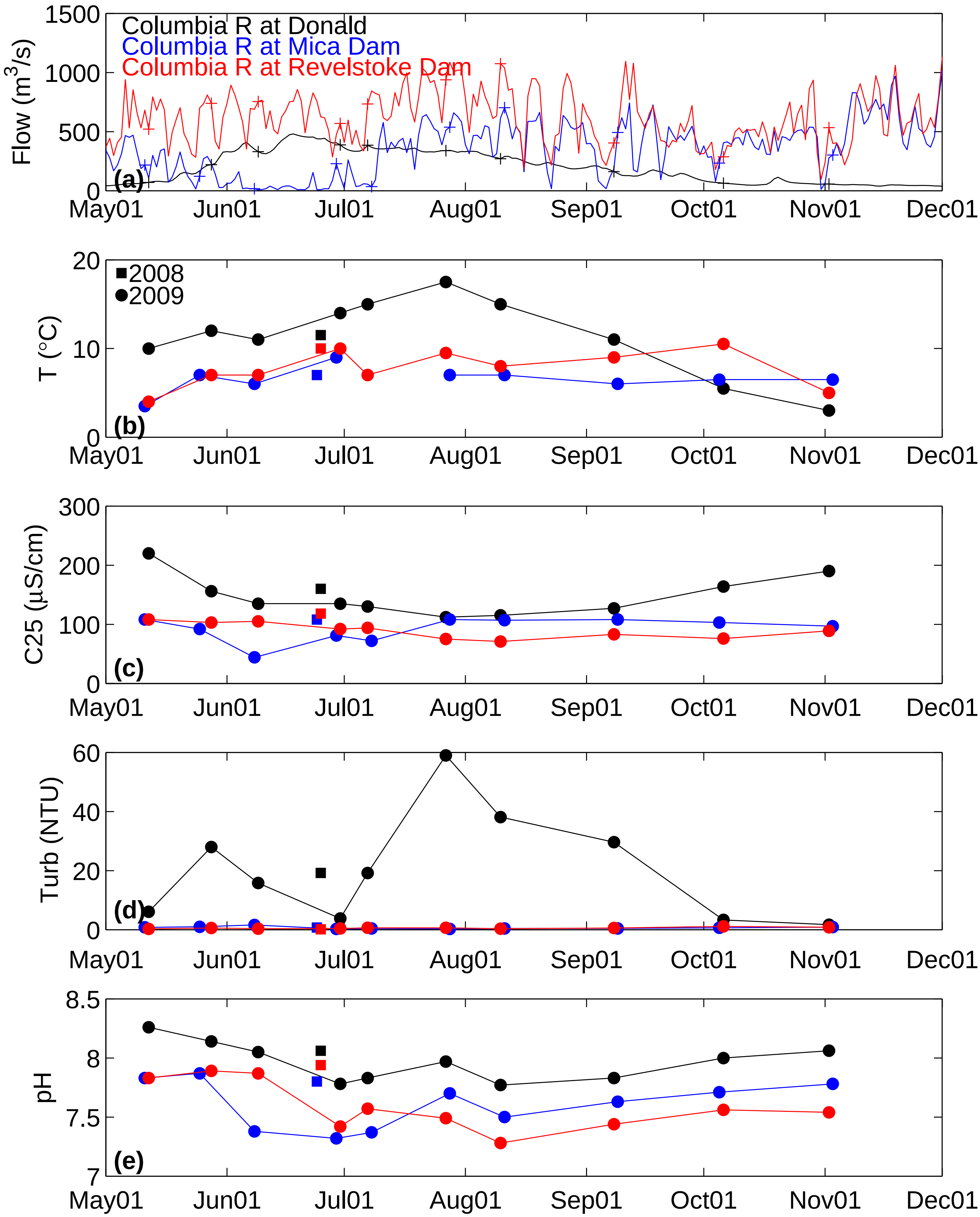

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Figure 4 con't Flow and water quality of Columbia River, 2009

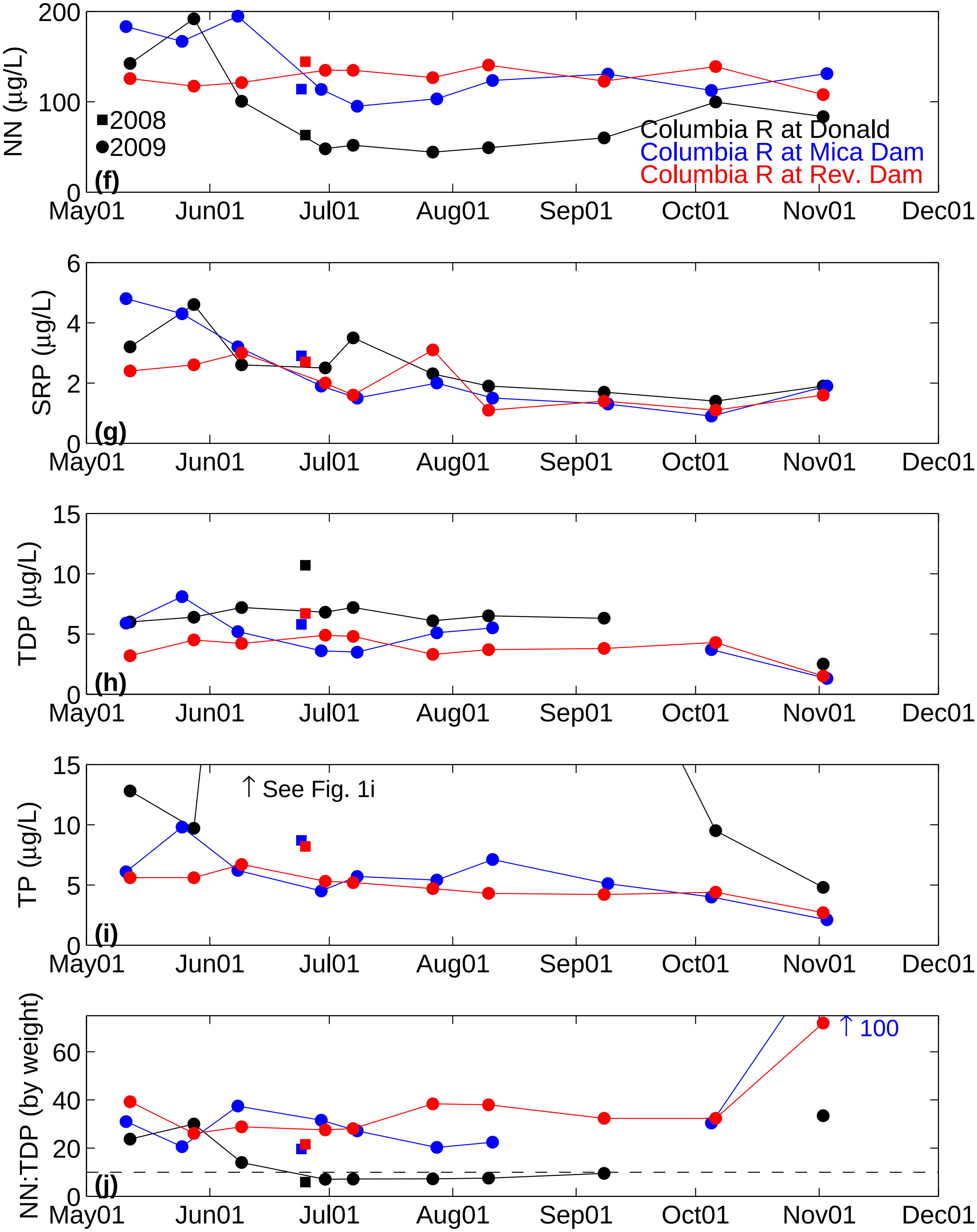

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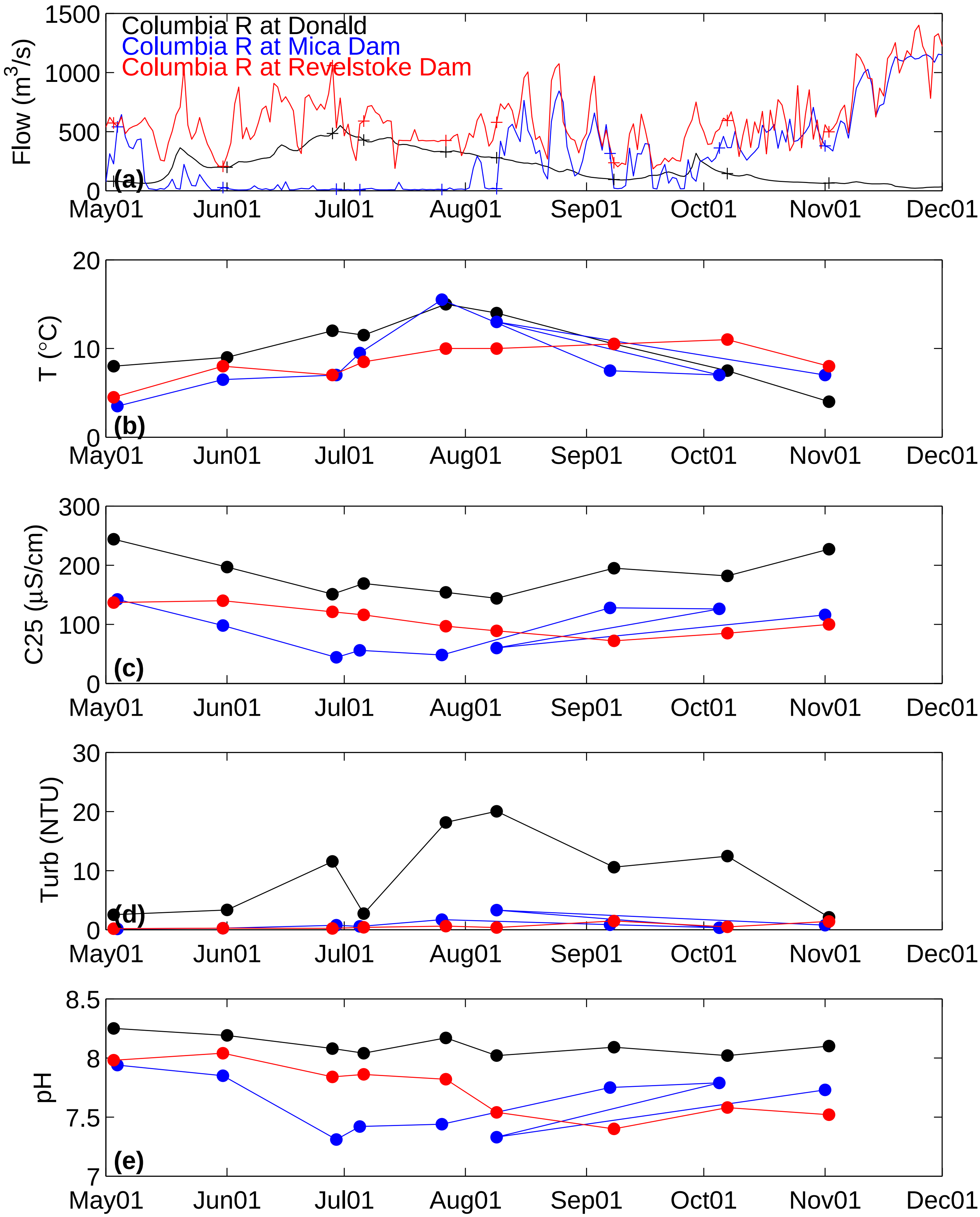
Figure 5 Flow and water quality of Columbia River, 2010



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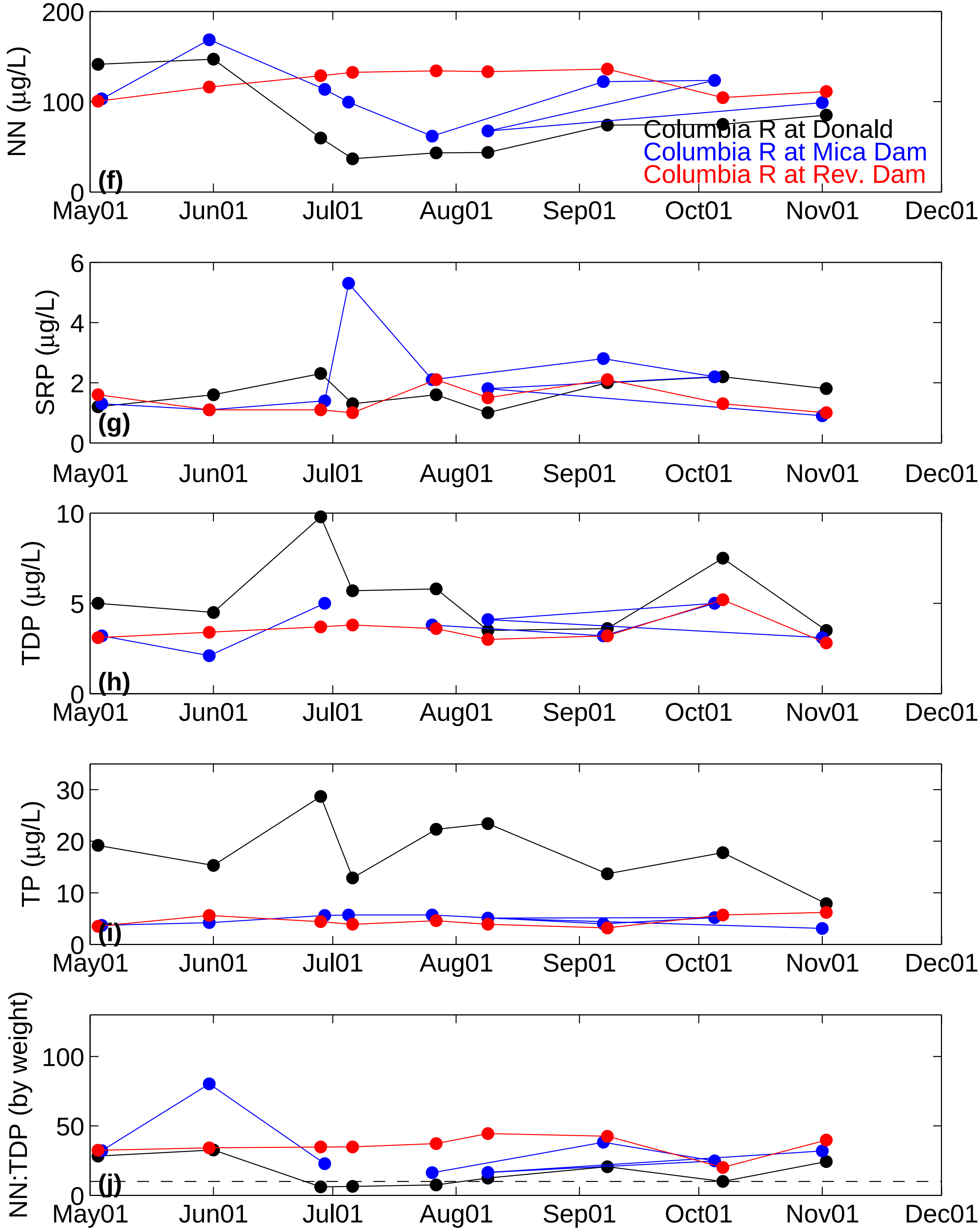

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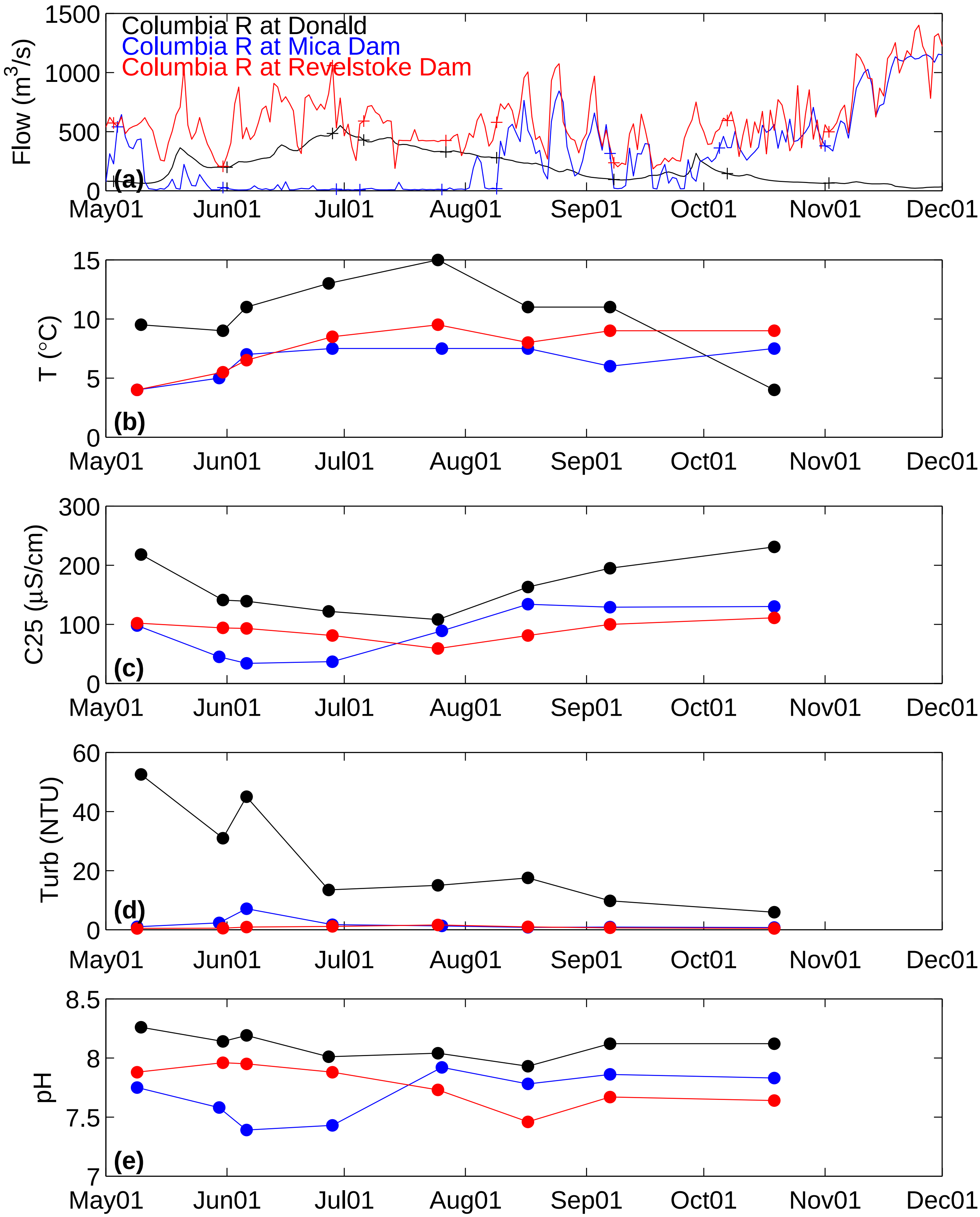

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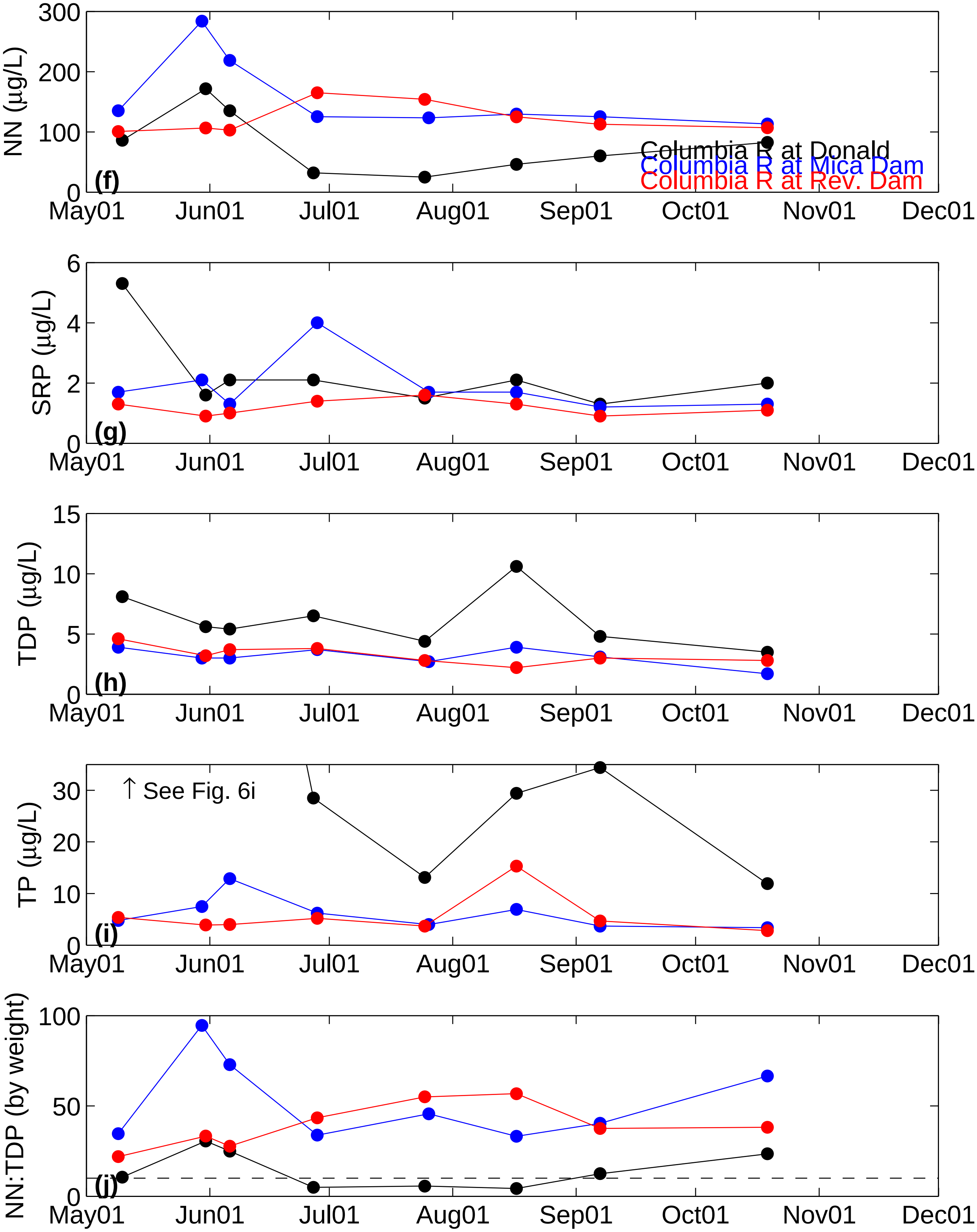

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Figure 7 Comparison of Columbia R. at Donald, 2009, 2010 & 2011

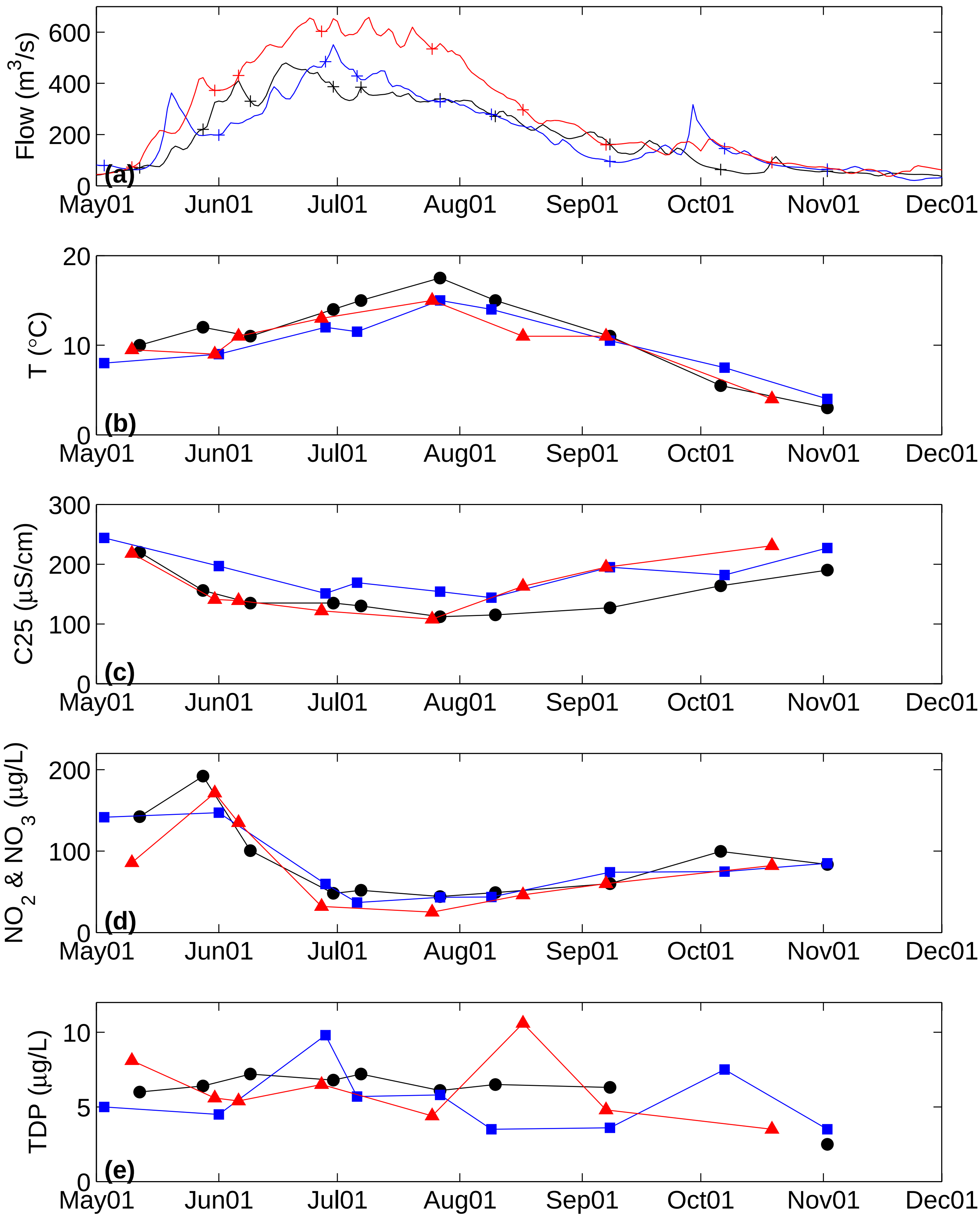

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Figure 8 Comparison of Goldstream River, 2009, 2010 & 2011

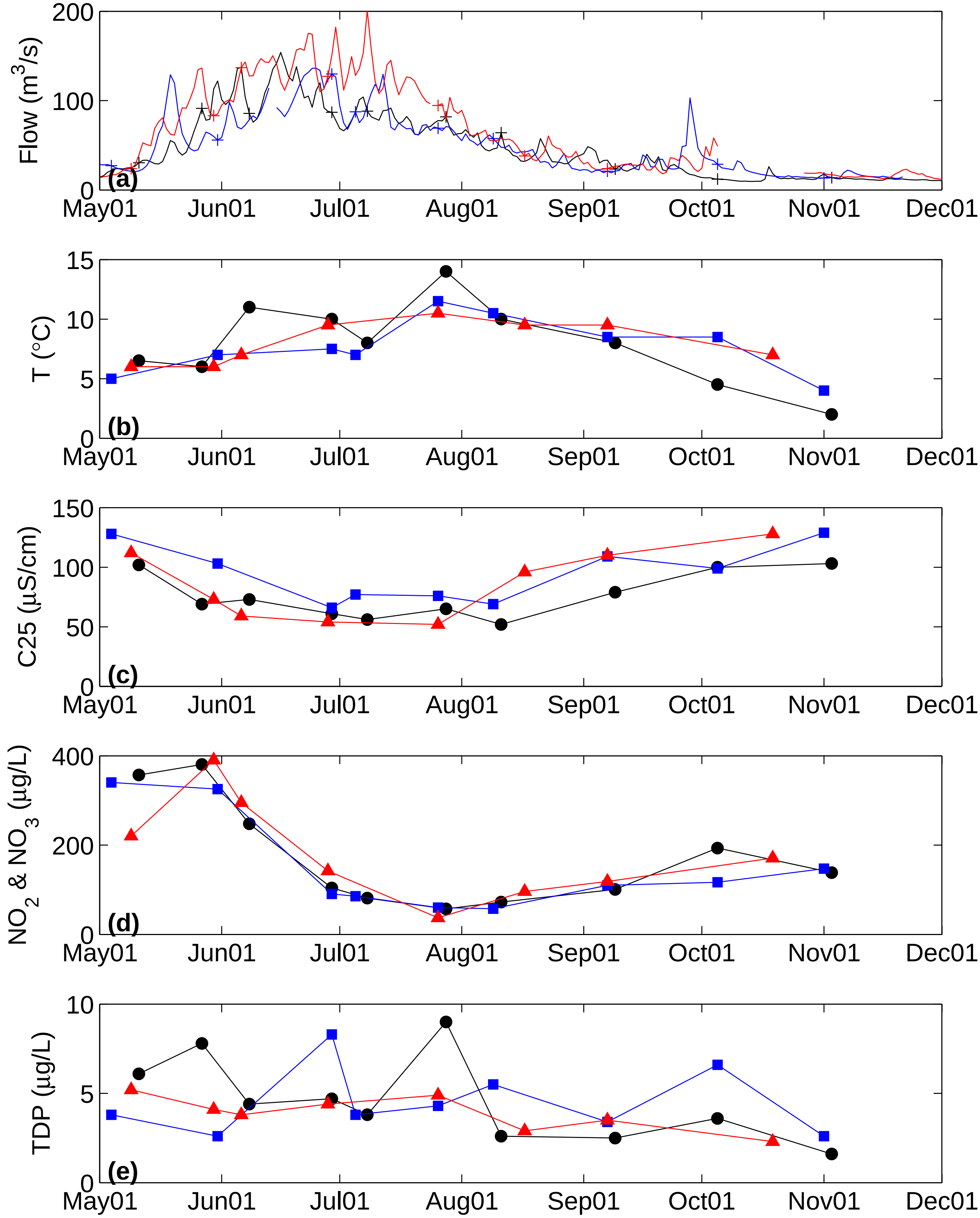

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Figure 9 Comparison of Beaver River, 2009, 2010 & 2011

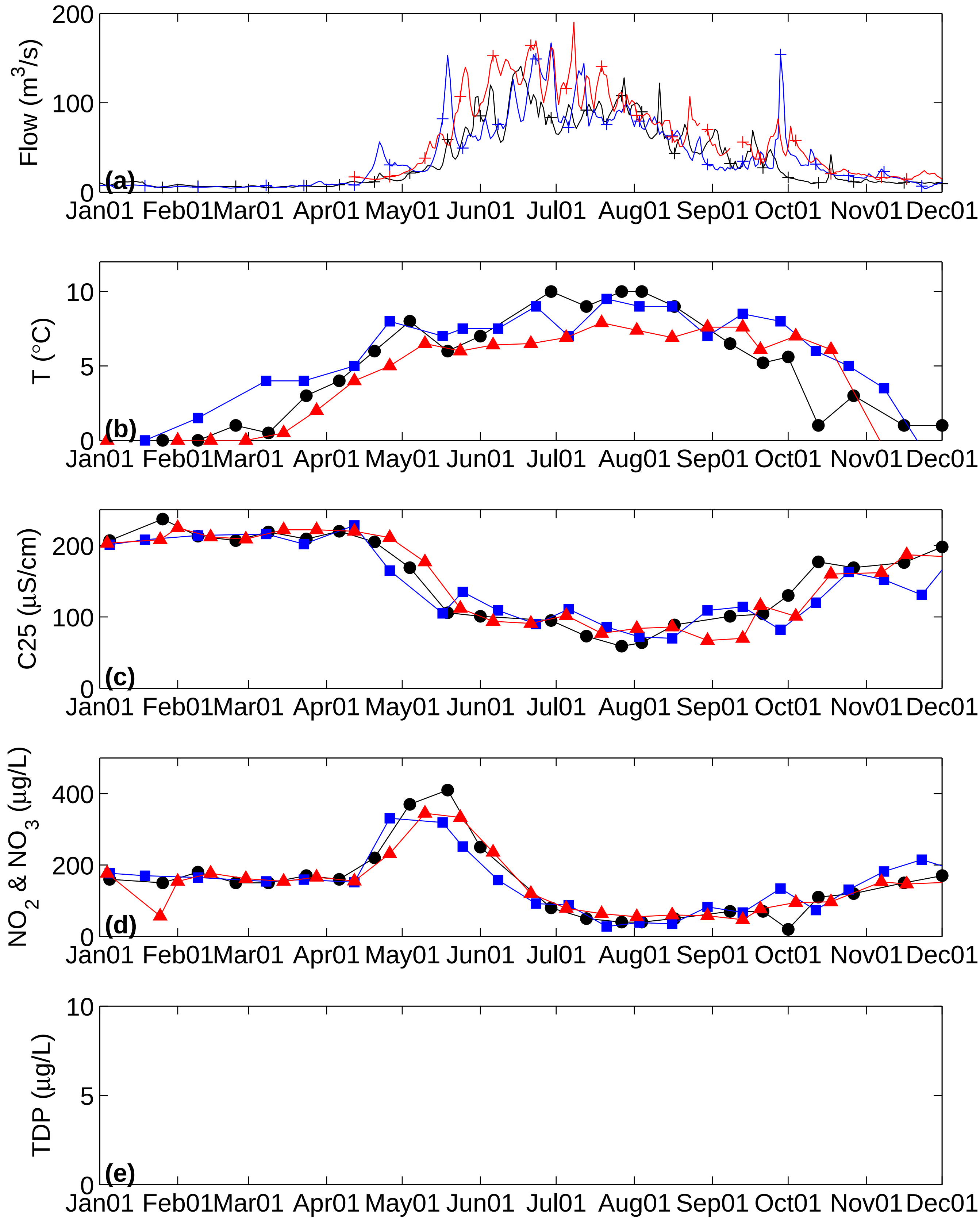

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Figure 10 Water quality of Illecillewaet River, 1997−2001

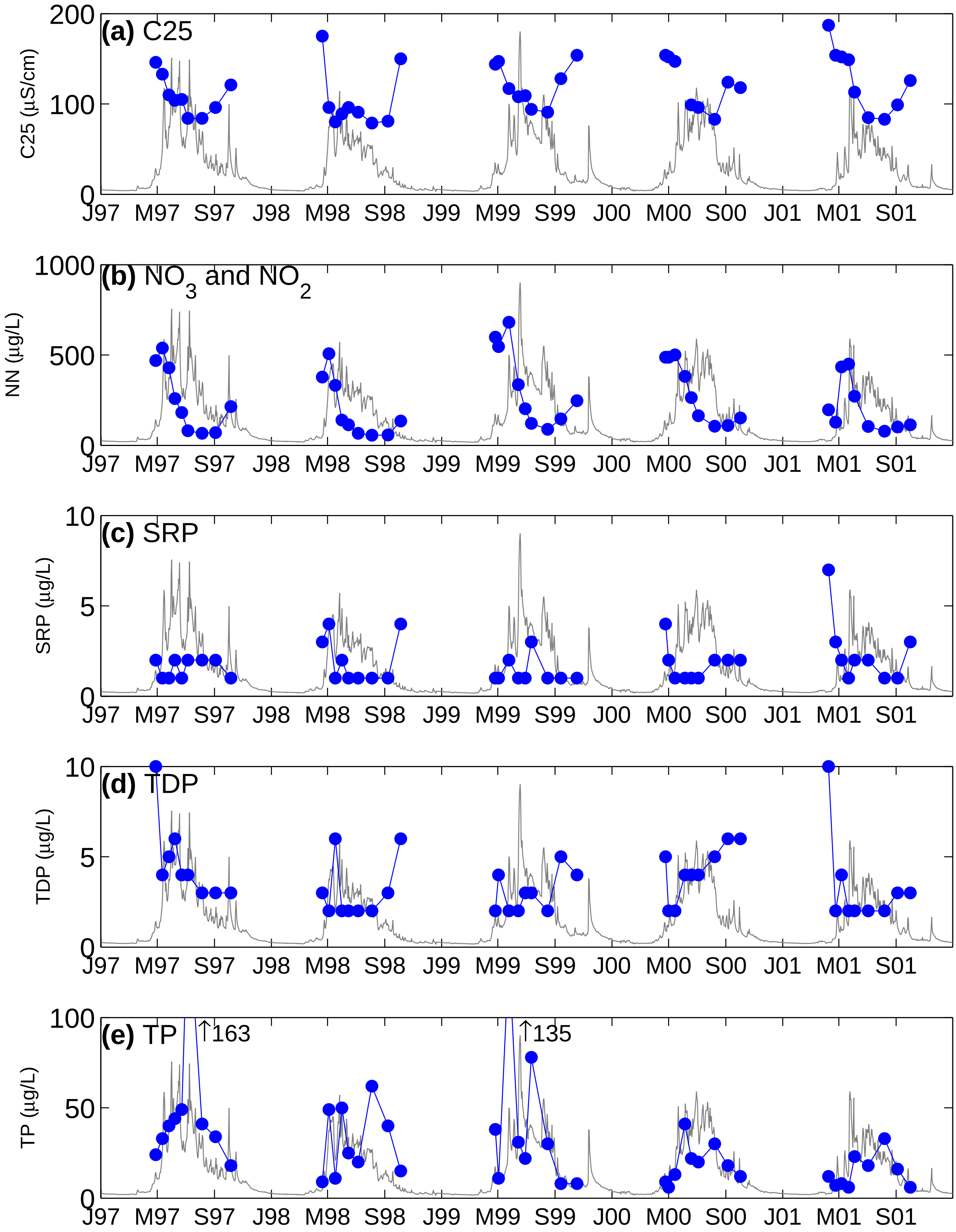

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Figure 10 con't Water quality of Illecillewaet River, 1997−2001

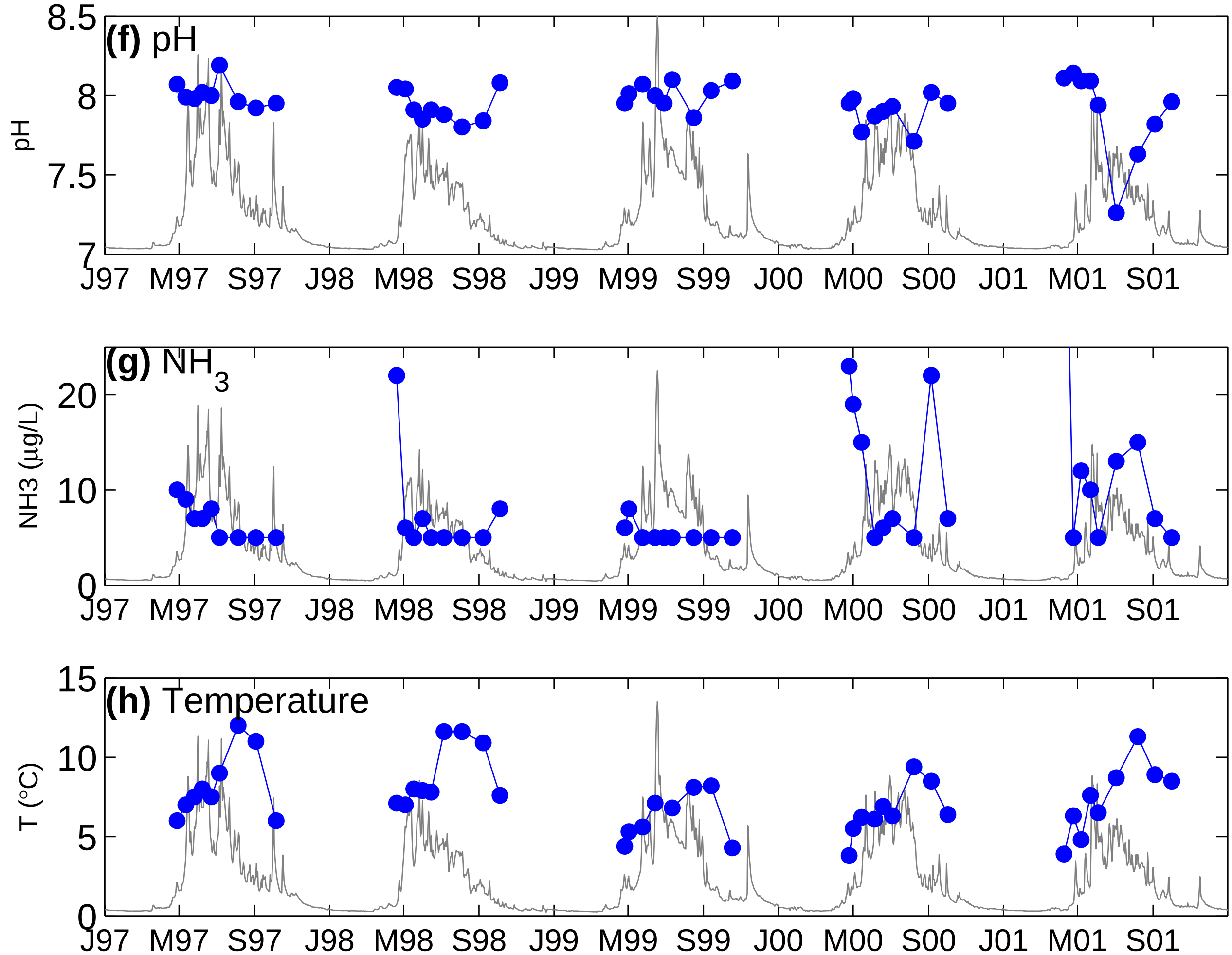

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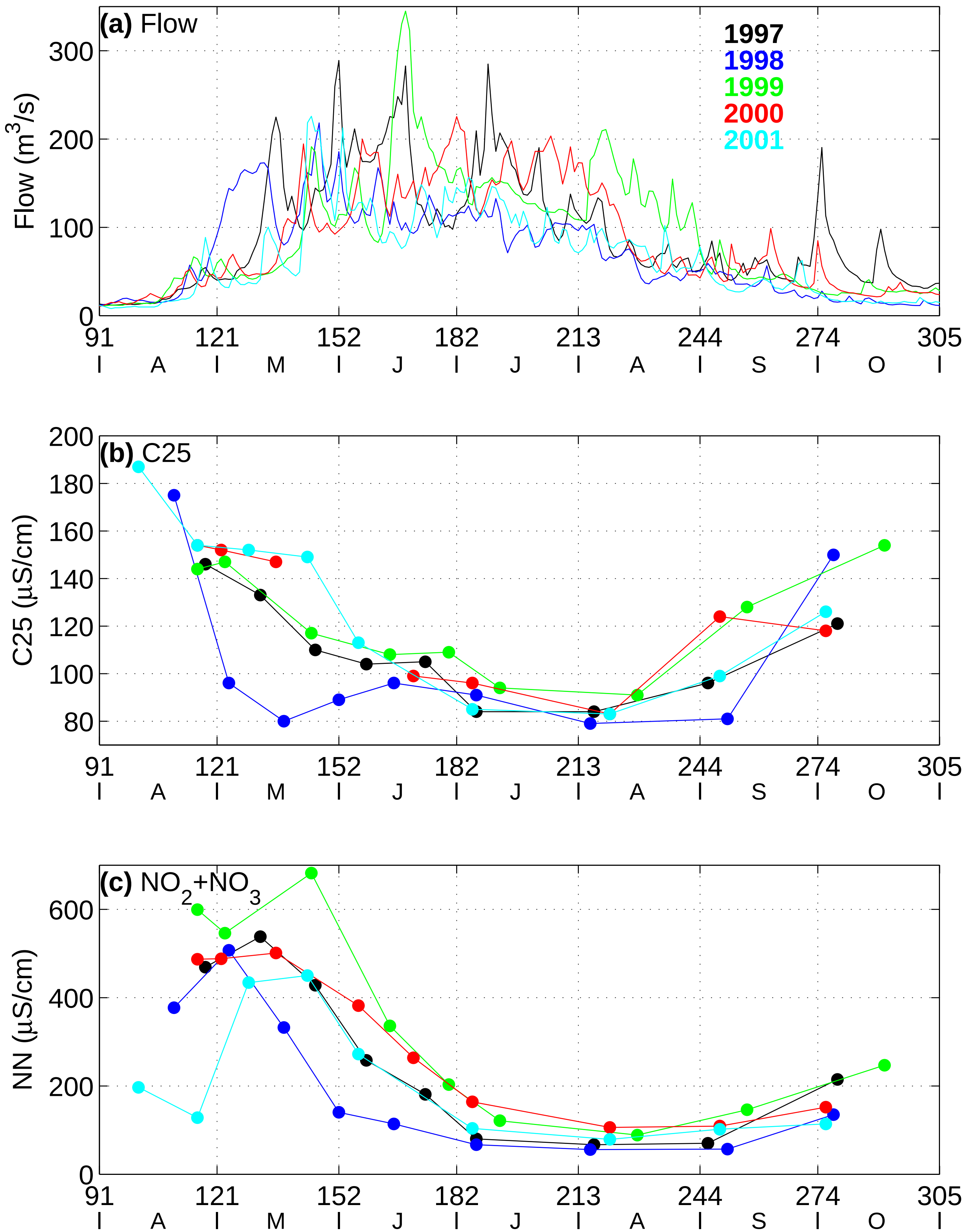
Figure 11 Flow, C25 and NN in the Illecillewaet River, 1997−2001



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Appendix 1
Summary of Methods

A summary of selected laboratory methods is given as follows. Samples for NO3+NO2, SRP and TDP required filtration. Filtration was done using a 47 mm Swinnex holder with 60 cc syringe. Filters were 0.8 μm glass-fiber (GFF), ashed and washed with distilled/ deionized water before use. The samples for NO3+NO2 and SRP were frozen.

Nitrate and Nitrite

This method was developed from the sea water technique of P. G. Brewer and J. P. Riley 1965, and is similar to that described in APHA (1975). The buffered sample is passed through a cadmium column, which reduces nitrates to nitrites. The reduced sample is reacted with sulphanilamide and N-(1-Naphthyl)ethylenediamine Dihydrochloride (N.N.E.D.) to form a coloured azodye. The intensity of the colour produced is measured. The range of detection of this method is 1 to 224 μg NO_2.N / litre.

Soluble Reactive Phosphorus

Orthophosphates are reacted with ammonium molybdate and stannous chloride and determined as the blue phospho-molybdenum complex. The range of detection of this method is 0.5 to 50 μg P / litre.

Total and Total Dissolved Phosphorus

The methods for total phosphorus (TP) and total dissolved phosphorus (TDP) are the same except for the filtration of the TDP sample. The sample is digested with a persulphate-sulphuric acid mixture. Polyphosphates and organically bound phosphorus are converted to orthophosphate. Orthophosphates are reacted with ammonium molybdate and stannous chloride and determined as the blue phospho-molybdenum complex. The range of detection of this method is 0.5 to 50 μg P / litre. The values shown are not corrected for colour/turbidity.

Total Phosphorus Colour/Turbidity Correction

Colour or turbidity in the samples interferes with the determination. A correction of Total Phosphorus (TP) can be made for low levels of turbidity or colour by repeating the analysis of samples but replacing the reducing reagent and ammonium molybdate solution with distilled deionized water (DDW). These corrections are given in Appendix 3. Subtract these corrections from TP to obtain TP corrected for colour or turbidity. This correction is appropriate for use in coastal and glacial setting with fine sediments in which both colour and turbidity contributes to the absorption.

Alkalinity

A sulphuric acid titration was added incrementally to lower the sample's pH. Relating the quantity and normality of sulphuric acid to a given change in pH provides the total alkalinity of the sample, presented here in mg of $CaCO_3$/L.

Appendix 1
Summary of Methods (con't)

References

Brewer, P. G. and J. P. Riley 1965. The automatic determination of nitrate in sea water. Deep-Sea Research, v. 12, 765-772.

APHA 1975. Standard Methods for the examination of Water and Wastewater. 14th edn. American Public Health Association APHA-AWWA-WPCF. John D. Lucas Co. Baltimore.

Appendix 2
Tributaries

Table A2-1 Tributaries to Kinbasket Reservoir

Name	Lat (N)/Long (W)	Drainage Area[1] (km^2)
Columbia R. at Donald Station	51° 29.0 117° 10.5	9710
Beaver River	51° 23 117° 27	*600* [2]
Gold River	51° 41.5 117° 42.5	542
Bush Arm		
Bush River	51° 47.5 117° 22.4	1032
Prattle Creek[3]	51° 47.3 117° 25.4	199
Chatter Creek[3]	51° 47.1 117° 26.3	102
Columbia Reach		
Windy Creek	51° 52.5 118° 01.2	243
Sullivan River	51° 57.2 117° 51.4	593
Kinbasket Creek	51° 58.5 117° 57.5	*160*
Cummins	52° 03.1 118° 09.5	268
Wood Arm		
Wood Creek	52° 12.2 118° 10.3	451
Canoe Reach		
Canoe River	52° 46.4 119° 09.6	611
Dave Henry Creek	52° 44.4 119° 05.6	96
Yellowjacket Creek[3]	52° 42.1 119° 03.1	104
Bulldog Creek[3]	52° 38.4 118° 58.5	107
Ptarmigan Creek	52° 35.0 118° 39.5	295
Hugh Allan Creek	52° 26.4 118° 39.5	626
Foster Creek	52° 15.2 118° 38.1	187
Dawson Creek[3]	52° 15.6 118° 29.5	108
Molson Creek	52° 10.4 118° 21.8	77

[1] From Water Survey Canada and BC Hydro; estimated values in italics

[2] Beaver River near the mouth (WSC 08NB019 at 51° 30.58 N and 117° 27.70 W) drains 1,150 km^2. Tributary sampling by Environment Canada was upstream at Beaver River near East Park Gate (BC08NB00002) with approximately half the drainage.

Table A2-2 Tributaries to Revelstoke Reservoir

Name	Lat Long[2]	Drainage Area[2] (km^2)
Upper		
Columbia River at Mica Outflow	52° 02.6 118° 35.3	21500[1]
Nagle Creek	52° 03.1 118° 35.4	157
Soards Creek	52° 03.5 118° 37.3	161
Mica Creek	52° 00.4 118° 34.0	84
Pitt Creek	51° 57.3 118° 33.5	*5*
Birch Creek	51° 55.2 118° 33.5	27
Bigmouth Creek	51° 49.4 118° 32.4	588
Scrip Creek	51° 49.4 118° 39.2	160
Horne Creek	51° 46.4 118° 41.2	121
Hoskins Creek	51° 41.6 118° 40.1	101
Goldstream River	51° 40.0 118° 38.6	953
Kirbyville Creek	51° 39.1 118° 38.3	117
Lower		
Downie Creek	51° 30.1 118° 22.1	657
Bourne Creek	51° 23.5 118° 27.5	69
Big Eddy Creek	51° 19.5 118° 23.2	57
Carnes Creek	51° 18.1 118° 17.1	188
Martha Creek	51° 09.2 118° 12.0	13
Columbia R. above Jordan	51° 01.0 118° 13.3	26700[1]

[1] From Water Survey Canada
[2] Estimated values in italics

Appendix 3
Tributary Data

Appendix 3a Reference Tributaries

		Date	pH	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TP(1)**	**Turb**	**Alk**	**T**	**Color(2)**
				(uhoms)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	O3/L)	C	
Columbia at Donald	1	06/24/2008	8.06	160	63.2	2.7	10.7	43.0	25.5	17.5	19.20	162.8	11.5	B
Columbia at Donald	1	05/12/2009	8.26	220	142.3	3.2	6	12.8	3.1	9.7	6.08	261	10	TM
Columbia at Donald	1	05/28/2009	8.14	156	191.9	4.6	6.4	9.7	3.7	6	28	196.6	12	TB
Columbia at Donald	1	06/09/2009	8.05	135	100.6	2.6	7.2	46.5	NaN	NaN	15.8	162.9	11	TB
Columbia at Donald	1	06/30/2009	7.78	135	48	2.5	6.8	18	3.4	14.6	3.8	156.1	14	TB
Columbia at Donald	1	07/07/2009	7.83	130	51.8	3.5	7.2	25.4	5.8	19.6	19.2	151.7	15	MB
Columbia at Donald	1	07/27/2009	7.97	112	44.3	2.3	6.1	68.3	41.6	26.7	59	147.6	17.5	TM
Columbia at Donald	1	08/10/2009	7.77	115	49.1	1.9	6.5	60.6	33.8	26.8	38.1	142.4	15	TM
Columbia at Donald	1	09/08/2009	7.83	127	60	1.7	6.3	28	17	11	29.6	153.8	11	MB
Columbia at Donald	1	10/06/2009	8	164	99.6	1.4	NaN	9.5	5.8	3.7	3.31	204.7	5.5	C
Columbia at Donald	1	11/02/2009	8.06	190	83.7	1.9	2.5	4.8	1.9	2.9	1.7	226	3	C
Columbia at Donald	1	05/03/2010	8.25	244	141.5	1.2	5.0	19.2	6.7	12.5	2.56	227.4	8.0	MG
Columbia at Donald	1	06/01/2010	8.19	197	147.1	1.6	4.5	15.3	<0.1	15.2	3.35	184.0	9.0	TGB
Columbia at Donald	1	06/28/2010	8.08	151	59.7	2.3	9.8	28.7	12.3	16.4	11.55	152.2	12.0	TB
Columbia at Donald	1	07/06/2010	8.04	169	36.8	1.3	5.7	12.9	2.9	10.1	2.72	156.6	11.5	TGB
Columbia at Donald	1	07/27/2010	8.17	154	43.3	1.6	5.8	22.3	12.0	10.4	18.15	144.8	15.0	M
Columbia at Donald	1	08/09/2010	8.02	144	43.7	1.0	3.5	23.4	17.2	6.3	20.05	137.7	14.0	TB
Columbia at Donald	1	09/08/2010	8.09	195	74.0	2.0	3.6	13.7	7.1	6.6	10.59	189.4	10.5	T
Columbia at Donald	1	10/07/2010	8.02	182	74.9	2.2	7.5	17.8	9.0	8.7	12.45	180.0	7.5	TGB
Columbia at Donald	1	11/02/2010	8.10	227	85.1	1.8	3.5	7.9	3.8	4.1	2.11	223.3	4.0	C
Columbia at Donald	1	05/10/2011	8.26	218	85.9	5.3	8.1	84.5	65.5	19.0	52.5	285.8	9.5	TB
Columbia at Donald	1	05/31/2011	8.14	141	171.4	1.6	5.6	43.3	17.7	25.6	31.0	200.6	9.0	TB
Columbia at Donald	1	06/06/2011	8.19	139	135.0	2.1	5.4	107.1	73.5	33.6	45.0	207.3	11.0	TB
Columbia at Donald	1	06/27/2011	8.01	122	32.1	2.1	6.5	28.5	3.5	25.1	13.50	168.2	13.0	TB
Columbia at Donald	1	07/25/2011	8.04	108	25.0	1.5	4.4	13.1	3.5	9.6	15.00	154.6	15.0	TB
Columbia at Donald	1	08/17/2011	7.93	163	46.2	2.1	10.6	29.4	9.7	19.7	17.50	156.0	11.0	TB
Columbia at Donald	1	09/07/2011	8.12	195	60.0	1.3	4.8	34.4	8.7	25.6	9.80	187.1	11.0	TB
Columbia at Donald	1	10/19/2011	8.12	231	82.3	2.0	3.5	11.9	**	NaN	5.90	214.0	4.0	TB
Columbia at Mica Outflow	2	06/23/2008	7.80	108	114.0	2.9	5.8	8.7	0.9	7.8	0.74	102.1	7	n/a
Columbia at Mica Outflow	2	05/11/2009	7.83	108	183.2	4.8	6.1*	5.9	0.1	5.9	0.77	113.8	3.5	C
Columbia at Mica Outflow	2	05/25/2009	7.87	92	166.9	4.3	8.1	9.8	0.1	9.8	1.02	107.9	7	C
Columbia at Mica Outflow	2	06/08/2009	7.38	44	194.6	3.2	5.2	6.2	0.1	6.2	1.62	42	6	TB
Columbia at Mica Outflow	2	06/29/2009	7.32	81	113.6	1.9	3.6	4.5	0.1	4.5	0.25	94.4	9	C
Columbia at Mica Outflow	2	07/08/2009	7.37	72	95.1	1.5	3.5	5.7	0.1	5.7	0.42	86.1	NaN	n/a
Columbia at Mica Outflow	2	07/28/2009	7.7	108	103.3	2	5.1	5.4	0.1	5.4	0.29	139.3	7	C
Columbia at Mica Outflow	2	08/11/2009	7.5	107	123.6	1.5	5.5	7.1	0.1	7.1	0.42	137.7	7	C
Columbia at Mica Outflow	2	09/09/2009	7.63	108	130.7	1.3	NaN	5.1	0.1	5.1	0.48	137.9	6	C
Columbia at Mica Outflow	2	10/05/2009	7.71	103	112.5	0.9	4*	3.7	0.3	3.4	0.62	129.6	6.5	C
Columbia at Mica Outflow	2	11/03/2009	7.78	97	131.3	1.9	1.3	2.1	0.1	2.1	0.88	121.7	6.5	C

		Date	pH	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TP(1)**	**Turb**	**Alk**	**T**	**Color(2)**
				(uhoms)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	O3/L)	C	
Columbia at Mica Outflow	2	05/04/2010	7.94	142	103.0	1.3	3.2	3.7	<0.1	3.6	0.15	135.6	3.5	C
Columbia at Mica Outflow	2	05/31/2010	7.85	98	168.6	1.1	2.1	4.2	<0.1	4.1	0.27	86.3	6.5	C
Columbia at Mica Outflow	2	06/29/2010	7.31	44	113.6	1.4	5.0	5.6	1.4	4.2	0.75	33.7	7.0	T
Columbia at Mica Outflow	2	07/05/2010	7.42	56	99.5	5.3	**	5.7	<0.1	5.6	0.57	44.0	9.5	C
Columbia at Mica Outflow	2	07/26/2010	7.44	48	61.8	2.1	3.8	5.7	1.7	4.1	1.71	37.5	15.5	C
Columbia at Mica Outflow	2	09/07/2010	7.75	128	122.2	2.8	3.2	4.0	<0.1	3.9	0.86	127.3	7.5	C
Columbia at Mica Outflow	2	10/05/2010	7.79	126	123.7	2.2	5.0	5.2	<0.1	5.1	0.35	125.9	7.0	C
Columbia at Mica Outflow	2	08/09/2010	7.33	60	67.5	1.8	4.1	5.1	0.8	4.3	3.30	51.0	13.0	C
Columbia at Mica Outflow	2	11/01/2010	7.73	116	99.0	0.9	3.1	3.1	<0.1	3.0	0.78	117.8	7.0	C
Columbia at Mica Outflow	2	05/09/2011	7.75	98	135.0	1.7	3.9	4.8	<0.1	4.7	1.00	119.7	4.0	C
Columbia at Mica Outflow	2	05/30/2011	7.58	45	283.9	2.1	3.0	7.5	2.4	5.1	2.30	50.2	5.0	TLB
Columbia at Mica Outflow	2	06/06/2011	7.39	34	218.6	1.3	3.0	12.9	4.2	8.7	7.10	37.5	7.0	TSM
Columbia at Mica Outflow	2	06/28/2011	7.43	37	125.2	4.0	3.7	6.2	<0.1	6.1	1.70	42.6	7.5	C
Columbia at Mica Outflow	2	07/26/2011	7.92	89	123.3	1.7	2.7	4.0	0.5	3.5	1.30	120.6	7.5	C
Columbia at Mica Outflow	2	08/17/2011	7.78	134	129.5	1.7	3.9	6.9	0.4	6.5	0.80	129.7	7.5	C
Columbia at Mica Outflow	2	09/07/2011	7.86	129	125.1	1.2	3.7*	3.1	**	NaN	0.88	124.8	6.0	C
Columbia at Mica Outflow	2	10/19/2011	7.83	130	113.1	1.3	1.7	3.4	<0.1	3.3	0.75	123.9	7.5	C
Goldstream River	3	06/23/2008	7.73	75	1172.5	2.0	18.3	22.9	2.2	20.7	1.01	74.2	9.5	n/a
Goldstream River	3	08/04/2008	7.69	78	71.8	2.1	0.0	20.8	7.5	13.3	2.71	79.8	13	n/a
Goldstream River	3	05/11/2009	7.88	102	357.1	3.4	6.1	11.2	0.7	10.5	0.76	123.9	6.5	C
Goldstream River	3	05/27/2009	7.72	69	380.7	4	7.8	46.6	3.1	43.5	9.26	87.5	6	TB
Goldstream River	3	06/08/2009	7.77	73	247.7	2.3	4.4	9.1	0.6	8.5	1.86	89.4	11	TB
Goldstream River	3	06/29/2009	7.28	61	104.2	1.6	4.7	10.4	0.8	9.6	1.38	77.7	10	TB
Goldstream River	3	07/08/2009	7.31	56	81.2	0.9	3.8	13.1	1.6	11.5	4.11	73.1	8	C
Goldstream River	3	07/28/2009	7.64	65	57.2	2.2	9	177.3	116	61.3	189	78.6	14	TB
Goldstream River	3	08/11/2009	7.23	52	72.5	1	2.6	91.9	33	58.9	45.6	67.5	10	TB
Goldstream River	3	09/09/2009	7.58	79	100.8	1.2	2.5	13.3	3.7	9.6	2.55	99.9	8	C
Goldstream River	3	10/05/2009	7.76	100	193.4	1.4	4.9*	3.6	0.6	3	1.72	126.8	4.5	C
Goldstream River	3	11/03/2009	7.81	103	138.6	1.6	1.6	2.2	0.1	2.2	1.35	131.9	2	C
Goldstream River	3	05/04/2010	8.02	128	340.4	1.8	3.8	9.9	0.5	9.4	0.20	127.9	5.0	C
Goldstream River	3	05/31/2010	7.99	103	325.3	1.1	2.6	7.0	<0.1	6.9	0.44	100.0	7.0	C
Goldstream River	3	06/29/2010	7.61	66	90.8	2.3	8.3	65.3	6.7	58.6	14.10	64.9	7.5	TB
Goldstream River	3	07/05/2010	7.71	77	85.7	0.8	3.8	12.4	1.3	11.1	1.05	72.1	7.0	TB
Goldstream River	3	07/26/2010	7.82	76	60.0	1.0	4.3	95.6	24.9	70.7	44.75	71.9	11.5	TB
Goldstream River	3	08/09/2010	7.49	69	57.6	1.4	5.5	40.3	10.3	30.0	16.55	66.3	10.5	T
Goldstream River	3	09/07/2010	7.73	109	109.8	1.5	3.4	10.3	1.1	9.1	3.20	108.8	8.5	C
Goldstream River	3	10/05/2010	7.79	99	116.7	1.8	6.6	6.7	3.8	3.0	8.66	100.0	8.5	MGB
Goldstream River	3	11/01/2010	7.82	129	147.4	0.9	2.6	3.2	<0.1	3.1	0.46	133.9	4.0	C
Goldstream River	3	05/09/2011	7.99	112	220.3	1.8	5.2	9.5	<0.1	9.4	2.15	149.6	6.0	TGB
Goldstream River	3	05/30/2011	7.87	73	390.3	1.6	4.1	32.3	2.4	29.8	8.20	99.8	6.0	TB
Goldstream River	3	06/06/2011	7.80	59	295.2	1.5	3.8	151.0	13.7	137.3	30.0	78.0	7.0	TB

		Date	pH	Cond	NN	SRP	TDP	TP	TP Turb	TP(1)	Turb	Alk	T	Color(2)
				(uhoms)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	O3/L)	C	
Goldstream River	3	06/28/2011	7.80	54	142.1	1.2	4.4	146.9	**	NaN	4.50	75.0	9.5	TB
Goldstream River	3	07/26/2011	7.73	52	37.2	1.2	4.9	14.0	1.9	12.2	8.15	73.0	10.5	TLB
Goldstream River	3	08/17/2011	7.66	96	96.2	1.4	2.9	6.3	0.9	5.5	1.60	92.0	9.5	C
Goldstream River	3	09/07/2011	7.88	110	118.7	1.1	3.5	17.6	**	NaN	7.10	108.9	9.5	TB
Goldstream River	3	10/19/2011	7.75	128	170.9	1.6	2.3	4.0	<0.1	3.9	1.20	125.9	7.0	C
Columbia above Jordan (3)	4	06/24/2008	7.94	118	144.3	2.7	6.7	8.2	1.0	7.2	0.16	97.7	10	n/a
Columbia above Jordan	4	05/12/2009	7.83	108	125.7	2.4	5.6*	3.2	0.1	3.2	0.32	125.6	4	C
Columbia above Jordan	4	05/28/2009	7.89	103	117.3	2.6	4.5	5.6	0.1	5.6	0.59	123.6	7	C
Columbia above Jordan	4	06/09/2009	7.87	105	121.2	3	6.7*	4.2	0.1	4.2	0.37	125.1	7	C
Columbia above Jordan	4	06/30/2009	7.42	92	134.9	2	5.3*	4.9	0.1	4.9	0.43	109.9	10	C
Columbia above Jordan	4	07/07/2009	7.57	94	134.9	1.6	4.8	5.2	0.1	5.2	0.63	114.6	7	C
Columbia above Jordan	4	07/27/2009	7.49	75	126.7	3.1	3.3	4.7	0.1	4.7	0.63	95.5	9.5	C
Columbia above Jordan	4	08/10/2009	7.28	71	140.5	1.1	3.7	4.3	0.1	4.3	0.36	88.8	8	C
Columbia above Jordan	4	09/08/2009	7.44	83	122.8	1.4	4.2*	3.8	0.7	3.1	0.58	103	9	C
Columbia above Jordan	4	10/06/2009	7.56	76	138.9	1.1	4.4*	4.3	0.8	3.5	1.09	97.4	10.5	C
Columbia above Jordan	4	11/02/2009	7.54	89	107.9	1.6	1.5	2.7	0.1	2.7	0.83	108.2	5	C
Columbia above Jordan	4	05/03/2010	7.98	137	100.5	1.6	3.1	3.5	<0.1	3.4	0.17	125.4	4.5	C
Columbia above Jordan	4	05/31/2010	8.04	140	116.2	1.1	5.6*	3.4	<0.1	3.3	0.25	130.9	8.0	C
Columbia above Jordan	4	06/28/2010	7.84	121	128.7	1.1	4.4*	3.7	<0.1	3.6	0.22	116.8	7.0	C
Columbia above Jordan	4	07/06/2010	7.86	116	132.6	1.0	3.9*	3.8	<0.1	3.7	0.39	109.8	8.5	C
Columbia above Jordan	4	07/27/2010	7.82	97	134.2	2.1	3.6	4.6	0.8	3.9	0.62	91.4	10.0	C
Columbia above Jordan	4	08/09/2010	7.54	89	133.3	1.5	3.0	3.9	<0.1	3.8	0.37	86.4	10.0	C
Columbia above Jordan	4	09/08/2010	7.40	72	136.2	2.1	3.2	3.2	<0.1	3.1	1.49	67.5	10.5	C
Columbia above Jordan	4	10/07/2010	7.58	85	104.5	1.3	5.7*	5.2	<0.1	5.1	0.49	81.9	11.0	C
Columbia above Jordan	4	11/02/2010	7.52	100	111.2	1.0	2.8	6.2	4.0	2.2	1.40	100.0	8.0	C
Columbia above Jordan	4	05/09/2011	7.88	102	100.7	1.3	5.4*	4.6	<0.1	4.5	0.48	125.9	4.0	C
Columbia above Jordan	4	05/31/2011	7.96	94	106.4	0.9	3.2	3.9	<0.1	3.8	0.50	121.4	5.5	C
Columbia above Jordan	4	06/06/2011	7.95	93	102.8	1.0	4.0*	3.7	<0.1	3.6	0.90	117.9	6.5	C
Columbia above Jordan	4	06/28/2011	7.88	81	165.1	1.4	3.8	5.2	<0.1	5.1	1.10	108.9	8.5	C
Columbia above Jordan	4	07/25/2011	7.73	59	154.1	1.6	2.8	3.7	0.7	2.9	1.60	81.8	9.5	C
Columbia above Jordan	4	08/17/2011	7.46	81	124.9	1.3	15.3*	2.2	0.3	1.9	0.95	74.2	8.0	C
Columbia above Jordan	4	09/07/2011	7.67	100	112.8	0.9	3.0	4.7	**	NaN	0.60	92.1	9.0	C
Columbia above Jordan	4	10/19/2011	7.64	111	107.0	1.1	2.8*	2.8	<0.1	2.7	0.45	101.1	9.0	C

1 TP=TP-Tpturb Total phosphorus corrected for turbidity
2 (C)lear, (T)urbid, (M)ilky, (G)reen, (B)rown, (S)lightly, (L)ight
3 Columbia above Jordan is located just below Revelstoke Dam
* TDP > TP, values swapped in figures and analysis
** TPTurb not measured

Appendix 3b Beaver River

Station: Beaver River near East Park Gate (BC08NB0002)
Description: At Highway 1 bridge near east gate of Glacier National Park.
Latitude: 51.38338 Longitude: -117.45035
Start Date: 2011/01/01
End Date: 2012/01/01

Sample Time	PH	SPECIFIC COND	AMMONIA DISSOLVED	NITROGEN NITRITE	NITROGREN NITRATE	PHOSPHORUS DISSOLVED ORTHO	PHOSPHORUS TOTAL	TURBIDITY	ALKALINITY TOTAL CaCO3	T
Units	PH UNITS	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	NTU	mg/L	DEG C
01 04 2011 06 35	8.11	203		0.005	0.172	0.001	0.002	0.79	88.7	0
01 25 2011 11 12	8.08	208		0.005	0.052	0.001	0.003	1.65	89	-0.2
02 01 2011 10 00	7.89	225		0.005	0.149	0.001	0.035	2.21	95.3	0
02 14 2011 09 45	8.01	212		0.005	0.172	0.001	0.002	1.06	90.2	0
02 28 2011 09 20	7.92	209		0.005	0.157	0.001	0.002	0.58	93.2	0
03 15 2011 08 30	8.02	222		0.005	0.149	0.001	0.002	0.53	94.7	0.5
03 28 2011 10 32	8.01	222		0.005	0.161	0.001	0.002	0.64	91.2	2
04 12 2011 10 33	8.01	220		0.005	0.15	0.001	0.002	0.9	91.7	4
04 26 2011 10 10	7.93	211		0.005	0.227	0.001	0.002	1.41	89	5
05 10 2011 11 40	7.93	177		0.005	0.34	0.001	0.016	7.62	71	6.5
05 24 2011 09 55	7.9	112		0.005	0.328	0.001	0.078	47.9	44.8	6
06 06 2011 08 45	7.84	94		0.005	0.231	0.001	0.083	53	40.2	6.4
06 21 2011 08 10	7.86	91		0.005	0.115	0.001	0.074	42.8	38.7	6.5
07 05 2011 09 20	7.85	102		0.006	0.073	0.001	0.017	12.6	43.6	6.9
07 19 2011 08 10	7.78	77		0.005	0.059	0.001	0.106	71.5	34.8	7.9
08 02 2011 10 00	7.83	84		0.005	0.05	0.001	0.032	14.6	36.7	7.4
08 16 2011 08 00	7.82	86		0.005	0.055	0.001	0.025	17.1	39.3	6.9
08 30 2011 08 30	7.68	67		0.005	0.053	0.001	0.017	13.9	30	7.6
09 13 2011 07 30	7.69	70		0.005	0.042	0.001	0.024	27.8	31	7.6
09 20 2011 11 34	7.87	116		0.005	0.072	0.001	0.005	6.18	51.3	6.1
10 04 2011 08 28	7.8	101		0.005	0.09	0.001	0.003	7.54	42	7
10 18 2011 09 56	7.98	160		0.005	0.092	0.001	0.002	1.33	67.6	6.1
11 07 2011 11 15	7.96	162		0.005	0.148	0.001	0.002	1.13	77.4	-0.2
11 17 2011 10 02	7.99	187		0.005	0.142	0.001	0.003	1.33	81.2	-0.5
12 12 2011 11 30	8.06	183		0.005	0.149	0.001	0.002	1.03	83.9	NaN

Appendix 3

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2011

Roger Pieters and Greg Lawrence
University of British Columbia

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2011

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Kinbasket Reservoir, 13 Sep 2012

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January 14, 2013

Contents

List of Figures

1. Introduction

We report on CTD (conductivity-temperature-depth) profiles collected from Kinbasket and Revelstoke Reservoirs in 2011. This is the fourth year of data collected for the B.C. Hydro project "CLBMON-3 Kinbasket and Revelstoke Ecological Productivity Monitoring".*

2. Methods

Sampling stations

Sampling was conducted in both reservoirs monthly from May to October, 2011. In addition, an intensive CTD survey was conducted on 8 – 10 June 2011 with a large number of extra stations in both reservoirs. No CTD profiles were collected from Kinbasket Reservoir in September, as very high water levels and the presence of large amounts of woody debris prevented the boat from being launched.

Sampling Kinbasket and Revelstoke Reservoirs is a challenge because of their size. The Columbia and Canoe Reaches of Kinbasket Reservoir stretch over 180 km (Figure A1). Revelstoke Reservoir is not quite as long with 130 km between Mica and Revelstoke Dams. Kinbasket is particularly difficult to sample because of limited road access, the frequency and severity of wind storms, the presence of woody debris, and the absence of sheltered locations along much of the reservoir.

The approximate location of the sampling stations is shown in Figure A1. Production of a more accurate map awaits shoreline and bathymetry data from B.C. Hydro. Station names are also provisional with stations numbered either from the dam or from the mouth of an arm. In Kinbasket there are five main stations: Forebay (K1fb), Middle (K2mi), Columbia Reach (K3co), Canoe Arm (Kca1), and Wood Arm (Kwo1). In Revelstoke there are three main stations: Forebay (R1fb), Middle (R2mi) and Upper (R3up). Stations sampled are given in Appendix 1.

A list of the profiles collected in 2011 is given in Appendix 2, and summarized in Tables 2.1 and 2.2. In addition to the main stations, casts were collected at additional stations during the intensive surveys of 8 – 10 June 2011 to provide a more detailed picture of the reservoir. This complements the intensive surveys conducted on 15 – 17 September 2008 (Pieters and Lawrence 2010), 31 August – 2 September 2009 (Pieters and Lawrence 2011b) and 4 – 6 October 2010 (Pieters and Lawrence 2012). In 2008, high wind, waves and excessive debris permitted sampling of only the south end of Canoe Reach during the intensive survey; in 2009-2010 more of Canoe Reach was accessible. Some regions of

* Previous data include profiles from Revelstoke Reservoir and the Mica Forebay (Watson 1984; Fleming and Smith 1988). Monthly profiles at four stations in Kinbasket Reservoir (2003, 2004 and 2005) and three stations in Revelstoke Reservoir (2003) were collected with an YSI multiparameter probe (K. Bray, personal communication).

both reservoirs were not sampled, including the uppermost part of Canoe Reach, upstream of K4 in the Columbia Reach and the region in Revelstoke Reservoir below Mica Dam. (Figure A1).

Additional casts were also collected during measurement of primary production in Kinbasket Reservoir, and these data are shown in Appendix 3.

Profiler

Profiles were collected using a Sea-Bird Electronics SBE 19plus V2 profiler with the following additional sensors:

- Turner SCUFA II fluorometer and optical back scatter (OBS) sensor,
- Biospherical QSP-2300L (4 pi) photosynthetically active radiation (PAR) sensor,
- Sea-Bird SBE 43 dissolved oxygen sensor, and
- Wetlabs CStar transmissometer (red with 25 cm path).

Secchi depths were collected with a 20 cm black and white disk, lowered from the side of the boat away from the sun. The Secchi depth is given as the average of the depths at which the disk disappeared going down and reappeared going up. Multiplying the Secchi depth by 2.5 provides an estimate of the 1% light level (Figure A4).

Pump problems A pump on the Sea-Bird profiler draws water across the temperature sensor, and through the conductivity and dissolved oxygen sensors. Two parameters in the profiler control pump operation. The first is the 'minimum conductivity frequency'. For ocean going vessels it is often hard to tell how much time it will take for the profiler to be lifted from the deck and lowered into the water. To avoid turning on early, the profiler waits for the conductivity to exceed a minimum value before starting the pump. This minimum is given by the 'minimum conductivity frequency', which is set by Sea-Bird to 3,320 Hz, corresponding to a conductivity of about 5,300 μS/cm. For use in freshwater (e.g. in Kinbasket and Revelstoke with a conductivity of 200 μS/cm), this parameter should be set to zero to ensure the pump turns on. If the pump does not turn on, the descent of the instrument will force water through the plumbing and data will still be collected, with slightly reduced vertical resolution. The sensors which are not in the pump path - PAR, fluorescence, OBS and light transmission - are not affected by pump operation.

After the Sea-Bird has been turned on and placed in the water to soak, there is a second delay before the pump begins, controlled by the 'pump delay' setting, to allow air in the plumbing to escape from a bleed valve. If the air does not escape before the pump turns on, the pump may not prime properly, and it may draw little or no water across the sensors. The pump will eventually prime, but this may occur well into the downcast.

Table 2.1 Kinbasket surveys, 2011

Date	FB K1	K1.5	MI K2	CO K3	CA Kca1	WO Kwo1
24-25 May	✓		✓	✓	✓	✓
8-9 June	✓		✓+1	✓+7	✓+6	✓+3
20 June		✓*				
4-5 July	✓		✓	✓	✓	✓
18 July		✓*				
15-16 August	✓		✓	✓	✓	✓
22 August		✓*				
24-25 October	✓			✓	✓	✓

* Collected during measurement of primary production (see Appendix 3)
** Additional casts

Table 2.2 Revelstoke surveys, 2011

Date	FB	MI	UP
16-17 May	✓	✓	✓
10 June	✓+5		✓
21-22 June	✓*	✓*	✓
19-20 July	✓*	✓*	✓
23-24 August	✓*	✓*	✓
19-20 September	✓*	✓*	✓
17-18 October	✓	✓	✓

* Primary production (see Appendix 3)
** Additional casts

In 2008 the minimum conductivity frequency was set to zero. However, in 2009, 2010 and 2011, after calibration of the instrument by Sea-Bird, the minimum conductivity frequency was set for ocean use, and the pump did not run. Nevertheless, most of the temperature and conductivity data collected is satisfactory as descent forced water through the plumbing.

To avoid these problems the parameters controlling the pump should be checked before each cruise. It may also be necessary to increase the soak time and to clean the pump bleed valve more often. Under calm conditions, the functioning of the bleed valve can be checked by watching the flow of bubbles from the bleed valve during the soak time. If it is possible to reach the pump outlet, the flow from the pump can occasionally be felt to ensure proper operation. Alternatively, the momentary flow of water from the pump outlet can be observed as the profiler is lifted from the water at the end of the cast.

In 2011, there were 12 casts (out of a total of 69 casts) where it appears that the air had not bled from the plumbing by the start of the cast, and the flow of water through the plumbing was reduced or blocked. These casts were identified by comparing up and down casts, comparing to adjacent stations, and comparing to casts from the previous and following month, as well as the presence of unusual features such as large inversions in temperature. The casts with problem temperature, conductivity and dissolved oxygen are noted in the text and marked with an asterisk in the figures. Some data was also trimmed from the top 1-2 m of many of the casts to account for the time to established flow through the plumbing.

3. Results

We first look at the water levels and flows during 2011, shown in Figure A2. In Kinbasket Reservoir the surveys begin in May, just after the minimum water level, and end in October, just after the maximum water level (Figure A2a). Note the water level rose very high in 2011, within 0.2 m of full pool on 4 August 2011 (Figure A2a inset). The center of the outlet from Kinbasket Reservoir is located 64.6 m below normal full pool; in 2011, the mid-depth of the outlet varied from 35 m on 7 May to 64.4 m in October. In Revelstoke Reservoir there is normally little variation in water level and in 2011 the water level varied by less than 1.3 m (Figure A2b). The mid-depth of the outlet at Revelstoke Dam is 28 m below full pool.

Next consider the conductivity of the tributary inflows. For example, the main inflow to Kinbasket Reservoir is the Columbia River and at where water quality parameters were measured under the Canada - British Columbia Water Quality Monitoring Agreement every two weeks from 1984-1995 including during ice-cover in winter. Water temperature, conductivity and flow for this period are shown in Figure A3. Water temperature varied from 12 to 18 ºC in summer and cooled to 0-5 ºC in winter.

The conductivity of the Columbia River at Donald varied significantly over the year. In winter the flow was more saline with a conductivity of 300-350 µS/cm. At the start of freshet in spring, the conductivity decreased rapidly to 150-200 µS/cm, about half of the winter value. During freshet, the contribution of more saline groundwater to the river is diluted by fresh snowmelt and rain. In the fall the conductivity gradually increased as the freshet flow declined. A similar pattern was seen for the Beaver, Goldstream and Illecillewaet rivers (Pieters et al. 2013b). This seasonal change in the conductivity of the inflow will assist in identifying water masses as discussed below.

3.1 Kinbasket Reservoir

May 2011 Line plots for the five monthly surveys of Kinbasket Reservoir are shown in Figures B1-5. In May 2011, it is apparent that flow through the plumbing had not been established until 95 m and 22 m in the casts at K1fb and Kwo1, respectively (Figure B1b). From the remaining three casts, the surface temperature varied from 5 to 8 ºC. There was no clearly defined surface mixed layer; instead there was a broad thermocline, which extended from the surface to around 20 m. During this time, the outlet from Kinbasket reservoir was 38 m below the surface, as marked in Figure B1.

The conductivity varied from ~150 µS/cm near the surface to ~180 µS/cm at depth through most of the reservoir except for the Columbia reach (station K3co, black), which had a higher conductivity of ~200 µS/cm, Figure B1c. The station at K3co is located at the former Kinbasket Lake on the Columbia Reach, and the conductivity of the water below 80 m remained distinctly different (Figures B1-5) and relatively unchanged (Figure B8) throughout the summer. In Canoe Reach (green, Figure B1c), slightly reduced conductivity near the surface suggests low-conductivity inflow.

Dissolved oxygen was high (>8 mg/L) throughout the reservoir (Figure B1e). Below 20 m the reservoir was very clear (high light transmission), while in the top 20 m the water was a little less clear (slightly reduced light transmission, Figure B1d). The nominal concentration of chlorophyll was generally low (< 1 ug/L) and confined to the top 20 m (Figure B1g). The 1% light level determined from PAR is marked with dashed lines; the 1% light level varied from 15 to 30 m, just below the chlorophyll layer.

June 2011 In June, additional casts were collected along the length of the reservoir. Of these, three casts were identified as having poor flow through the plumbing; these casts should be ignored. In June, surface temperature varied from 8 to 13 ºC (Figure B2b). As in May, there was a broad thermocline, now extending from the surface to 40 m depth. The stratification is reduced in the top 5 to 10 m of some of the casts, suggesting some surface mixing. In conductivity, the most notable feature is a strong gradient along the basin, with lower conductivity in the Canoe Reach and higher conductivity in the Columbia Reach (Figures B2c).

In June, turbidity in the top 40 m increased from that in May, including layers of very high turbidity (low light transmission) in Wood Arm. Oxygen remained high (Figure

B2e,f) and chlorophyll values were a little higher than in May with most peaks around 1 μg/L (Figure B2g)with the exception of a few higher peaks in Wood Arm.

July 2011 The temperature at the surface warmed to ~15 ºC at all stations, and the broad thermocline extended to about the depth of the outlet at 55 m (Figure B3b). The overall conductivity of the surface layer continued to decline (Figure B3c). Wood Arm, Columbia Reach and Canoe Reach all showed layers of turbidity between 10 and 40 m (Figure B3d). The chlorophyll layer around 10 m had increased slightly over that in June (figure B3g).

The solubility of oxygen is sensitive to temperature, decreasing as temperature increases. As a result, the concentration of oxygen in the warmer surface layer was slightly lower (Figure B3e). To remove the effect of temperature, dissolved oxygen is also plotted as percent saturation in Figure B3f. The saturation of dissolved oxygen was highest at the surface and decreased to 75% at depth, indicating that the water was well oxygenated as would be expected for an oligotrophic system.

August 2011 The temperature, conductivity and oxygen in the cast at the fore bay (K1fb, red) suggests problems with flow through the plumbing and will be ignored. For the other casts, the temperature and conductivity structure remained much the same as in July. Layers of turbidity (low light transmission), likely the result of inflow, were observed in Wood Arm around 40 m depth.

October 2011 By late October, the surface layer had cooled to 11-13 ºC and mixed to a depth of about 40 m over much of the reservoir. Below 40 m, the broad thermocline extended to 63 m depth and the temperature was similar across the reservoir (Figure B5b). A layer of high turbidity was still observed in Wood Arm (Figure B6d).

Seasonal changes Seasonal changes at the Forebay (K1fb), Middle (K2mi), Columbia (K3co), Canoe (Kca1) and Wood (Kwo1) stations, are shown in Figures B6 to B10, respectively. To account for the increase in the water level, the casts are plotted relative to full pool, 754.4 mASL. In each case, changes in temperature and conductivity below 60 m are small. Oxygen below 60 m declines only slightly (≤1 mg/L) over the summer.

Contour plots The profiles along the length of Kinbasket Reservoir are shown as contour plots in Figures C1-5. Each contour shows Canoe Reach (Kca1), the main pool (K2mi) and Columbia Arm (K3co), with additional profiles for the survey of 8 – 9 June 2011 (Figure C2). Contour plots highlight variations along the reservoir; however, care must be taken when interpreting features between the stations marked. Note, the black line does not give the bathymetry along the thalweg, but simply connects the maximum depth from the sounder at each station.

The most detailed contour plot was that for 8 – 9 June 2011 when many additional casts were collected (Figure C2); this figure will be the focus of the discussion as follows. As already noted, the temperature stratification was relatively uniform along the length of the reservoir at this time (Figure C2a).

The conductivity shows a marked gradient across the basin. In Canoe Reach the conductivity is much lower than in the Columbia Reach (Figure C2b), consistent with the lower conductivity of tributaries to the Canoe Reach (Pieters et al. 2011a). In addition there is a vertical gradient; through Canoe Reach and even into the Columbia Reach, the conductivity of the top 25 m is reduced over that of the deeper water (Figure C2b).

Low light transmission shows regions of high turbidity in the top 30 m. High turbidity occurs at the south end of the Columbia Reach, possibly from the Columbia River at Donald (Figure C2c). There are also lenses of turbidity in the Canoe Reach, likely originating from local tributaries. Dissolved oxygen is high throughout the reservoir, with a slight reduction at the surface due to warmer temperatures (Figure C2d). Chlorophyll is generally low, with peaks <1.4 μg/L in the top 20 m, just above the 1% light level (marked by black bars).

3.2 Revelstoke Reservoir

May 2011 The surface temperature varied from 7 to 9 ºC, below which a broad thermocline extended to about 30 m (Figure D1b). The conductivity of the top 30 m was similar or slightly less than that of the water below (Figure D1c), while the turbidity was slightly higher in the top 30 m at some stations (Figure D1d), both likely the result of freshet inflow. Dissolved oxygen was high with 80 to 90% saturation throughout (Figure D1f). Chlorophyll fluorescence shows small peaks up to ~1.1 μg/L above the depth of the one percent light level (Figure D1g).

June to October 2011

In June, July and August, the surface temperature varied from 13 to 15 ºC (Figure D2-D4) and the conductivity of the top 30 m remained generally lower throughout this time. However, in August, water with increased conductivity (~140 μS/cm) was seen at all depths at the upper station and between 20 and 60 m at the mid station (Figure D5c). In September, the influence of this higher conductivity water is seen between 20 and 60 m at all stations (Figure D6c), and this continues in mid-October (Figure D7c). This higher conductivity water is primarily outflow from Mica dam, forming an interflow. The interflow can be seen in the layer of relatively uniform temperature between 20 and 50 m (Figure D6b). By mid October, surface cooling has mixed the surface layer to 15 m, almost to the top of this interflow layer (Figure D7b,c).

The interflow can also be seen in the contour plots. In July, the top 50 m of Revelstoke Reservoir is fresher (Figure E4b). In August and September, higher conductivity water at 30 m can be seen progressing to the outlet (Figures E5b and E6b), suggesting that the inflow from Mica short circuits through Revelstoke Reservoir.

Comparison of casts in the fore bay (Figure D8) indicate slight changes to the deep water (> 60 m) through the summer, with a slight increase in temperature and a decrease in conductivity, likely due to a small degree of exchange with overlying water. The decrease in oxygen over the summer was ~1 mg/L.

4. Discussion

Trophic Status

As an indicator of trophic status, Wetzel (2001) gives the following general ranges for chlorophyll concentrations:

- 0.05-0.5 µg/L ultraoliogotrophic;
- 0.3-3 µg/L oligotrophic; and
- 2-15 µg/L mesotrophic.

The low concentrations of chlorophyll in both Kinbasket and Revelstoke Reservoirs (<2 nominal µg/L) are consistent with oligotrophic conditions.

The reduction in hypolimnetic oxygen over the summer was low in both Kinbasket and Revelstoke Reservoirs (≤1 mg/L). The use of hypolimnetic oxygen demand as an indicator of trophic status comes with a number of caveats (Wetzel 2000), including the problem of decomposing allochthonous debris. The decrease in oxygen in Kinbasket and Revelstoke Reservoirs is consistent with oligotrophy, and are comparable to those of Harrison Lake (0.3 mg/L, Pieters et al. 2002) and Coquitlam Reservoir (1.5 mg/L, Pieters et al. 2007).

Circulation and nutrients

Both Kinbasket and Revelstoke Reservoirs display unusually broad and deep thermoclines. Typically, thermal structure in summer is dominated by surface heat fluxes and wind. The thermal structure observed in Kinbasket and Revelstoke Reservoirs suggests that the deep outlets (35 to 64 m in Kinbasket and 28 m in Revelstoke), high inflow and short residence time (< 1 yr) are also important.

The variation in the conductivity of the tributary inflows provides a tracer to identify water masses. Both Kinbasket and Revelstoke Reservoirs have a surface layer of reduced conductivity, which suggests surface waters are composed largely of freshet inflow.

Based on the given data we can tentatively sketch the circulation of Kinbasket and Revelstoke Reservoirs and speculate on the supply of nitrate. As described in Pieters et al. (2013a), late spring and summer can be broken into two periods based on flow: May and June and July to September. In the first period of May and June, the top 30 m of Kinbasket Reservoir is filled with freshet inflow and there is little outflow from Mica Dam. The lack of outflow from Mica Dam means that the circulation in Revelstoke Reservoir is dominated by local inflow during this time (Figure A2d). During the second period of July to September, the tail of the freshet is passed through Mica and this water appears to short circuit through Revelstoke Reservoir as an interflow directly to the outlet. Nutrients from Mica may pass below the photic zone until fall cooling mixes the interflow into the surface layer later in October.

Consider inflow nitrate, which like conductivity, varied widely through the freshet (Pieters et al 2013b). At the start of freshet, inflow nitrate concentrations are higher and these, along with nitrate in the lake may supply spring productivity. However, the nitrate concentrations in the freshet inflows decline rapidly at the same time as the reservoir fills. The low conductivity of the water above the photic zone in July suggests that nitrate supply will be reduced through much of the first period. At the start of the second period, deep cold water is released from Kinbasket Reservoir. Based on conductivity, the initial water released from Mica may have relatively higher nitrate concentrations. However, this cold water plunges, and appears to short circuit to the outlet of Revelstoke Dam.

Also of interest is the way in which higher conductivity, and potentially higher nutrient water is mixed through the reservoir in winter, and to what extent this contributes to the initial productivity in spring.

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References

Fleming, J.O. and H.A. Smith. 1988. Revelstoke Reservoir aquatic monitoring program, 1986, progress report. B.C. Hydro Report No. ER 88-03.

Pieters, R., R. Pawlowicz, and G. A. Lawrence. 2002. Harrison Lake Hydrographic Surveys, November 2000 – April 2002. Prepared for Dayton and Knight Ltd. and the Fraser Valley Regional District, September 2002, 102 pp.

Pieters, R., L.C. Thompson, L. Vidmanic, S. Harris, J. Stockner, H. Andrusak, M. Young, K. Ashley, B. Lindsay, G. Lawrence, K. Hall, A. Eskooch, D. Sebastian, G.

Scholten and P.E. Woodruff. 2003. Arrow Reservoir fertilization experiment, year 2 (2000/2001) report. RD 87, Fisheries Branch, Ministry of Water, Land and Air Protection, Province of British Columbia.

Pieters, R., Lawrence, G., Pawlowicz, R. and Rahmani, M. 2007. Lake Processes and Turbidity, Coquitlam Reservoir 2004 & 2005. Prepared for Utility Analysis and Environmental Management Division, Policy and Planning Department, Greater Vancouver Regional District. March 2007, 143 pp.

Pieters, R., and G. Lawrence. 2010. CTD Surveys, Kinbasket and Revelstoke Reservoirs, 2008. University of British Columbia. 42 pp. Appendix 3 in BC Hydro. 2010. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 1 (2008). BC Hydro, Water Licence Requirements. Study No. CLBMON-3.

Pieters, R., H. Keller and G. Lawrence. 2011a. Tributary Water Quality, Kinbasket and Revelstoke Reservoirs, 2009. 52 pp. Appendix 2 in BC Hydro. 2011. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 2 (2009). BC Hydro, Water Licence Requirements. Study No. CLBMON-3.

Pieters, R., and G. Lawrence. 2011b. CTD Surveys, Kinbasket and Revelstoke Reservoirs, 2009. 54 pp. Appendix 3 in BC Hydro. 2011. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 2 (2009). BC Hydro, Water Licence Requirements. Study No. CLBMON-3.

Pieters, R., and G. Lawrence. 2012. CTD Surveys, Kinbasket and Revelstoke Reservoirs, 2010. 61 pp. Appendix 3 in Bray K. 2012. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2010). BC Hydro, Environment. Study No. CLBMON-3. 274pp.

Pieters, R., and G. Lawrence. 2013a. Hydrology of Kinbasket and Revelstoke Reservoirs, 2011. 53 pp. Appendix 1 in Bray K. 2013. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2011). BC Hydro, Environment. Study No. CLBMON-3.

Pieters, R., and G. Lawrence. 2013b. Tributary Water Quality, Kinbasket and Revelstoke Reservoirs, 2011. 34 pp. Appendix 2 in Bray K. 2013. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2011). BC Hydro, Environment. Study No. CLBMON-3.

Watson, T.A. 1985. Revelstoke Project Water Quality Studies 1978-1984. B.C. Hydro Report No. ESS-108, Jul 1985. 237pp.

Wetzel, R.G. 2001. Limnology. Academic Press, San Diego.

Figure A1 Map showning approximate location of profile stations

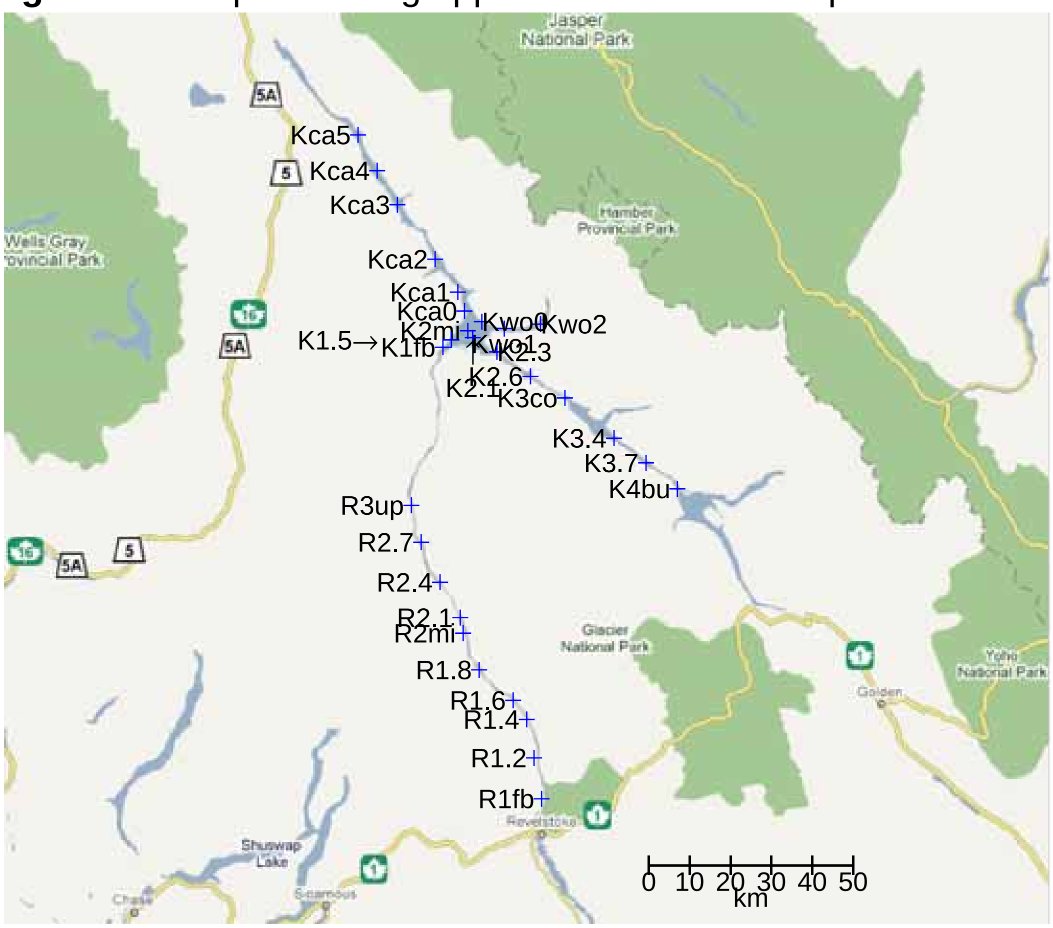


Figure A2 Water level and flow, Kinbasket and Revelstoke Reservoirs, 2011

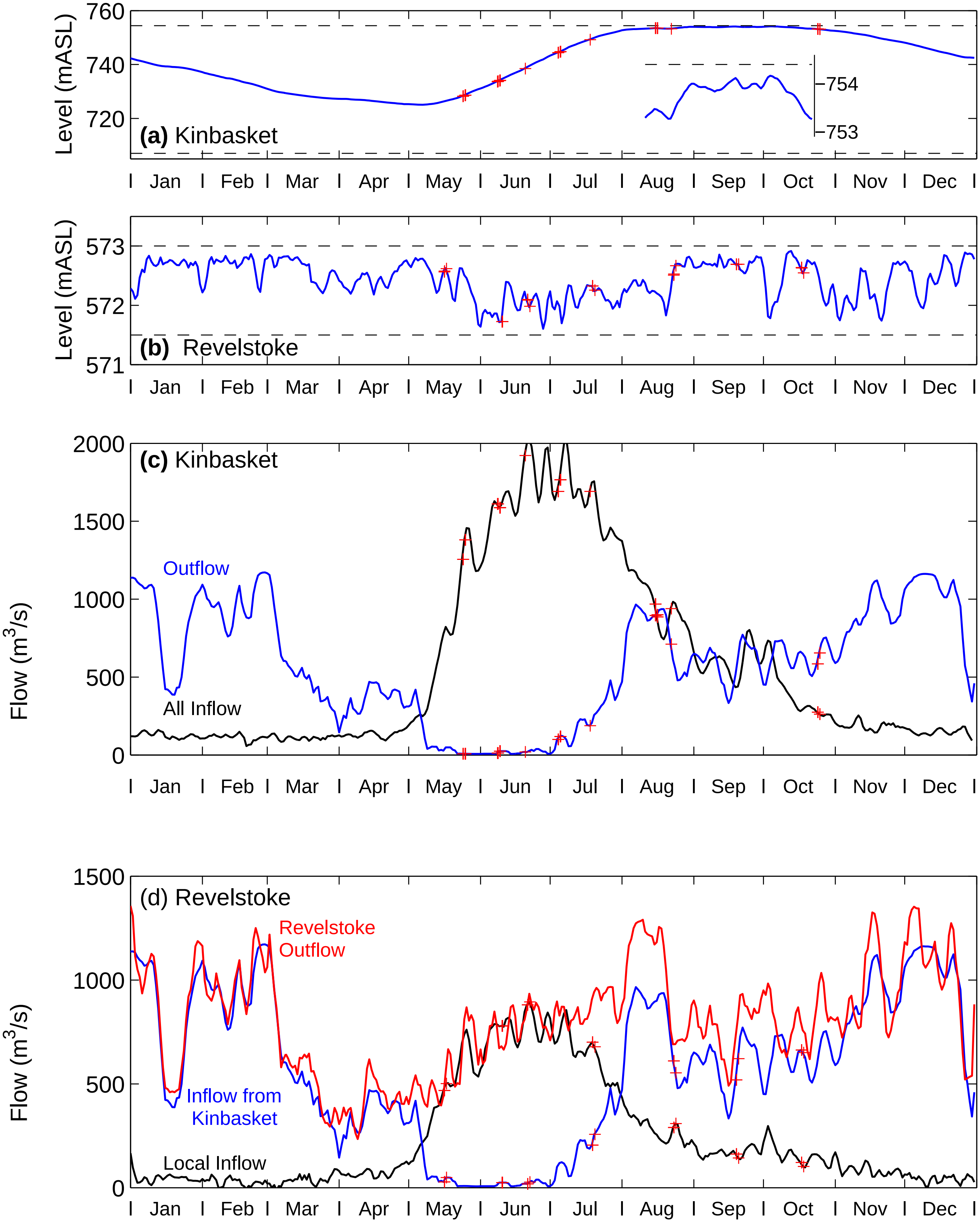
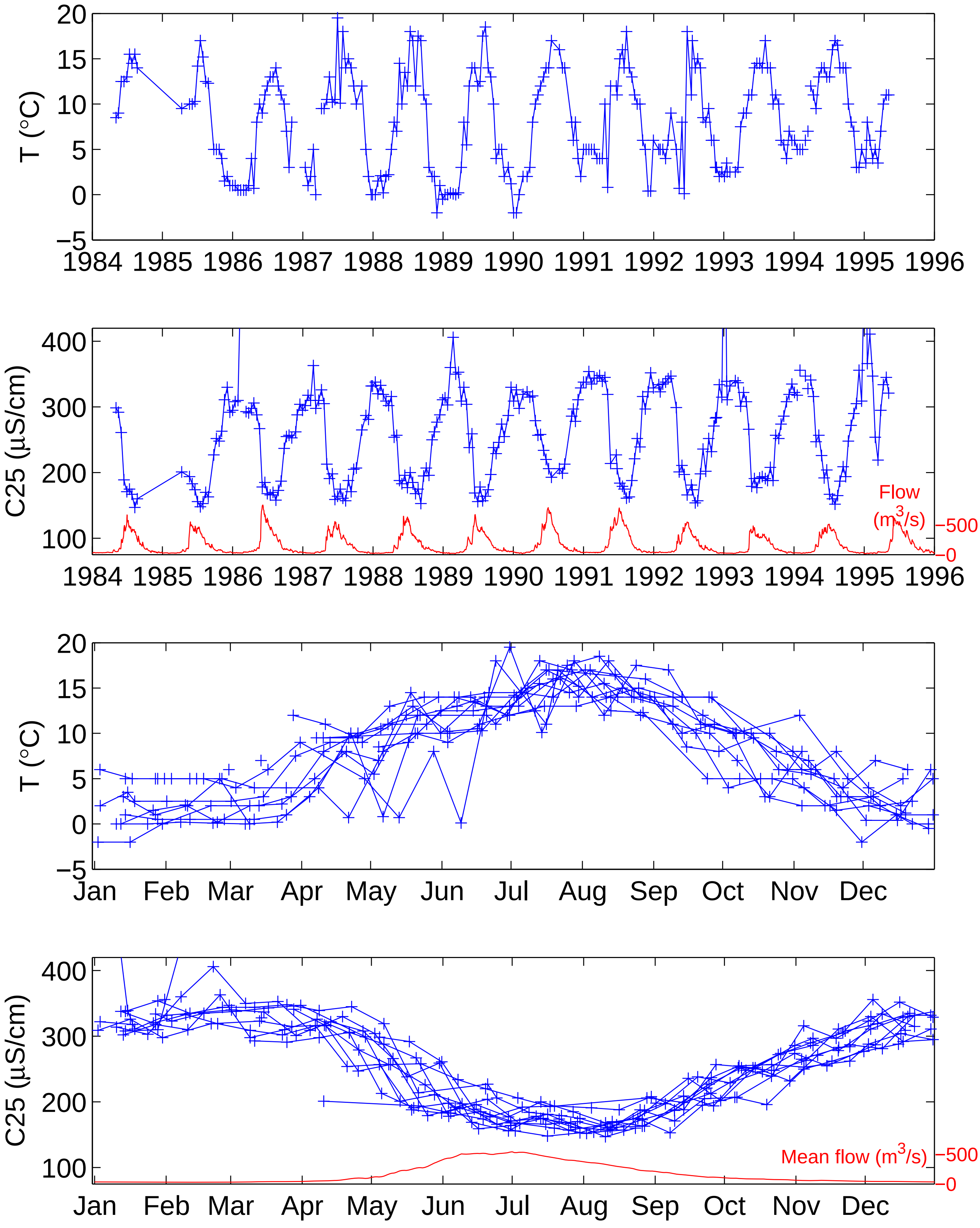
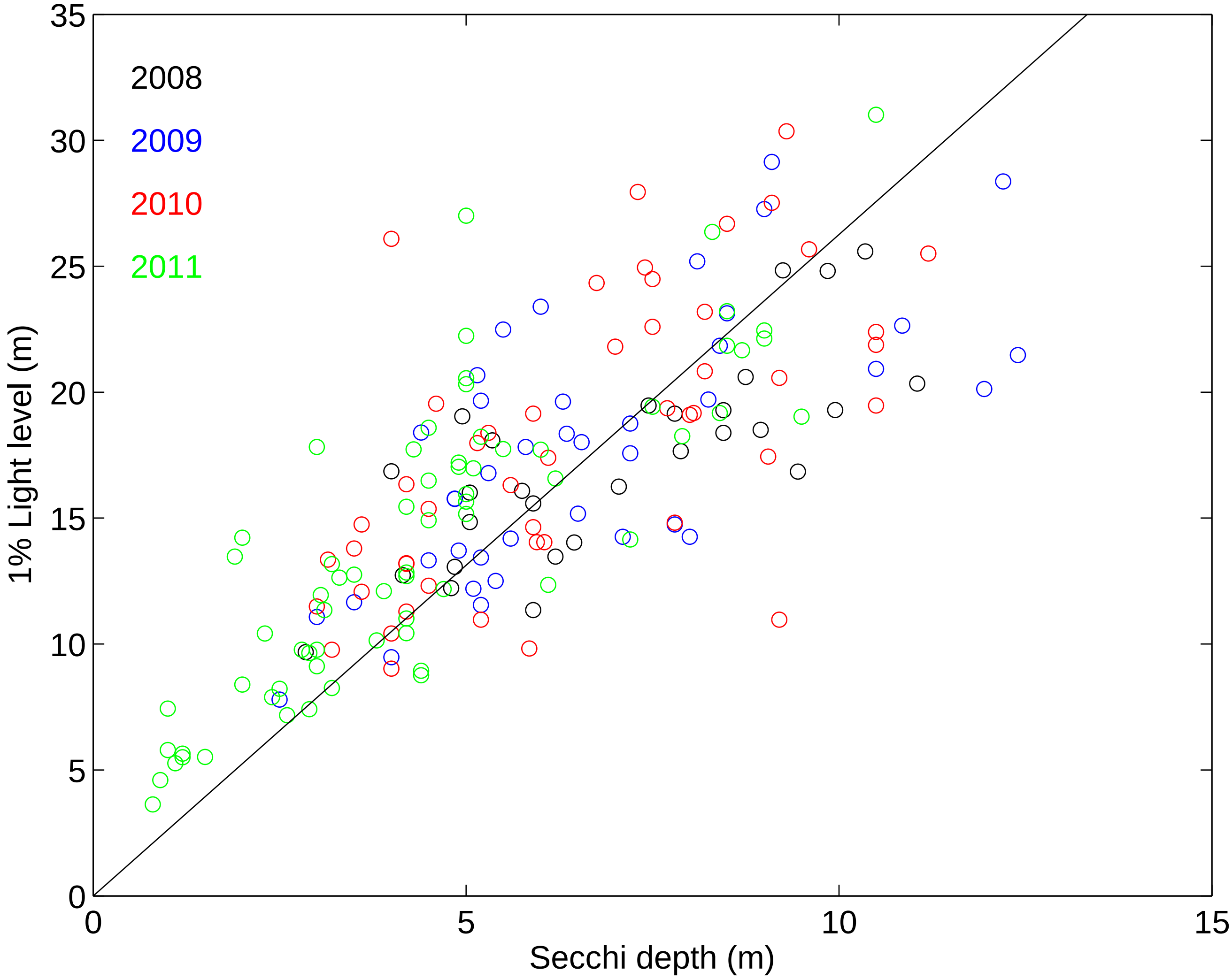


Figure A3 Columbia River at Donald, T and C25, 1984−1995



/ocean/rpieters/kr/flow/ecan/plot/plotcoldo.m fig= 1 2009−Jun−01

Figure A4 1% Light Level = 2.5 X Secchi Depth,



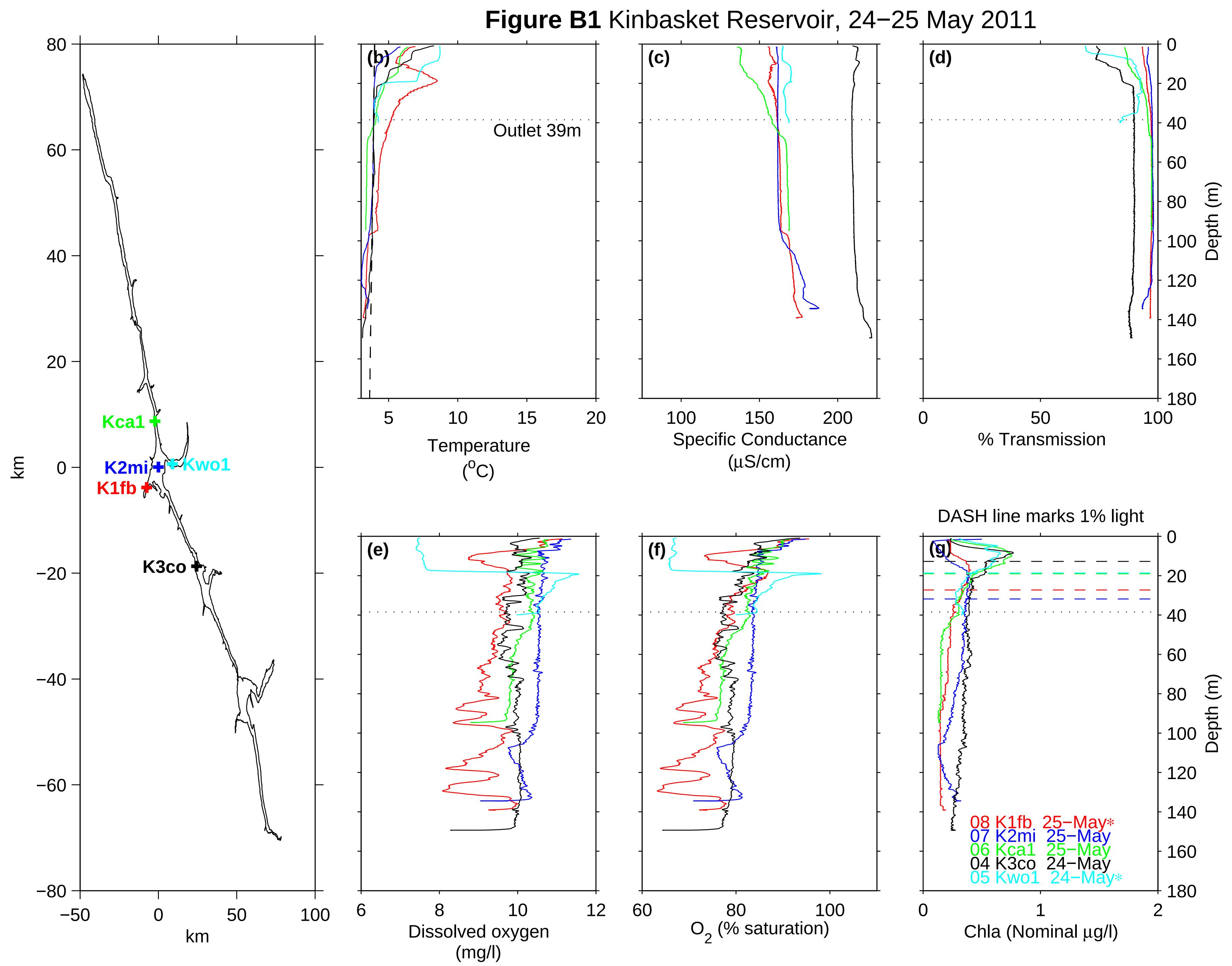


Figure B1 Kinbasket Reservoir, 24−25 May 2011
Kca1
K2mi
Kwo1
K1fb
K3co
km
(b)
(c)
(d)
Outlet 39m
Temperature (°C)
Specific Conductance (µS/cm)
% Transmission
Depth (m)
DASH line marks 1% light
(e)
(f)
(g)
Dissolved oxygen (mg/l)
O2 (% saturation)
Chla (Nominal µg/l)
08 K1fb 25−May*
07 K2mi 25−May
06 Kca1 25−May
04 K3co 24−May
05 Kwo1 24−May*

Figure B2 Kinbasket Reservoir, 8−9 Jun 2011

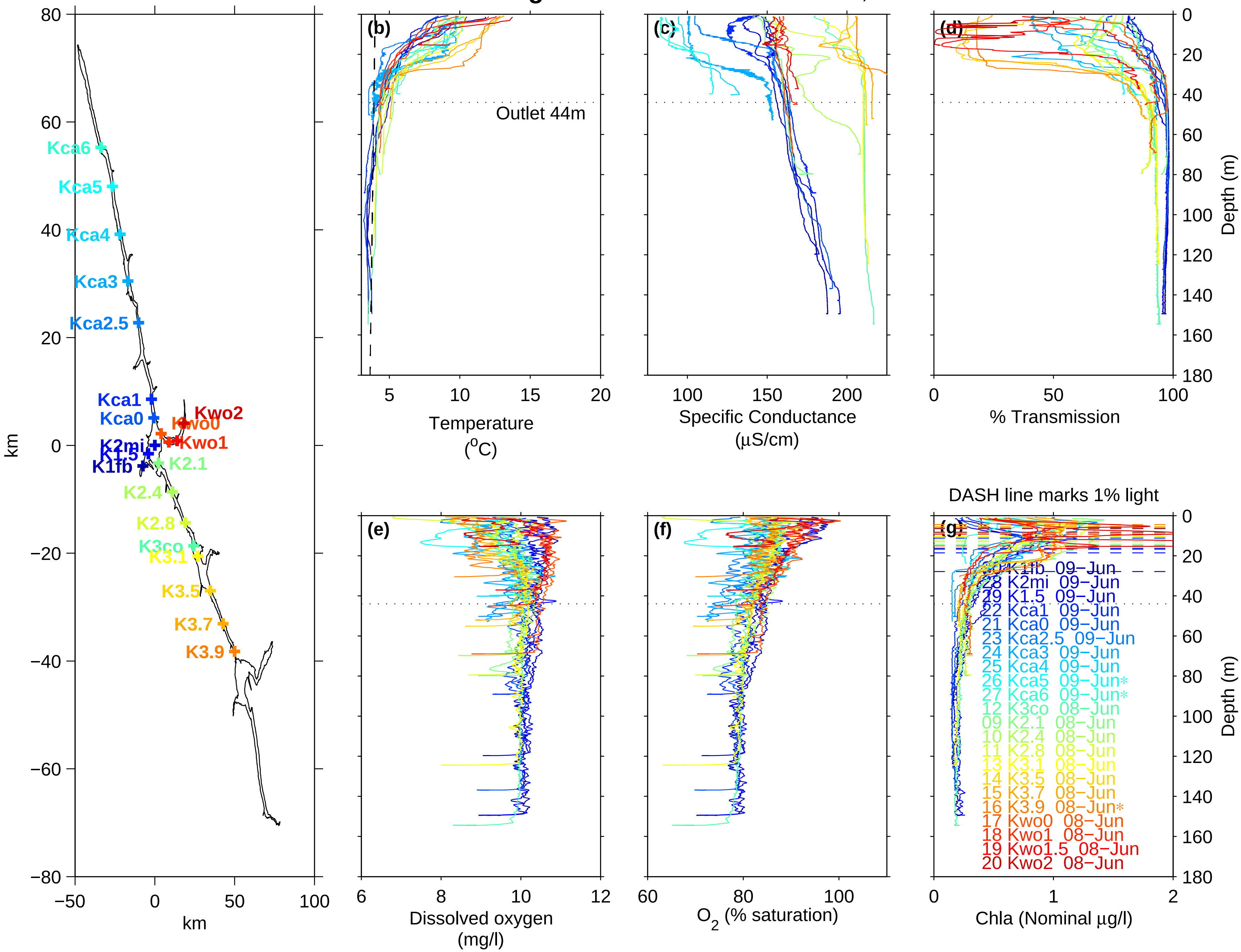


Figure B3 Kinbasket Reservoir, 4−5 Jul 2011

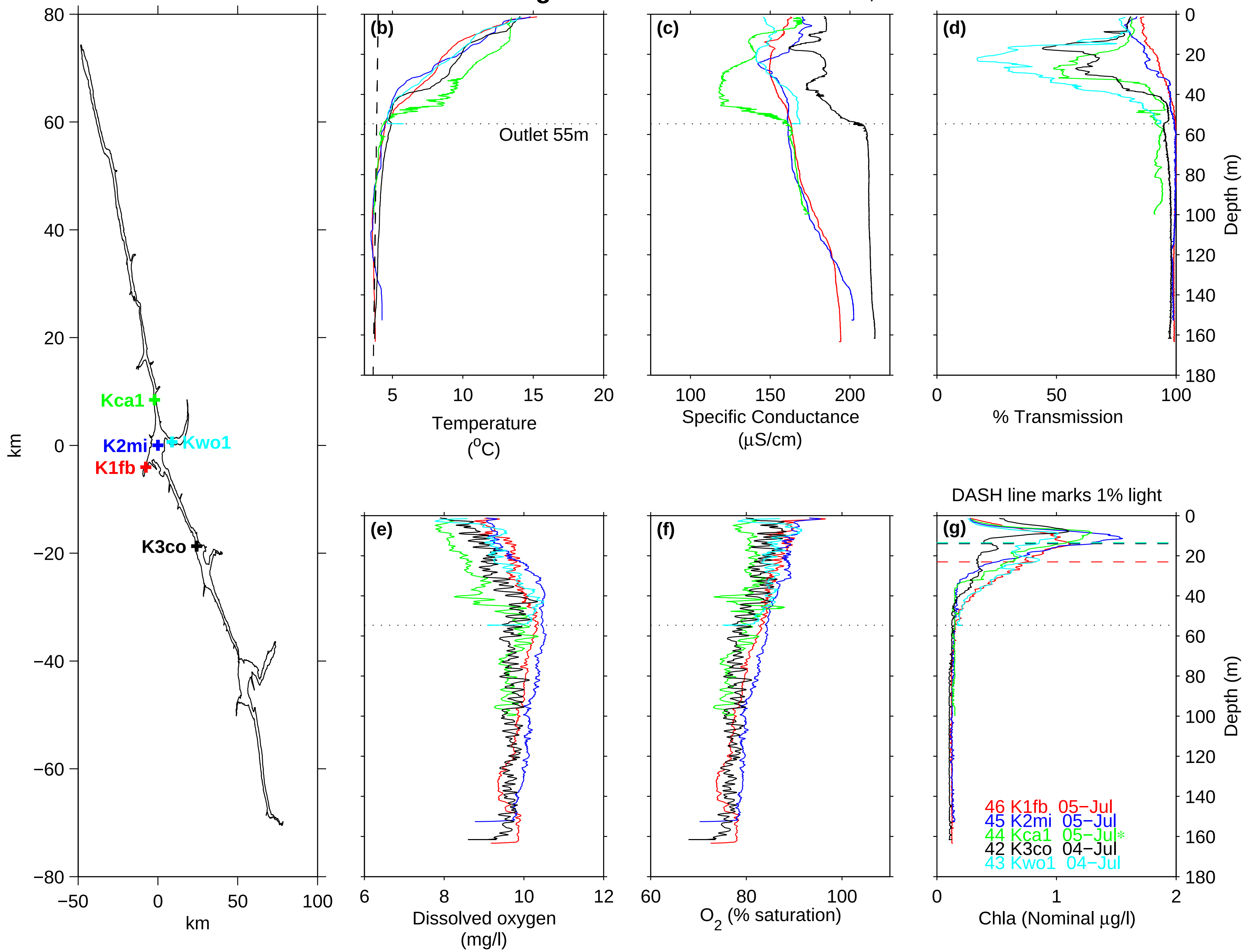


Figure B4 Kinbasket Reservoir, 15−16 Aug 2011

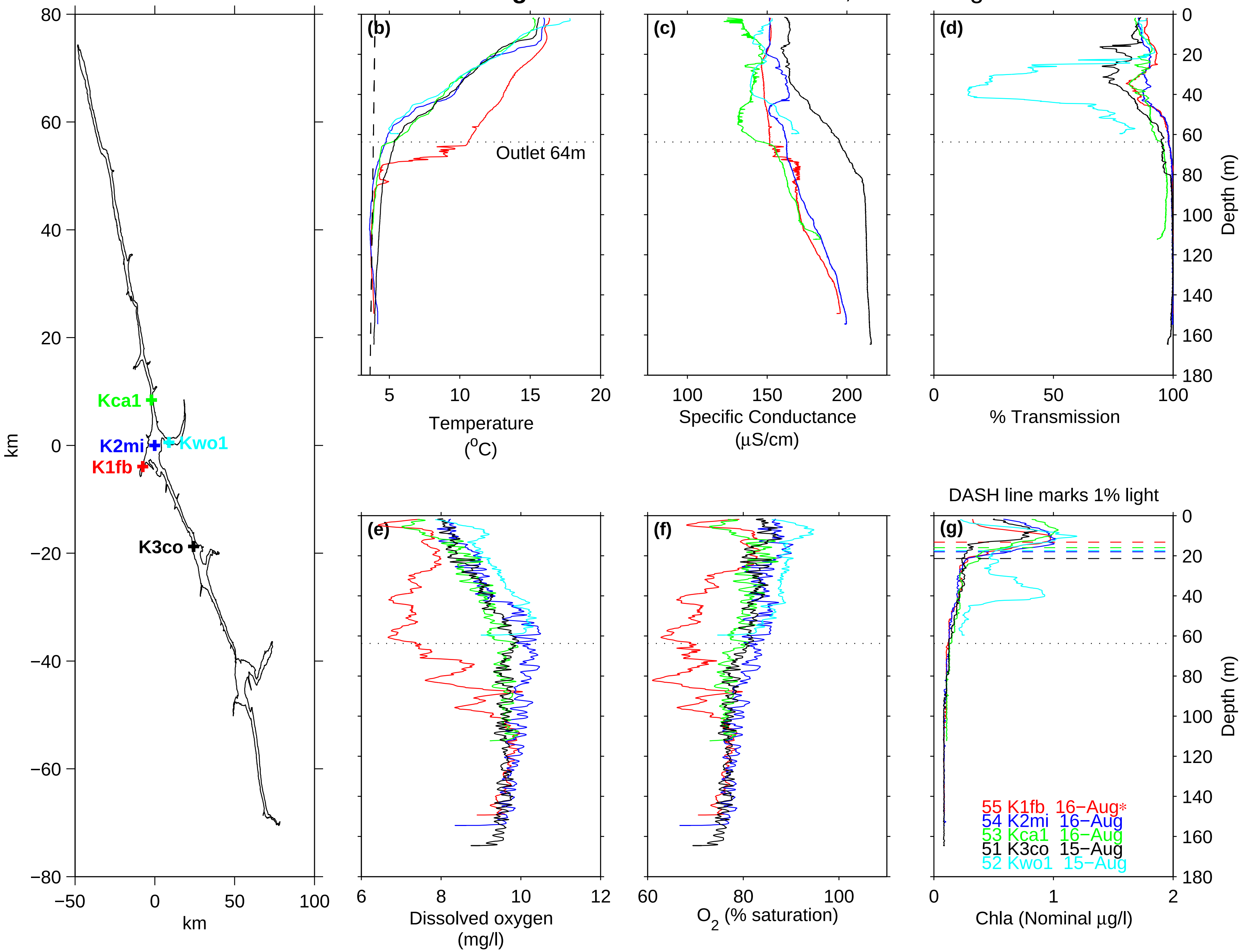
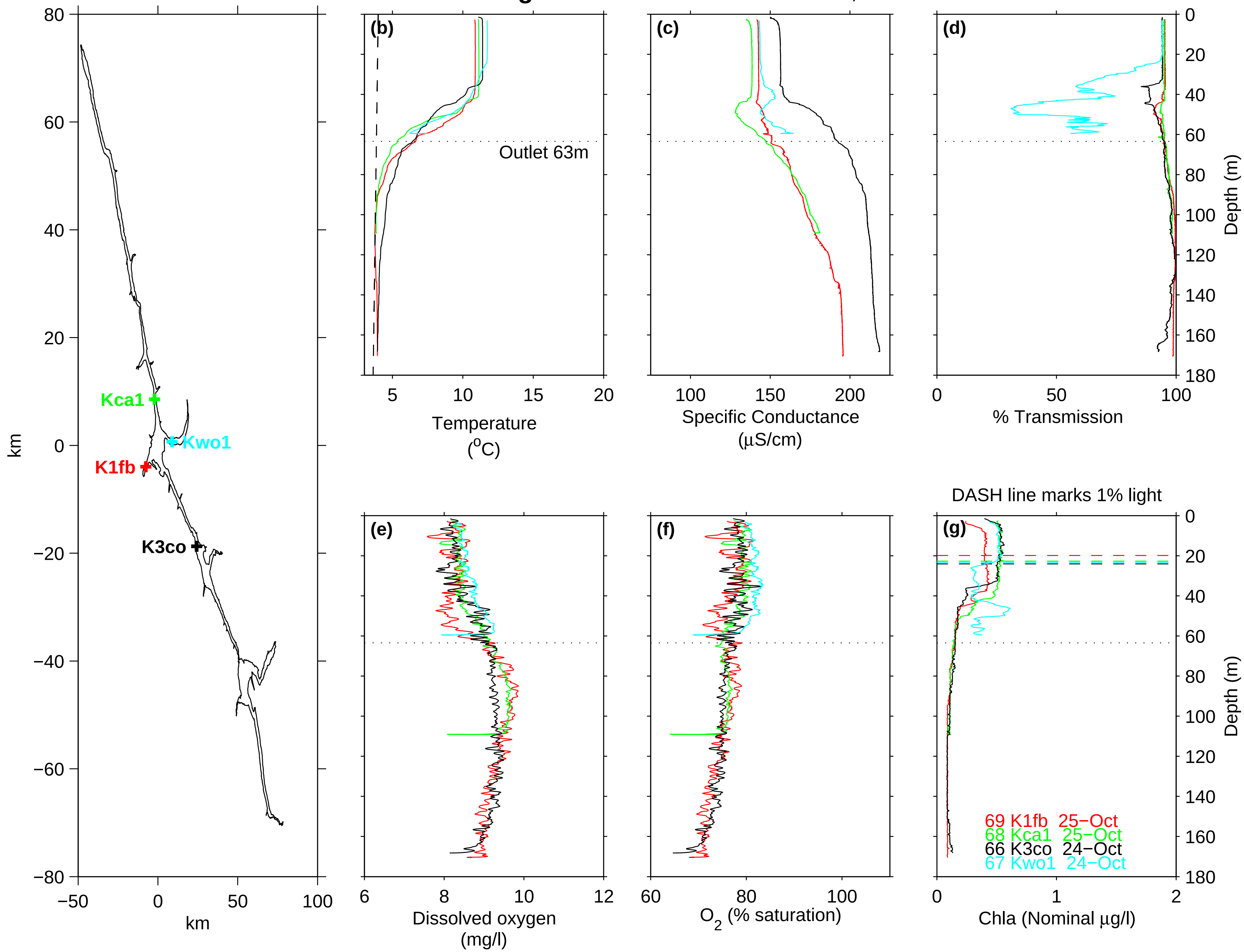


Figure B5 Kinbasket Reservoir, 24−25 Oct 2011



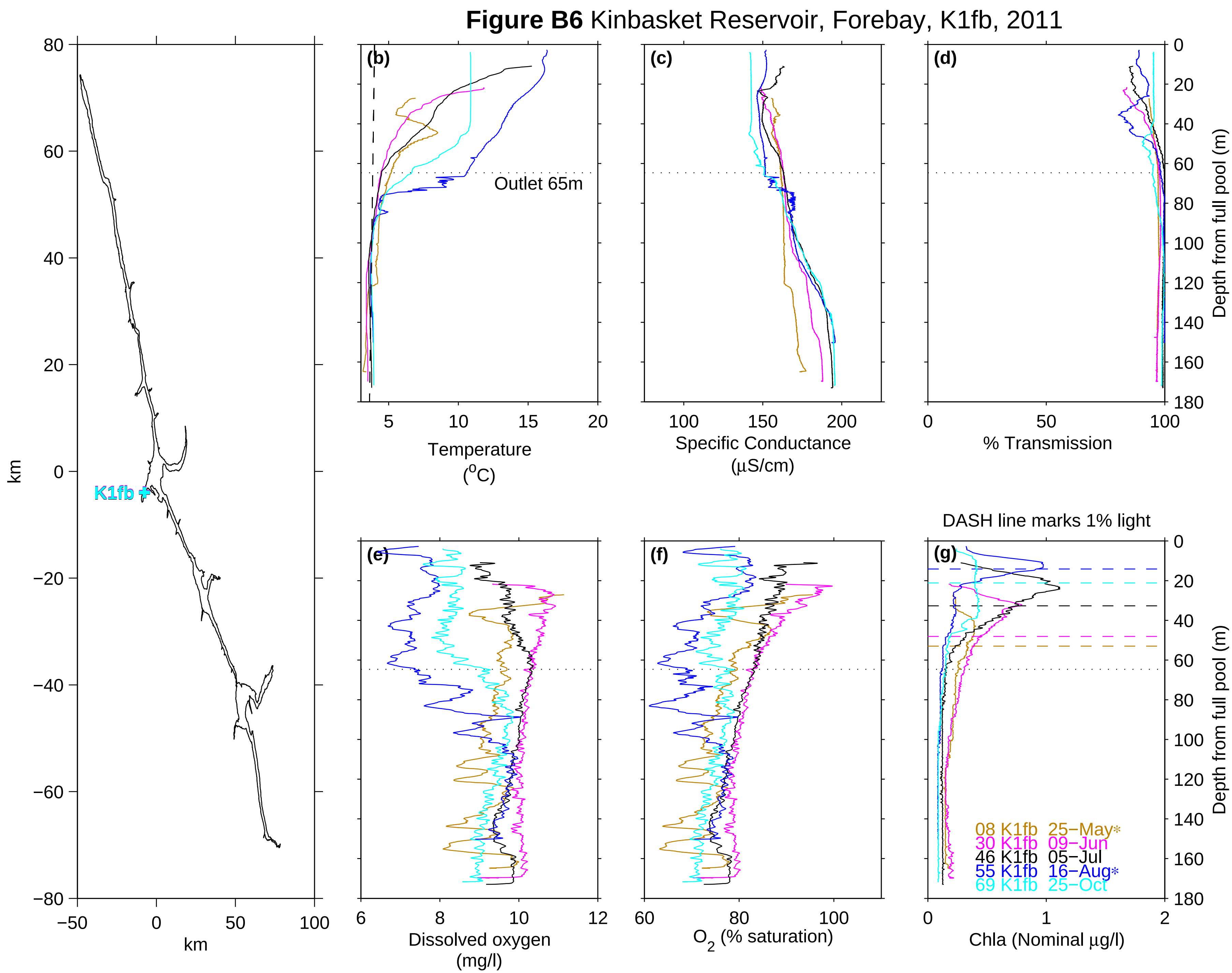
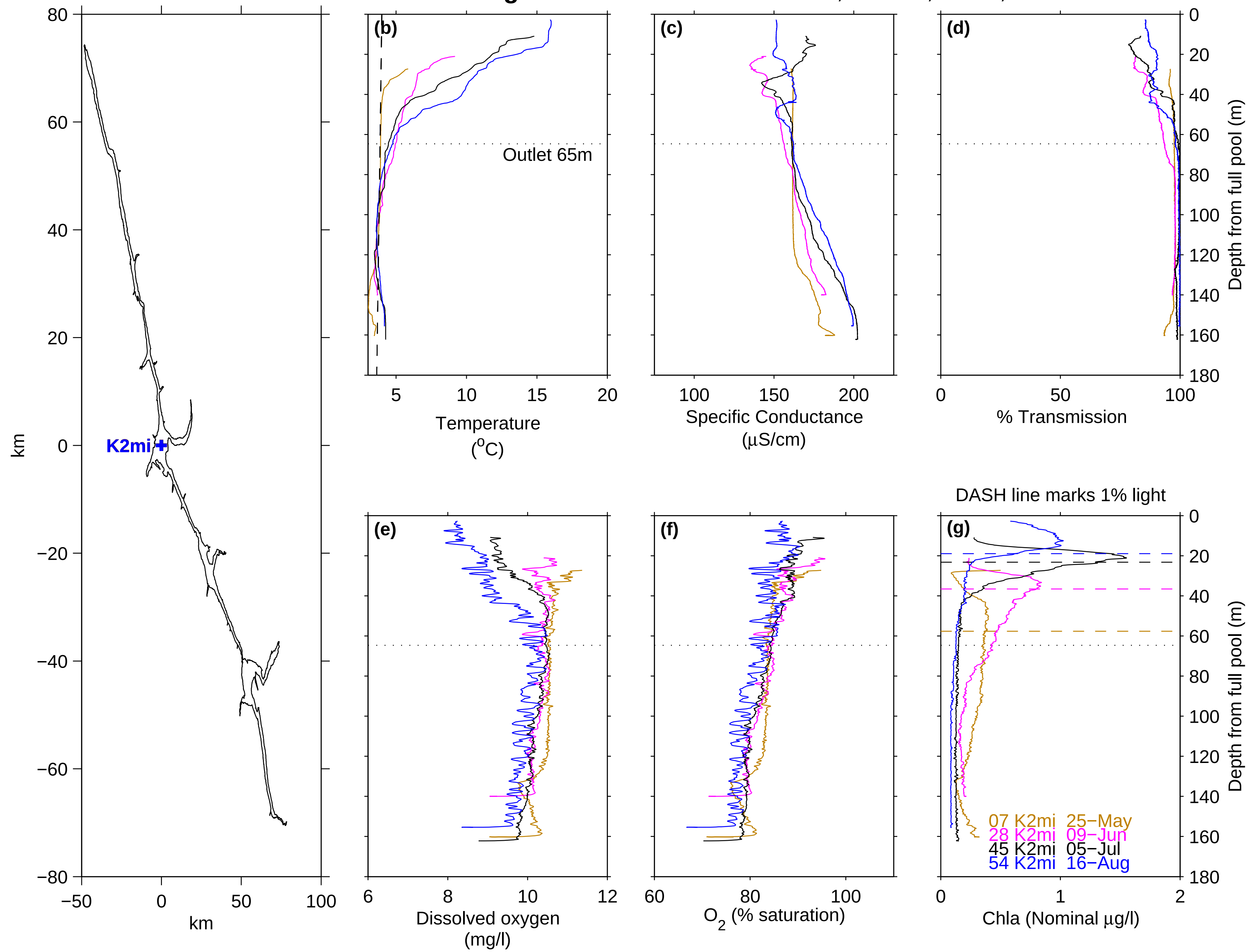


Figure B6 Kinbasket Reservoir, Forebay, K1fb, 2011
km
K1fb
(b)
Outlet 65m
Temperature
(°C)
(c)
Specific Conductance
(µS/cm)
(d)
% Transmission
Depth from full pool (m)
DASH line marks 1% light
(e)
Dissolved oxygen
(mg/l)
(f)
O2 (% saturation)
(g)
Chla (Nominal µg/l)
08 K1fb 25−May*
30 K1fb 09−Jun
46 K1fb 05−Jul
55 K1fb 16−Aug*
69 K1fb 25−Oct

Figure B7 Kinbasket Reservoir, Middle, K2mi, 2011



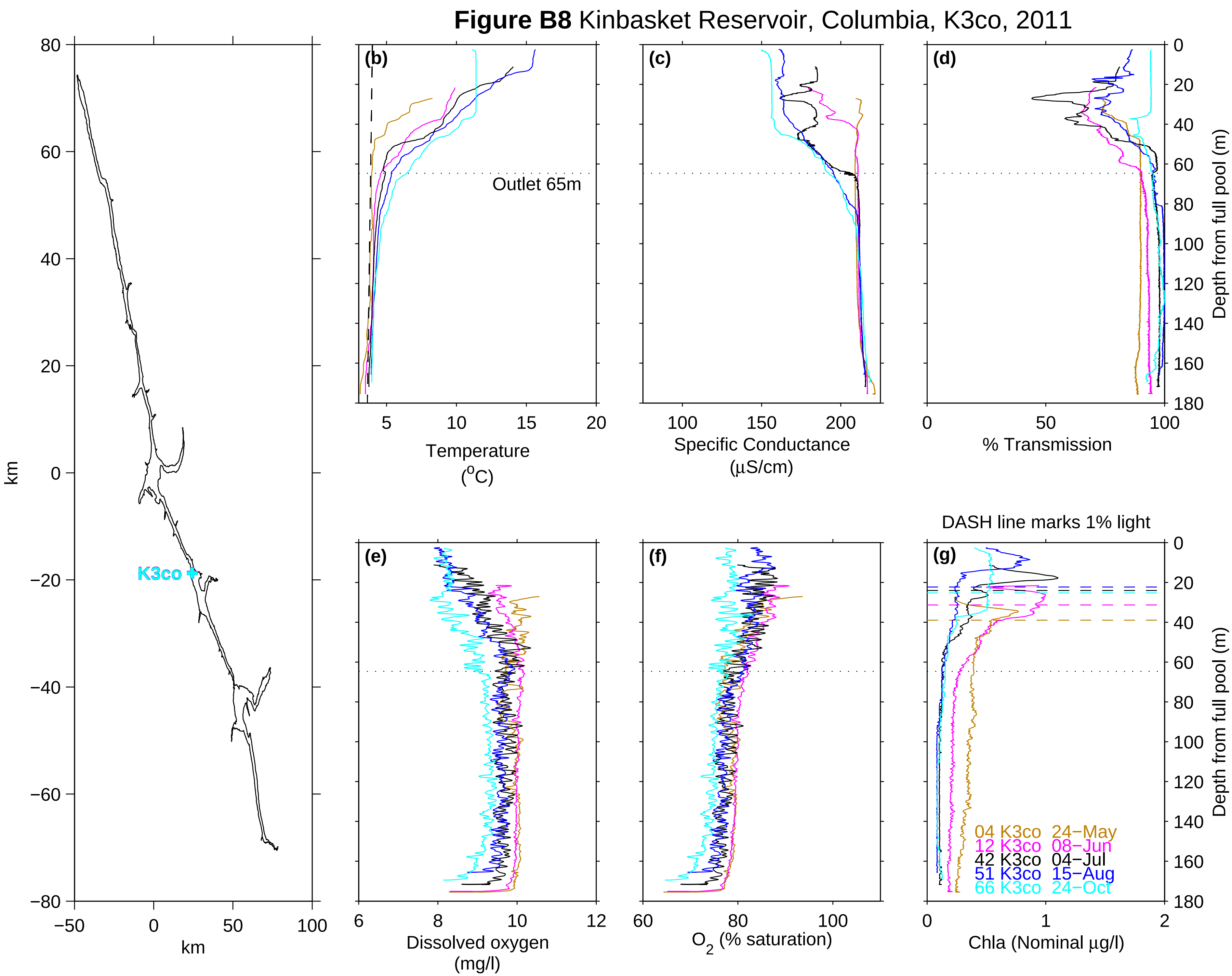


Figure B8 Kinbasket Reservoir, Columbia, K3co, 2011
K3co
km
(b)
(c)
(d)
Outlet 65m
Temperature
(°C)
Specific Conductance
(µS/cm)
% Transmission
Depth from full pool (m)
DASH line marks 1% light
(e)
(f)
(g)
Dissolved oxygen
(mg/l)
O2 (% saturation)
Chla (Nominal µg/l)
04 K3co 24−May
12 K3co 08−Jun
42 K3co 04−Jul
51 K3co 15−Aug
66 K3co 24−Oct

Figure B9 Kinbasket Reservoir, Canoe, Kca1, 2011

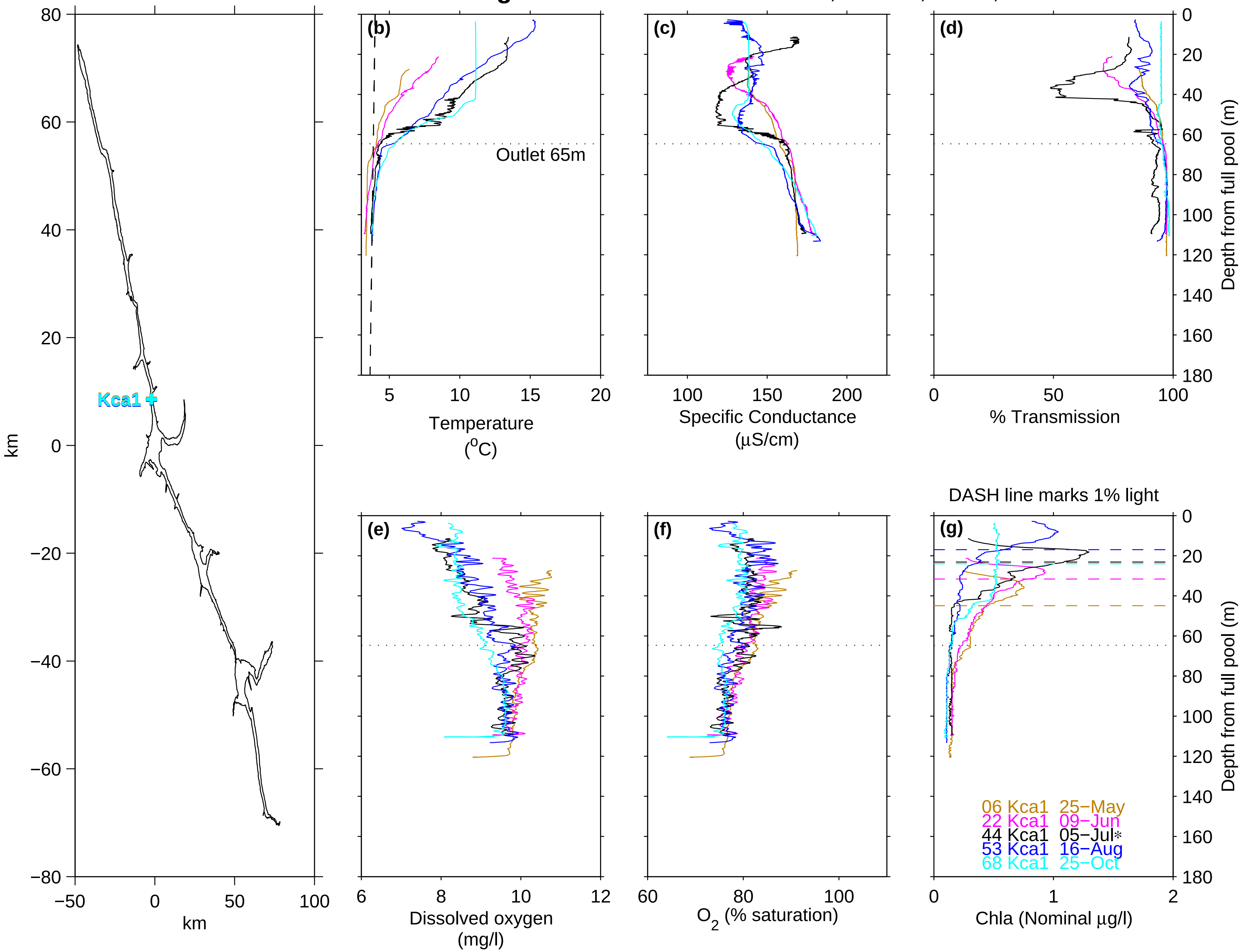
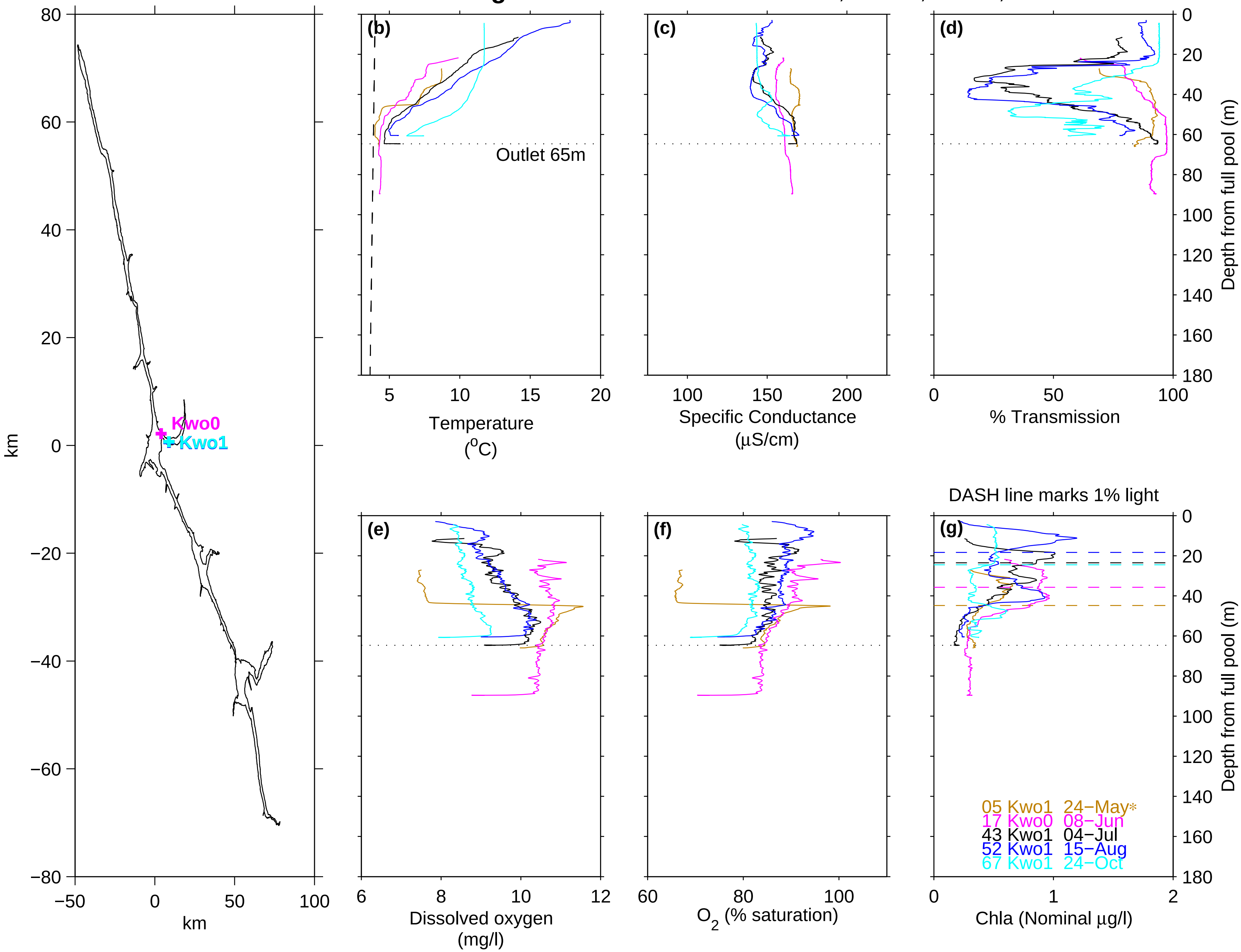


Figure B10 Kinbasket Reservoir, Wood, Kwo1, 2011



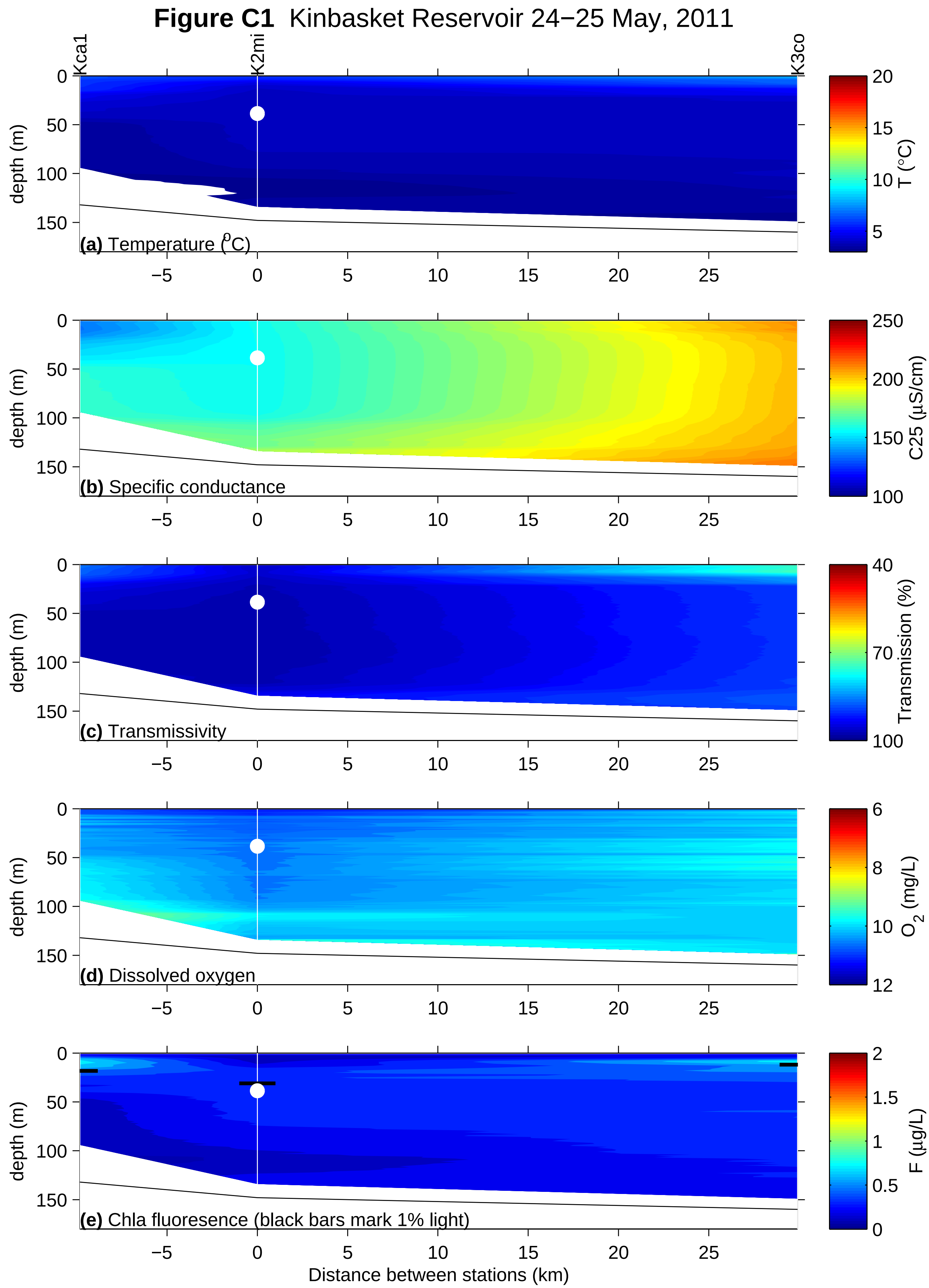
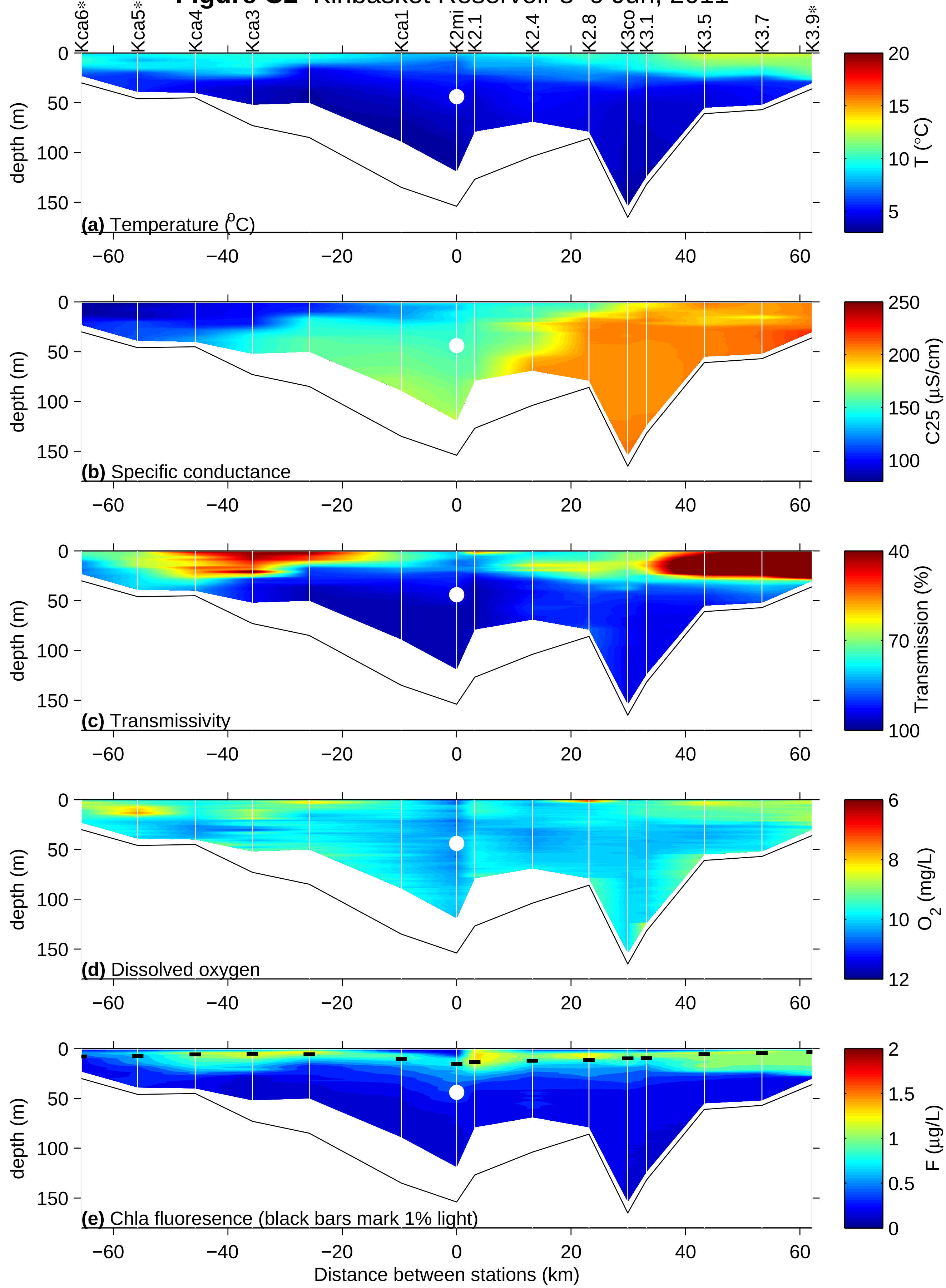


Figure C1 Kinbasket Reservoir 24−25 May, 2011
Kca1
K2mi
K3co
depth (m)
(a) Temperature (°C)
T (°C)
(b) Specific conductance
C25 (μS/cm)
(c) Transmissivity
Transmission (%)
(d) Dissolved oxygen
O2 (mg/L)
(e) Chla fluoresence (black bars mark 1% light)
F (μg/L)
Distance between stations (km)

Figure C2 Kinbasket Reservoir 8−9 Jun, 2011



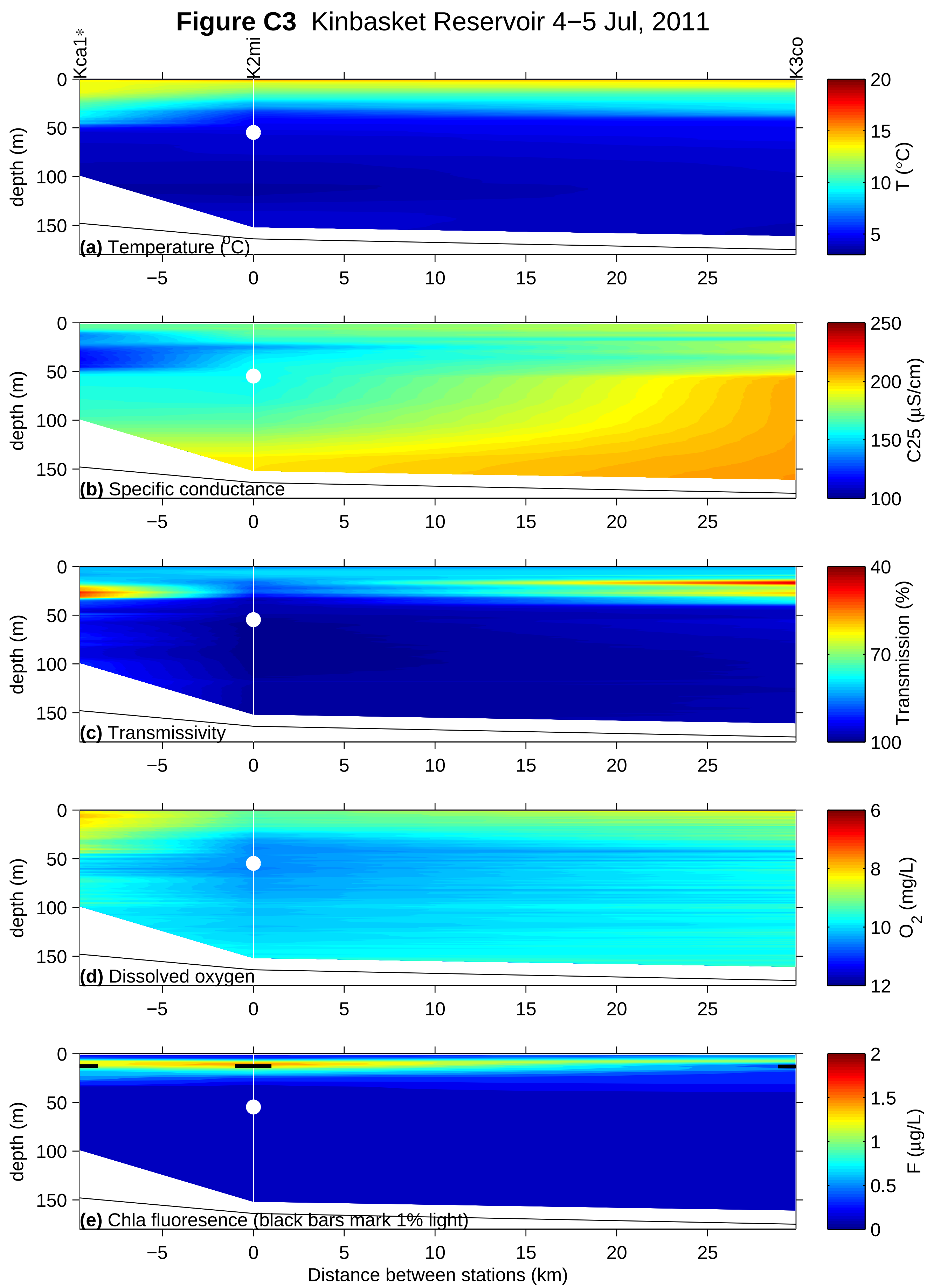


Figure C3 Kinbasket Reservoir 4−5 Jul, 2011
Kca1*
K2mi
K3co
depth (m)
(a) Temperature (°C)
T (°C)
(b) Specific conductance
C25 (μS/cm)
(c) Transmissivity
Transmission (%)
(d) Dissolved oxygen
O2 (mg/L)
(e) Chla fluoresence (black bars mark 1% light)
F (μg/L)
Distance between stations (km)

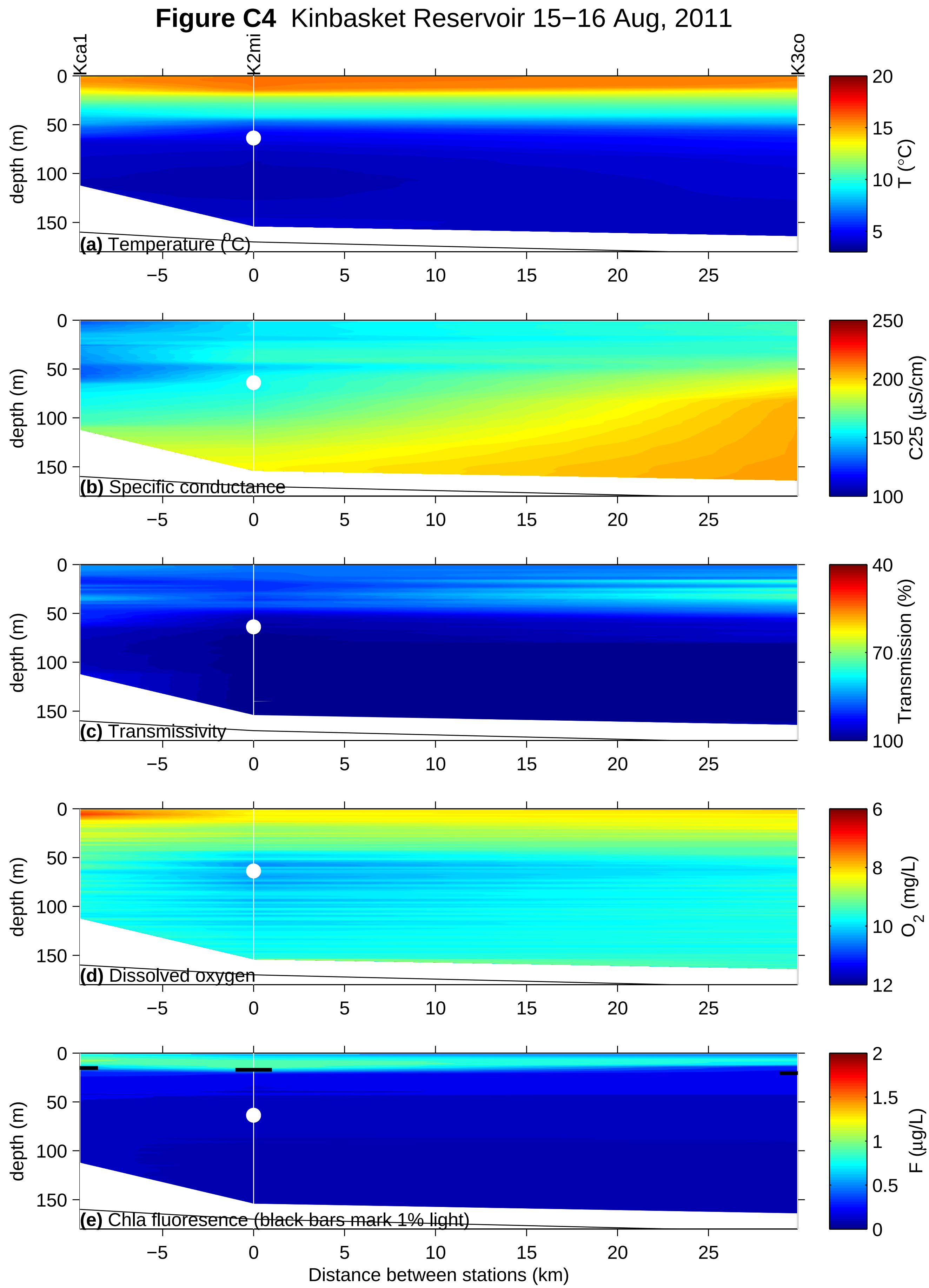


Figure C4 Kinbasket Reservoir 15−16 Aug, 2011
Kca1
K2mi
K3co
depth (m)
(a) Temperature (°C)
T (°C)
(b) Specific conductance
C25 (µS/cm)
(c) Transmissivity
Transmission (%)
(d) Dissolved oxygen
O2 (mg/L)
(e) Chla fluoresence (black bars mark 1% light)
F (µg/L)
Distance between stations (km)

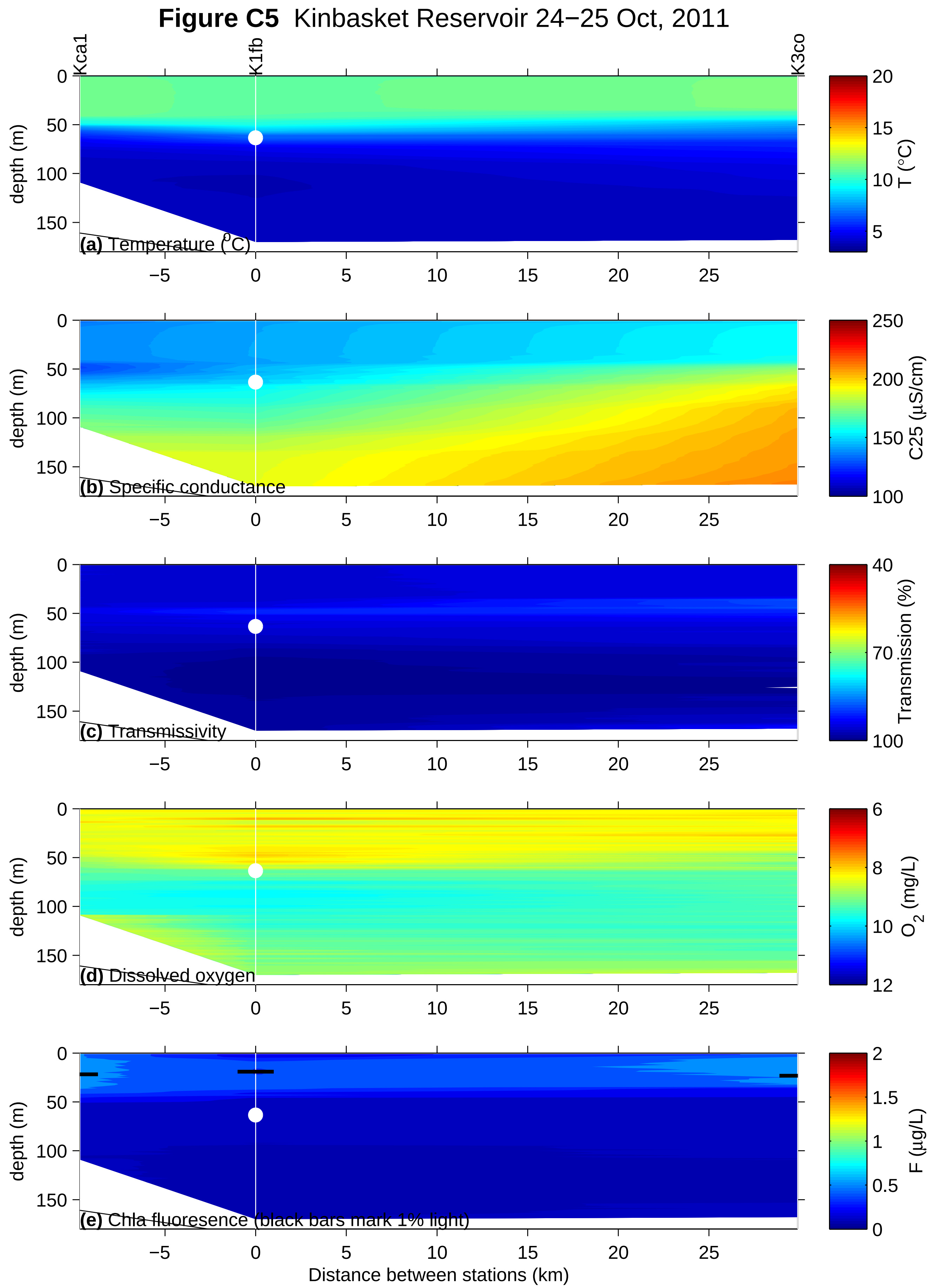


Figure C5 Kinbasket Reservoir 24−25 Oct, 2011
Kca1
K1fb
K3co
depth (m)
T (°C)
(a) Temperature (°C)
(b) Specific conductance
C25 (µS/cm)
(c) Transmissivity
Transmission (%)
(d) Dissolved oxygen
O2 (mg/L)
(e) Chla fluoresence (black bars mark 1% light)
F (µg/L)
Distance between stations (km)

Figure D1 Revelstoke Reservoir, 16−17 May 2011

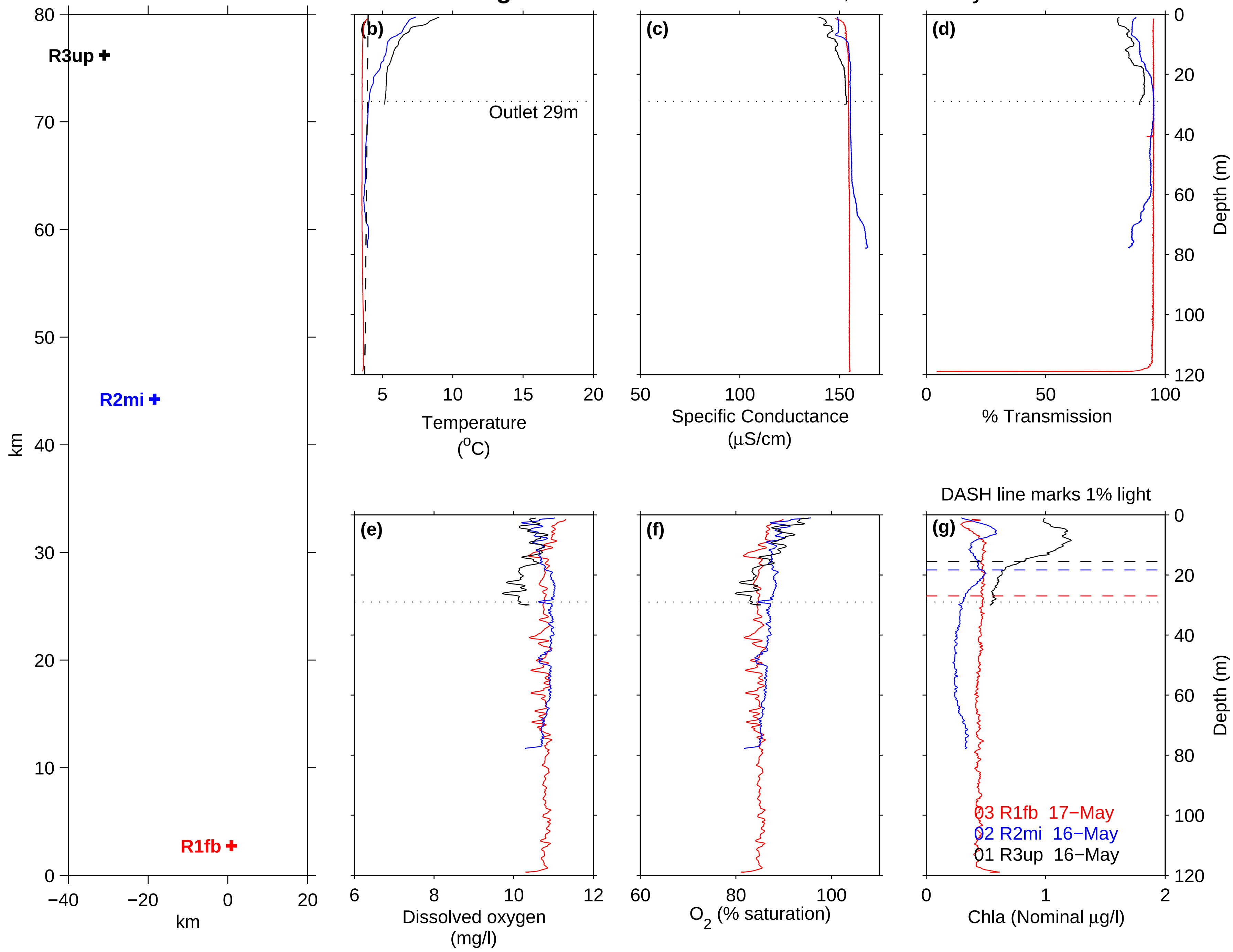


Figure D2 Revelstoke Reservoir, 10 Jun 2011

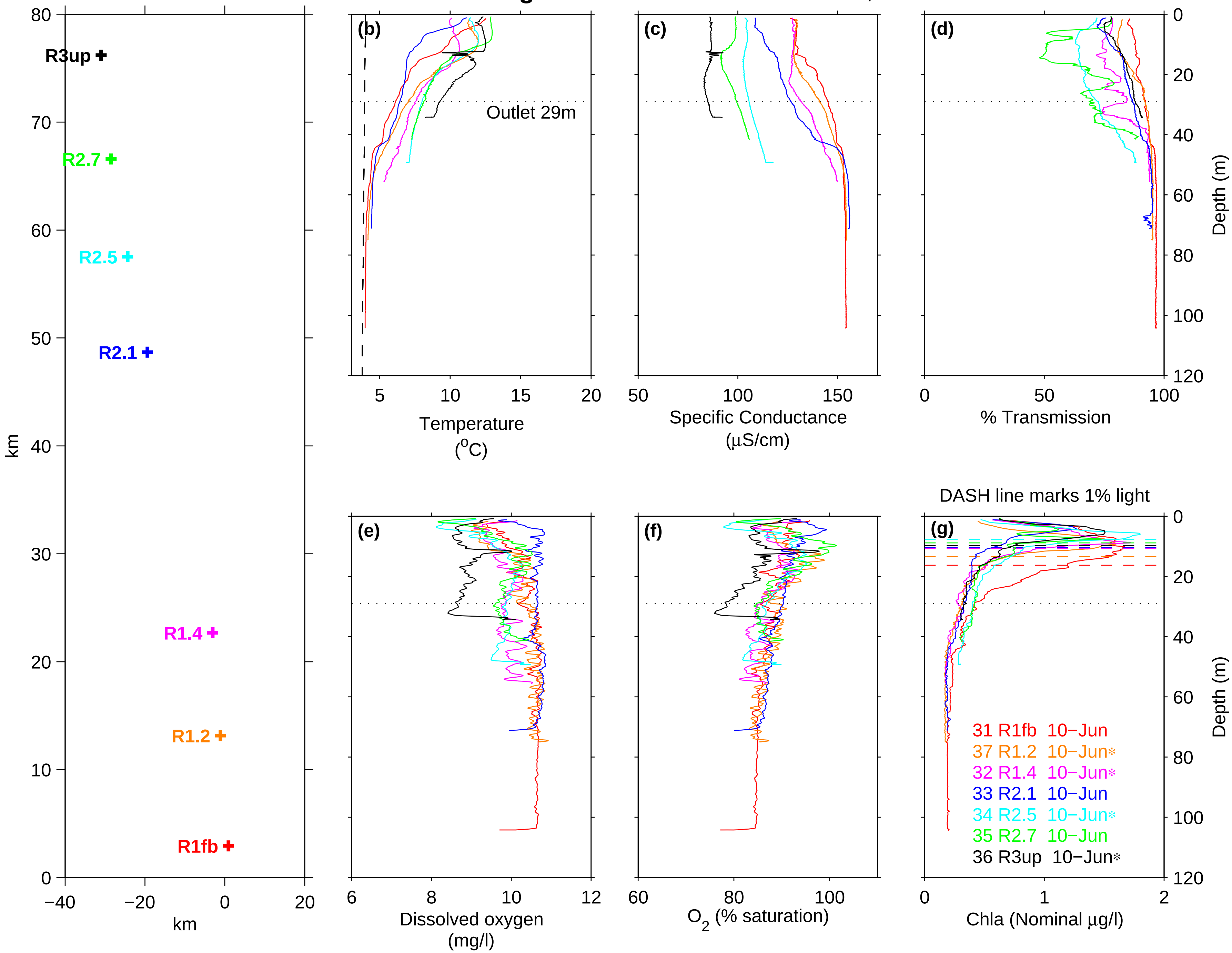
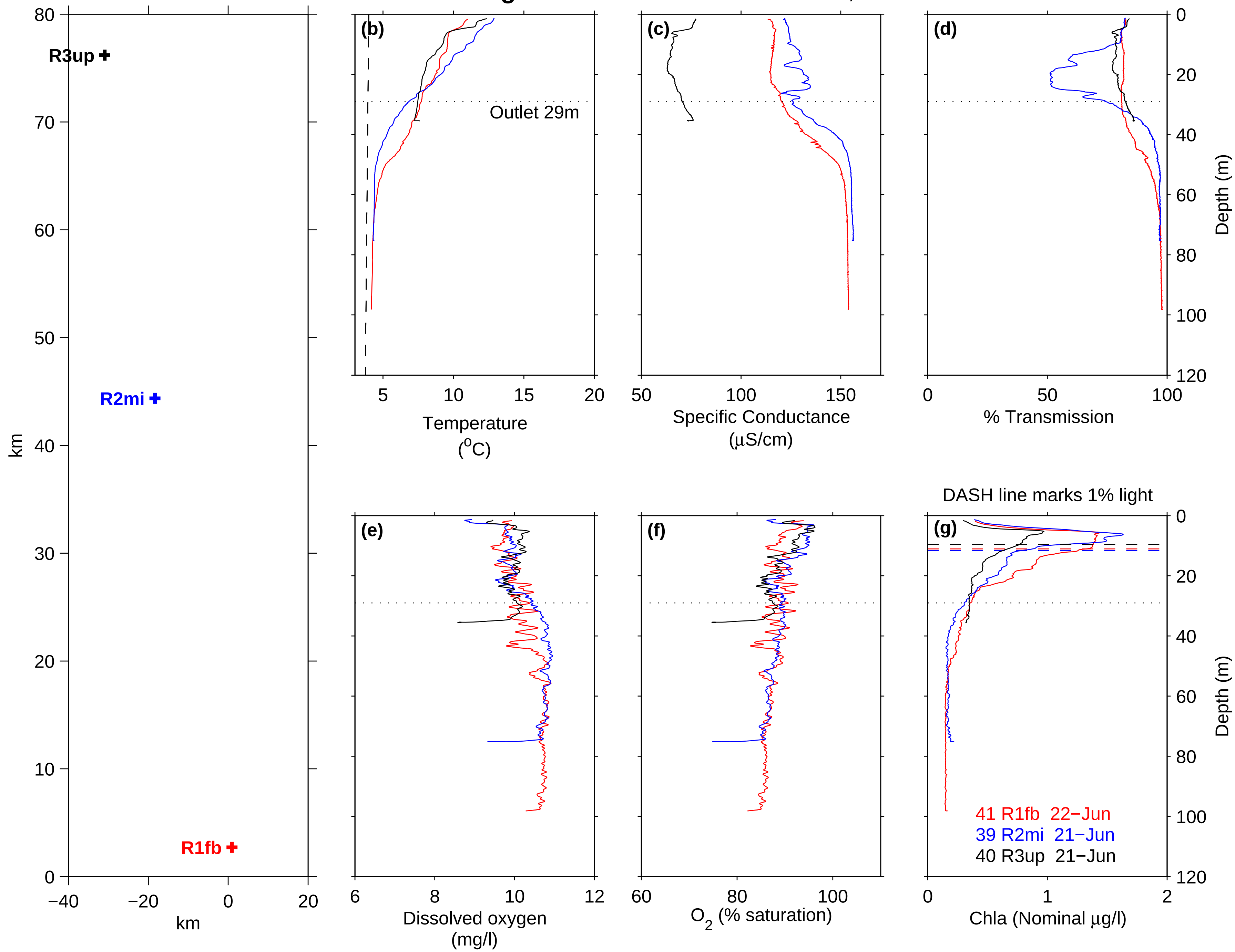


Figure D3 Revelstoke Reservoir, 21−22 Jun 2011



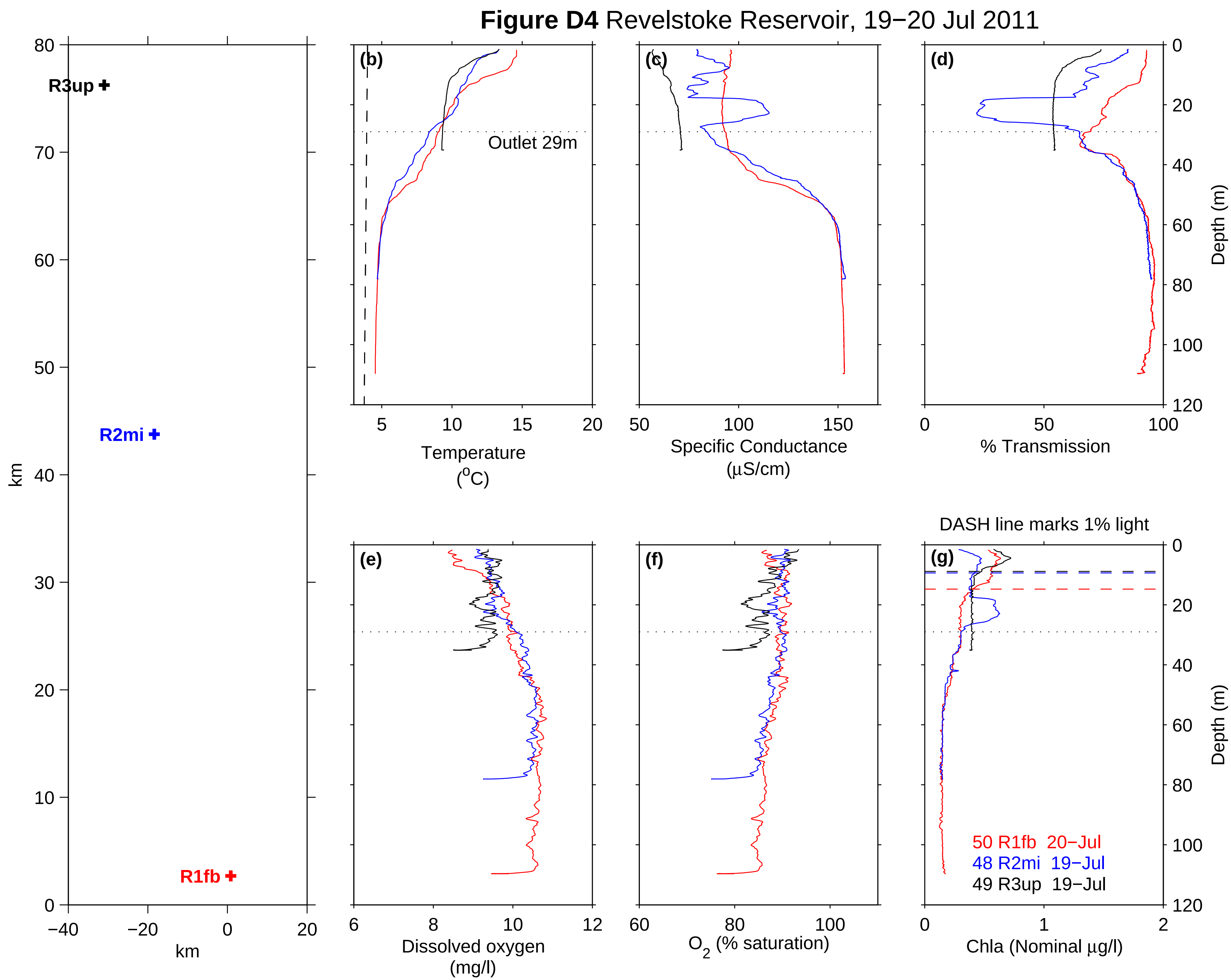


Figure D4 Revelstoke Reservoir, 19−20 Jul 2011
R3up
R2mi
R1fb
km
(b)
Outlet 29m
Temperature
(°C)
(c)
Specific Conductance
(µS/cm)
(d)
% Transmission
Depth (m)
DASH line marks 1% light
(e)
Dissolved oxygen
(mg/l)
(f)
O2 (% saturation)
(g)
50 R1fb 20−Jul
48 R2mi 19−Jul
49 R3up 19−Jul
Chla (Nominal µg/l)

Figure D5 Revelstoke Reservoir, 23−24 Aug 2011

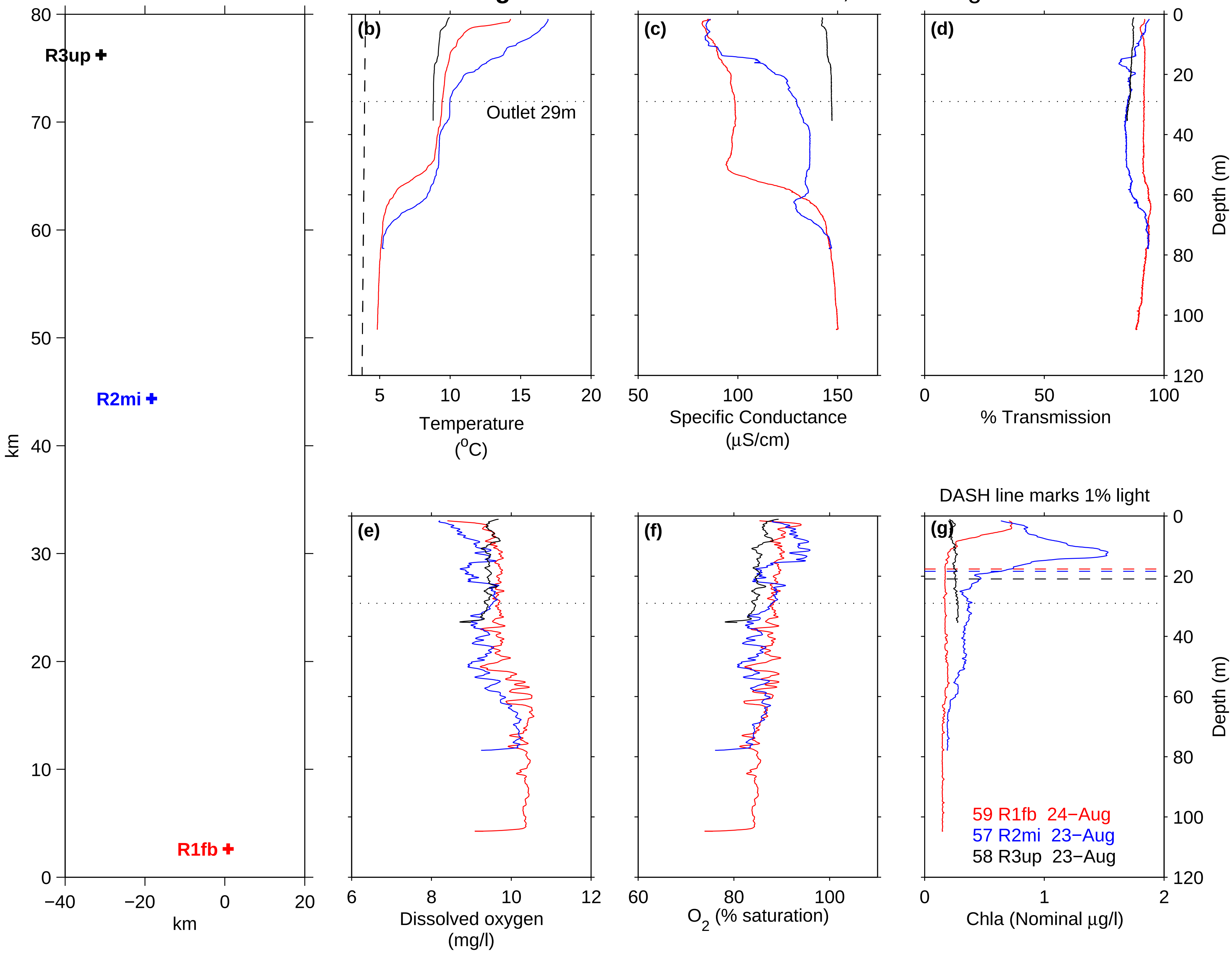


Figure D6 Revelstoke Reservoir, 19−20 Sep 2011

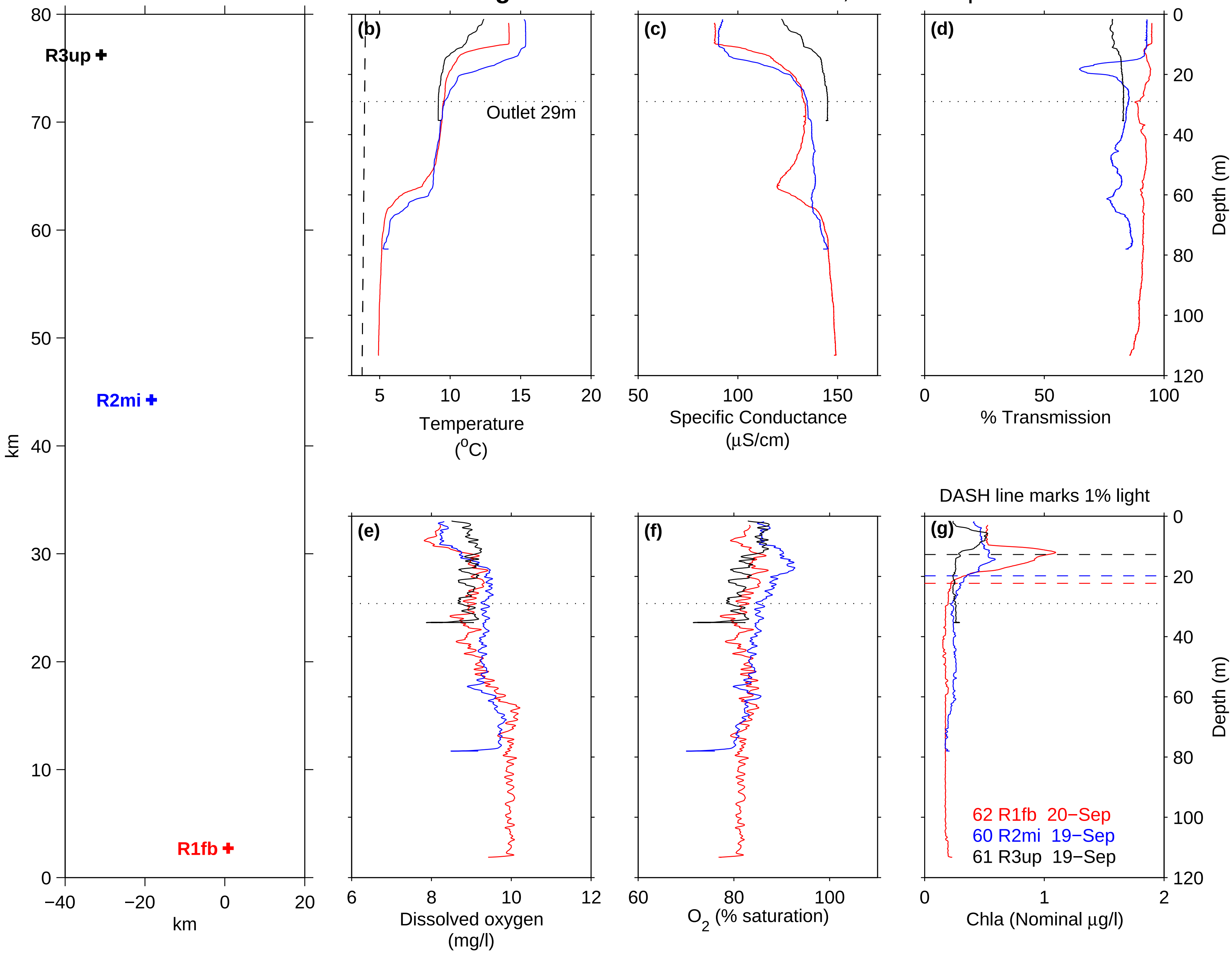


Figure D7 Revelstoke Reservoir, 17−18 Oct 2011

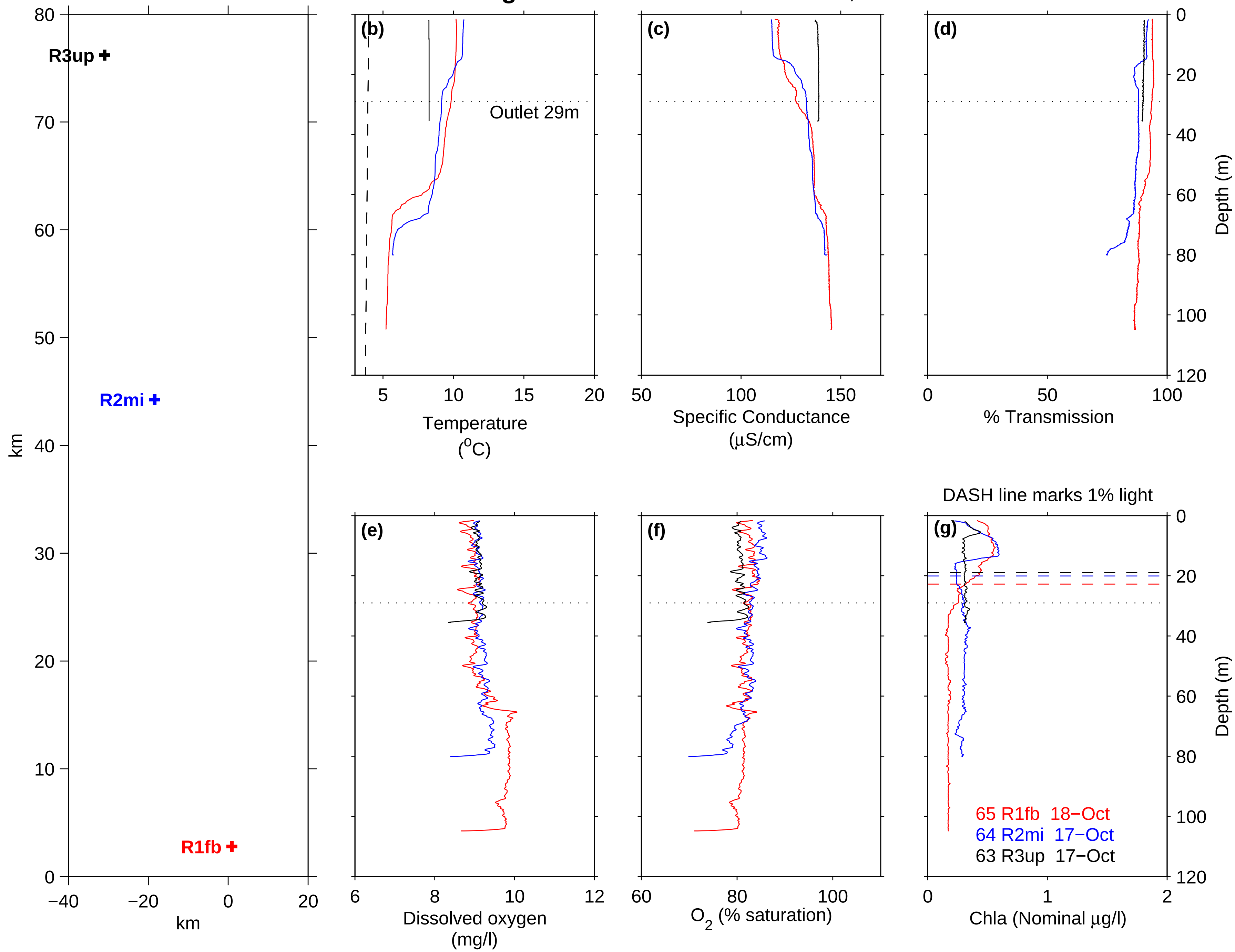


Figure D8 Revelstoke Reservoir, Forebay 2011

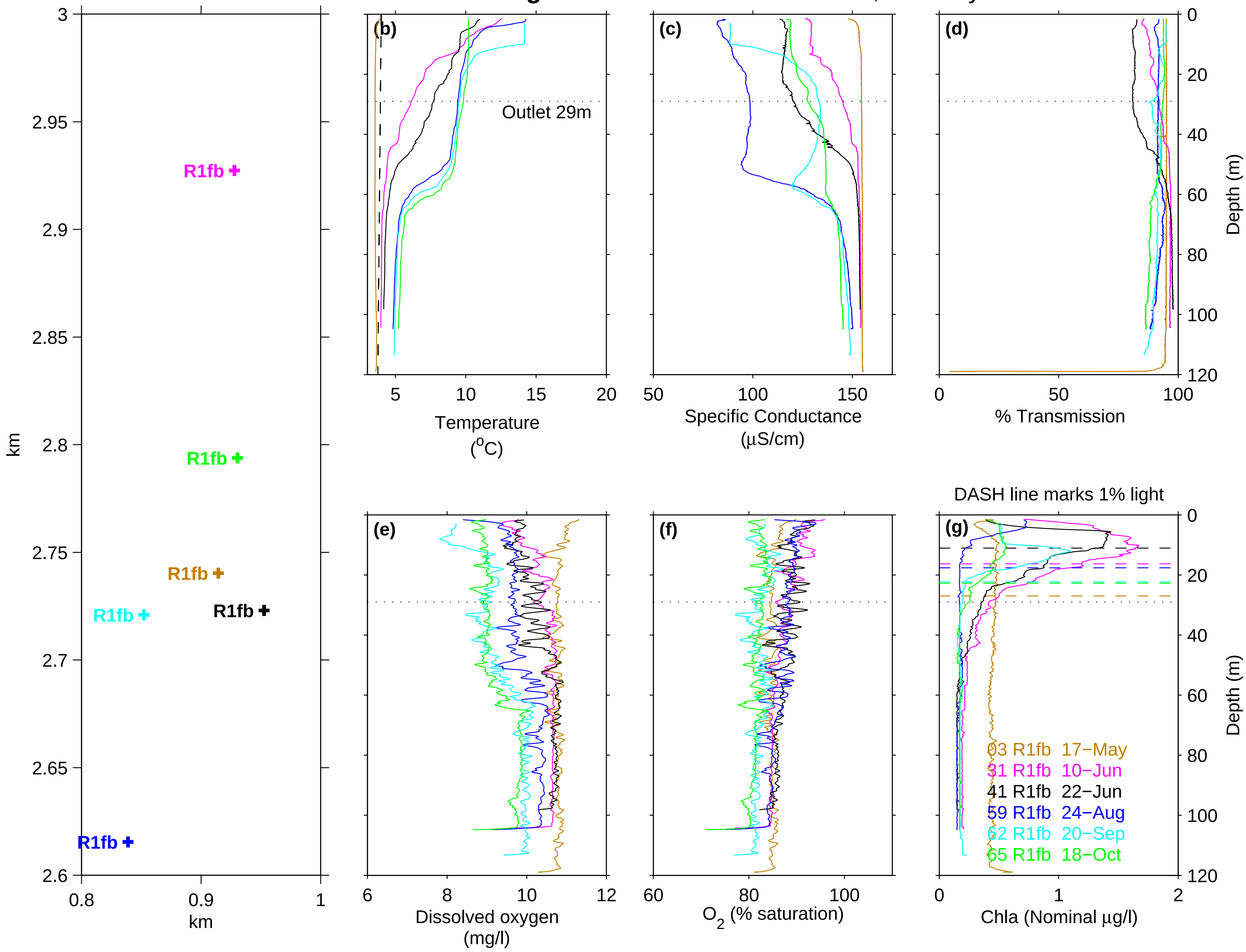


Figure D9 Revelstoke Reservoir, Middle 2011

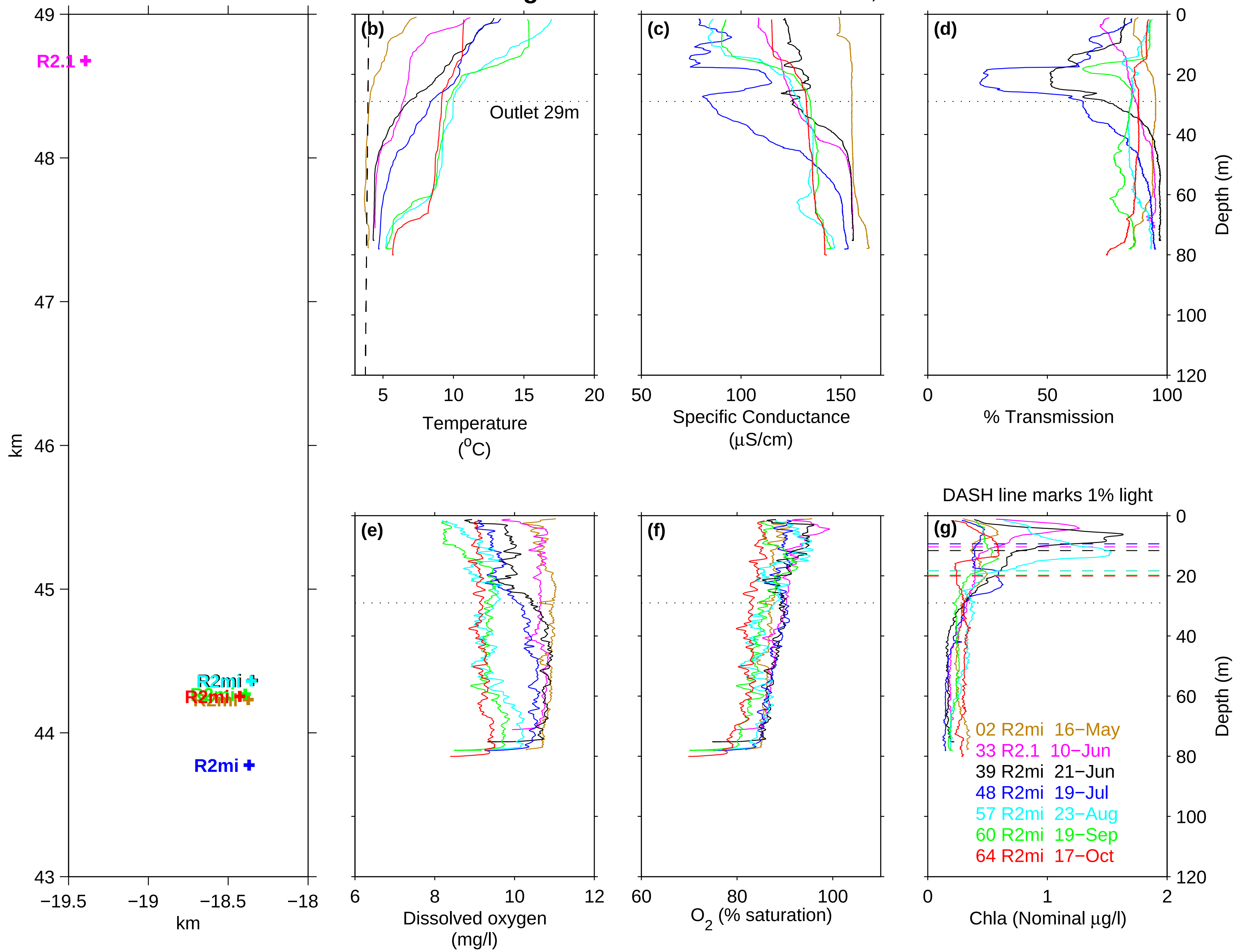


Figure D10 Revelstoke Reservoir, Upper 2011

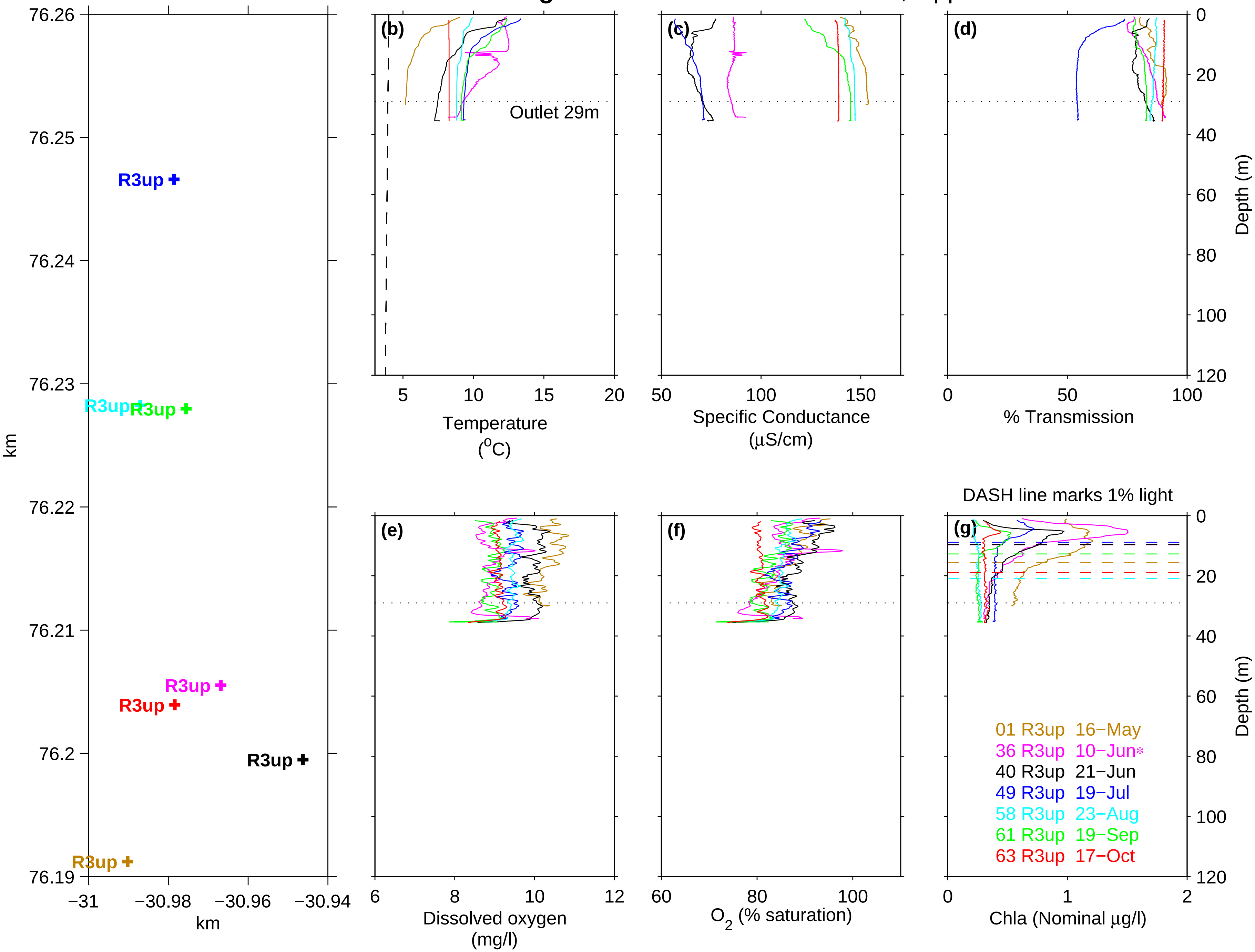


Figure E1 Revelstoke Reservoir 16−17 May, 2011

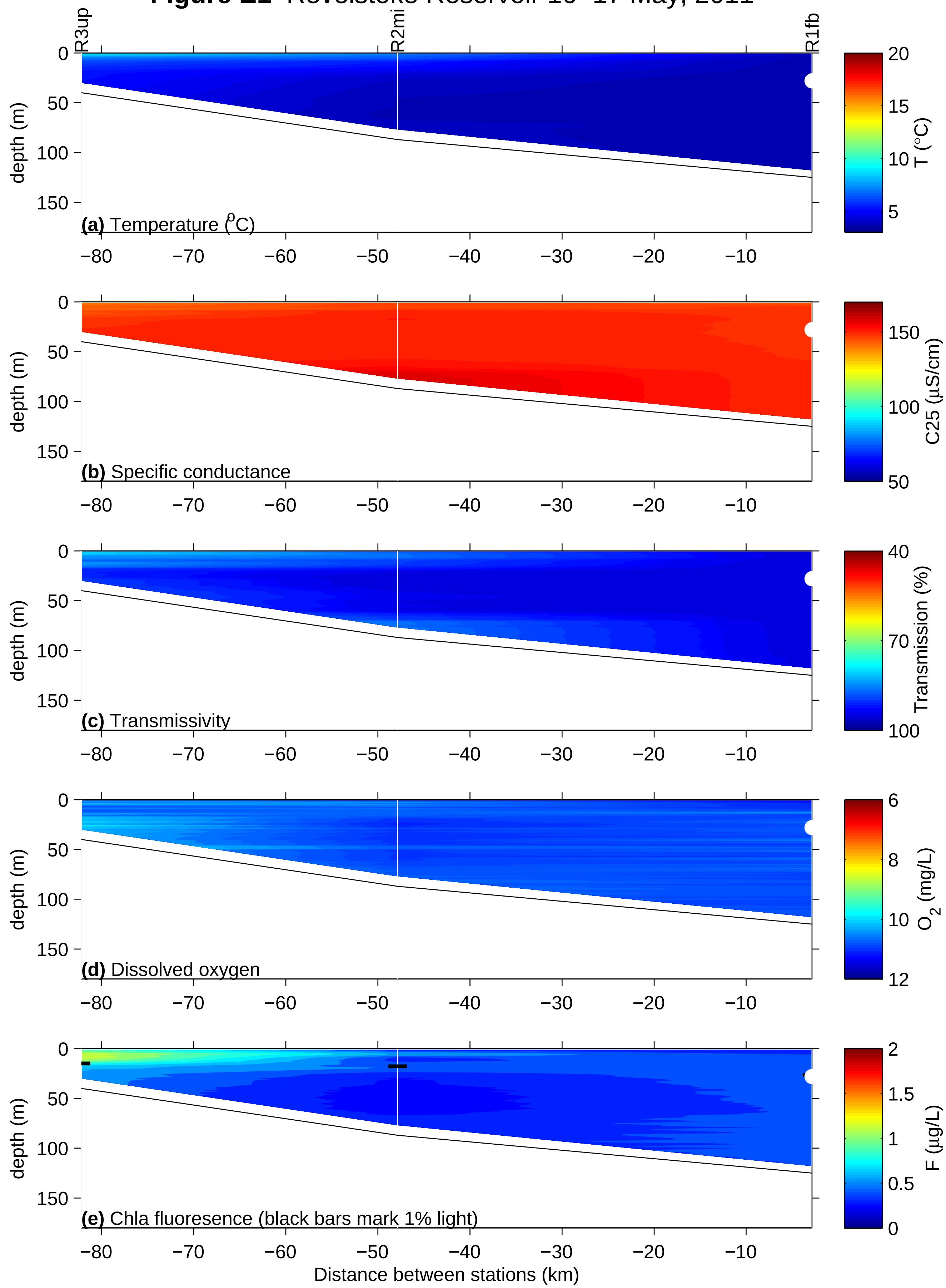


Figure E2 Revelstoke Reservoir 10 Jun, 2011

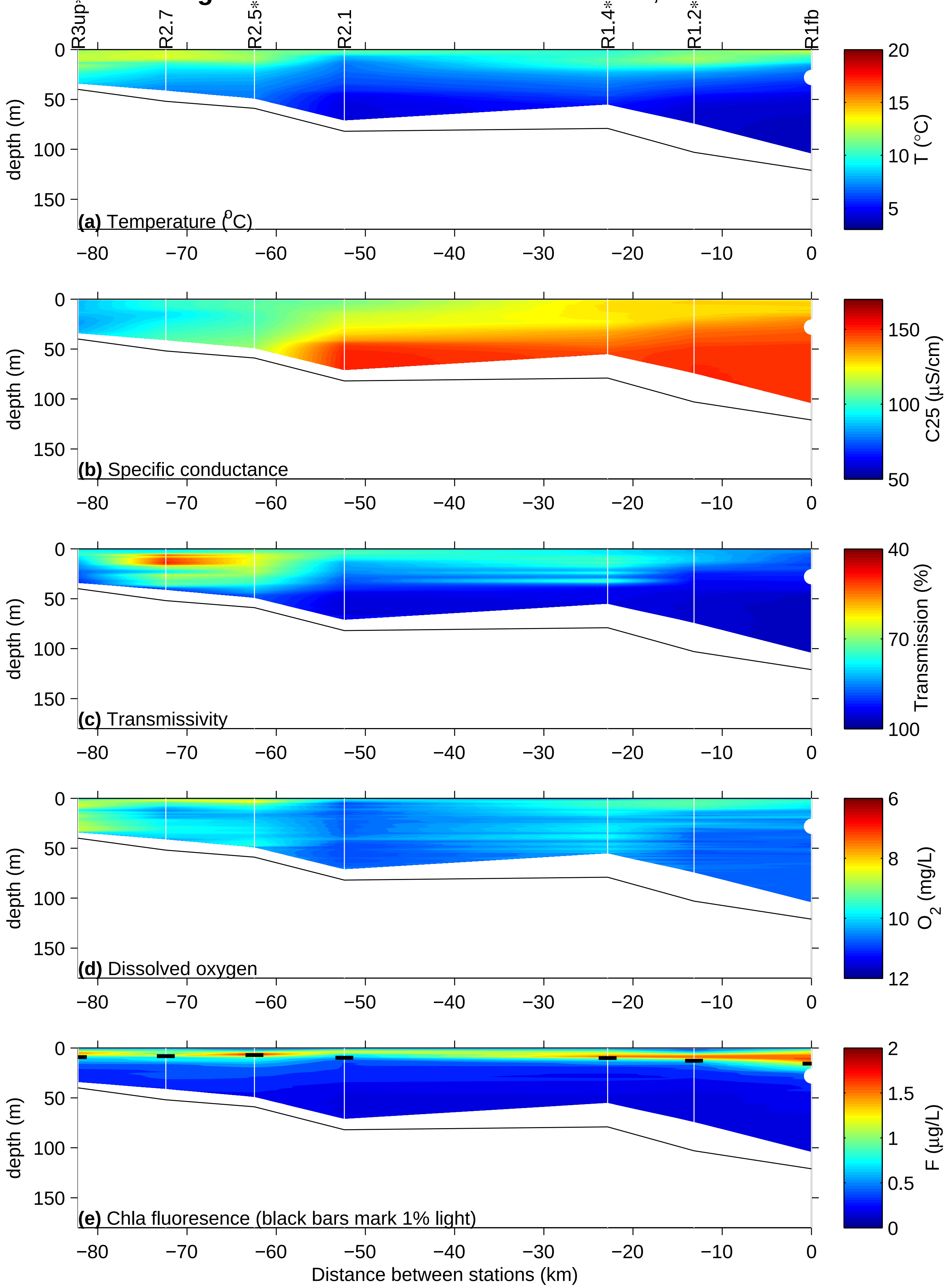


Figure E3 Revelstoke Reservoir 21−22 Jun, 2011

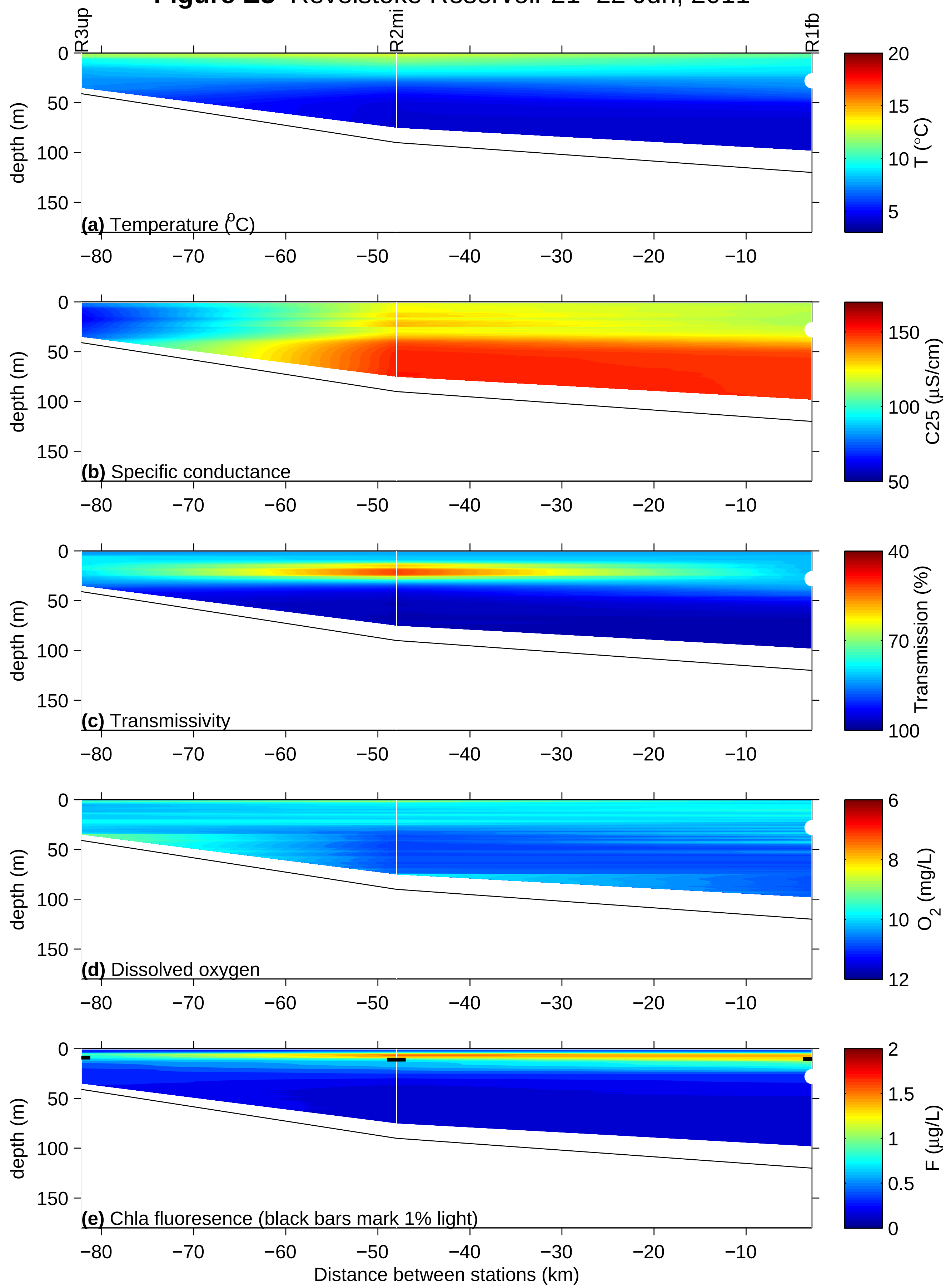


Figure E4 Revelstoke Reservoir 19−20 Jul, 2011

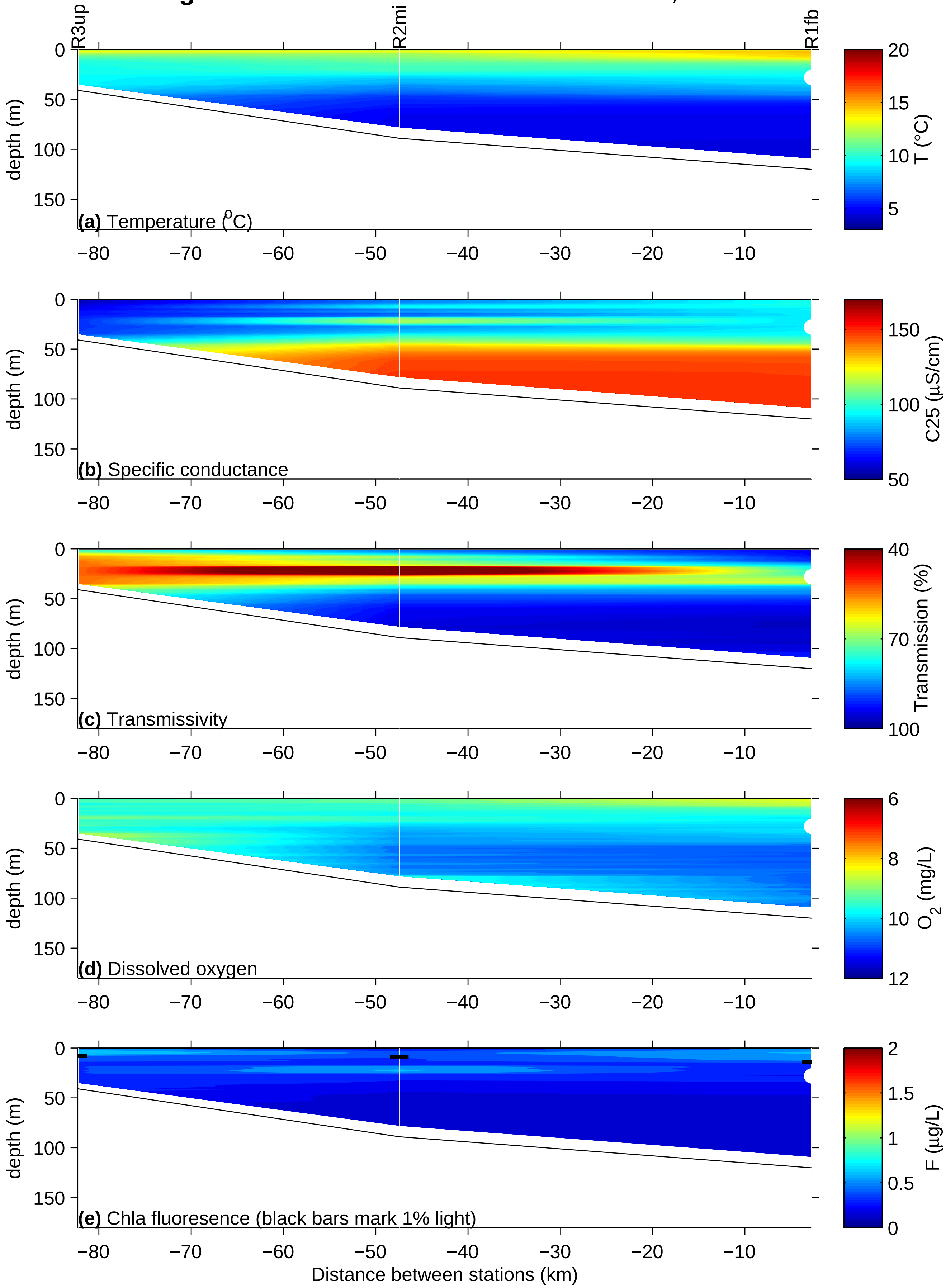


Figure E5 Revelstoke Reservoir 23−24 Aug, 2011

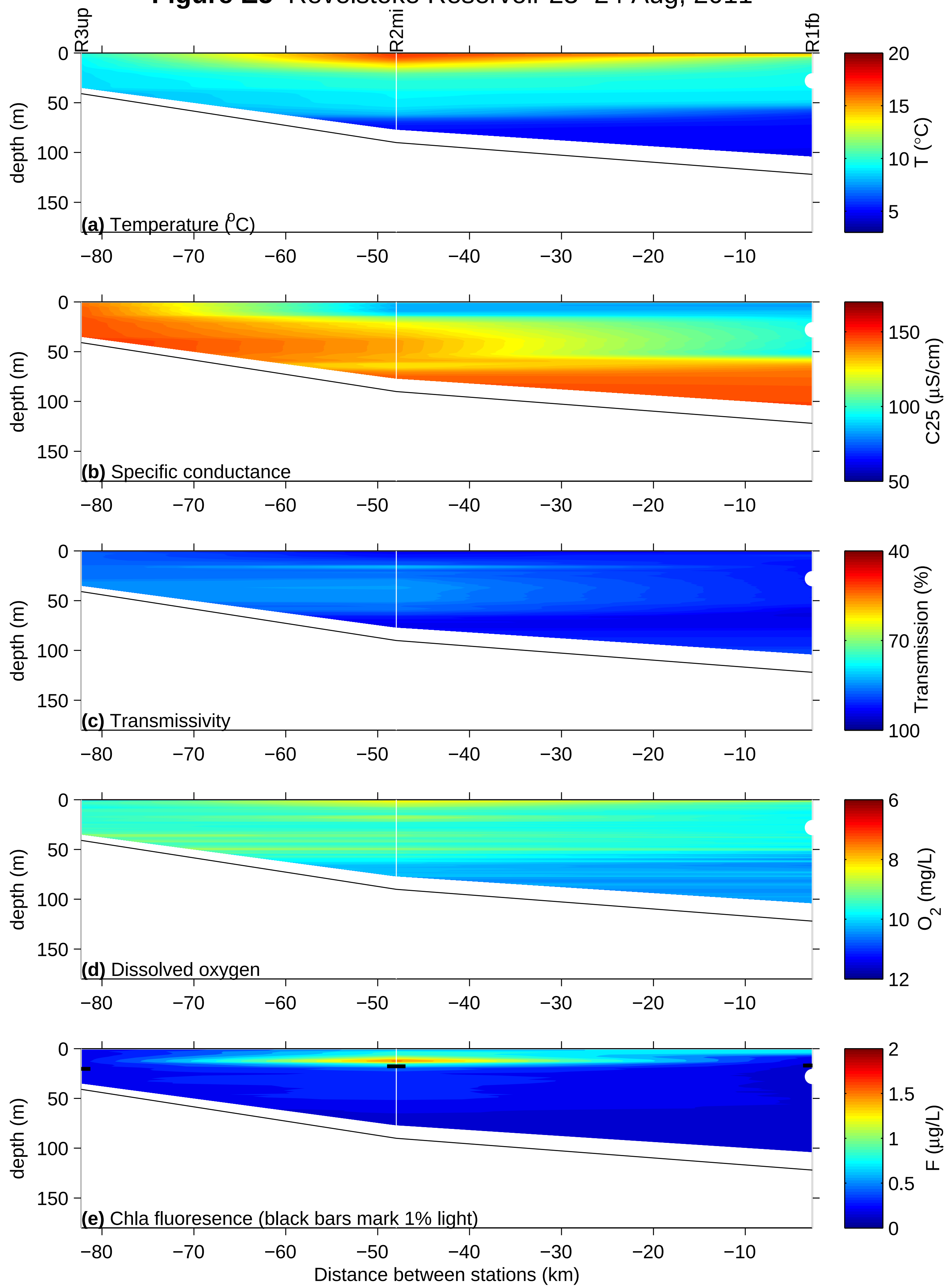


Figure E6 Revelstoke Reservoir 19−20 Sep, 2011

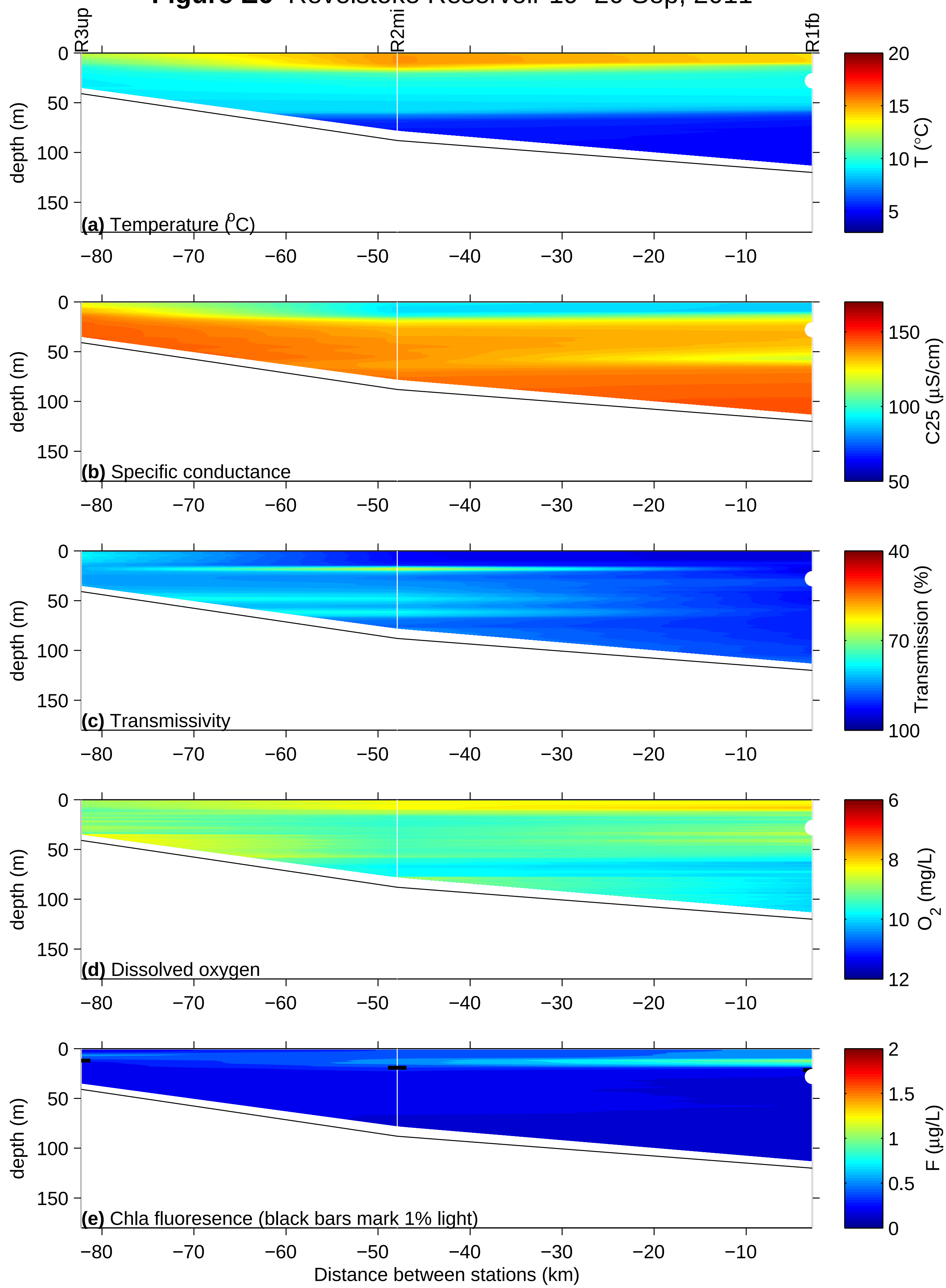


Figure E7 Revelstoke Reservoir 17−18 Oct, 2011

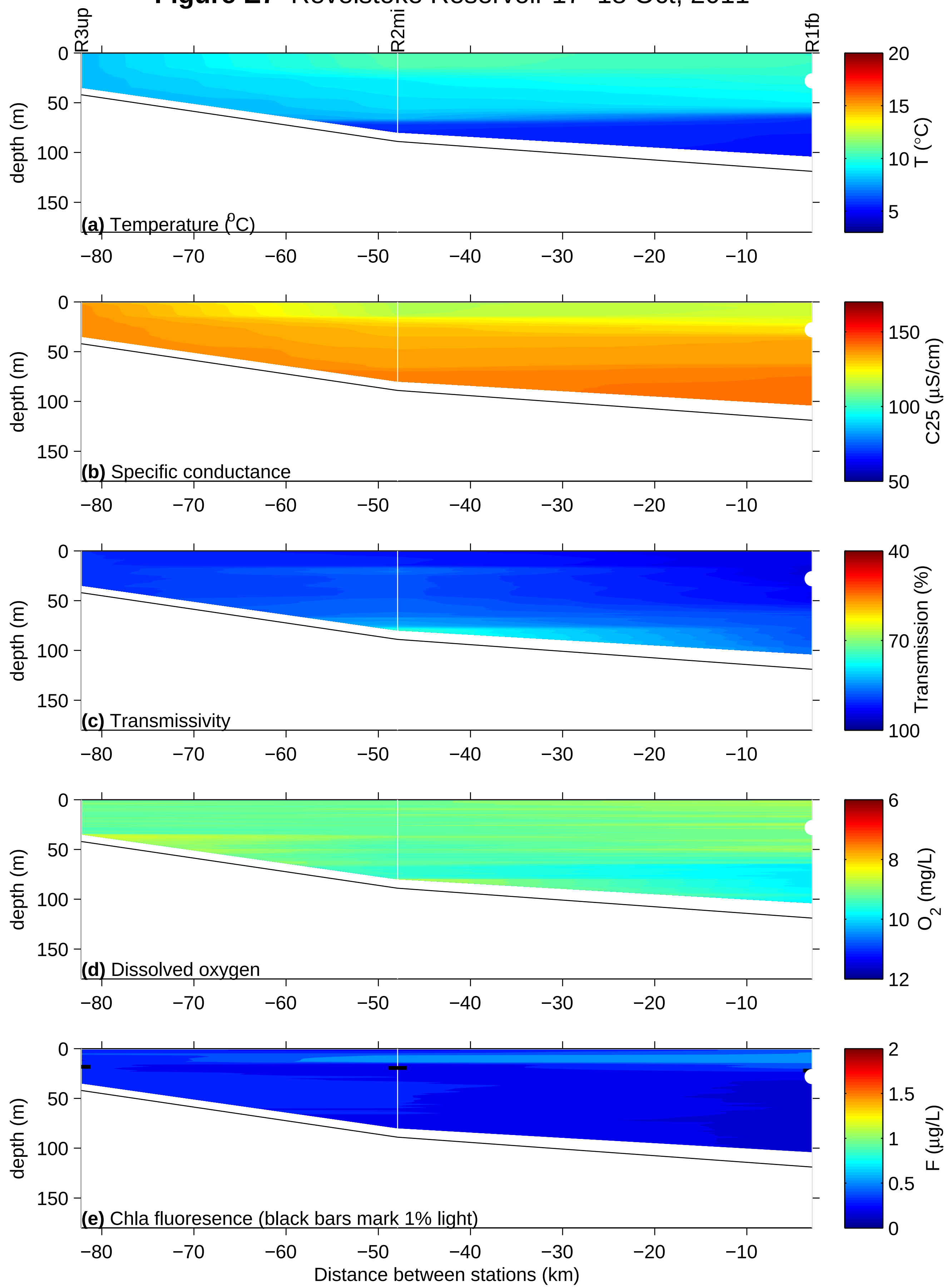
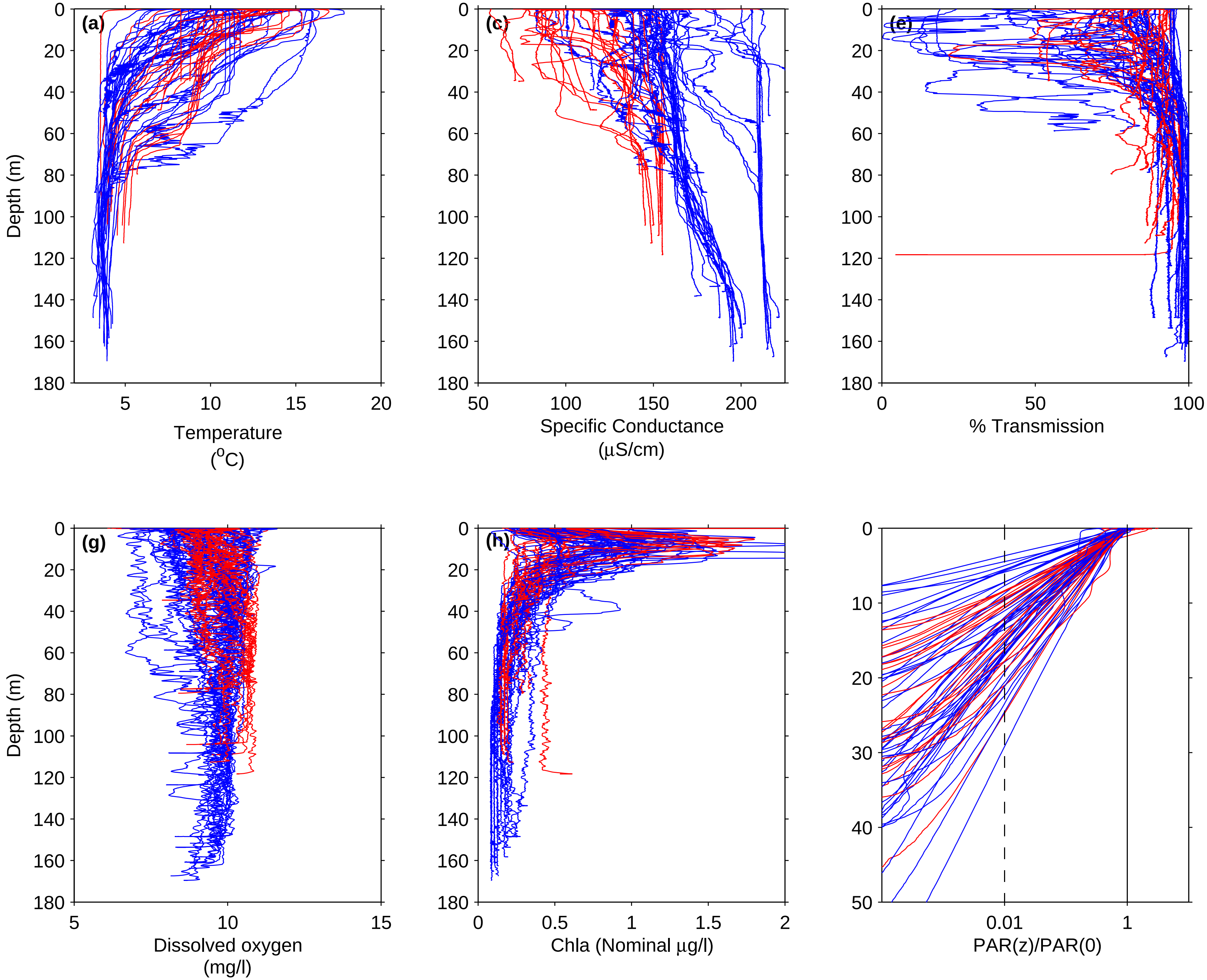


Figure F1 All Kinbasket (BLU) and Revesltoke (RED) Data, 2011



Appendix 1
Provisional Station Names

Name*	Description	Approximate Location
Kinbasket-Columbia Arm		
K1fb	**Forebay**	52°05.673 118°32.902
K1.5	Kin-PP	52°06.889 118°30.501
K2mi	**Middle**	52°07.858 118°26.363
K2.1	Kin-Mouth of Columbia to Kinbasket	52°06.044 118°24.264
K2.4	10 km from mouth of Columbia	52°03.246 118°16.766
K2.8	20 km from mouth of Columbia	52°00.219 118°09.401
K3co	**Columbia Reach**	51°58.438 118°05.030
K3.1	30 km from mouth of Columbia	51°57.067 118°02.334
K3.5	40 km from mouth of Columbia	51°53.595 117°55.577
K3.7	50 km from mouth of Columbia	51°50.381 117°48.576
K4	60 km from mouth of Columbia	51°47.010 117°41.750
Kinbasket-Wood Arm		
Kwo0	Mouth of Wood to Kinbasket	52°09.004 118°22.994
Kwo1	**Wood Arm**	52°08.269 118°18.024
Kwo2	End of Wood Arm	52°10.738 118°10.020
Kinbasket-Canoe Arm		
Kca0	Mouth of Canoe to Kinbasket	52°10.631 118°27.049
Kca1	**Canoe Reach**	52°12.547 118°28.516
Kca1.5	10 km from mouth of Canoe	52°15.509 118°31.235
Kca2.5	20 km from mouth of Canoe	52°20.025 118°35.804
Kca3	30 km from mouth of Canoe	52°24.198 118°41.857
Kca4	40 km from mouth of Canoe	52°28.714 118°46.355
Kca5	50 km from mouth of Canoe	52°33.452 118°50.709
Revelstoke		
R1fb	**Rev-Forebay**	51°04.584 118°10.929
R1.2	Rev-10 km from Forebay	51°09.988 118°12.677
R1.4	Rev-20 km from Forebay	51°15.179 118°14.332
R1.6	Rev-30 km from Forebay	51°19.593 118°20.842
R1.9	Rev-40 km from Forebay	51°23.852 118°26.552
R2mi	**Rev-Mid**	51°26.612 118°27.939
R2.1	Rev-50 km from Forebay	51°29.082 118°29.093
R2.5	Rev-60 km from Forebay	51°33.778 118°33.541
R2.7	Rev-70 km from Forebay	51°38.586 118°37.338
R3up	**Rev-Upper**	51°43.891 118°39.633

* Main stations are bold

Appendix 2
List of Profiles

Appendix 2 List of Profiles

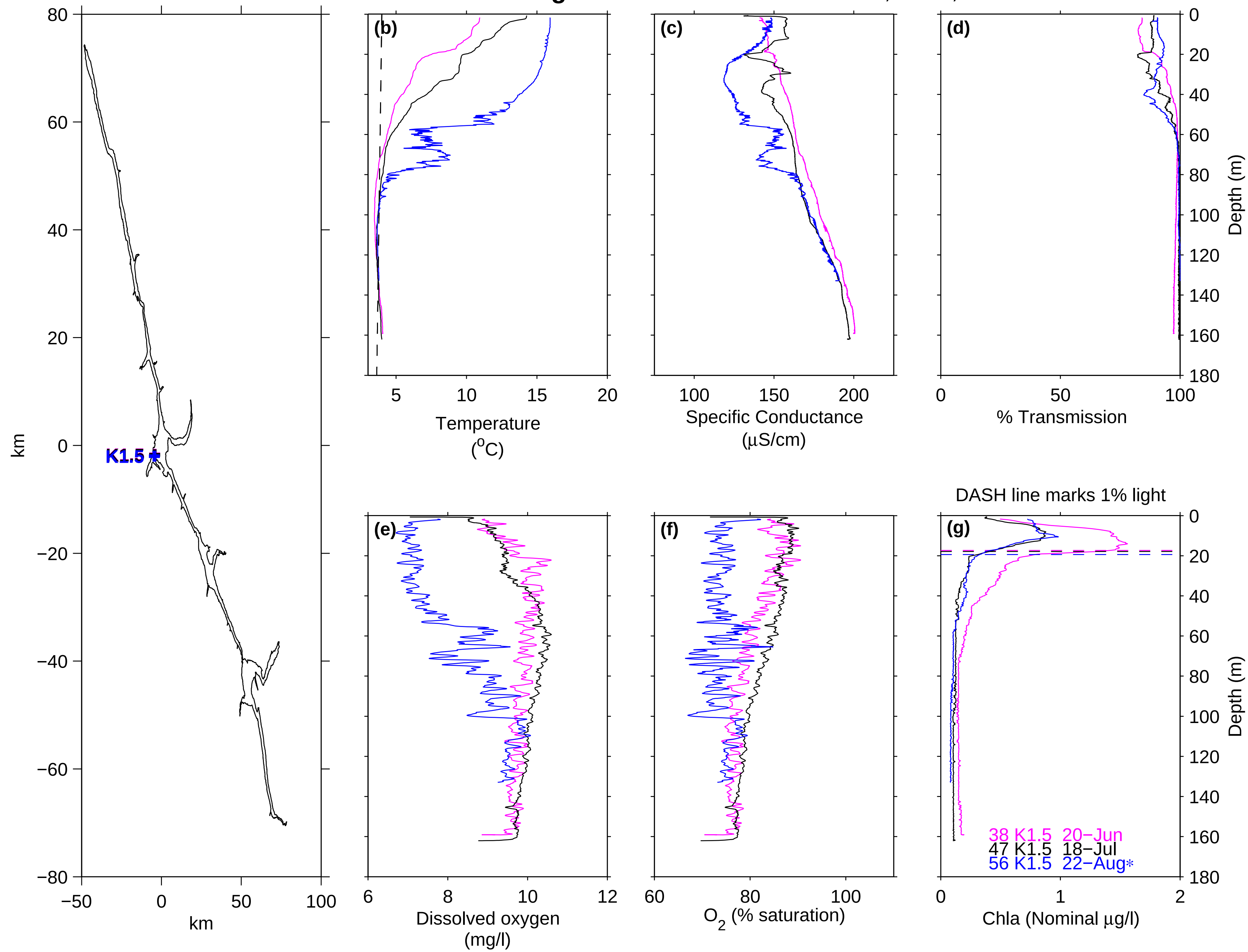
Cast Number	Date	Location	Time On	Time Off	GPS	Depth	Stn
1	16/May/2011	Rev - Upper	09:26	09:31	51°43.750 118°39.625	40	R3up
2	16/May/2011	Rev - Middle	11:53	12:02	51°26.660 118°28.111	87	R2mi
3	17/May/2011	Rev - Forebay	08:29	08:42	51°04.468 118°10.886	125	R1fb
4	24/May/2011	Kin - Columbia	10:56	11:11	51°57.997 118°04.856	160	K3co
5	24/May/2011	Kin - Wood	13:43	13:49	52°08.279 118°18.648	46	Kwo1
6	25/May/2011	Kin - Canoe	07:45	07:55	52°12.519 118°28.494	132	Kca1
7	25/May/2011	Kin - Middle	11:12	11:26	52°07.873 118°26.429	148	K2mi
8	25/May/2011	Kin - Forebay	13:10	13:25	52°05.707 118°32.909	163	K1fb
9	08/Jun/2011	Kin - Columbia mouth	07:57	08:06	52°06.105 118°24.361	127	K2.1
10	08/Jun/2011	Kin- Columbia 10km from mouth	08:23	08:31	52°03.295 118°16.632	104	K2.4
11	08/Jun/2011	Kin- Columbia 20km from mouth	08:47	08:56	52°00.293 118°09.500	86	K2.8
12	08/Jun/2011	Kin- Columbia	09:09	09:25	51°58.028 118°04.838	165	K3co
13	08/Jun/2011	Kin- Columbia 30km from mouth	09:34	09:47	51°57.011 118°02.514	132	K3.1
14	08/Jun/2011	Kin- Columbia 40km from mouth	10:05	10:12	51°53.621 117°55.586	61	K3.5
15	08/Jun/2011	Kin- Columbia 50km from mouth	10:27	10:34	51°50.362 117°48.570	57	K3.7
16	08/Jun/2011	Kin- Columbia 58.8km from mouth	11:08	11:13	51°47.635 117°42.295	36	K3.9
17	08/Jun/2011	Kin- Wood mouth	13:18	13:27	52°09.063 118°22.990	101	Kwo0
18	08/Jun/2011	Kin- Wood	13:38	13:44	52°08.277 118°18.710	52	Kwo1
19	08/Jun/2011	Kin - Wood 10km from mouth	13:55	14:00	52°08.464 118°14.118	43	Kwo1.5
20	08/Jun/2011	Kin- Wood 15km from mouth	14:10	14:14	52°10.247 118°10.409	20	Kwo2
21	09/Jun/2011	Kin- Canoe mouth	07:43	07:57	52°10.589 118°27.086	148	Kwo0
22	09/Jun/2011	Kin - Canoe	08:06	08:16	52°12.447 118°28.403	135	Kca1
23	09/Jun/2011	Kin- Canoe 20km from mouth	08:47	08:54	52°19.998 118°35.766	85	Kca2.5
24	09/Jun/2011	Kin- Canoe 30km from mouth	09:11	09:18	52°24.086 118°41.869	73	Kca3
25	09/Jun/2011	Kin- Canoe 40km from mouth	09:34	09:40	52°28.712 118°46.373	45	Kca4
26	09/Jun/2011	Kin- Canoe 50km from mouth	09:55	10:01	52°33.428 118°50.767	46	Kca5
27	09/Jun/2011	Kin- Canoe 60km from mouth	10:16	10:21	52°32.237 118°57.294	30	Kca6
28	09/Jun/2011	Kin - Middle	12:14	12:27	52°07.859 118°26.395	154	K2mi
29	09/Jun/2011	Kin - 4.25km from middle toward forebay site	12:36	12:52	52°06.971 118°29.944	162	K1.5
30	09/Jun/2011	Kin - Forebay	13:01	13:16	52°05.709 118°32.907	166	K1fb
31	10/Jun/2011	Rev - Forebay	07:37	07:49	51°04.569 118°10.877	121	R1fb
32	10/Jun/2011	Rev - 20km from forebay	08:14	08:21	51°15.185 118°14.572	79	R1.5
33	10/Jun/2011	Rev - 50km from forebay	09:03	09:12	51°29.046 118°29.068	82	R2.1
34	10/Jun/2011	Rev - 60km from forebay	09:27	09:34	51°33.762 118°33.501	59	R2.5

35	10/Jun/2011	Rev - 70km from forebay	09:48	09:54	51°38.594 118°37.260	52	R2.7
36	10/Jun/2011	Rev - Upper	10:08	10:13	51°43.758 118°39.605	40	R3up
37	10/Jun/2011	Rev - 10km from forebay	11:44	11:54	51°10.066 118°12.733	103	R1.2
38	20/Jun/2011	Kin - PP	08:33	08:50	52°06.923 118°30.073	169	K1.5
39	21/Jun/2011	Rev - Middle/PP	08:15	08:24	51°26.732 118°28.090	90	R2mi
40	21/Jun/2011	Rev - Upper	09:52	10:00	51°43.755 118°39.587	41	R3up
41	22/Jun/2011	Rev - Forebay/PP	08:13	08:24	51°04.459 118°10.853	120	R1fb
42	04/Jul/2011	Kin - Columbia	11:04	11:21	51°58.002 118°04.916	175	K3co
43	04/Jul/2011	Kin - Wood	14:15	14:23	52°08.281 118°18.667	62	Kwo1
44	05/Jul/2011	Kin - Canoe	09:30	09:41	52°12.379 118°28.415	148	Kca1
45	05/Jul/2011	Kin - Middle	10:53	11:09	52°07.853 118°26.408	164	K2mi
46	05/Jul/2011	Kin - Forebay	13:57	14:21	52°05.587 118°32.973	176	K1fb
47	18/Jul/2011	Kin- PP	07:18	07:34	52°06.876 118°30.097	172	K1.5
48	19/Jul/2011	Rev - Middle/PP	07:40	07:49	51°26.414 118°28.098	89	R2mi
49	19/Jul/2011	Rev - Upper	09:17	09:23	51°43.780 118°39.616	41	R3up
50	20/Jul/2011	Rev - Forebay/PP	07:46	07:57	51°04.442 118°10.947	120	R1fb
51	15/Aug/2011	Kin - Columbia	10:12	10:29	51°57.972 118°04.910	183	K3co
52	15/Aug/2011	Kin - Wood	13:02	13:10	52°08.234 118°18.730	70	Kwo1
53	16/Aug/2011	Kin - Canoe	07:22	07:34	52°12.373 118°28.431	160	Kca1
54	16/Aug/2011	Kin - Middle	08:34	08:50	52°07.838 118°26.521	170	K2mi
55	16/Aug/2011	Kin - Forebay	10:06	10:22	52°05.645 118°32.982	186	K1fb
56	22/Aug/2011	Kin - PP	07:06	07:21	52°06.736 118°30.270	158	K1.5
57	23/Aug/2011	Rev - Middle/PP	08:23	08:32	51°26.730 118°28.097	90	R2mi
58	23/Aug/2011	Rev - Upper	09:48	09:54	51°43.770 118°39.623	41	R3up
59	24/Aug/2011	Rev - Forebay/PP	07:41	07:52	51°04.400 118°10.949	122	R1fb
60	19/Sep/2011	Rev - Middle/PP	09:09	09:18	51°26.680 118°28.128	88	R2mi
61	19/Sep/2011	Rev - Upper	10:49	10:55	51°43.770 118°39.613	41	R3up
62	20/Sep/2011	Rev - Forebay/PP	07:45	07:57	51°04.457 118°10.939	120	R1fb
63	17/Oct/2011	Rev - Upper	10:37	10:43	51°43.757 118°39.615	42	R3up
64	17/Oct/2011	Rev - Middle	12:54	13:03	51°26.671 118°28.157	89	R2mi
65	18/Oct/2011	Rev - Forebay	09:57	10:08	51°04.497 118°10.873	119	R1fb
66	24/Oct/2011	Kin - Columbia	11:14	11:31	51°57.977 118°04.920	183	K3co
67	24/Oct/2011	Kin - Wood	13:52	13:59	52°08.299 118°18.726	70	Kwo1
68	25/Oct/2011	Kin - Canoe	08:10	08:22	52°12.450 118°28.457	161	Kca1
69	25/Oct/2011	Kin - Forebay	10:24	10:42	52°05.635 118°32.997	187	K1fb

Appendix 3
Additional Profiles

Profiles collected during measurement of primary production in Kinbasket Reservoir, see Tables 2.1 and 2.2.

Figure A3 Kinbasket Reservoir, K1.5, 2011



Appendix 4

Reservoir Water Chemistry
Kinbasket and Revelstoke Reservoirs, 2011

Karen Bray
BC Hydro

Reservoir Water Chemistry
Kinbasket and Revelstoke Reservoirs, 2011

Launching the research vessel NAIAD on Revelstoke Reservoir, September 2011

Prepared By:
Karen Bray
Revelstoke, B.C.

January 2013

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1. Introduction

This report summarises Year 4 (2011) water chemistry information from Kinbasket and Revelstoke Reservoirs sampling. These results are a component of the study CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity conducted under the Columbia Water Use Plan.

2. Methods

Water samples were collected at four stations in Kinbasket Reservoir (Table 1, Figure 1) and three stations in Revelstoke Reservoir (Table 2). Regularly scheduled sampling sessions are once a month from May to October; however, in 2011 the June session was not conducted due to a crew injury and the September session was missed as high reservoir levels prevented boat access. The July session was conducted in between the regularly scheduled June and July sampling. Revelstoke sample sessions were conducted for all six months as planned.

Five litre Niskin bottles were lowered by cable in series to collect discrete depth samples at 2, 5, 10, 15, 20, 35, 45, and 60m. An additional sample at 5m above bottom was collected at all stations except for REV Upper and Kinbasket Wood as they are <65m depth. The 35m and 45m samples were added this year to provide more data from the metalimnion. Samples were field filtered for TDP and SRP and kept cold or frozen before shipping to the Cultus Lake Laboratory for analyses. Samples were analysed for nitrite+nitrate (NO_2+NO_3), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), alkalinity, conductivity, pH, turbidity, and TP turbidity. A 20m tube with inside diameter of 2.54cm was used to obtain a 0-20m integrated depth sample for analysis of silica (Si) and chlorophyll *a* at each station. A summary of sample preparation, analytical methods, and laboratory detection limits is contained in Pieters and Lawrence (2012a). The ratio of NO_2+NO_3 to TDP (weight:weight) was calculated to evaluate nutrient limitation in lieu of DIN:TDP with a minimum target ratio of 7.5:1 (Ashley and Stockner 2003). In this case, NO_2+NO_3 is considered an adequate replacement for dissolved inorganic nitrogen as both NO_2 and NH_4 are in low concentrations, the latter found to be below detection limits in 2003 sampling (Bray, unpubl. data).

Secchi disk readings were taken at each site using a standard 20cm Secchi disk. The disk was lowered on the shady side of the boat (no sunglasses were worn) to a depth where it could no longer be seen and then raised to where it became visible; the two depths were averaged to arrive at the final reading.

Table 1: Summary of Kinbasket Reservoir station coordinates, maximum sampled depths, and dates of 2011 sampling.

Station*	Coordinates	Maximum Depth Sampled (m)	Dates Sampled in 2011
KIN Forebay	52°05.611 118°32.932	187	May 25, July 5, Aug 16,Oct 25
Canoe Reach	52°12.400 118°28.417	161	May 25, July 5, Aug 16, Oct 25
Wood Arm	52°08.314 118°18.637	70	May 24, July 4, Aug 15, Oct 24
Columbia Reach	51°58.448 118°05.061	183	May 24, July 4, Aug 15, Oct 24

Table 2: Summary of Revelstoke Reservoir station coordinates, maximum sampled depths, and dates of 2011 sampling sessions.

Station*	Coordinates	Maximum Depth Sampled (m)	Dates Sampled in 2011
REV Forebay	51°04.504 118°10.981	125	May 17, June 22, July 20, Aug 24, Sep 20, Oct 18
REV Middle	51°26.495 118°28.116	90	May 16, June 21, July 19, Aug 23, Sep 19, Oct 17
REV Upper	51°43.797 118°39.579	42	May 16, June 21, July 19, Aug 23, Sep 19, Oct 17

3. Results

3.1 Kinbasket Reservoir

Stations were sampled at reservoir elevations between 728.2m and 753.2m; full pool is 754.4m and minimum level is 707.1m (Figure 2). The reservoir reached its minimum level (725m) for the year on May 7, 2011, and its maximum level (754.2m) on October 4, 2011. The range of elevation in 2011 was 29.1m whereas the maximum range possible is 47m. The average elevation range for the reservoir (1977-2011) is 25.2 m. Raw data are attached as Appendix 1.

Nitrite and Nitrate (NO_2 +NO_3 or NN) – Average NN was similar across stations in Kinbasket Reservoir (101 to 107µg/L), with the greatest range in the upper 40m of KIN Columbia (Table 3, Figure 3). In the epilimnion (0-20m), NN was greatest in May and July (Figure 8) reflecting tributary inputs described in Pieters and Lawrence (2012a), particularly noticeable at the KIN Columbia site which is influenced to a greater degree by freshet inflows (Pieters and Lawrence 2012b). Hypolimnetic NN (>60m) shows an opposite trend with lower early season values increasing into the fall at all stations except KIN Wood (Figure 3).

Total Phosphorus (TP) – Average TP ranged from 5.4 – 7.9 µg/L with highest values in KIN Wood and KIN Columbia stations, notably in August (Table 3, Figure 4). TP was also similar throughout the epilimnion and hypolimnion across the months, generally with lowest values in May and October (Figure 9). Corrections for colour and turbidity of 0.1 µg/L to as much as 3.5 µg/L in KIN Wood were made from July to October and usually <0.1 µg/L in May.

Total Dissolved Phosphorus (TDP) – Average TDP was between 4.7 and 6.7 µg/L) with a total range between 0.6 µg/L at KIN Forebay and 12 µg/L at KIN Wood and Columbia stations (Table 3, Figure 5). As with TP, August TDP in KIN Wood and Columbia was notably high throughout the water column. In some cases TDP values exceeded TP (corrected). Some of these are considered errors due to contamination in the field and some are considered to be due to the very low levels of TP and TDP in this system and natural variability in water samples. (pers. comm. E. MacIsaac, Cultus Lake Lab). Values of TDP in excess of TP were not used in calculations of means or N:P ratios. This occurred in 27% of samples, predominantly in KIN Forebay station. Seasonally, epilimnetic TDP peaked in July and August (Figure 10).

Soluble Reactive Phosphorus (SRP) – Average SRP across Kinbasket Reservoir stations ranged from 1.1 to 1.3 µg/L (Table 3, Figure 6). Values peaked in July and August at all stations, being lowest in May and October (Figure 11).

DIN:TDP – Using NN:TDP, average N:P ratios across Kinbasket Reservoir stations was 25 at al stations except KIN Wood at 19 (Table 3, Figure 7). Total phosphorus (corrected for colour and turbidity) was used in lieu of total dissolved phosphorus where TDP was in excess of TP. With the exception of KIN Columbia, July and August ratios were lowest and May/October were highest. At KIN Columbia, May and July demonstrated highest ratios. August ratios were lowest in KIN Wood and Columbia, driven by high

TP/TDP in that month. Seasonally, N:P ratios peaked in May at all stations except KIN Columbia. Highest NN at KIN Columbia is reflected in that month's high epilimnetic NN:TDP ratio (Figure 12).

Table 3. Average water chemistry values at four stations and all depths combined on Kinbasket Reservoir sampled monthly May, July, August, and October, 2011. Range of values shown in parentheses.

Parameter	Units	STATIONS			
		KIN Forebay	Canoe Reach	Wood Arm	Columbia Reach
NO_2+NO_3 (NN)	µg/L	103 (79 – 125)	107 (79 – 141)	101 (73 – 150)	106 (59 - 155)
TP	µg/L	5.4 (3.2 – 10.1)	5.7 (3.4 – 10.5)	7.9 (3.3 – 14)	7.4 (3.8 – 17)
TP (corrected)	µg/L	5.2 (2.0 – 9.9)	5.5 (3.3 – 10)	7.4 (3.0 – 14)	7.1 (3.6 – 17)
TDP	µg/L	4.7 (0.6 – 10)	4.8 (2.8 – 7.4)	6.7 (2.9 – 12)	5.6 (2.7 – 12)
SRP	µg/L	1.2 (0.4 – 1.9)	1.3 (0.9 – 2.0)	1.1 (0.6 – 1.5)	1.2 (0.6 – 1.9)
NN:TDP*		25 (11 – 40)	25 (15 – 41)	19 (7.3 – 39)	25 (6.6 – 43)
Alkalinity	mg$CaCO_3$/L	129 (116 – 163)	120 (92 - 152)	128 (119 - 145)	157 (132 - 184)
pH		8.0 (7.8 – 8.2)	7.9 (7.6 – 8.2)	8.1 (8.0 – 8.2)	8.1 (7.9 – 8.2)
Conductivity	µohms	114 (90.0 – 168)	107 (71 - 156)	112 (85.0 - 147)	133 (102 - 184)
Turbidity	NTU	0.5 (0.1 – 1.0)	0.6 (0.2 – 2.1)	1.3 (0.3 – 5.9)	0.9 (0.3 – 2.4)
Silica**	mg/L	1.19 (1.08 – 1.30)	1.35 (1.21 – 1.44)	1.24 (1.11 – 1.30)	1.31 (0.97 – 1.51)
Secchi	m	6.4 (5.0 – 9.5)	4.9 (2.3 – 8.5)	4.7 (2.0 -9.0)	4.5 (2.8 – 8.5)

*NN:TP(corrected) used where TDP values were removed.
**Silica values are from a single 0-20 integrated sample per month.

Alkalinity – Average alkalinity across Kinbasket Reservoir stations ranged from 120 to 157 mg$CaCO_3$/L with Columbia Reach having consistently the highest values (Table 3).

pH – pH was slightly alkaline and varied little among stations (Table 3), seasons, or depths in Kinbasket Reservoir with a total range of 7.6 to 8.2 (mean=8.0).

Conductivity – Average conductivity across stations had low variability ranging from 107 to 133 µohms with Columbia Reach having the highest values (Table 3).

Turbidity – Average turbidity was similar across stations (0.5 – 1.3 NTUs) with the greatest range at KIN Wood (Table 3). KIN Columbia Wood had the highest turbidity levels.

Silica (Si) – Silica concentrations across all stations were very similar and trended down through the sampling season (Figure 13). The average concentration across the season ranged from 1.19 to 1.35 mg/L (Table 3). No sample was available for July at KIN Forebay.

Secchi – Secchi depths averaged from 4.5 – 6.4 m across the four Kinbasket Reservoir stations in 2011 (Table 3). Lowest values occurred in May/July and peaked in October (Figure 14). KIN Forebay has generally higher Secchi depths than the other stations.

3.2 Revelstoke Reservoir

In 2011, Revelstoke Reservoir daily average elevations ranged by 1.3m between 571.6m and 572.9m. Full pool is 573m and while larger drawdowns can occur in certain circumstances (e.g. extreme weather events), the normal operating range is within 1.5m (to 571.5m). 2011 represents the first full year of minimum 142 m^3/s discharge at Revelstoke Generating Station.

Nitrite and Nitrate (NO_2+NO_3 or NN) – Average NN was similar across stations in Revelstoke Reservoir (121-130 µg/L), with overall, values ranging from 65 to 230 µg/L (Table 4). Highest NN was recorded in June at all stations, although July was also high at REV Middle and Forebay stations. REV Upper station displays the greatest uniformity across depths, reflecting its shallowness and more riverine characteristics, being more influenced by discharge from Mica (Figure 15). In the epilimnion, NN was peaked in June at all three stations, likely reflecting tributary inputs described in Pieters and Lawrence (2012a). By September, values have dropped to their lowest and increase only slightly into late fall (Figure 20).

Total Phosphorus (TP) – Average TP was similar across stations at 3.8 to 4.1 µg/L with REV Middle station in July showing the greatest variability and highest point values (Table 4, Figure 16). Colour and turbidity corrections were made in most months except for May. Epilimnetic TP also showed a peak in July at REV Upper and Middle stations with little variation the remainder of the year (Figure 21).

Total Dissolved Phosphorus (TDP) – TDP varied from 1.4 to 6.3 µg/L with a small average range of 2.8 to 3.0 µg/L (Table 4, Figure 17). Epilimnetic TDP was generally stable across the sampling period (Figure 22).

Soluble Reactive Phosphorus (SRP) – Average SRP was 1.2 or 1.3µg/L, with a total range of 0.7 to 2.1 µg/L (Table 4, Figure 18). Variability across the season was low with June and July having highest readings (Figure 23).

DIN:TDP – Using NN:TDP [or TP (corrected) as noted above], the average N:P ratio across Revelstoke Reservoir stations had a large range in 2011, from 22 to 150 (Table 4, Figure 19). Unusually high ratios at all stations in June (>100) were driven by very high NN and lowest TDP values. While July NN was also often high in 2011, corresponding TDP was also higher than in June, bringing the N:P ratios closer to average. Epilimnetic values peaked in June and had low variability the remainder of the sampling period (Figure 24).

Alkalinity – Average alkalinity varied little, from 95 to 103 mg$CaCO_3$/L, and, as usual, lower than in Kinbasket Reservoir (Table 4).

pH – Revelstoke Reservoir was slightly alkaline with pH varying little among stations (Table 4), seasons, or depths in Revelstoke Reservoir (7.4 to 8.0).

Conductivity – Average conductivity varied little, ranging between 90 and 92 µohms, and as with alkalinity, lower than in Kinbasket Reservoir (Table 4).

Turbidity – Average turbidity across stations ranged from 0.8 to 1.3 NTUs with declining values from the Upper station to the Forebay (Table 4)

Silica (Si) – Average silica was similar with a total range of 1.37 to 1.47mg/L across the three stations (Table 4). Monthly values varied little across seasons and generally peaked in June/July freshet. (Figure 25).

***Secchi* -** Secchi depths averaged from 4.5 to 6.8 m across Revelstoke Reservoir stations with increasing values from north to south (Upper to Forebay stations) (Table 4). Seasonally, Secchi depths generally declined through the freshet period (Figure 26).

Table 4. Average water chemistry values at three stations and all depths combined on Revelstoke Reservoir sampled monthly May to October, 2011. Range of values shown in parentheses.

Parameter	Units	STATIONS		
		REV Forebay	REV Middle	REV Upper
NO_2+NO_3 (NN)	µg/L	126 (74 – 189)	121 (65 - 183)	130 (84 - 230)
TP	µg/L	3.8 (2.0 – 5.4)	4.1 (2.2 – 11)	4.0 (2.5 – 6.5)
TP (corrected)	µg/L	3.5 (1.8 – 5.3)	3.8 (1.9 – 10.6)	3.5 (1.9 – 5.8)
TDP	µg/L	2.8 (1.5 – 4.7)	3.0 (1.7 – 6.3)	2.9 (1.4 – 5.4)
SRP	µg/L	1.3 (0.8 – 2.1)	1.2 (0.7 – 2.0)	1.2 (0.7 – 1.7)
NN:TDP*		49 (22 – 116)	44 (22 – 102)	53 (25 – 150)
Alkalinity	mg$CaCO_3$/L	101 (67 - 127)	103 (63 – 136)	95 (42 – 125)
pH		7.7 (7.5 – 7.9)	7.8 (7.5 – 7.9)	7.7 (7.4 – 8.0)
Conductivity	µohms	90 (54 - 129)	92 (47 - 128)	90 (33 – 128)
Turbidity	NTU	0.8 (0.1 – 2.4)	1.0 (0.3- 4.1)	1.3 (0.3 – 3.9)
Silica**	mg/L	1.37 (1.25 – 1.50)	1.39 (1.20 – 1.57)	1.47 (1.22 – 1.87)
Secchi	m	6.8 (4.2 – 9.0)	6.0 (4.2 – 8.4)	4.5 (2.5 – 7.9)

*NN:TP(corrected) used where TDP values were removed.
**Silica values are from a single 0-20 integrated sample per month.

4. Discussion

The 2011 results represent the fourth year of sampling sessions on Kinbasket and Revelstoke Reservoirs, adding to the dataset begun mid-season in 2008.

Total phosphorus in all samples ranged from 2.0 to 17 µg/L and SRP from 0.4 to 2.1 µg/L, confirming the oligotrophic status of both reservoirs according to Wetzel's (2001) classification of productivity. NN:TDP ratios usually >10 and as high as 150 demonstrate phosphorous limitation in both reservoirs and in all seasons, particularly in Revelstoke Reservoir. In 2011, very high levels of nitrates and nitrites in the spring freshet (late May to early July) were noticeable in both reservoirs, although not at all stations in Kinbasket. Both reservoirs can experience higher epilimnetic nitrates and nitrites and TP in the spring period when inflows are high.

An additional discrete depth sample of 80m is recommended in 2012 to fill a data gap for water chemistry and nutrient information in the hypolimnion. Between 20 and 60m, depths can be changed to 30m and 40m to accommodate the additional hypolimnetic sample. As conditions permit, the sampling season should also be extended later into November and earlier in April/May to help determine the boundaries of the productive season in the reservoirs.

Future years of sampling will provide more information on seasonal and annual variability of pelagic water chemistry parameters. A synthesis of 2008-2011 data from physical and biological processes is expected to begin to shed light on the study's management questions. The influence of hydrologic events on the seasonality of nutrients in the photic zone and the connection with plankton abundance and growth will be explored in the synthesis report. Several years of monitoring data are required to begin analysing for trends and it is expected this reservoir sampling program will continue as part of the project plan for several more years.

5. References

K.I. Ashley and J.G. Stockner. 2003. Protocol for applying limiting nutrients to inland waters. Pages 245-260. *In:* J.G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland:

Pieters, R. and G. Lawrence. 2012a. Tributary Water Quality Kinbasket and Revelstoke Reservoirs, 2010. University of British Columbia. Prepared for BC Hydro. 8 pp. + figures and appendices. Appendix 2 *In* Bray, K. 2012. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2010). BC Hydro, Study No. CLBMON-3. 4pp. + appendices.

Pieters, R. and G. Lawrence. 2012b. Hydrology of Kinbasket and Revelstoke Reservoirs, 2010. University of British Columbia. Prepared for BC Hydro 12 pp. + figures and appendices. Appendix 1 *In* Bray, K. 2012. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 3 (2010). BC Hydro, Study No. CLBMON-3. 4pp. + appendices.

Wetzel, R. 2001. Limnology. Third Edition. Academic Press, San Diego, USA.

Acknowledgements

Thanks are extended to Beth Manson and Pierre Bourget who collected, field processed, and shipped water samples. The Department of Fisheries and Oceans Cultus Lake Laboratory performed all the water chemistry analyses.

Figure 1. Location of reservoir sampling stations on Kinbasket and Revelstoke Reservoirs, 2011.

Figure 2. Kinbasket Reservoir elevation and sampling dates, 2011. Elevations for 2008-2010 are shown for comparison.

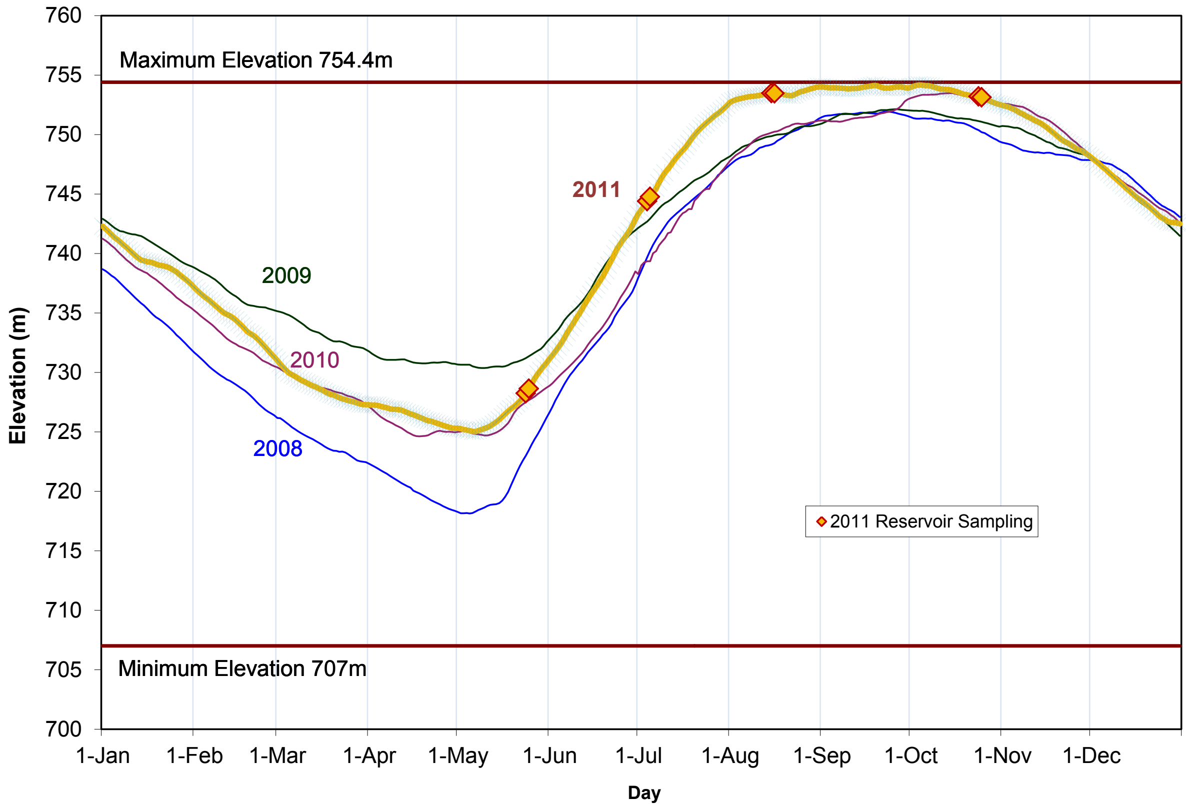


Figure 3. Discrete depth nitrate and nitrite (µg/L) at Kinbasket Reservoir stations, 2011.

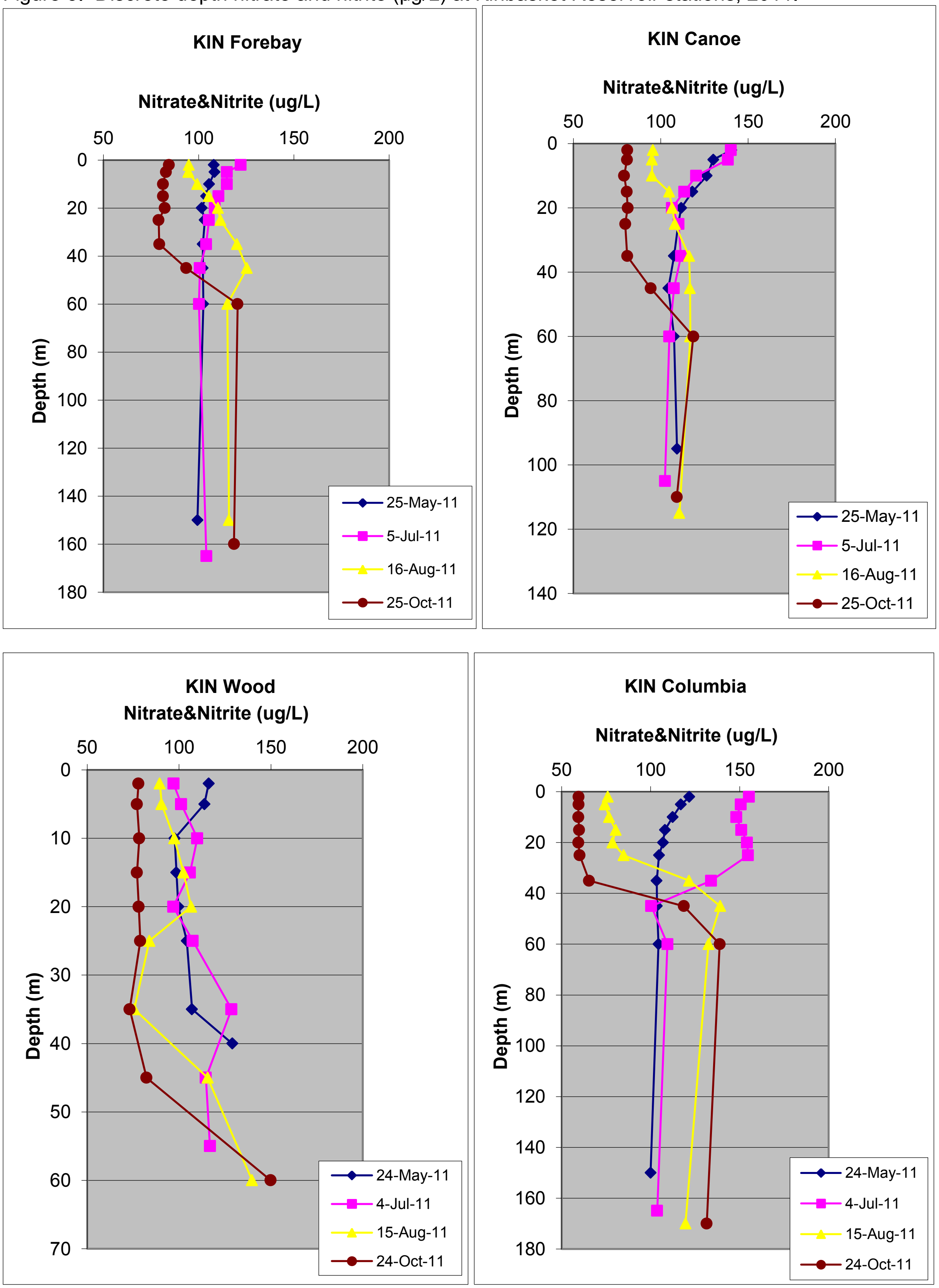


Figure 4. Discrete depth total phosphorus (µg/L) at Kinbasket Reservoir stations, 2011.

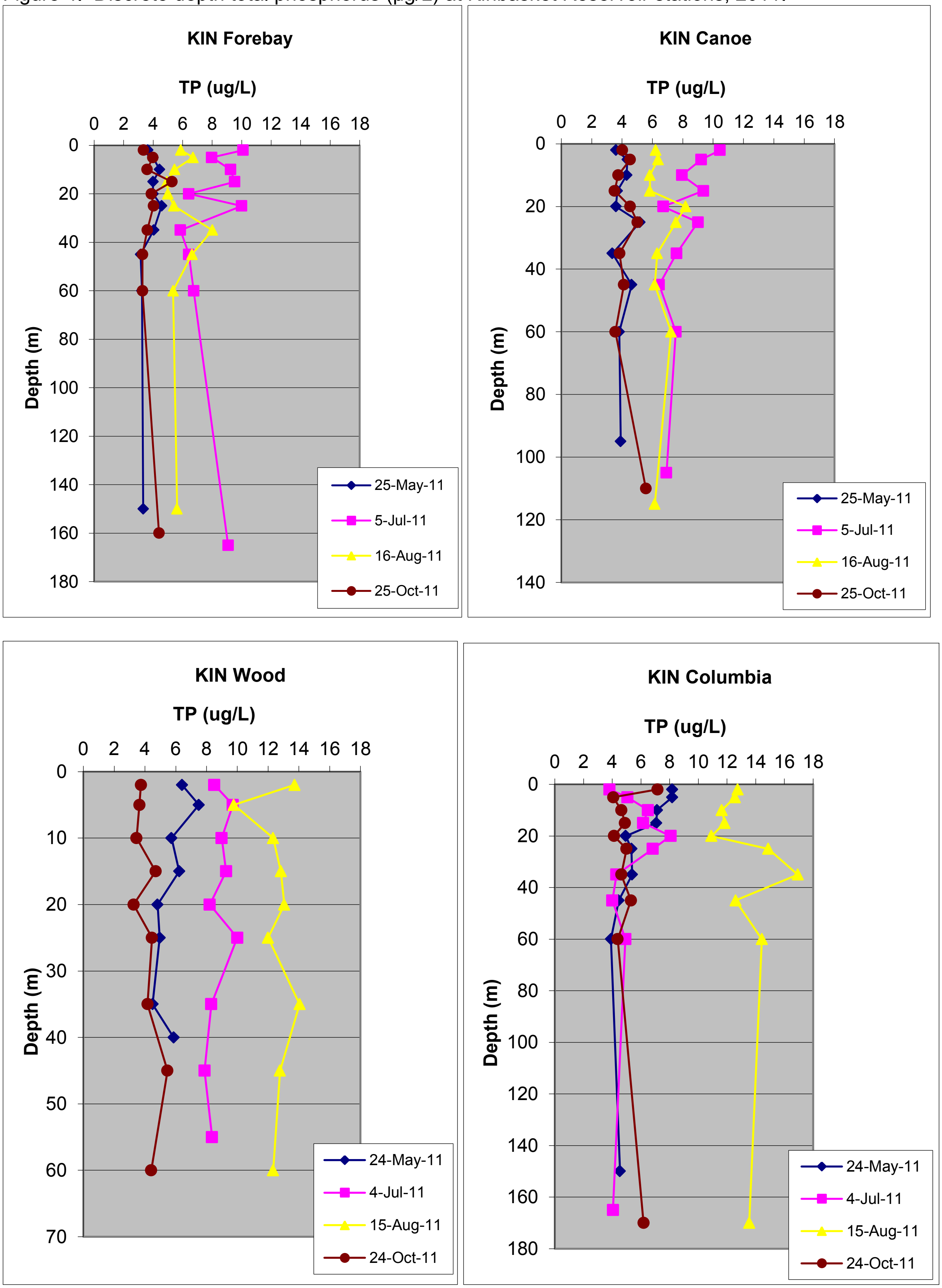


Figure 5. Discrete depth total dissolved phosphorus (µg/L) at Kinbasket Reservoir stations, 2011.

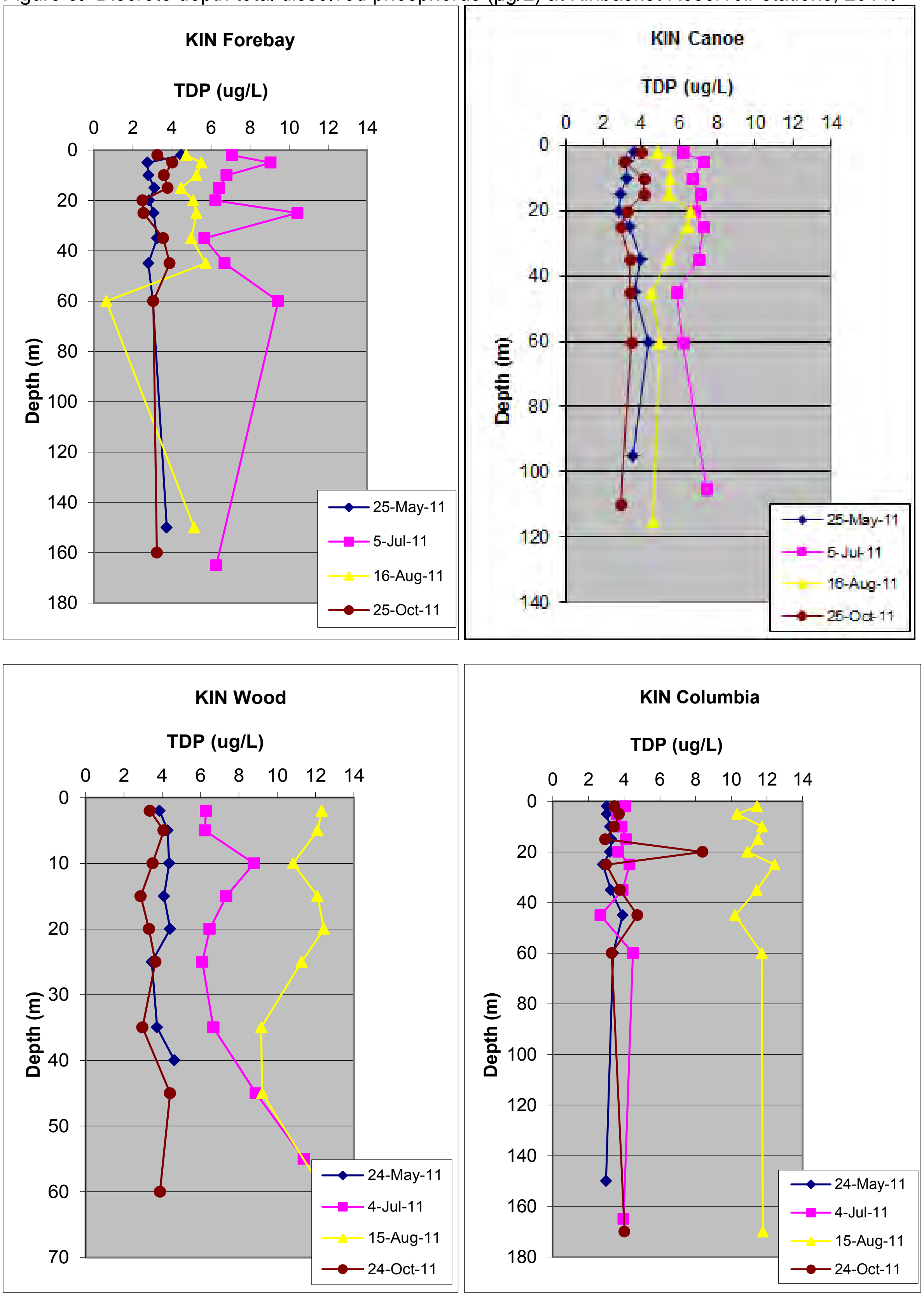


Figure 6. Discrete depth soluble reactive phosphorus (µg/L) at Kinbasket Reservoir stations, 2011.

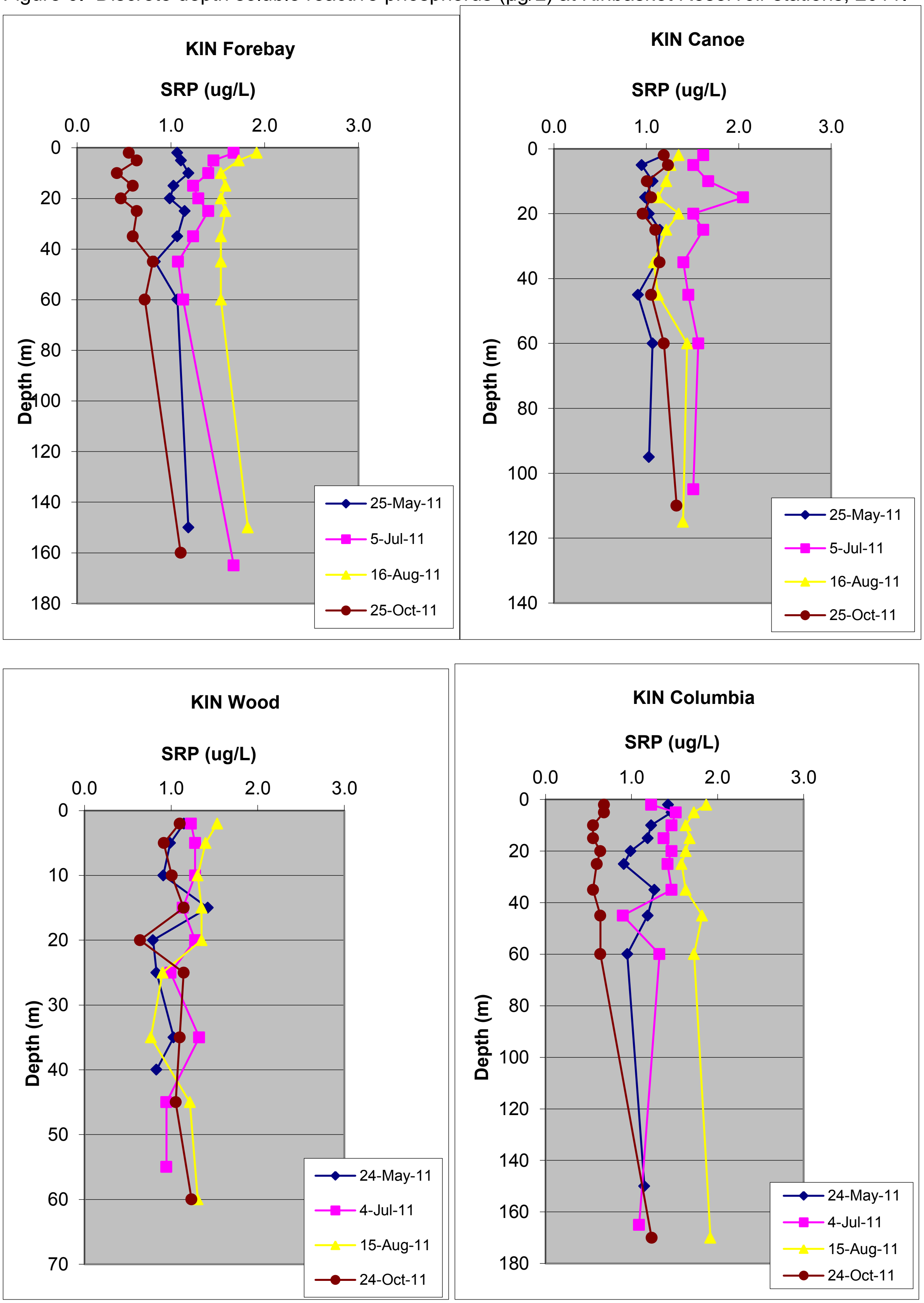


Figure 7. DIN:TDP ratios at Kinbasket Reservoir stations, 2011.

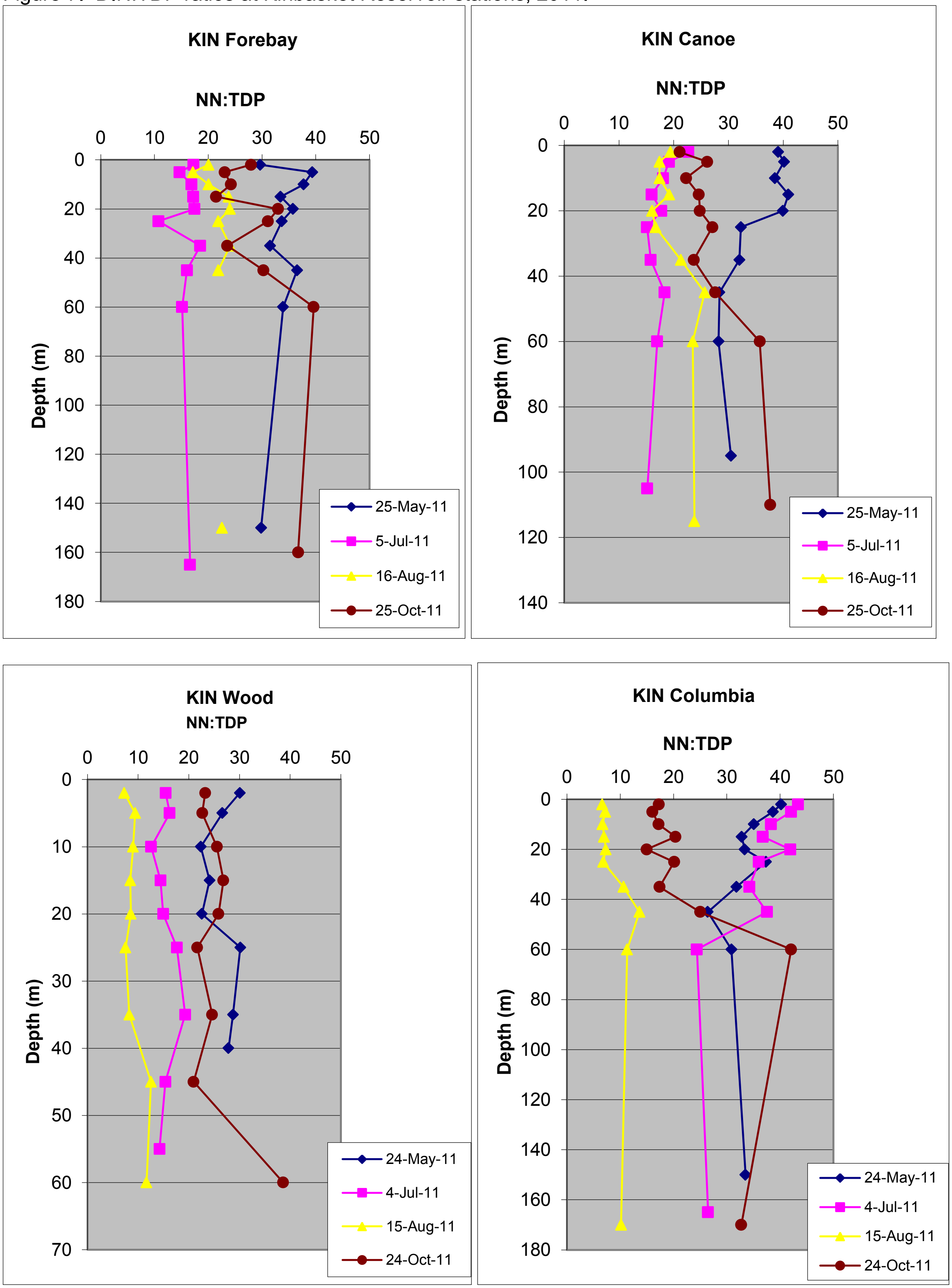


Figure 8. Seasonal average epilimnetic (0-20m) nitrate and nitrite (µg/L) at Kinbasket stations, 2011.

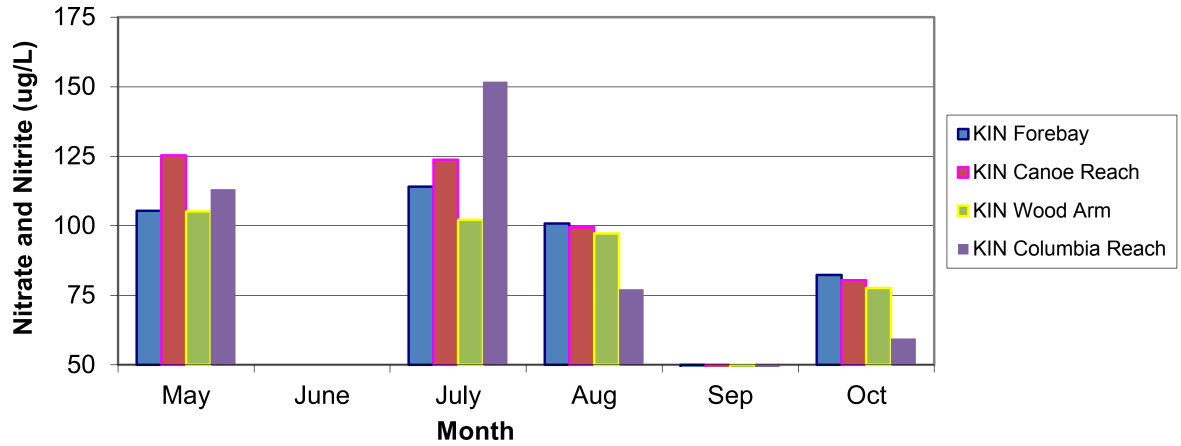


Figure 9. Seasonal average epilimnetic (0-20m) total phosphorus (µg/L) at Kinbasket stations, 2011.

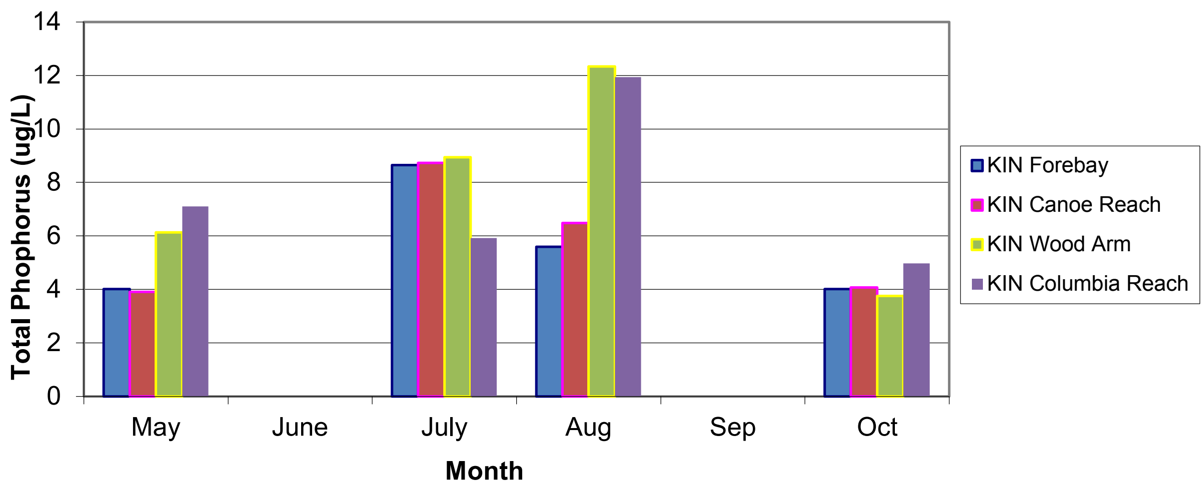


Figure 10. Seasonal average epilimnetic (0-20m) total dissolved phosphorus (µg/L) Kinbasket stations, 2011.

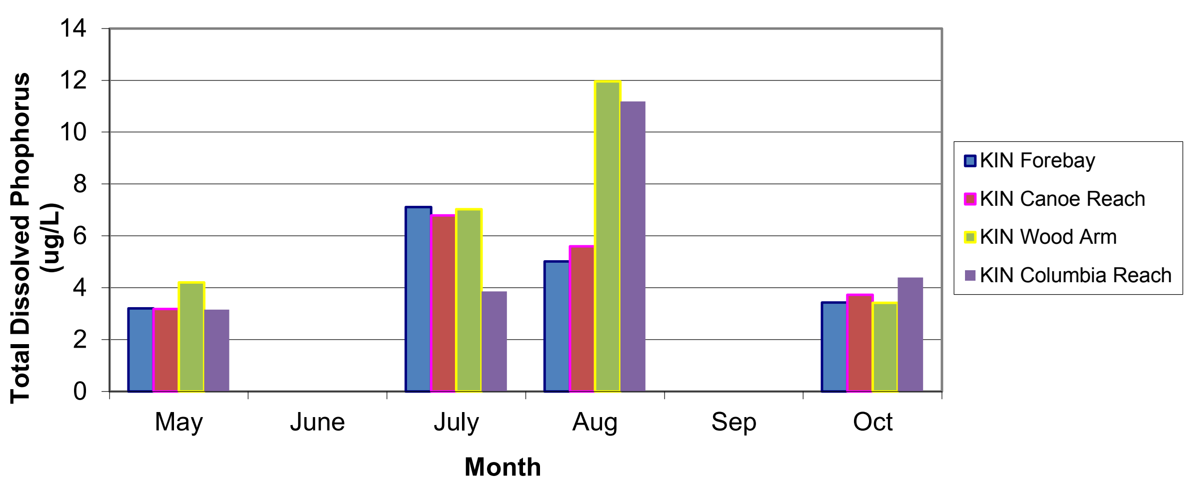


Figure 11. Seasonal average epilimnetic (0-20m) soluble reactive phosphorus (µg/L) at Kinbasket stations, 2011.

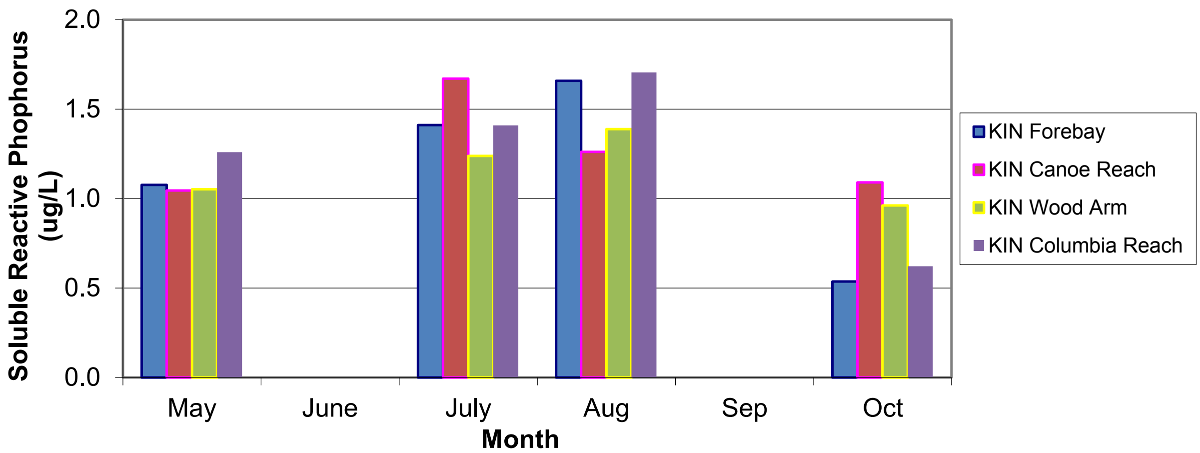


Figure 12. Seasonal average epilimnetic (0-20m) DIN:TDP at Kinbasket stations, 2011.

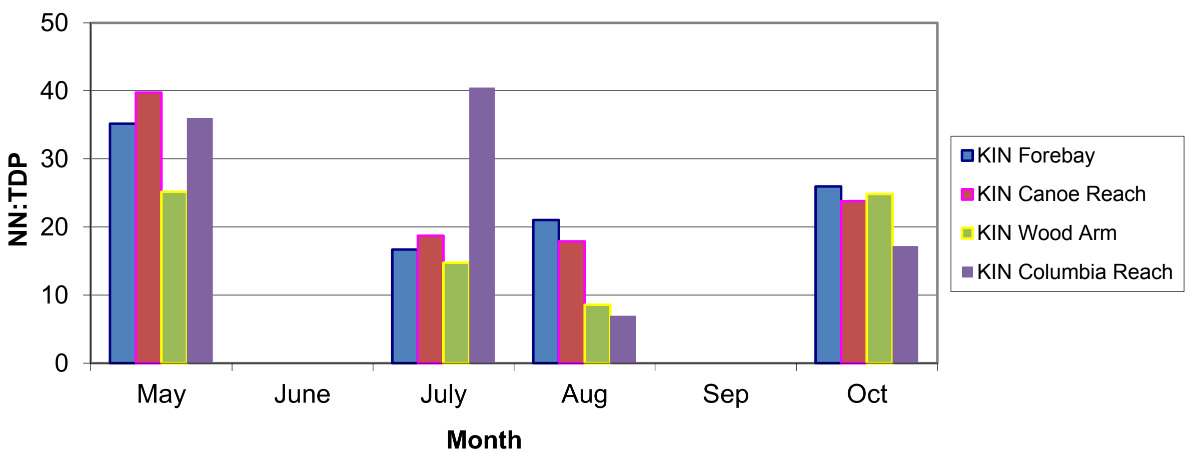


Figure 13. Seasonal silica (mg/L) from a 0-20m integrated tube sample at Kinbasket stations, 2011.

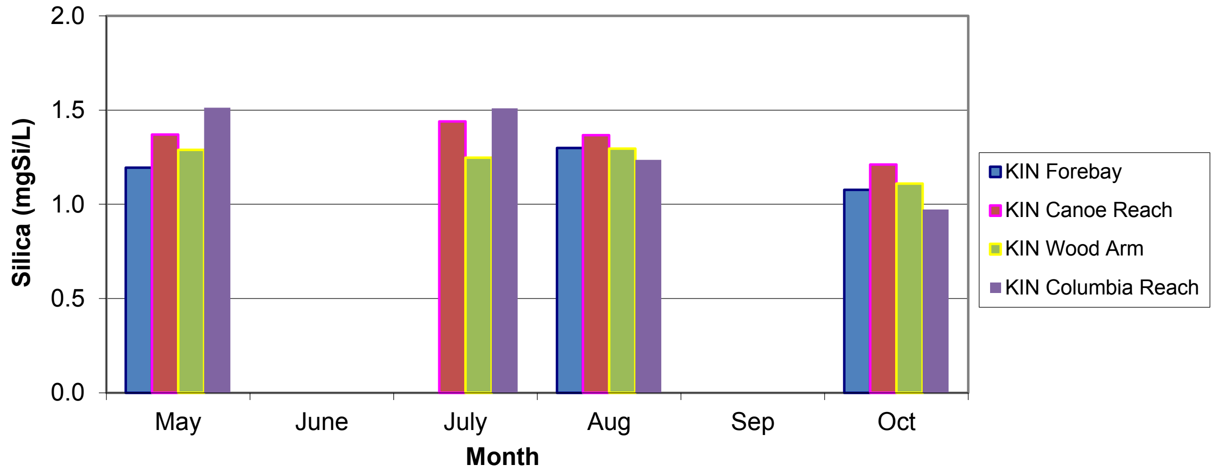


Figure 14. Seasonal Secchi depth (m) at Kinbasket stations, 2011.

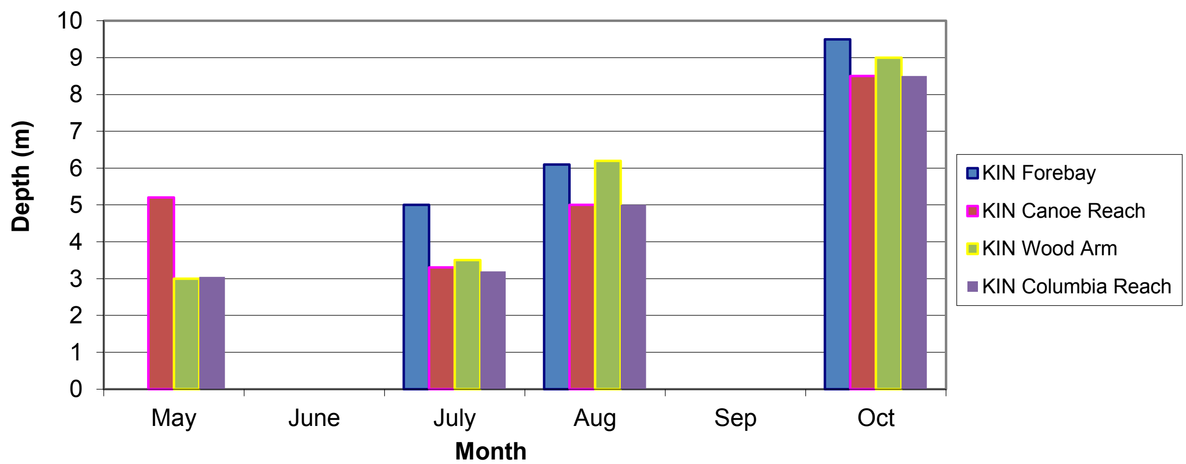
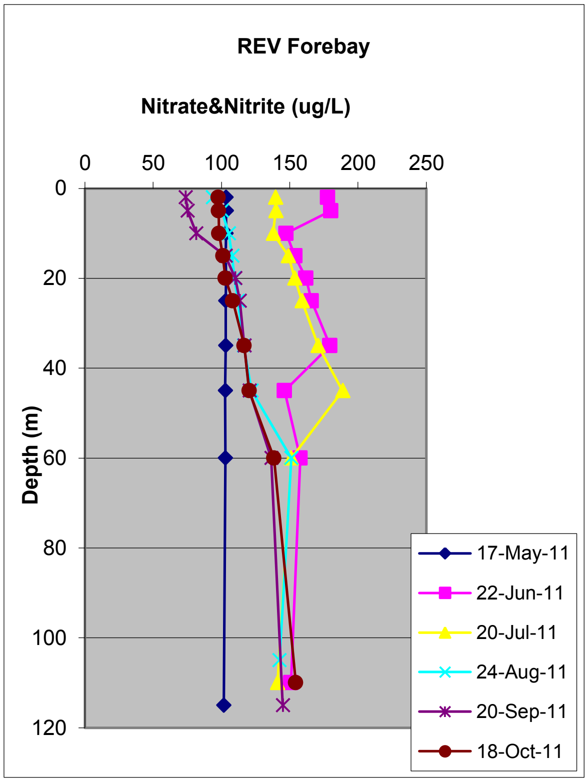
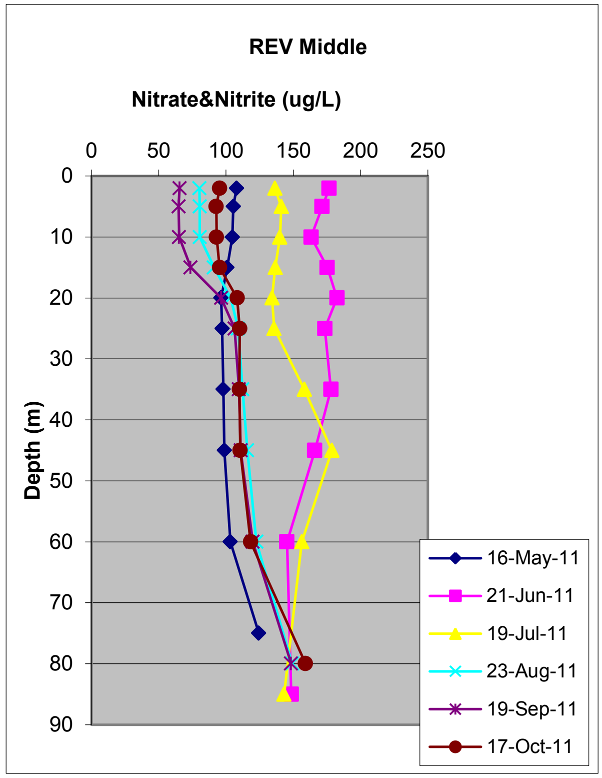


Figure 15 Discrete depth nitrite and nitrate (µg/L) at Revelstoke Reservoir stations, 2011.





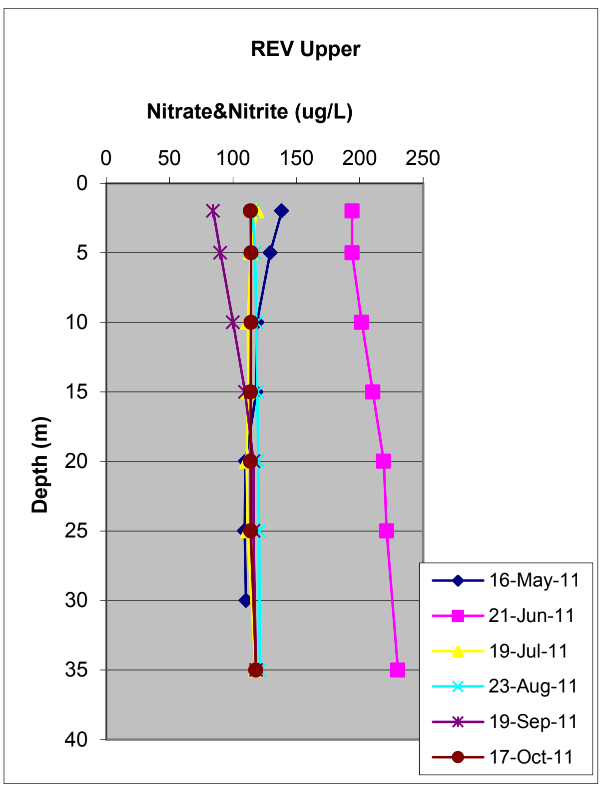
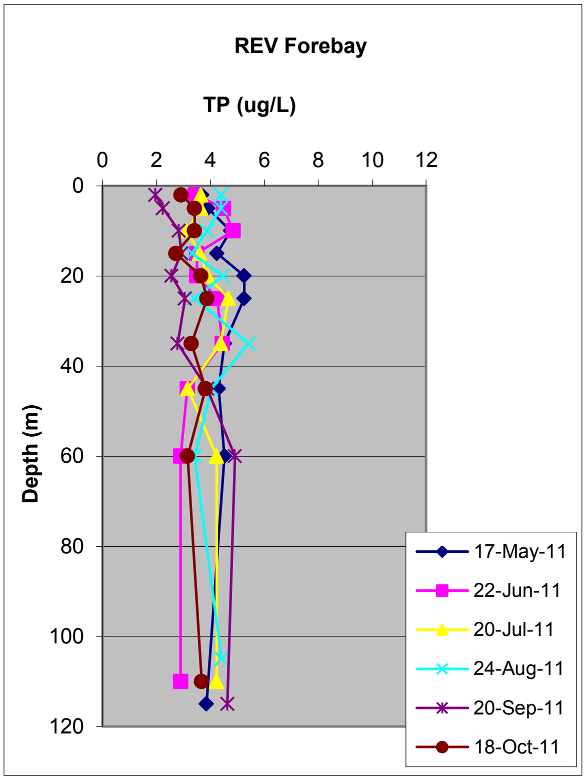
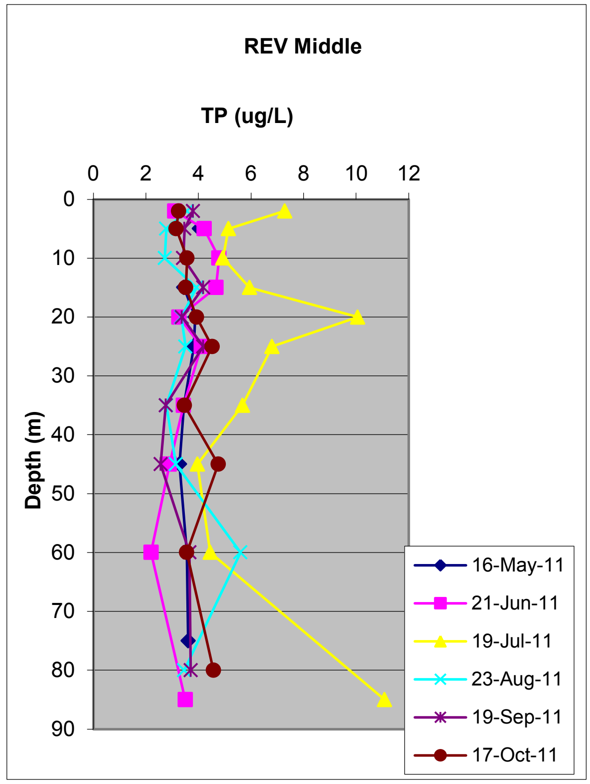


Figure 16. Discrete depth total phosphorus (µg/L) at Revelstoke Reservoir stations, 2011.





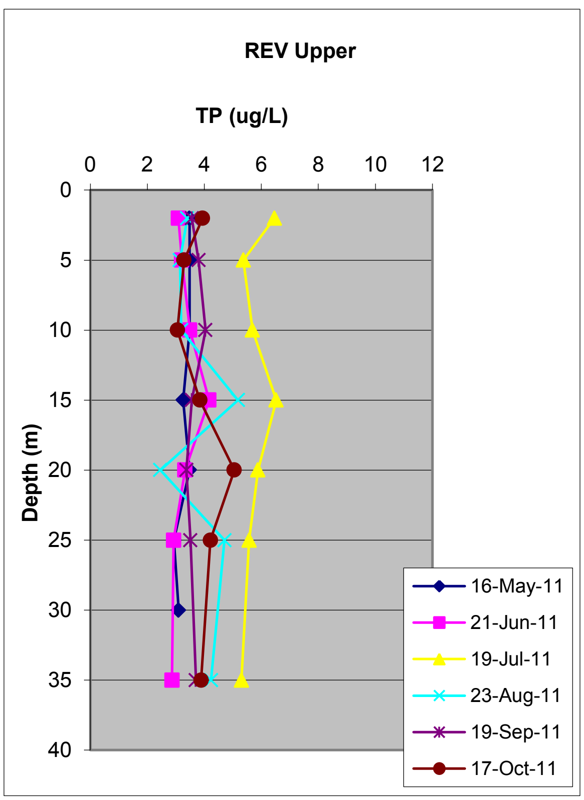
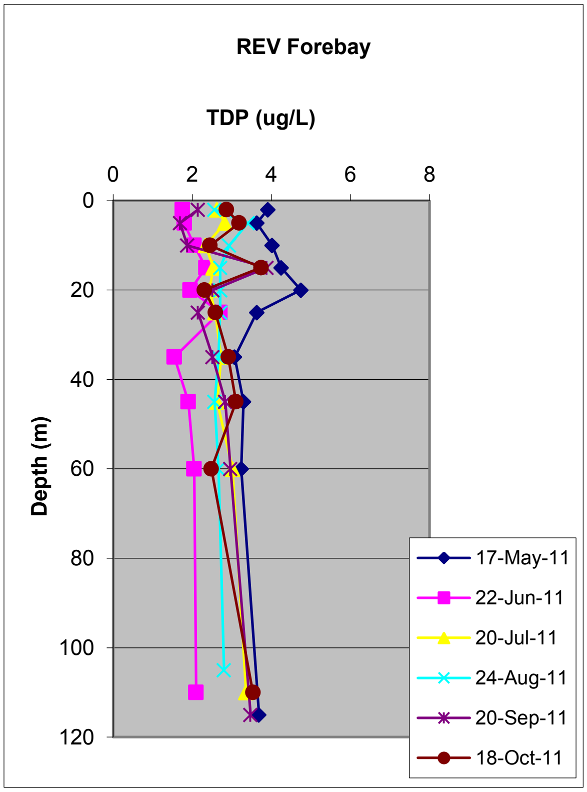
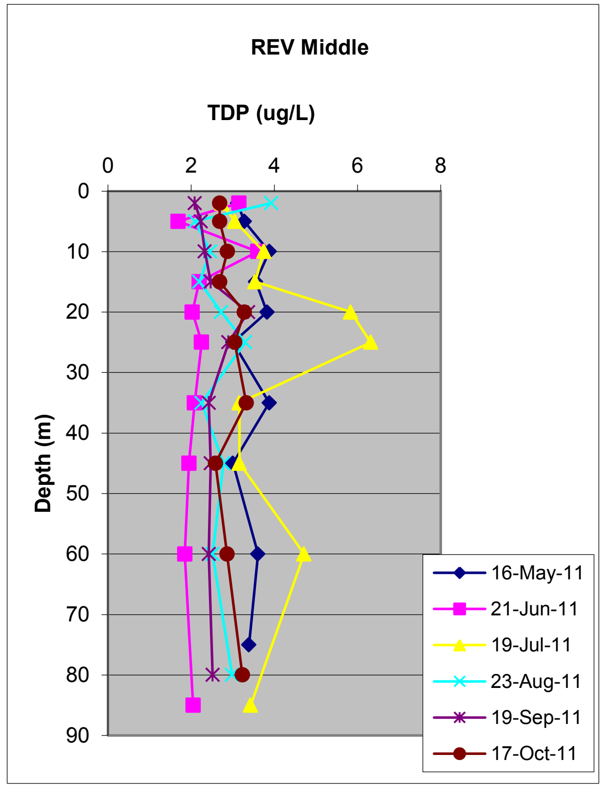


Figure 17. Discrete depth total dissolved phosphorus (µg/L) at Revelstoke Reservoir stations, 2011.





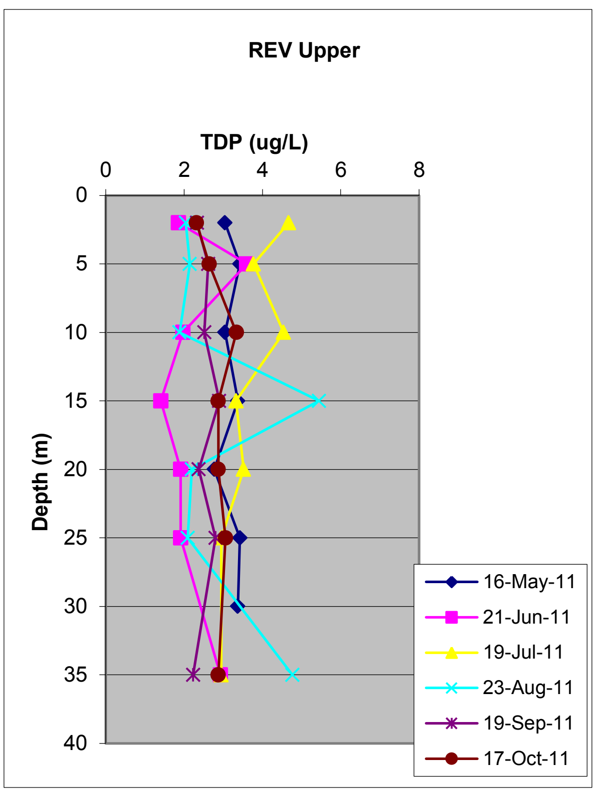
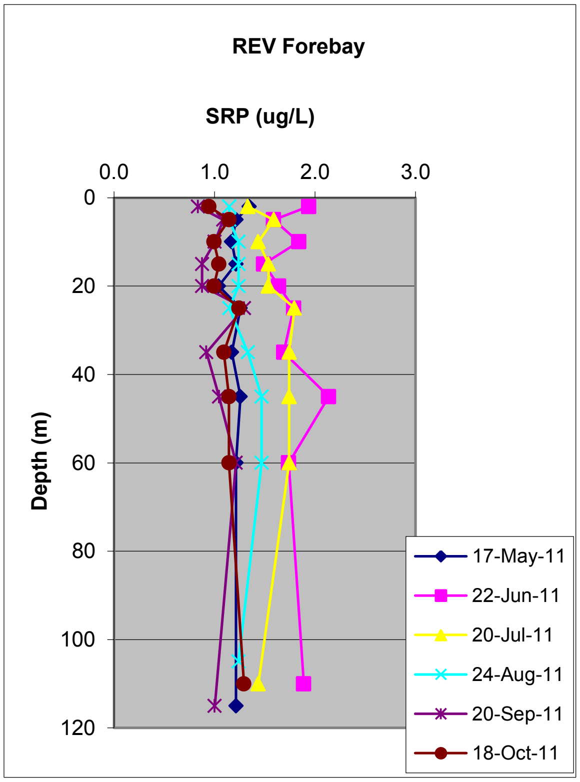
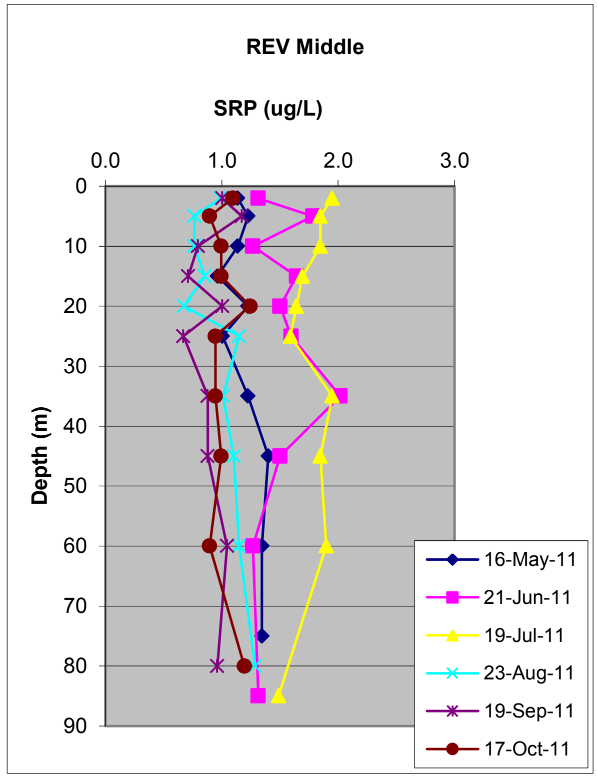


Figure 18. Discrete depth soluble reactive phosphorus (µg/L) at Revelstoke Reservoir stations, 2011.





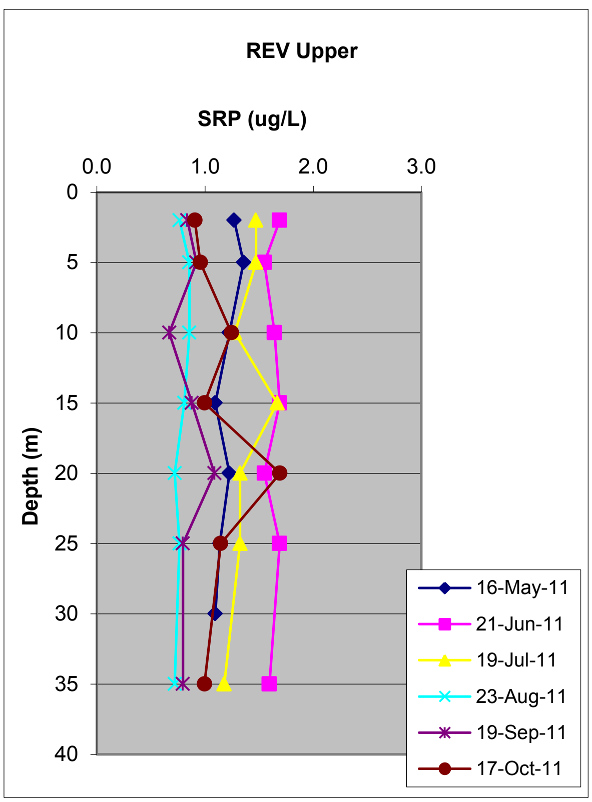


Figure 19. DIN:TDP ratios at Revelstoke Reservoir stations, 2011.

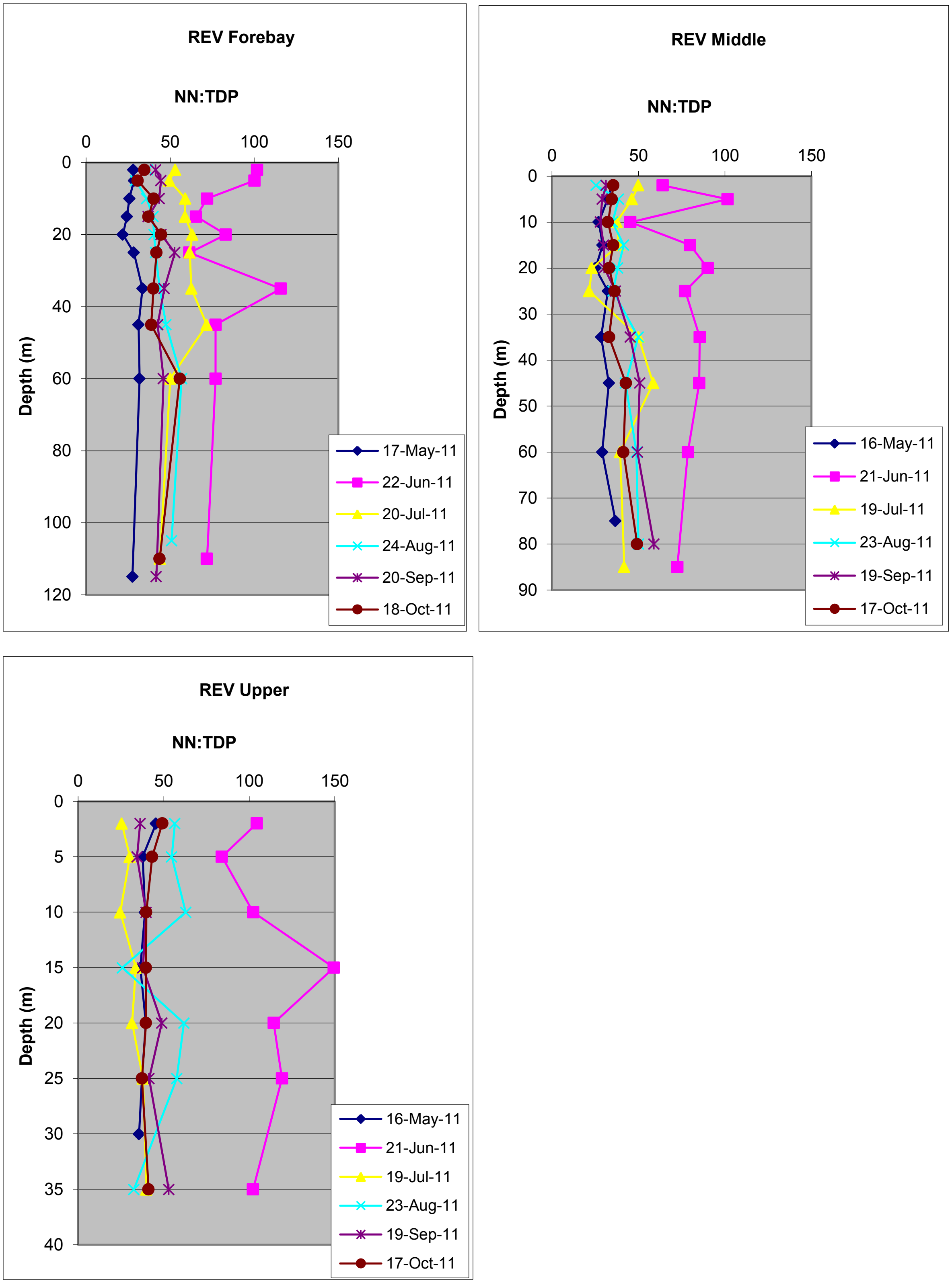


Figure 20. Seasonal average epilimnetic (0-20m) nitrate and nitrite (µg/L) at Revelstoke stations, 2011.

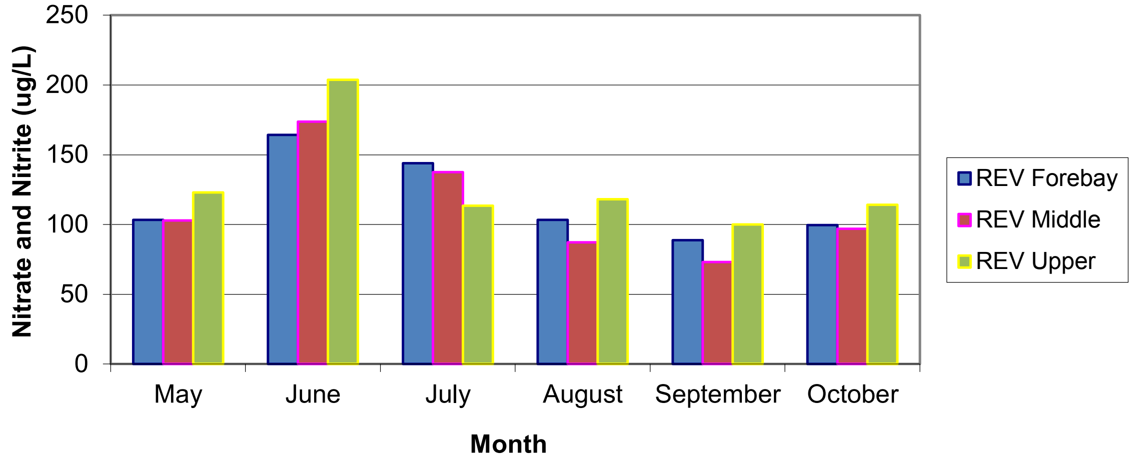


Figure 21. Seasonal average epilimnetic (0-20m) total phosphorus (µg/L) at Revelstoke stations, 2011.

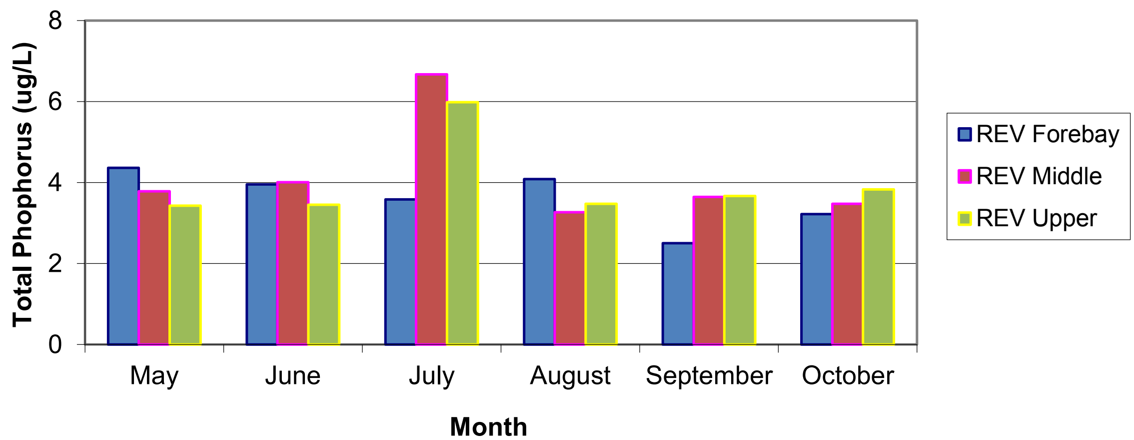


Figure 22. Seasonal average epilimnetic (0-20m) total dissolved phosphorus (µg/L) at Revelstoke stations, 2011.

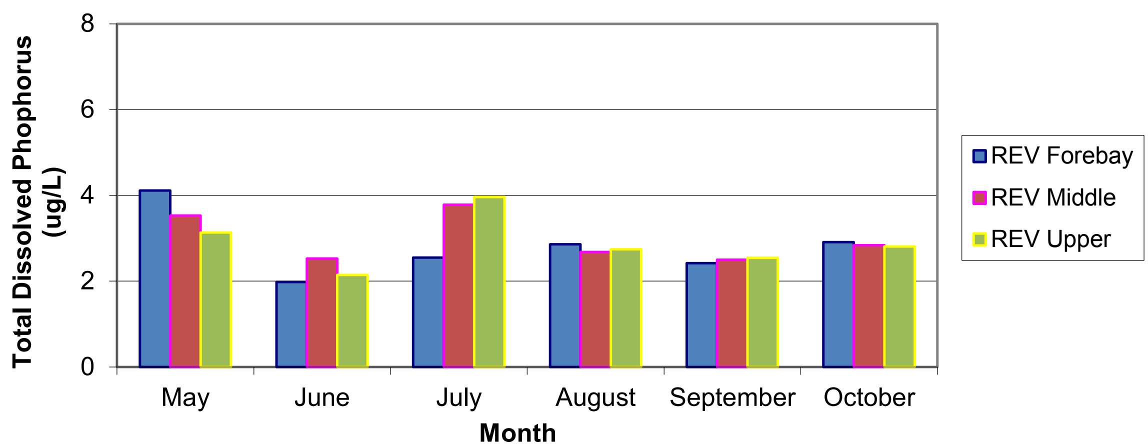


Figure 23. Seasonal average epilimnetic (0-20m) soluble reactive phosphorus (µg/L) at Revelstoke stations, 2011.

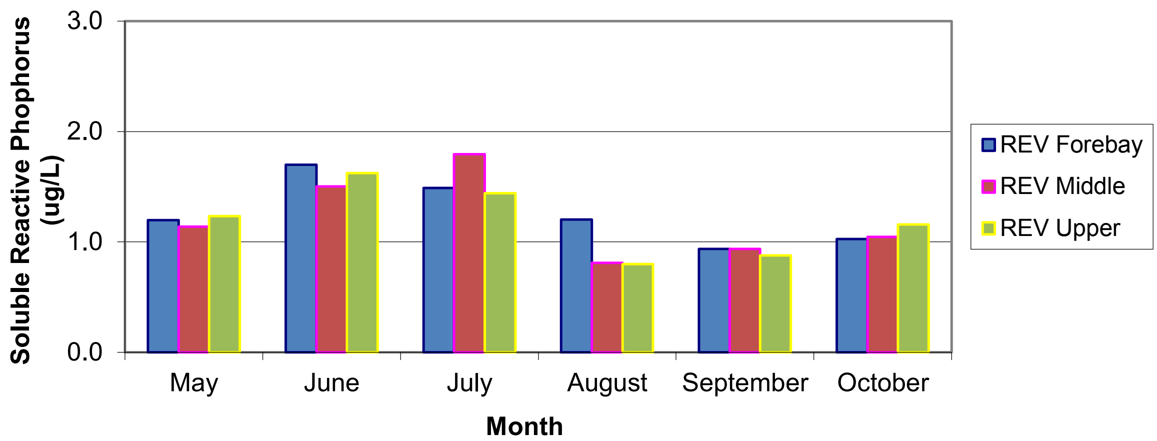


Figure 24. Seasonal average epilimnetic (0-20m) DIN:TDP at Revelstoke stations, 2011.

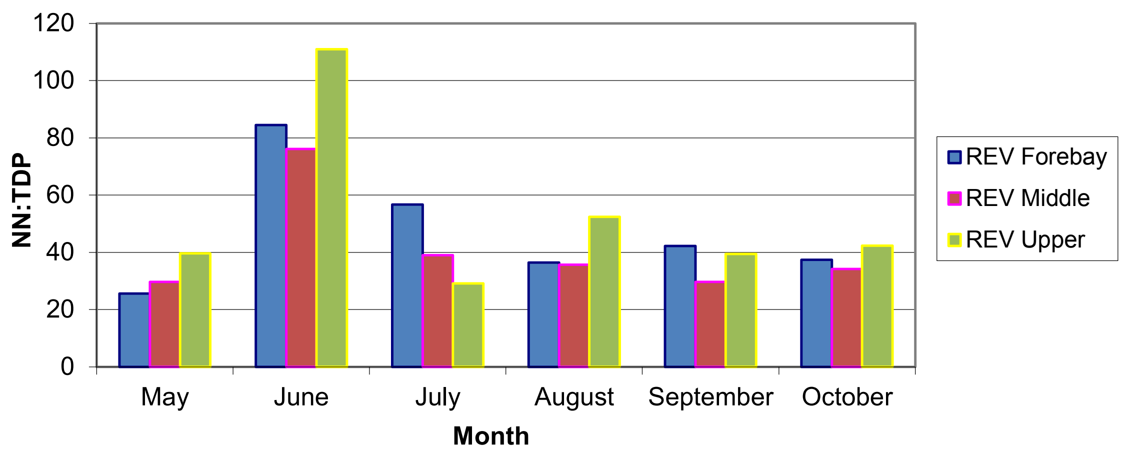


Figure 25. Seasonal silica (mg/L) from a 0-20m integrated tube sample at Revelstoke stations, 2011.

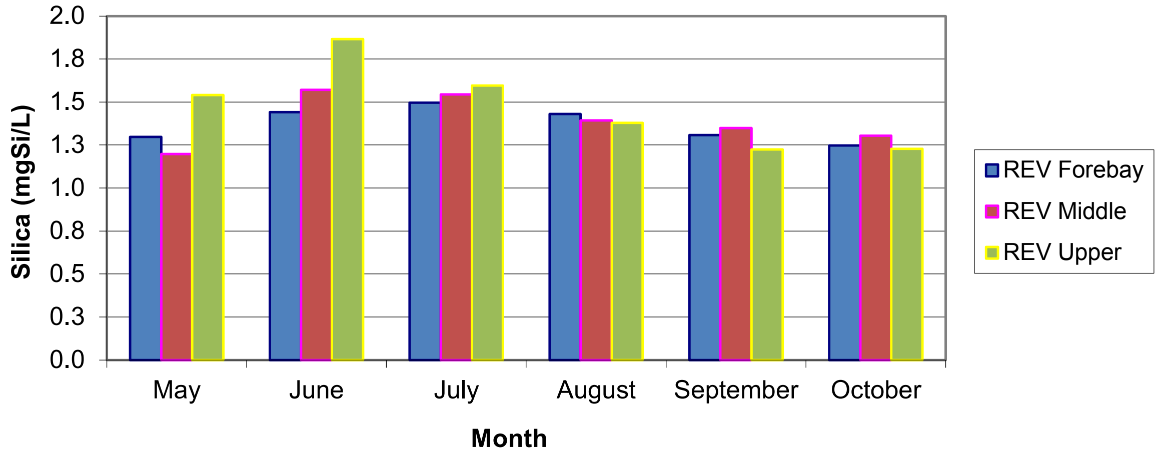
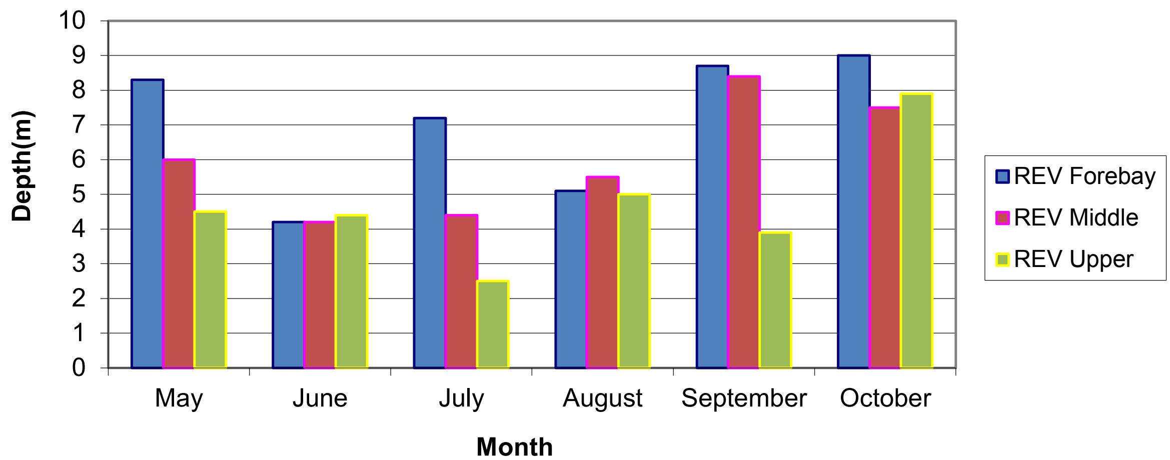


Figure 26. Seasonal Secchi depth (m) at Revelstoke stations, 2011.



Appendix 1 - Data

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Kinbasket - Columbia	0 - 20	24-May-11	.	.	.	.	.	1.51	.	.	.	.
Kinbasket - Columbia	2	24-May-11	121.8	1.4	8.2	1.4	3.0	.	183.6	8.09	1.70	137
Kinbasket - Columbia	5	24-May-11	117.0	1.5	8.2	1.6	3.0	.	179.6	8.05	1.10	135
Kinbasket - Columbia	10	24-May-11	112.4	1.2	7.1	<0.1	3.2	.	179.4	7.98	1.40	133
Kinbasket - Columbia	15	24-May-11	108.0	1.2	7.1	<0.1	3.3	.	174.0	8.01	0.65	131
Kinbasket - Columbia	20	24-May-11	107.0	1.0	4.9	<0.1	3.2	.	174.8	8.03	0.55	131
Kinbasket - Columbia	25	24-May-11	104.7	0.9	5.3	<0.1	2.8	.	171.6	8.00	0.70	130
Kinbasket - Columbia	35	24-May-11	103.4	1.3	5.4	<0.1	3.3	.	172.5	8.01	0.68	130
Kinbasket - Columbia	45	24-May-11	103.5	1.2	4.5	<0.1	3.9	.	173.6	8.00	0.73	131
Kinbasket - Columbia	60	24-May-11	104.5	1.0	3.9	<0.1	3.4	.	173.6	8.00	0.65	132
Kinbasket - Columbia	150	24-May-11	100.0	1.1	4.5	<0.1	3.0	.	180.6	7.96	1.00	139
Kinbasket - Forebay	0 - 20	25-May-11	.	.	.	.	.	1.19	.	.	.	.
Kinbasket - Forebay	2	25-May-11	107.9	1.1	3.6	<0.1	4.5	.	129.6	7.97	0.20	99
Kinbasket - Forebay	5	25-May-11	108.3	1.1	4.0	<0.1	2.8	.	128.9	7.98	0.15	98
Kinbasket - Forebay	10	25-May-11	105.5	1.2	4.4	<0.1	2.8	.	129.8	7.97	0.10	99
Kinbasket - Forebay	15	25-May-11	103.9	1.0	4.0	<0.1	3.1	.	129.9	7.96	0.35	99
Kinbasket - Forebay	20	25-May-11	101.6	1.0	4.0	<0.1	2.8	.	130.9	7.97	0.25	100
Kinbasket - Forebay	25	25-May-11	103.2	1.1	4.6	<0.1	3.1	.	132.8	7.96	0.30	100
Kinbasket - Forebay	35	25-May-11	102.1	1.1	4.0	<0.1	3.2	.	133.8	7.89	0.10	102
Kinbasket - Forebay	45	25-May-11	102.1	0.8	3.2	<0.1	2.8	.	133.7	7.95	0.40	102
Kinbasket - Forebay	60	25-May-11	102.4	1.1	3.2	<0.1	3.0	.	134.7	7.95	0.20	102
Kinbasket - Forebay	150	25-May-11	99.3	1.2	3.3	<0.1	3.7	.	145.8	7.94	0.35	112
Kinbasket - Canoe	0 - 20	25-May-11	.	.	.	.	.	1.37	.	.	.	.
Kinbasket - Canoe	2	25-May-11	140.5	1.2	3.6	<0.1	3.7	.	109.6	7.92	0.50	86
Kinbasket - Canoe	5	25-May-11	130.1	1.0	4.3	<0.1	3.2	.	109.4	7.88	0.40	86
Kinbasket - Canoe	10	25-May-11	126.4	1.1	4.3	<0.1	3.3	.	110.0	7.88	0.40	86
Kinbasket - Canoe	15	25-May-11	118.1	1.0	3.7	<0.1	2.9	.	113.8	7.88	0.28	89
Kinbasket - Canoe	20	25-May-11	111.7	1.0	3.6	<0.1	2.8	.	117.7	7.89	0.35	92
Kinbasket - Canoe	25	25-May-11	110.0	1.1	5.2	<0.1	3.4	.	121.9	7.91	0.40	95
Kinbasket - Canoe	35	25-May-11	107.6	1.1	3.4	<0.1	4.0	.	125.8	7.91	0.45	98
Kinbasket - Canoe	45	25-May-11	104.4	0.9	4.6	<0.1	3.7	.	129.9	7.92	0.35	101
Kinbasket - Canoe	60	25-May-11	107.6	1.1	3.8	<0.1	4.4	.	137.8	7.89	0.25	105
Kinbasket - Canoe	95	25-May-11	109.3	1.0	3.9	<0.1	3.6	.	137.8	7.86	0.15	106
Kinbasket - Wood	0 - 20	24-May-11	.	.	.	.	.	1.29	.	.	.	.
Kinbasket - Wood	2	24-May-11	116.2	1.1	6.4	<0.1	3.9	.	134.6	8.14	1.30	103
Kinbasket - Wood	5	24-May-11	113.8	1.0	7.5	<0.1	4.3	.	134.8	8.14	1.30	102
Kinbasket - Wood	10	24-May-11	97.6	0.9	5.7	<0.1	4.4	.	133.8	8.05	0.50	102
Kinbasket - Wood	15	24-May-11	98.6	1.4	6.2	<0.1	4.1	.	133.7	8.04	0.70	102
Kinbasket - Wood	20	24-May-11	99.6	0.8	4.8	<0.1	4.4	.	133.8	8.01	0.50	102
Kinbasket - Wood	25	24-May-11	104.3	0.8	5.0	<0.1	3.5	.	134.8	8.02	0.43	103
Kinbasket - Wood	35	24-May-11	107.0	1.0	4.5	<0.1	3.7	.	134.9	8.01	0.45	104
Kinbasket - Wood	40	24-May-11	129.0	0.8	5.9	<0.1	4.6	.	139.7	8.08	1.10	107
Kinbasket - Columbia	0 - 20	4-Jul-11	.	.	.	.	.	1.51	.	.	.	.
Kinbasket - Columbia	2	4-Jul-11	155.3	1.2	3.8	0.2	4.1	.	164.8	8.22	1.40	114
Kinbasket - Columbia	5	4-Jul-11	150.7	1.5	5.1	0.2	3.6	.	163.7	8.23	1.30	113
Kinbasket - Columbia	10	4-Jul-11	148.1	1.5	6.5	0.3	3.9	.	159.7	8.19	1.90	111
Kinbasket - Columbia	15	4-Jul-11	151.0	1.4	6.2	0.2	4.1	.	153.8	8.11	1.85	108
Kinbasket - Columbia	20	4-Jul-11	154.1	1.5	8.1	0.5	3.7	.	142.8	8.08	2.40	102
Kinbasket - Columbia	25	4-Jul-11	154.7	1.4	6.8	0.3	4.3	.	160.7	8.09	1.30	112
Kinbasket - Columbia	35	4-Jul-11	134.0	1.5	4.3	0.1	3.9	.	146.8	8.07	1.30	105
Kinbasket - Columbia	45	4-Jul-11	100.4	0.9	4.0	0.2	2.7	.	149.7	8.00	0.45	110
Kinbasket - Columbia	60	4-Jul-11	109.5	1.3	4.9	0.2	4.5	.	174.7	8.01	1.30	128
Kinbasket - Columbia	165	4-Jul-11	103.7	1.1	4.1	0.1	4.0	.	177.6	7.99	0.40	130
Kinbasket - Forebay	0 - 20	5-Jul-11	.	.	.	.	.	.	.	.	.	.
Kinbasket - Forebay	2	5-Jul-11	122.0	1.7	10.1	0.2	7.1	.	117.5	8.15	0.90	100
Kinbasket - Forebay	5	5-Jul-11	114.8	1.5	8.0	0.1	9.1	.	130.8	8.01	0.80	96
Kinbasket - Forebay	10	5-Jul-11	114.8	1.4	9.2	0.2	6.8	.	128.8	8.11	0.75	95

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Kinbasket - Forebay	15	5-Jul-11	110.5	1.2	9.5	0.3	6.4	.	120.9	8.03	1.00	90
Kinbasket - Forebay	20	5-Jul-11	108.4	1.3	6.4	0.2	6.2	.	122.7	8.03	0.90	91
Kinbasket - Forebay	25	5-Jul-11	105.4	1.4	10.0	0.2	10.4	.	120.9	8.00	0.70	90
Kinbasket - Forebay	35	5-Jul-11	103.9	1.2	5.9	0.2	5.7	.	121.9	7.98	0.65	92
Kinbasket - Forebay	45	5-Jul-11	100.6	1.1	6.4	0.1	6.7	.	127.8	7.95	0.50	96
Kinbasket - Forebay	60	5-Jul-11	100.2	1.1	6.8	0.1	9.4	.	132.8	7.93	0.35	99
Kinbasket - Forebay	165	5-Jul-11	104.0	1.7	9.1	0.3	6.3	.	157.8	7.93	0.50	118
Kinbasket - Canoe	0 - 20	5-Jul-11	.	.	.	.	.	1.44	.	.	.	.
Kinbasket - Canoe	2	5-Jul-11	140.2	1.6	10.5	0.3	6.2	.	145.8	8.22	0.85	105
Kinbasket - Canoe	5	5-Jul-11	138.5	1.5	9.2	0.4	7.2	.	146.8	8.22	1.00	104
Kinbasket - Canoe	10	5-Jul-11	120.3	1.7	7.9	0.2	6.7	.	129.8	8.06	1.15	95
Kinbasket - Canoe	15	5-Jul-11	113.5	2.0	9.4	0.3	7.1	.	117.5	8.04	1.20	86
Kinbasket - Canoe	20	5-Jul-11	106.5	1.5	6.7	0.7	6.8	.	97.4	7.89	1.70	74
Kinbasket - Canoe	25	5-Jul-11	110.2	1.6	9.0	1.0	7.3	.	91.9	7.85	2.10	71
Kinbasket - Canoe	35	5-Jul-11	111.6	1.4	7.6	0.2	7.1	.	107.0	7.83	0.88	82
Kinbasket - Canoe	45	5-Jul-11	107.6	1.5	6.4	0.2	5.9	.	125.9	7.91	0.45	94
Kinbasket - Canoe	60	5-Jul-11	104.9	1.6	7.5	0.2	6.2	.	132.8	7.91	0.40	98
Kinbasket - Canoe	105	5-Jul-11	102.5	1.5	6.9	0.2	7.4	.	141.8	7.91	0.50	105
Kinbasket - Wood	0 - 20	4-Jul-11	.	.	.	.	.	1.25	.	.	.	.
Kinbasket - Wood	2	4-Jul-11	97.0	1.2	8.5	0.3	6.3	.	120.8	8.21	1.10	89
Kinbasket - Wood	5	4-Jul-11	101.2	1.3	9.7	0.2	6.2	.	122.0	8.21	1.10	90
Kinbasket - Wood	10	4-Jul-11	109.9	1.3	9.0	0.2	8.8	.	128.0	8.15	1.30	93
Kinbasket - Wood	15	4-Jul-11	105.9	1.1	9.3	0.3	7.3	.	123.8	8.14	2.55	89
Kinbasket - Wood	20	4-Jul-11	96.9	1.3	8.2	0.2	6.5	.	121.9	8.18	3.10	85
Kinbasket - Wood	25	4-Jul-11	107.5	1.0	10.0	1.5	6.1	.	124.8	8.19	5.90	88
Kinbasket - Wood	35	4-Jul-11	128.6	1.3	8.3	0.3	6.7	.	131.8	8.14	2.80	95
Kinbasket - Wood	45	4-Jul-11	114.6	0.9	7.9	0.4	8.9	.	136.8	8.08	0.95	100
Kinbasket - Wood	55	4-Jul-11	116.9	0.9	8.4	0.1	11.4	.	137.8	8.03	1.00	102
Kinbasket - Columbia	0 - 20	15-Aug-11	.	.	.	.	.	1.24	.	.	.	.
Kinbasket - Columbia	2	15-Aug-11	75.9	1.9	12.8	0.3	11.5	.	146.2	8.10	0.55	143
Kinbasket - Columbia	5	15-Aug-11	74.3	1.7	12.6	0.2	10.3	.	145.8	8.23	0.50	143
Kinbasket - Columbia	10	15-Aug-11	76.7	1.6	11.6	0.2	11.7	.	145.6	8.21	0.50	141
Kinbasket - Columbia	15	15-Aug-11	80.4	1.7	11.8	0.1	11.5	.	144.2	8.13	1.00	141
Kinbasket - Columbia	20	15-Aug-11	78.6	1.6	10.9	0.1	10.9	.	143.6	8.09	0.85	140
Kinbasket - Columbia	25	15-Aug-11	84.9	1.6	14.9	0.6	12.4	.	143.8	8.06	1.00	141
Kinbasket - Columbia	35	15-Aug-11	121.7	1.6	16.9	0.3	11.4	.	146.7	7.96	0.55	143
Kinbasket - Columbia	45	15-Aug-11	139.1	1.8	12.6	0.2	10.2	.	153.9	8.07	0.55	151
Kinbasket - Columbia	60	15-Aug-11	132.6	1.7	14.4	0.2	11.7	.	162.2	8.02	0.45	163
Kinbasket - Columbia	170	15-Aug-11	119.6	1.9	13.6	0.1	11.8	.	178.7	7.97	0.65	184
Kinbasket - Forebay	0 - 20	16-Aug-11	.	.	.	.	.	1.30	.	.	.	.
Kinbasket - Forebay	2	16-Aug-11	94.9	1.9	5.9	0.4	4.7	.	130.8	8.24	0.55	132
Kinbasket - Forebay	5	16-Aug-11	94.6	1.7	6.7	0.3	5.5	.	129.8	8.24	0.45	132
Kinbasket - Forebay	10	16-Aug-11	99.2	1.5	5.5	0.5	5.3	.	126.9	8.18	0.45	127
Kinbasket - Forebay	15	16-Aug-11	105.3	1.6	4.9	0.5	4.5	.	123.0	8.06	0.70	125
Kinbasket - Forebay	20	16-Aug-11	110.1	1.5	5.0	0.4	5.1	.	125.9	8.02	0.45	128
Kinbasket - Forebay	25	16-Aug-11	111.4	1.6	5.4	0.3	5.3	.	131.0	7.98	0.48	131
Kinbasket - Forebay	35	16-Aug-11	120.1	1.5	8.0	0.9	5.0	.	132.9	8.00	0.55	132
Kinbasket - Forebay	45	16-Aug-11	125.3	1.5	6.6	0.5	5.7	.	129.9	7.91	0.80	131
Kinbasket - Forebay	60	16-Aug-11	115.0	1.5	5.4	0.3	0.6	.	127.9	7.92	0.55	133
Kinbasket - Forebay	150	16-Aug-11	115.9	1.8	5.6	0.3	5.1	.	162.8	7.87	0.45	168
Kinbasket - Canoe	0 - 20	16-Aug-11	.	.	.	.	.	1.37	.	.	.	.
Kinbasket - Canoe	2	16-Aug-11	95.6	1.4	6.2	0.5	4.9	.	113.9	7.91	0.75	120
Kinbasket - Canoe	5	16-Aug-11	95.0	1.3	6.4	0.3	5.5	.	113.9	8.03	0.75	120
Kinbasket - Canoe	10	16-Aug-11	95.0	1.2	5.8	0.4	5.5	.	115.8	8.04	0.50	121
Kinbasket - Canoe	15	16-Aug-11	104.9	1.1	5.8	0.3	5.5	.	117.8	7.96	0.45	122
Kinbasket - Canoe	20	16-Aug-11	106.6	1.4	8.2	0.4	6.6	.	121.3	8.00	0.80	126
Kinbasket - Canoe	25	16-Aug-11	108.1	1.2	7.5	0.4	6.5	.	116.0	7.94	0.45	120

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Kinbasket - Canoe	35	16-Aug-11	116.3	1.1	6.3	0.5	5.5	.	114.0	7.94	0.70	119
Kinbasket - Canoe	45	16-Aug-11	116.8	1.1	6.2	0.4	4.6	.	106.9	7.78	0.60	114
Kinbasket - Canoe	60	16-Aug-11	116.9	1.4	7.2	0.4	5.0	.	108.0	7.66	0.65	115
Kinbasket - Canoe	115	16-Aug-11	110.7	1.4	6.2	0.3	4.7	.	151.7	7.84	0.55	156
Kinbasket - Wood	0 - 20	15-Aug-11	.	.	.	.	.	1.30	.	.	.	.
Kinbasket - Wood	2	15-Aug-11	89.5	1.5	13.7	0.2	12.3	.	131.8	8.22	0.65	134
Kinbasket - Wood	5	15-Aug-11	90.5	1.4	9.8	0.2	12.1	.	128.8	8.19	0.63	132
Kinbasket - Wood	10	15-Aug-11	97.4	1.3	12.3	0.3	10.8	.	120.8	8.17	0.65	126
Kinbasket - Wood	15	15-Aug-11	102.4	1.4	12.8	0.3	12.1	.	119.3	8.06	0.75	121
Kinbasket - Wood	20	15-Aug-11	106.6	1.4	13.1	0.2	12.4	.	127.8	8.12	0.75	129
Kinbasket - Wood	25	15-Aug-11	83.8	0.9	12.0	0.8	11.3	.	127.5	8.18	0.65	124
Kinbasket - Wood	35	15-Aug-11	75.7	0.8	14.1	3.5	9.2	.	125.9	8.18	4.45	122
Kinbasket - Wood	45	15-Aug-11	115.6	1.2	12.8	1.2	9.2	.	129.9	8.11	1.50	132
Kinbasket - Wood	60	15-Aug-11	139.8	1.3	12.3	0.3	12.4	.	144.8	8.10	1.10	147
Kinbasket - Columbia	0 - 20	24-Oct-11	.	.	.	.	.	0.97	.	.	.	.
Kinbasket - Columbia	2	24-Oct-11	59.5	0.7	7.2	0.5	3.5	.	133.0	8.10	0.50	129
Kinbasket - Columbia	5	24-Oct-11	59.5	0.7	4.1	0.4	3.7	.	132.0	8.06	0.60	128
Kinbasket - Columbia	10	24-Oct-11	59.4	0.6	4.6	0.3	3.5	.	133.0	8.06	0.45	129
Kinbasket - Columbia	15	24-Oct-11	59.8	0.6	4.9	0.3	2.9	.	133.0	8.09	0.25	128
Kinbasket - Columbia	20	24-Oct-11	59.4	0.6	4.1	0.2	8.4	.	132.9	8.06	0.60	130
Kinbasket - Columbia	25	24-Oct-11	60.2	0.6	5.0	0.3	3.0	.	133.0	8.09	0.75	130
Kinbasket - Columbia	35	24-Oct-11	65.4	0.6	4.6	0.3	3.8	.	132.9	8.06	0.65	130
Kinbasket - Columbia	45	24-Oct-11	118.6	0.6	5.3	0.3	4.7	.	141.9	8.00	0.73	140
Kinbasket - Columbia	60	24-Oct-11	138.8	0.6	4.4	0.3	3.3	.	156.8	7.96	0.40	157
Kinbasket - Columbia	170	24-Oct-11	131.5	1.2	6.2	0.5	4.0	.	178.8	7.92	0.45	180
Kinbasket - Forebay	0 - 20	25-Oct-11	.	.	.	.	.	1.08	.	.	.	.
Kinbasket - Forebay	2	25-Oct-11	84.3	0.6	3.4	0.3	3.3	.	119.3	8.03	0.40	119
Kinbasket - Forebay	5	25-Oct-11	82.8	0.6	4.0	0.4	4.0	.	118.9	8.02	0.50	118
Kinbasket - Forebay	10	25-Oct-11	81.2	0.4	3.6	0.2	3.6	.	118.9	8.03	0.45	119
Kinbasket - Forebay	15	25-Oct-11	81.2	0.6	5.3	0.2	3.8	.	118.9	7.97	0.50	119
Kinbasket - Forebay	20	25-Oct-11	82.2	0.5	3.9	0.2	2.5	.	119.8	8.01	0.28	119
Kinbasket - Forebay	25	25-Oct-11	79.0	0.6	4.0	0.1	2.5	.	119.4	8.02	0.40	119
Kinbasket - Forebay	35	25-Oct-11	79.3	0.6	3.6	0.2	3.6	.	118.4	8.03	0.40	119
Kinbasket - Forebay	45	25-Oct-11	93.5	0.8	3.3	0.2	3.9	.	116.0	7.86	0.65	118
Kinbasket - Forebay	60	25-Oct-11	120.4	0.7	3.3	0.1	3.0	.	118.9	7.83	0.45	122
Kinbasket - Forebay	160	25-Oct-11	118.5	1.1	4.4	0.1	3.2	.	156.7	7.79	0.25	161
Kinbasket - Canoe	0 - 20	25-Oct-11	.	.	.	.	.	1.21	.	.	.	.
Kinbasket - Canoe	2	25-Oct-11	80.8	1.2	4.0	0.2	4.0	.	113.0	7.87	0.25	117
Kinbasket - Canoe	5	25-Oct-11	80.7	1.2	4.5	0.3	3.1	.	113.4	8.00	0.60	115
Kinbasket - Canoe	10	25-Oct-11	79.1	1.0	3.7	0.2	4.1	.	114.0	8.01	0.45	115
Kinbasket - Canoe	15	25-Oct-11	80.5	1.1	3.5	0.2	4.1	.	113.8	8.00	0.50	116
Kinbasket - Canoe	20	25-Oct-11	81.2	1.0	4.5	0.1	3.3	.	113.9	7.94	0.50	115
Kinbasket - Canoe	25	25-Oct-11	79.7	1.1	5.0	0.2	2.9	.	114.0	8.01	0.45	115
Kinbasket - Canoe	35	25-Oct-11	80.8	1.1	3.8	0.1	3.4	.	113.9	8.01	0.50	114
Kinbasket - Canoe	45	25-Oct-11	94.2	1.1	4.1	0.2	3.4	.	109.0	7.85	0.55	111
Kinbasket - Canoe	60	25-Oct-11	118.7	1.2	3.6	0.2	3.5	.	109.0	7.61	0.45	115
Kinbasket - Canoe	110	25-Oct-11	109.2	1.3	5.6	0.2	2.9	.	144.0	7.80	0.30	147
Kinbasket - Wood	0 - 20	24-Oct-11	.	.	.	.	.	1.11	.	.	.	.
Kinbasket - Wood	2	24-Oct-11	77.9	1.1	3.7	0.4	3.4	.	118.7	8.06	0.45	120
Kinbasket - Wood	5	24-Oct-11	77.1	0.9	3.6	0.2	4.1	.	119.4	8.05	0.30	120
Kinbasket - Wood	10	24-Oct-11	78.3	1.0	3.4	0.4	3.5	.	119.1	7.99	0.35	120
Kinbasket - Wood	15	24-Oct-11	77.1	1.1	4.7	0.5	2.9	.	118.7	8.02	0.30	121
Kinbasket - Wood	20	24-Oct-11	78.1	0.6	3.3	0.2	3.3	.	119.4	8.04	0.55	121
Kinbasket - Wood	25	24-Oct-11	78.9	1.1	4.5	0.4	3.6	.	119.3	8.05	0.25	121
Kinbasket - Wood	35	24-Oct-11	73.1	1.1	4.2	0.7	3.0	.	123.8	8.13	0.90	122
Kinbasket - Wood	45	24-Oct-11	82.3	1.1	5.5	1.5	4.4	.	125.9	8.14	4.30	124
Kinbasket - Wood	60	24-Oct-11	149.9	1.2	4.4	0.3	3.9	.	136.8	8.09	0.90	137

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Revelstoke - Upper	0 - 20	16-May-11	.	.	.	.	.	1.54	.	.	.	.
Revelstoke - Upper	2	16-May-11	138.5	1.3	3.5	<0.1	3.0	.	117.7	7.92	1.15	91
Revelstoke - Upper	5	16-May-11	129.5	1.4	3.5	<0.1	3.4	.	119.0	7.94	0.73	91
Revelstoke - Upper	10	16-May-11	119.0	1.2	3.5	<0.1	3.0	.	121.3	7.95	0.60	93
Revelstoke - Upper	15	16-May-11	118.4	1.1	3.3	<0.1	3.4	.	121.9	7.91	0.33	95
Revelstoke - Upper	20	16-May-11	109.8	1.2	3.5	<0.1	2.8	.	123.9	7.90	0.53	96
Revelstoke - Upper	25	16-May-11	109.2	1.1	2.9	<0.1	3.4	.	123.9	7.91	0.40	97
Revelstoke - Upper	30	16-May-11	110.4	1.1	3.1	<0.1	3.4	.	124.8	7.92	0.43	97
Revelstoke - Middle	0 - 20	16-May-11	.	.	.	.	.	1.20	.	.	.	.
Revelstoke - Middle	2	16-May-11	107.8	1.1	*	<0.1	3.1	.	121.8	7.88	0.60	95
Revelstoke - Middle	5	16-May-11	105.4	1.2	4.0	<0.1	3.3	.	122.0	7.88	0.83	95
Revelstoke - Middle	10	16-May-11	104.7	1.1	*	<0.1	3.9	.	125.0	7.88	0.58	97
Revelstoke - Middle	15	16-May-11	100.8	1.0	3.4	<0.1	3.6	.	126.8	7.90	0.40	97
Revelstoke - Middle	20	16-May-11	96.3	1.2	3.9	<0.1	3.8	.	125.7	7.93	0.25	98
Revelstoke - Middle	25	16-May-11	97.1	1.0	3.8	<0.1	3.0	.	125.9	7.90	0.25	98
Revelstoke - Middle	35	16-May-11	98.0	1.2	3.4	<0.1	3.9	.	125.8	7.92	0.40	98
Revelstoke - Middle	45	16-May-11	98.8	1.4	3.3	<0.1	3.0	.	126.9	7.92	0.40	98
Revelstoke - Middle	60	16-May-11	103.1	1.3	3.6	<0.1	3.6	.	126.9	7.90	0.38	98
Revelstoke - Middle	75	16-May-11	124.3	1.3	3.6	<0.1	3.4	.	135.9	7.92	0.80	102
Revelstoke - Forebay	0 - 20	17-May-11	.	.	.	.	.	1.30	.	.	.	.
Revelstoke - Forebay	2	17-May-11	103.1	1.3	3.7	<0.1	3.9	.	121.0	7.91	0.20	95
Revelstoke - Forebay	5	17-May-11	103.4	1.2	3.9	<0.1	3.6	.	124.7	7.94	0.23	97
Revelstoke - Forebay	10	17-May-11	103.3	1.2	4.7	<0.1	4.0	.	125.3	7.92	0.25	97
Revelstoke - Forebay	15	17-May-11	103.0	1.2	4.2	<0.1	4.2	.	125.9	7.92	0.10	98
Revelstoke - Forebay	20	17-May-11	103.4	1.0	5.3	<0.1	4.7	.	125.8	7.92	0.13	98
Revelstoke - Forebay	25	17-May-11	103.0	1.3	5.3	<0.1	3.6	.	125.9	7.94	0.30	98
Revelstoke - Forebay	35	17-May-11	103.0	1.2	4.5	<0.1	3.1	.	126.9	7.92	0.20	98
Revelstoke - Forebay	45	17-May-11	102.7	1.3	4.3	<0.1	3.3	.	125.9	7.92	0.10	98
Revelstoke - Forebay	60	17-May-11	102.9	1.2	4.5	<0.1	3.2	.	126.7	7.94	0.23	98
Revelstoke - Forebay	115	17-May-11	101.6	1.2	3.9	<0.1	3.7	.	126.3	7.92	0.10	98

*Note: Accident in lab, test tube broke.

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Revelstoke - Upper	0 - 20	21-Jun-11	.	.	.	.	.	1.87	.	.	.	.
Revelstoke - Upper	2	21-Jun-11	194.0	1.7	3.1	0.7	1.9	.	61.8	7.61	1.00	48
Revelstoke - Upper	5	21-Jun-11	194.0	1.5	3.2	0.9	3.6	.	58.2	7.51	1.00	45
Revelstoke - Upper	10	21-Jun-11	201.6	1.6	3.5	1.5	2.0	.	50.2	7.46	1.70	40
Revelstoke - Upper	15	21-Jun-11	210.4	1.7	4.2	1.1	1.4	.	48.4	7.42	1.30	39
Revelstoke - Upper	20	21-Jun-11	218.9	1.5	3.3	0.7	1.9	.	47.1	7.38	1.55	39
Revelstoke - Upper	25	21-Jun-11	221.4	1.7	2.9	1.1	1.9	.	49.3	7.39	1.30	41
Revelstoke - Upper	35	21-Jun-11	230.2	1.6	2.9	0.6	2.9	.	57.1	7.40	0.85	47
Revelstoke - Middle	0 - 20	21-Jun-11	.	.	.	.	.	1.57	.	.	.	.
Revelstoke - Middle	2	21-Jun-11	176.7	1.3	3.1	0.3	3.2	.	100.8	7.90	0.95	76
Revelstoke - Middle	5	21-Jun-11	171.4	1.8	4.2	0.8	1.7	.	103.9	7.92	1.00	77
Revelstoke - Middle	10	21-Jun-11	163.1	1.3	4.8	0.6	3.6	.	108.0	7.91	1.60	80
Revelstoke - Middle	15	21-Jun-11	175.2	1.6	4.7	1.1	2.2	.	84.0	7.72	1.50	64
Revelstoke - Middle	20	21-Jun-11	182.5	1.5	3.3	1.0	2.0	.	76.9	7.66	1.30	58
Revelstoke - Middle	25	21-Jun-11	173.4	1.6	4.1	0.8	2.3	.	82.9	7.65	1.40	63
Revelstoke - Middle	35	21-Jun-11	178.0	2.0	3.4	0.7	2.1	.	105.6	7.77	1.20	78
Revelstoke - Middle	45	21-Jun-11	166.0	1.5	2.9	0.3	1.9	.	125.9	7.85	0.55	94
Revelstoke - Middle	60	21-Jun-11	145.2	1.3	2.2	0.2	1.8	.	126.8	7.85	0.65	96
Revelstoke - Middle	85	21-Jun-11	148.5	1.3	3.5	0.5	2.0	.	128.9	7.83	0.70	96
Revelstoke - Forebay	0 - 20	22-Jun-11	.	.	.	.	.	1.44	.	.	.	.
Revelstoke - Forebay	2	22-Jun-11	177.9	1.9	3.4	0.5	1.7	.	98.8	7.90	1.10	74
Revelstoke - Forebay	5	22-Jun-11	180.1	1.6	4.5	0.5	1.8	.	98.0	7.85	1.00	73
Revelstoke - Forebay	10	22-Jun-11	147.4	1.8	4.8	0.4	2.0	.	97.9	7.70	1.00	73
Revelstoke - Forebay	15	22-Jun-11	153.8	1.5	3.5	0.7	2.3	.	97.8	7.83	1.35	72

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Revelstoke - Forebay	20	22-Jun-11	161.9	1.6	3.5	0.5	1.9	.	97.5	7.62	1.40	71
Revelstoke - Forebay	25	22-Jun-11	165.9	1.8	4.2	0.6	2.7	.	98.0	7.82	1.20	72
Revelstoke - Forebay	35	22-Jun-11	179.5	1.7	4.4	0.4	1.5	.	105.7	7.82	1.10	78
Revelstoke - Forebay	45	22-Jun-11	146.2	2.1	3.1	0.3	1.9	.	113.7	7.54	0.40	88
Revelstoke - Forebay	60	22-Jun-11	157.7	1.7	2.9	0.3	2.0	.	125.0	7.87	0.55	94
Revelstoke - Forebay	110	22-Jun-11	150.9	1.9	2.9	0.3	2.1	.	125.9	7.88	0.50	95
Revelstoke - Upper	0 - 20	19-Jul-11	.	.	.	.	.	1.60	.	.	.	.
Revelstoke - Upper	2	19-Jul-11	119.0	1.5	6.5	0.7	4.7	.	41.6	7.39	2.20	33
Revelstoke - Upper	5	19-Jul-11	113.9	1.5	5.4	0.4	3.8	.	42.9	7.39	2.45	35
Revelstoke - Upper	10	19-Jul-11	111.7	1.3	5.7	1.1	4.5	.	44.7	7.38	3.90	36
Revelstoke - Upper	15	19-Jul-11	111.9	1.7	6.5	0.8	3.3	.	49.3	7.43	3.30	40
Revelstoke - Upper	20	19-Jul-11	110.9	1.3	5.9	1.2	3.5	.	50.3	7.42	3.50	41
Revelstoke - Upper	25	19-Jul-11	111.5	1.3	5.6	1.2	2.9	.	51.3	7.39	3.70	42
Revelstoke - Upper	35	19-Jul-11	117.8	1.2	5.3	1.0	2.9	.	51.7	7.41	3.90	42
Revelstoke - Middle	0 - 20	19-Jul-11	.	.	.	.	.	1.54	.	.	.	.
Revelstoke - Middle	2	19-Jul-11	136.3	1.9	7.3	0.4	2.7	.	63.0	7.51	2.00	47
Revelstoke - Middle	5	19-Jul-11	141.1	1.8	5.1	0.4	3.1	.	71.5	7.53	1.90	52
Revelstoke - Middle	10	19-Jul-11	140.0	1.8	4.9	0.6	3.7	.	74.9	7.66	1.30	54
Revelstoke - Middle	15	19-Jul-11	136.6	1.7	5.9	1.4	3.5	.	74.5	7.68	2.95	54
Revelstoke - Middle	20	19-Jul-11	134.2	1.6	10.1	0.8	5.8	.	91.8	7.70	4.10	65
Revelstoke - Middle	25	19-Jul-11	135.8	1.6	6.8	0.5	6.3	.	64.1	7.52	3.10	48
Revelstoke - Middle	35	19-Jul-11	158.2	1.9	5.7	0.5	3.2	.	76.5	7.58	2.40	57
Revelstoke - Middle	45	19-Jul-11	178.7	1.8	4.0	0.9	3.2	.	105.8	7.70	0.95	78
Revelstoke - Middle	60	19-Jul-11	156.3	1.9	4.5	0.5	4.7	.	123.0	7.79	1.00	90
Revelstoke - Middle	85	19-Jul-11	143.2	1.5	11.1	0.5	3.4	.	126.8	7.79	0.65	92
Revelstoke - Forebay	0 - 20	20-Jul-11	.	.	.	.	.	1.50	.	.	.	.
Revelstoke - Forebay	2	20-Jul-11	139.5	1.3	3.7	0.3	2.6	.	81.1	7.71	0.90	58
Revelstoke - Forebay	5	20-Jul-11	139.7	1.6	3.7	0.2	2.8	.	78.9	7.61	1.00	58
Revelstoke - Forebay	10	20-Jul-11	137.9	1.4	3.1	0.3	2.3	.	78.0	7.74	1.30	55
Revelstoke - Forebay	15	20-Jul-11	149.0	1.5	3.6	0.4	2.5	.	78.0	7.67	0.85	55
Revelstoke - Forebay	20	20-Jul-11	153.7	1.5	3.9	0.9	2.4	.	77.8	7.71	2.20	54
Revelstoke - Forebay	25	20-Jul-11	159.0	1.8	4.7	0.9	2.6	.	76.0	7.69	2.20	55
Revelstoke - Forebay	35	20-Jul-11	170.8	1.7	4.4	1.2	2.7	.	79.0	7.70	2.40	57
Revelstoke - Forebay	45	20-Jul-11	188.7	1.7	3.2	0.4	2.6	.	90.0	7.70	1.10	65
Revelstoke - Forebay	60	20-Jul-11	151.1	1.7	4.2	0.2	3.0	.	121.9	7.82	0.75	89
Revelstoke - Forebay	110	20-Jul-11	141.1	1.4	4.2	1.0	3.4	.	124.9	7.82	1.40	92
Revelstoke - Upper	0 - 20	23-Aug-11	.	.	.	.	.	1.38	.	.	.	.
Revelstoke - Upper	2	23-Aug-11	115.4	0.8	3.4	0.7	2.0	.	117.0	7.93	0.85	122
Revelstoke - Upper	5	23-Aug-11	117.4	0.9	3.1	0.4	2.1	.	119.0	7.91	1.00	124
Revelstoke - Upper	10	23-Aug-11	118.6	0.9	3.2	0.6	1.9	.	119.4	7.91	0.60	125
Revelstoke - Upper	15	23-Aug-11	119.1	0.8	5.2	0.6	5.4	.	122.0	7.94	0.40	126
Revelstoke - Upper	20	23-Aug-11	119.8	0.7	2.5	0.5	2.2	.	123.0	7.94	0.50	127
Revelstoke - Upper	25	23-Aug-11	120.7	0.8	4.7	0.6	2.1	.	122.4	7.93	0.60	127
Revelstoke - Upper	35	23-Aug-11	121.1	0.7	4.2	0.5	4.8	.	123.4	7.92	0.65	128
Revelstoke - Middle	0 - 20	23-Aug-11	.	.	.	.	.	1.39	.	.	.	.
Revelstoke - Middle	2	23-Aug-11	80.2	1.0	3.6	0.4	3.9	.	70.0	7.75	0.60	74
Revelstoke - Middle	5	23-Aug-11	80.5	0.8	2.8	0.5	2.1	.	70.1	7.83	0.60	72
Revelstoke - Middle	10	23-Aug-11	80.5	0.8	2.7	0.4	2.5	.	70.8	7.82	0.85	74
Revelstoke - Middle	15	23-Aug-11	91.1	0.9	3.9	0.4	2.2	.	91.0	7.92	0.75	92
Revelstoke - Middle	20	23-Aug-11	103.5	0.7	3.4	0.5	2.7	.	100.0	7.75	0.50	105
Revelstoke - Middle	25	23-Aug-11	108.9	1.1	3.5	0.4	3.3	.	102.0	7.82	0.45	107
Revelstoke - Middle	35	23-Aug-11	112.2	1.0	2.8	0.3	2.3	.	111.0	7.83	0.80	117
Revelstoke - Middle	45	23-Aug-11	115.7	1.1	3.1	0.4	2.8	.	113.0	7.78	0.85	119
Revelstoke - Middle	60	23-Aug-11	122.6	1.1	5.6	0.3	2.5	.	112.4	7.49	0.70	118
Revelstoke - Middle	80	23-Aug-11	149.2	1.3	3.5	0.2	3.0	.	122.9	7.59	0.58	128
Revelstoke - Forebay	0 - 20	24-Aug-11	.	.	.	.	.	1.43	.	.	.	.

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Revelstoke - Forebay	2	24-Aug-11	93.5	1.1	4.4	0.4	2.6	.	68.1	7.72	0.75	70
Revelstoke - Forebay	5	24-Aug-11	100.3	1.1	4.4	0.3	3.4	.	67.1	7.50	0.85	71
Revelstoke - Forebay	10	24-Aug-11	105.3	1.2	3.9	0.3	2.9	.	71.1	7.57	0.60	75
Revelstoke - Forebay	15	24-Aug-11	107.8	1.2	3.3	0.1	2.7	.	74.0	7.58	0.60	80
Revelstoke - Forebay	20	24-Aug-11	109.4	1.2	4.5	0.3	2.7	.	77.0	7.61	0.55	82
Revelstoke - Forebay	25	24-Aug-11	111.9	1.1	3.4	0.2	2.7	.	79.0	7.60	0.55	84
Revelstoke - Forebay	35	24-Aug-11	116.3	1.3	5.4	0.2	2.7	.	79.0	7.59	0.85	85
Revelstoke - Forebay	45	24-Aug-11	122.0	1.5	4.0	0.3	2.6	.	79.0	7.56	1.00	84
Revelstoke - Forebay	60	24-Aug-11	151.1	1.5	3.4	0.1	2.7	.	105.9	7.70	1.00	110
Revelstoke - Forebay	105	24-Aug-11	142.4	1.2	4.4	0.3	2.8	.	123.9	7.82	0.50	129
Revelstoke - Upper	0 - 20	19-Sep-11	.	.	.	.	.	1.22	.	.	.	.
Revelstoke - Upper	2	19-Sep-11	84.4	0.8	3.6	0.3	2.3	.	100.4	7.93	1.60	105
Revelstoke - Upper	5	19-Sep-11	90.1	0.9	3.8	0.2	2.6	.	102.0	7.89	1.30	109
Revelstoke - Upper	10	19-Sep-11	100.0	0.7	4.0	0.4	2.5	.	107.9	7.95	0.78	115
Revelstoke - Upper	15	19-Sep-11	109.6	0.9	3.6	0.2	2.9	.	114.0	7.91	2.90	121
Revelstoke - Upper	20	19-Sep-11	116.3	1.1	3.4	0.1	2.4	.	118.0	7.88	1.10	124
Revelstoke - Upper	25	19-Sep-11	116.3	0.8	3.5	0.1	2.8	.	118.0	7.92	1.30	125
Revelstoke - Upper	35	19-Sep-11	118.2	0.8	3.7	0.3	2.2	.	118.0	7.82	0.60	124
Revelstoke - Middle	0 - 20	19-Sep-11	.	.	.	.	.	1.35	.	.	.	.
Revelstoke - Middle	2	19-Sep-11	65.5	1.0	3.8	0.2	2.1	.	75.2	7.63	0.85	79
Revelstoke - Middle	5	19-Sep-11	64.8	1.2	3.5	0.2	2.2	.	76.1	7.61	0.85	79
Revelstoke - Middle	10	19-Sep-11	65.1	0.8	3.4	0.3	2.3	.	74.0	7.75	0.85	81
Revelstoke - Middle	15	19-Sep-11	73.6	0.7	4.2	0.2	2.5	.	89.0	7.86	1.70	92
Revelstoke - Middle	20	19-Sep-11	96.4	1.0	3.4	0.2	3.4	.	104.4	7.78	1.10	109
Revelstoke - Middle	25	19-Sep-11	106.3	0.7	4.2	0.3	2.9	.	110.9	7.75	0.70	116
Revelstoke - Middle	35	19-Sep-11	109.5	0.9	2.8	0.2	2.4	.	113.0	7.83	1.05	120
Revelstoke - Middle	45	19-Sep-11	110.9	0.9	2.6	0.4	2.5	.	114.0	7.73	1.20	120
Revelstoke - Middle	60	19-Sep-11	119.8	1.0	3.7	0.3	2.4	.	113.8	7.77	1.40	119
Revelstoke - Middle	80	19-Sep-11	148.4	1.0	3.7	0.2	2.5	.	118.0	7.60	0.75	124
Revelstoke - Forebay	0 - 20	20-Sep-11	.	.	.	.	.	1.31	.	.	.	.
Revelstoke - Forebay	2	20-Sep-11	73.8	0.8	2.0	0.2	2.1	.	72.9	7.85	0.70	78
Revelstoke - Forebay	5	20-Sep-11	75.2	1.1	2.2	0.3	1.7	.	73.1	7.76	0.70	78
Revelstoke - Forebay	10	20-Sep-11	81.5	1.0	2.8	0.2	1.9	.	79.1	7.80	0.60	84
Revelstoke - Forebay	15	20-Sep-11	103.0	0.9	2.9	0.1	3.9	.	97.0	7.79	0.65	105
Revelstoke - Forebay	20	20-Sep-11	110.1	0.9	2.6	0.1	2.5	.	104.0	7.78	0.40	111
Revelstoke - Forebay	25	20-Sep-11	113.3	1.3	3.1	0.1	2.1	.	108.0	7.83	1.10	116
Revelstoke - Forebay	35	20-Sep-11	116.8	0.9	2.8	<0.1	2.5	.	109.0	7.82	0.55	116
Revelstoke - Forebay	45	20-Sep-11	120.6	1.0	3.9	0.3	2.8	.	106.0	7.75	0.75	114
Revelstoke - Forebay	60	20-Sep-11	136.5	1.2	4.9	0.1	3.0	.	98.0	7.66	0.80	105
Revelstoke - Forebay	115	20-Sep-11	144.9	1.0	4.6	0.2	3.5	.	121.0	7.69	0.93	126
Revelstoke - Upper	0 - 20	17-Oct-11	.	.	.	.	.	1.23	.	.	.	.
Revelstoke - Upper	2	17-Oct-11	114.0	0.9	3.9	0.1	2.3	.	113.3	7.70	0.90	121
Revelstoke - Upper	5	17-Oct-11	114.2	1.0	3.3	0.2	2.6	.	114.0	7.70	0.80	120
Revelstoke - Upper	10	17-Oct-11	114.2	1.2	3.1	0.2	3.3	.	114.9	7.70	0.90	120
Revelstoke - Upper	15	17-Oct-11	114.0	1.0	3.8	0.2	2.9	.	113.5	7.69	0.75	120
Revelstoke - Upper	20	17-Oct-11	114.0	1.7	5.0	0.1	2.9	.	114.0	7.72	0.35	120
Revelstoke - Upper	25	17-Oct-11	114.1	1.1	4.2	0.1	3.1	.	112.2	7.78	0.80	120
Revelstoke - Upper	35	17-Oct-11	118.1	1.0	3.9	0.1	2.9	.	113.0	7.78	0.65	121
Revelstoke - Middle	0 - 20	17-Oct-11	.	.	.	.	.	1.30	.	.	.	.
Revelstoke - Middle	2	17-Oct-11	95.2	1.1	3.2	0.1	2.7	.	95.4	7.74	0.75	101
Revelstoke - Middle	5	17-Oct-11	92.7	0.9	3.2	0.1	2.7	.	96.0	7.72	0.75	101
Revelstoke - Middle	10	17-Oct-11	93.0	1.0	3.6	0.1	2.9	.	100.0	7.70	0.70	101
Revelstoke - Middle	15	17-Oct-11	95.2	1.0	3.5	0.1	2.7	.	98.0	7.74	0.85	102
Revelstoke - Middle	20	17-Oct-11	108.3	1.2	3.9	0.1	3.3	.	106.0	7.73	1.00	111
Revelstoke - Middle	25	17-Oct-11	110.2	0.9	4.5	0.1	3.0	.	107.9	7.71	1.00	114
Revelstoke - Middle	35	17-Oct-11	109.9	0.9	3.5	0.1	3.3	.	108.9	7.74	0.90	115

Site	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TP Turbidity ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uohms
Revelstoke - Middle	45	17-Oct-11	110.5	1.0	4.8	0.2	2.6	.	109.8	7.61	0.90	116
Revelstoke - Middle	60	17-Oct-11	118.2	0.9	3.6	0.1	2.9	.	111.0	7.69	1.00	119
Revelstoke - Middle	80	17-Oct-11	159.1	1.2	4.6	0.1	3.2	.	113.0	7.53	1.20	122
Revelstoke - Forebay	0 - 20	18-Oct-11	.	.	.	.	.	1.25	.	.	.	.
Revelstoke - Forebay	2	18-Oct-11	97.7	0.9	2.9	0.1	2.9	.	97.1	7.72	0.35	104
Revelstoke - Forebay	5	18-Oct-11	97.8	1.1	3.4	0.1	3.2	.	98.0	7.72	0.55	103
Revelstoke - Forebay	10	18-Oct-11	98.1	1.0	3.4	0.1	2.4	.	98.0	7.70	0.70	103
Revelstoke - Forebay	15	18-Oct-11	101.1	1.0	2.7	<0.1	3.7	.	99.0	7.74	0.65	105
Revelstoke - Forebay	20	18-Oct-11	102.8	1.0	3.6	0.1	2.3	.	100.0	7.68	0.65	106
Revelstoke - Forebay	25	18-Oct-11	108.2	1.2	3.9	0.1	2.6	.	103.0	7.63	0.60	109
Revelstoke - Forebay	35	18-Oct-11	116.6	1.1	3.3	0.1	2.9	.	108.0	7.66	0.63	116
Revelstoke - Forebay	45	18-Oct-11	120.3	1.1	3.8	0.1	3.1	.	111.8	7.67	0.70	118
Revelstoke - Forebay	60	18-Oct-11	138.4	1.1	3.2	0.1	2.5	.	110.9	7.61	0.75	118
Revelstoke - Forebay	110	18-Oct-11	154.4	1.3	3.7	0.1	3.5	.	117.9	7.59	0.75	125

Appendix 5

Primary Productivity
Kinbasket and Revelstoke Reservoirs, 2011

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PRIMARY PRODUCTIVITY IN KINBASKET AND REVELSTOKE RESERVOIRS, 2011

by

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Introduction

Primary production is the foundation of all food webs and in order to increase our understanding of the impacts of reservoir operations on the sustainability of upper trophic levels a comprehensive understanding of trophic web dynamics is necessary. The work discussed in the report is a sub-component of the Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring project (CLBMON-3) with the objective of identifying key factors that regulate trophic web dynamics of Kinbasket and Revelstoke reservoirs. This large and comprehensive monitoring program is complementary to the Kokanee Population Monitoring program (CLBMON-2) which is concurrently being delivered. This report summarizes the primary productivity studies carried out on Kinbasket and Revelstoke Reservoirs in 2011. The study examined the size structure of the phytoplankton community in terms of chlorophyll and carbon update productivity, particularly the relative contribution of three commonly studied fractions: the picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm).

Methods

Field Sampling

Primary productivity was measured once a month during the growing season (June-September) on Kinbasket Reservoir at the Forebay station and on Revelstoke Reservoir at the Forebay station and Middle station. Sampling was not completed in September on Kinbasket due to log jams prohibiting access to the boat launch. Water samples for alkalinity, chlorophyll and primary productivity were collected between 8:00 and 9:00 am using Niskin bottles. Samples were collected from the surface down to the 1% light depth as determined with a Licor LI-185A quantum sensor and meter (Table 1). The alkalinity and chlorophyll samples were stored in the dark and on ice until processing back at the UBC lab or the Revelstoke lab. For primary productivity measurements, two light and one dark 300 ml acid-cleaned BOD bottles were rinsed three times with lake water before filling. Disposable latex gloves were used for all sampling to avoid contamination. Care was taken to eliminate contact with latex since latex is toxic to phytoplankton (Price *et al*. 1986). The samples were maintained under low light conditions during all manipulations until the start of the incubation. Samples were inoculated with 0.185 MBq (5 µCi) of $NaH^{14}CO_3$ New England Nuclear (NEC-086H). The BOD bottles were attached to acrylic plates and were suspended *in situ* for 3-4 h, generally between 9 am and 2 pm generally in the area where samples were collected. On occasion particularly on Kinbasket the incubations must be performed in a protected region due to excessive wind and waves. Alkalinity samples were collected from the surface and the deepest sample depth in 125 ml polycarbonate bottles. Table 1 provides field and incubation information for the 2011 study.

Water samples for chlorophyll (0.2-1 L) were filtered at the Revelstoke Lab using parallel filtration onto 47 mm diameter 0.2, 2.0 and 20.0 µm polycarbonate Nuclepore™ filters using a vacuum pressure differential of <100 mm of Hg. Samples were stored at –20°C prior to analysis at UBC. At the end of the primary productivity incubation period, the BOD incubation bottles were stored in a dark box until the incubations were terminated by filtration at the Revelstoke Lab. One hundred ml from each BOD bottle was filtered through each of a 0.2, 2 and 20 µm 47-mm polycarbonate filter using <100 mm Hg vacuum differential (Joint and Pomroy, 1983). Each filter was placed in a 7 ml scintillation vial and stored in the dark until processing at the UBC lab.

Table 1. Field observations and incubation information for the 2011 primary productivity study. KB=Kinbasket-Forebay, RM=Revelstoke-Middle, RF=Revelstoke-Forebay and AC=attenuation coefficient calculated from vertical profiles of photosynthetically active radiation.

Date	Stn	Weather	AC (cm^{-1})	Inc. start	Inc. end	Total Inc Time (hr.min)	Incubation depths (m)
20 June 2011	KB	partly sunny	0.31	9:44	12:45	3.02	0,1,2,5,10,15
19 July 2011	KB	overcast and rain	0.31	8:30	12:25	3.92	0,1,2,5,10,15
22 Aug 2011	KB	overcast, rain & dark	0.27	8:12	11:52	3.5	0,1,2,5,10,15,20
20 Sept 2011	KB	-	-	-	-	-	-
21 June 2011	RM	sunny with clouds	0.39	9:12	12:55	3.72	0,1,2,5,10,12
19 July 2011	RM	sunny with clouds	0.47	9:34	12:20	3.77	0,1,2,5,10,12
23Aug 2011	RM	overcast with sun breaks	0.32	9:08	12:25	3.28	0,1,2,5,10,15
19 Sept 2011	RM	partly cloudy	0.30	10:05	1:30	3.58	0,1,2,5,10,15,17
22 June 2011	RF	sunny	0.42	9:08	11:42	2.57	0,1,2,5,10,12
20 July 2011	RF	clouds burning off sunny	0.34	8:40	12:20	3.67	0,1,2,5,10,12
24 Aug 2011	RF	overcast with sunny breaks	0.35	8:34	11:08	2.57	0,1,2,5,10,15
20 Sept 2011	RF	clear and sunny	0.24	8:50	11:55	3.08	0,1,2,5,10,15,17

Laboratory Analysis at UBC

Alkalinity

A Beckman 44 pH meter and electrode were used to determine total alkalinity according to the standard potentiometric method of APHA (1995). Each sample was titrated with 0.02 N H_2SO_4 to pH 4.5. Titrations were performed in duplicate to check the analytical precision of the results.

Chlorophyll a

Chl *a* corrected for phaeopigment was determined by *in vitro* fluorometry (Yentsch and Menzel, 1963). It is important to correct for phaeopigment concentrations which may equal or exceed functional pigment. Chl *a* was extracted from the sample in 5 ml of 90% acetone and stored covered in the freezer for 20-24 h. The fluorescence of the acetone extract was measured before and after the addition of three drops of 10% HCl in a Turner Designs™ Trilogy fluorometer calibrated with a solution of commercially available Chl *a*. Calculations for Chl *a* were made using the equations of Parsons et al. (1984). Raw data are provided in Appendix A. The average phytoplankton biomass of the euphotic zone was determined by calculating the mean of all sampling depths. Areal biomass (mg/m^2) was calculated by vertical integration of all depths according to procedures of Ichimura et al. (1980). Fractionated chlorophyll is calculated as follows: 1) the picoplankton fraction equals the chlorophyll on the 0.2 µm filter minus the chlorophyll on the 2.0 µm filter, 2) the nanoplankton fraction equals chlorophyll on the 2.0 µm filter minus the chlorophyll on the 20.0 µm filter, and 3) the microplankton fraction equals the chlorophyll on the 20.0 µm filter. In 2008, the 20 µm filter was replaced with a 10 µm filter due to difficulty in obtaining 20 µm filters. This change in methodology prevents the direct comparison of 2008 data with other years due to lack of a clear separation of nanoplankton and microplankton. Results from the 2011 study are comparable to those collected in 2010, 2009 (Harris, 2010) and 2002 (Stockner and Korman 2002). In 2011, the field crew experienced problems with the 0.2 μm polycarbonate filters clogging; consequently results are not available for September.

Primary Productivity

In the fumehood, 100 μL of 0.5 N HCl were added to each vial to eliminate the unincorporated inorganic $NaH^{14}CO_3$. The scintillation vials were left uncapped in the fumehood until the filters were dry (approx. 48 h) and 5 ml of Scintisafe® scintillation fluor was then added to each vial. The specific activity of the ^{14}C stock was determined by adding 100 μL ^{14}C-bicarbonate solution to scintillation vials containing 100 μL of ethanolamine and 5 ml Scintisafe® scintillation cocktail. The vials were stored in the dark for >24 hours before the samples were counted using a Beckman® Model #LS 6500 liquid scintillation counter. Each vial was counted for up to 10 minutes while the counter operated in an external standard mode to correct for quenching.

Rates were calculated according to Parsons et al. (1984) to obtain hourly primary productivity and were vertically integrated according to procedures of Ichimura et al. (1980). Daily primary productivity was calculated by multiplying hourly primary productivity by the incubation time and by the ratio of the solar radiation during the incubation to the solar radiation of the incubation day. Raw data are provided in Appendix A. Fractionated productivity is calculated as follows: 1) the picoplankton fraction equals primary productivity on the 0.2 μm filter minus the primary productivity on the 2.0 μm filter, 2) the nanoplankton fraction equals primary productivity on the 2.0 μm filter minus the productivity on the 20.0 μm filter, and 3) the microplankton fraction equals the productivity on the 20.0 μm filter. Fractionated results are not available for June for Kinbasket and August for Revelstoke Middle due the filtration clogging problem noted above.

Results

Photosynthetically active radiation (PAR), defined as the radiation in the 400-700 nm waveband, was quite variable during the 2011 sampling season. For instance, at Kinbasket Forebay the PAR was relatively high in June, moderate in July and extremely low in August (Figure 1) which is in agreement with the noted field observations recorded in Table 1. As solar radiation is the major energy source driving productivity, conditions were not optimal for production during these low PAR sessions in August. PAR was high at all stations in June measuring over 1000 μ mols/m^2/s but dropped to ~400-500 μ mols/m^2/s in July at all stations. In August, PAR remained relatively low at Kinbasket and Revelstoke Middle whereas at Revelstoke Forebay conditions improved to ~800 μ mols/m^2/s. PAR in September at both Revelstoke stations remained moderate at ~800 μ mols/m^2/s. The mean euphotic zone depth was 17.7 m in Kinbasket Forebay, 15.5 m at Revelstoke Forebay and 13.5 m at the Revelstoke Middle station (Figure 1).

The attenuation coefficient, a measure of transparency, depends largely on the concentration and composition of suspended and dissolved matter. A high attenuation coefficient is indicative of low transparency/high turbidity and a low attenuation coefficient indicates high transparency and low turbidity. As was observed in 2010, the attenuation coefficients were similar at all stations and the lowest attenuation coefficient was measured at Kinbasket Forebay at 0.30 cm^{-1}, (about 70% transmission m^{-1}) and the highest attenuation coefficient was measured at Revelstoke Middle at 0.37 cm^{-1}, (about 63% transmission m^{-1}). On average, the seasonal mean attenuation coefficient was 0.30 cm^{-1} at Kinbasket Forebay, followed by 0.34 cm^{-1} at Revelstoke Forebay and highest at Revelstoke Middle at 0.37 cm^{-1}.

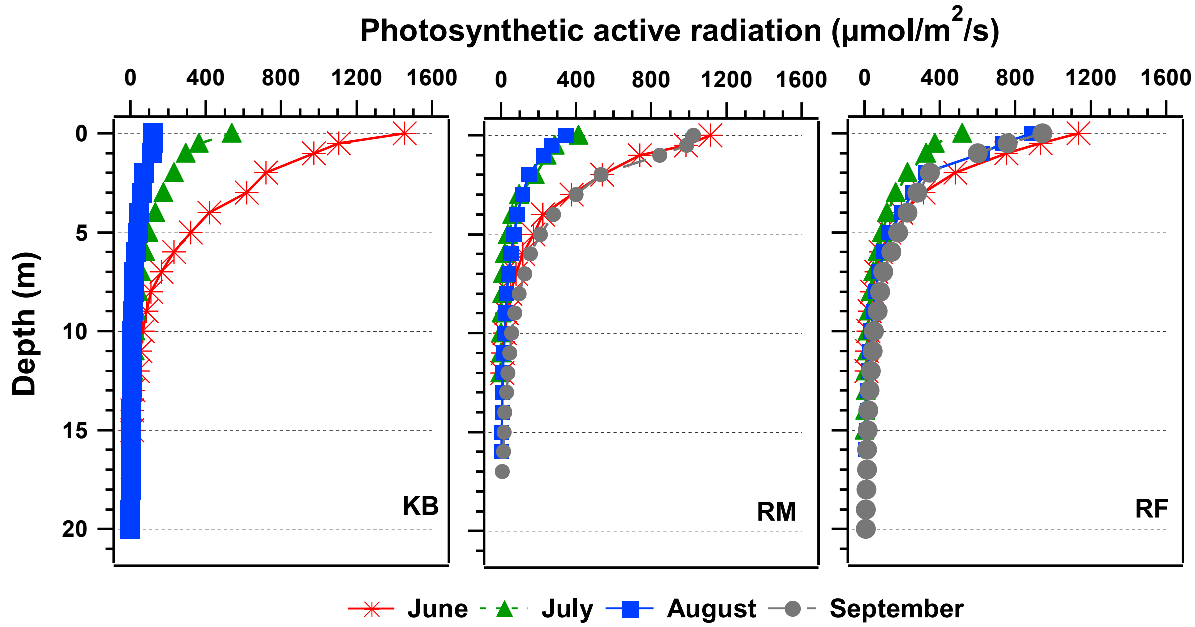

Figure 1. Photosynthetic active radiation ($\mu mol/m^2/s$) at Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2011. PAR measurements recorded to the depth of 1% of surface light.

Average euphotic zone phytoplankton biomass measured as Chl *a* concentration retained on the 0.2 μm filters, was generally highest in June with mean concentrations of 2.25 mg/m^3 at Kinbasket, 2.12 mg/m^3 at Revelstoke Forebay and 1.70 mg/m^3 at Revelstoke Middle. A subsurface chlorophyll peak of 3.0 mg/m^3 was observed at Kinbasket and Revelstoke Forebay between 10-15 m (Figure 2). The overall seasonal average Chl *a* concentrations were: 1.62 mg/m^3 in Kinbasket, 0.89 at Revelstoke Middle and 1.21 mg/m^3 at Revelstoke Forebay which are on average 15% higher than concentrations measured in 2010 (Harris 2010) but despite the moderate increase in chlorophyll concentration, the values measured are characteristic of oligotrophic systems (Wetzel, 2001).

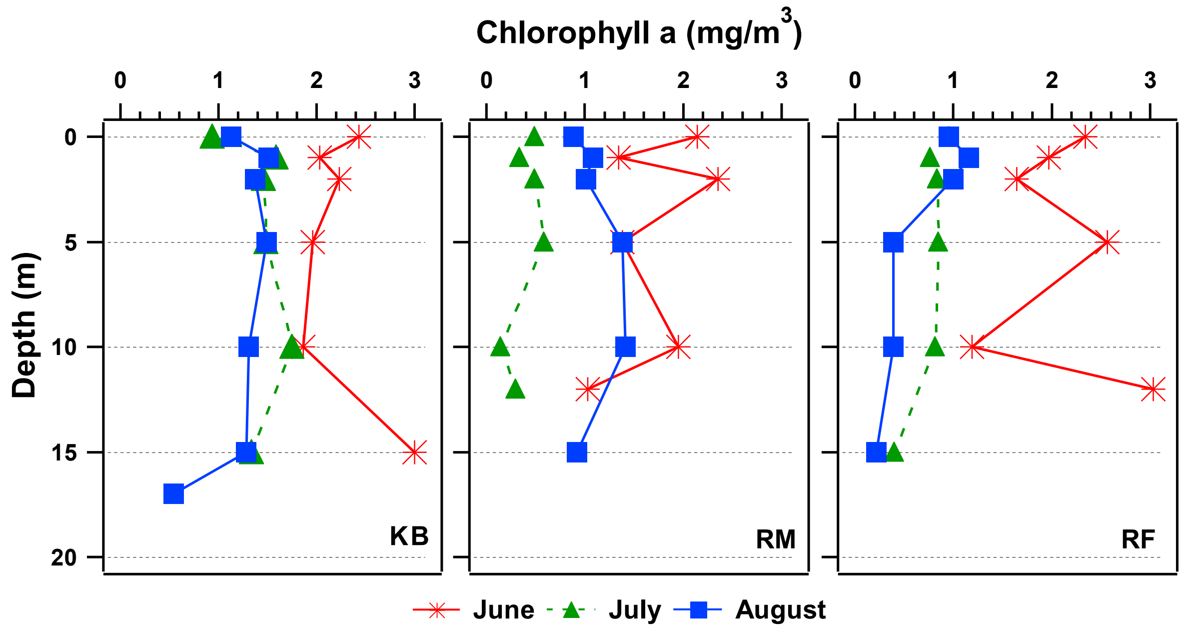

Figure 2. Vertical profiles of chlorophyll *a* (mg/m^3) for Kinbasket Forebay and Revelstoke Middle and Revelstoke Forebay in 2011. Note: no September data at Kinbasket due to boat access problems and no data for Revelstoke due to filtration issues (see methods section).

As was observed in 2010, the depth integrated biomass was higher in Kinbasket than in Revelstoke for all months. Likewise biomass was generally slightly higher at Revelstoke Forebay than Revelstoke Middle for all months (Table 2 and Figure 3). Depth integrated biomass was highest at all three stations in June (~25.6 mg/m^2) whereas in July to August considerable variability between stations was observed. It is important to note that biomass was relatively stable at Kinbasket throughout the season whereas a dramatic drop in chlorophyll biomass was observed at both Revelstoke stations in July which persisted throughout the sampling season. Peak biomass occurred in June at all stations possibly due to the poor light conditions in July and particularly in August. The seasonal average was 26.8 mg/m^2 in Kinbasket, 14.5 mg/m^2 at Revelstoke Middle, and 14.7 mg/m^2 at Revelstoke Forebay (Table 2). The 2009/10 seasonal averages were 22.2, 15.4, and 15.9 mg/m^2 for Kinbasket and Revelstoke Middle and Forebay, respectively, which are very similar to those found in the current study.

Table 2. Integrated chlorophyll *a* for Kinbasket and Revelstoke reservoir in 2011.

	Chlorophyll a (mg Chl *a*/m^2)		
Month	**KB**	**RM**	**RF**
June	32.3	20.5	23.9
July	23.0	4.8	11.4
Aug	25.1	18.4	8.9
Sept	-	-	-
Mean	26.8	14.5	14.7

On average, picoplankton sized cells (0.2-2 µm) accounted for 43% of the total phytoplankton biomass, followed closely by nanoplankton (2.0-20 µm) at 39% and microplankton (>20 µm) accounted for 18% (Figure 4). In 2011, picoplankton and nanoplankton sized cells accounted for 82% of the biomass in Kinbasket and Revelstoke which is similar to that found in 2010 where 85% of the biomass was composed picoplankton and nanoplankton.

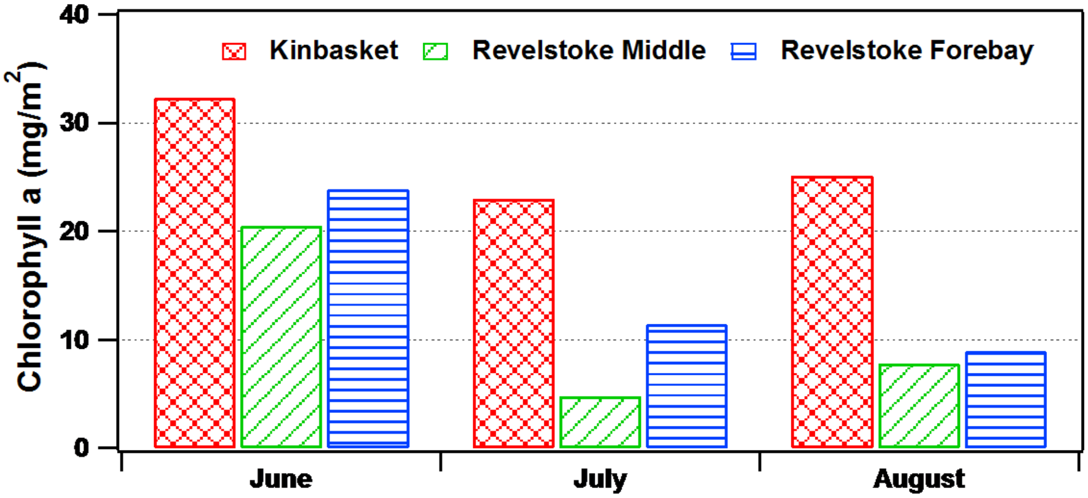

Figure 3. Integrated chlorophyll *a* (mg Chl *a*/m^2) in Kinbasket and Revelstoke in 2011. Note: no September data at Kinbasket due to boat access problems and no data for Revelstoke due to filtration issues (see methods section).

The size structure was relatively static with one notable exception in July when the relative importance of picoplankton, increased from 40% to 59% at Revelstoke Downie while the contribution of picoplankton decreased from 40% to 24%. It is noteworthy that microplankton (>20 µm) were more abundant in June compared to July and August possibly due to diatoms ability to phytosynthesize well at cooler water temperatures.

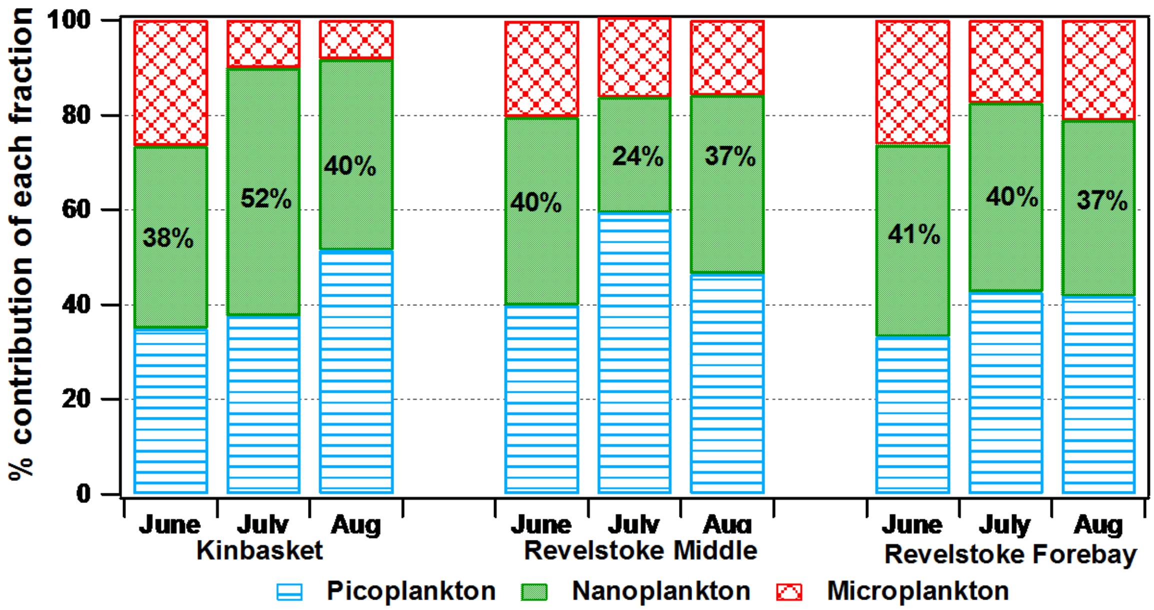

Figure 4. Relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to chlorophyll in Kinbasket and Revelstoke in 2011. Note: no September data at Kinbasket due to boat access problems and no data for Revelstoke due to filtration issues (see methods section).

Primary Productivity

As was shown in previous years the total primary production of all algal size fractions, measured as the radioactive carbon retained on the 0.2 µm filter, has remained extremely low and never exceeded 50 mg $C/m^2/d$ (Figure 5). Primary production was similar at all three stations in June at ~20 mg $C/m^2/d$, whereas in July production was clearly highest at Kinbasket and lowest further downstream at Revelstoke Forebay (Figure 5). For the Revelstoke stations, it appears a small fall bloom occurred where production increased 2 fold in September relative to August (Figure 5).

Primary production in 2011 was on average similar at Kinbasket and Revelstoke Middle at 32.10 and 32.58 mg $C/m^2/d$ respectively followed closely by Revelstoke Downie at 26.38 mg $C/m^2/d$ (Table 3). Primary productivity measurements are not available in August due to high variability in scintillation counts and samples were not collected in September due to boat access issues from a large log jam. The highest productivity was typically observed in Kinbasket from 2008-2010, but in 2011 the productivity of Kinbasket and Revelstoke Middle were similar. This apparent similarity may be due to the lack of data for August and September for Kinbasket rather than a true observation as suggested by the light attenuation and the chlorophyll data. These data clearly show Kinbasket had the highest water transparency and the highest biomass whereas Revelstoke had the least transparent water and the lowest phytoplankton biomass. The highest primary productivity rate of 44.22 mg $C/m^2/d$ was observed in September at Revelstoke Middle (Figure 5) which is still extremely low and indicative of ultra-oligotrophic conditions (Wetzel, 2001).

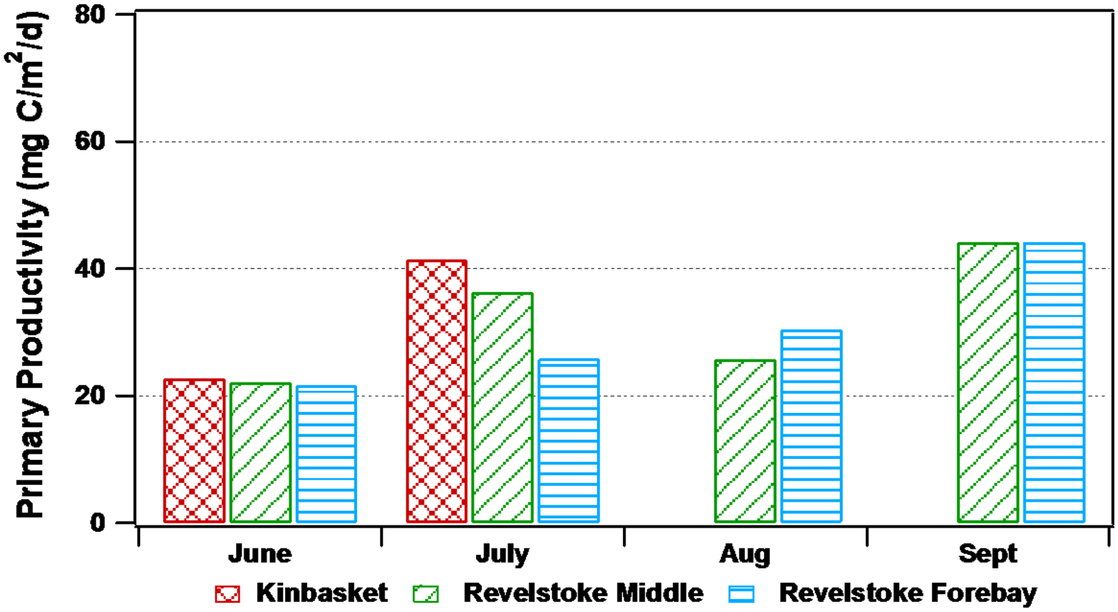

Figure 5. Primary productivity (mg C/m^2/d) in Kinbasket and Revelstoke in 2011. Data are not available in August for Kinbasket due to filtration issues and samples were not collected in September due to a log jam preventing use of the boat launch.

Table 3. Total daily primary productivity (mg C/m^2/d) in Kinbasket and Revelstoke in 2002 and 2008-2011.

Year	Month	Kinbasket Forebay	Revelstoke Mid	Revelstoke Forebay
2002	August	77.6	-	-
2008	July	84.4	33.6	51.8
2008	August	42.2	9.6	13.4
2008	September	25.3	11.0	18.8
2009	June	29.5	11.6	6.9
2009	July	11.0	12.1	29.8
2009	August	16.5	12.6	11.9
2009	September	13.1	10.4	0.5*
2010	June	14.8	27.1	32.5
2010	July	35.7	24.4	9.9
2010	Aug	43.9	33.8	17.4
2010	September	72.9	29.5	33.8
2011	June	22.8	24.1	21.6
2011	July	41.4	36.3	25.9
2011	August	-	25.8	20.5
2011	September	-	44.2	44.2
2008	Mean	50.6	6.04	9.32
2009	Mean	17.5	11.7	16.2
2010	Mean	41.8	28.7	20.0
2011	Mean	32.1	32.6	26.4

As was observed in early years, production in Kinbasket and Revelstoke in 2011 was dominated by phytoplankton less than 2.0 µm in size. Picoplankton and nanoplankton, phytoplankton less than 2.0 µm in size, accounted for 83% of the total production in Kinbasket, 80% at Revelstoke Middle and 81% at Revelstoke Forebay (Figure 6). On average, picoplankton production was highest at all stations, accounting for 44% of total production at Kinbasket, 44% at Revelstoke Middle and 62% at Revelstoke. Microplankton were the least productive fraction, accounting for just 19% of total production across all stations and all dates.

Fractionated primary production data for Kinbasket Reservoir is only available for July due to various filtration or access issues. In July, as was seen in 2010, picoplankton were the most productive fraction followed by nanoplankton then microplankton (Figure 6). In Revelstoke, the relative contribution of each fraction was extremely dynamic. For instance, at Revelstoke Middle, picoplankton was lowest in June accounting for 25% of total production whereas one month later picoplankton production increased to a high of 61% in July. Similar increases were observed at Revelstoke Forebay where at picoplankton increased from 44% in June to a high of 72% in July (Figure 6). Microplankton production was also quite dynamic ranging from 15-30% at Revelstoke Middle and from 12-30% at Revelstoke Forebay. As was seen for the size-fractionated chlorophyll data the largest contribution by microplankton occurred early in the growing season in June.

While the absolute production rates were similar throughout the three year study period, the size distribution of the phytoplankton community has differed. It appears that over the three year study period (2009-2011) the relative contribution of picoplankton is increasing. In 2009 picoplankton accounted for 18% of total production, while in 2010 the relative importance of picoplankton doubled to 36% and increased again in 2011 to 52%. This is in contrast to the relative contribution by nanoplankton production which accounted for 51% of total production in 2009, 39% in 2010 and just 30% in 2011. A similar trend was observed in microplankton production which showed a similar temporal pattern, decreasing in 2010, from 31% in 2009 to 25% in 2010 to 18% in 2011 (Figure 7).

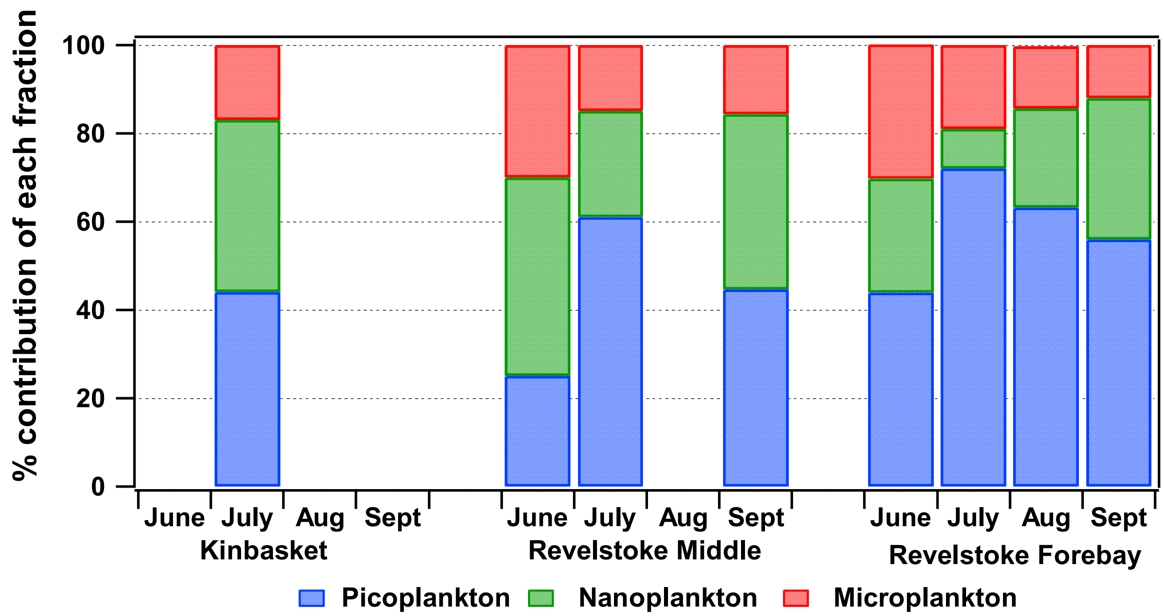

Figure 6. Relative contribution of picoplankton (0.2-2 μm), nanoplankton (2-20 μm), and microplankton (>20 μm) to primary productivity in Kinbasket and Revelstoke in 2011. Data are not available for Kinbasket in June and August due to filtration issues, in September due to boat access issues and in Revelstoke Middle again due to filtration issues noted in methods section.

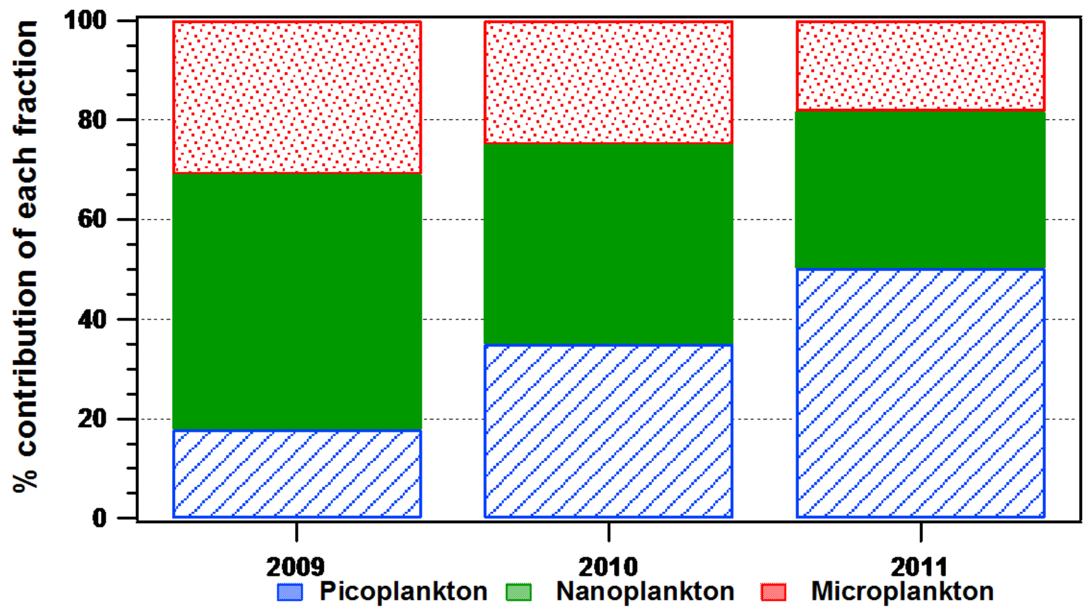

Figure 7. Mean annual contribution of each fraction to primary productivity in Kinbasket and Revelstoke in 2009-2011. Note: The means were calculated from all available monthly rates that were available for each study year for Kinbasket and Revelstoke.

Discussion

In order to predict changes in reservoir productivity due to hydroelectric operations we must clearly characterize the structure and functional relationships of the food web and have a clear understanding of how the biota of the ecosystem are controlled by the physical, chemical and biotic environments. It is important that we characterize the current state of the aquatic ecosystem in order to gain an understanding of how the aquatic ecosystem responds to current operations and to gain knowledge that will allow water managers to predict ecosystem responses to future operational changes. This report summaries data collected on the base of the food chain, which is just one component of the much larger monitoring program that encompasses physical flow and chemical dynamics. Ultimately, the integration of the findings from each component of the monitoring program will lead to a comprehensive understanding of the limnology of Kinbasket and Revelstoke Reservoirs.

Primary productivity is the foundation of all food webs and sets the upper threshold for productivity at upper trophic levels. The results of this study confirm earlier findings of extremely low phytoplankton biomass (<30 mg/m^2) and low rates of primary productivity (<50 mgC/m^2/d) in Kinbasket and Revelstoke reservoirs. Nearly 82% of the biomass and the primary productivity in the two reservoirs were composed of phytoplankton less than 2 µm in size which is not surprising given the low rates of productivity in these reservoirs. Kinbasket and Revelstoke were dominated by small celled phytoplankton (<2.0 µm) which is likely due to the high rates of growth due to the favorable surface area/volume ratios that allow small cells to outcompete larger cells for nutrients. It is recommended that the incubation periods should be increased to 5 hours in order to ensure adequate uptake of the labeled carbon. In 2011, primary productivity was similar in Kinbasket Forebay and Revelstoke Middle, but this is likely due to limited observations available in Kinbasket. It appears that light conditions have remained similar over the three study periods with light attenuation being higher in Revelstoke than in Kinbasket Reservoir. The low attenuation coefficients (~0.34) and deep euphotic zones (~15 m) in both reservoirs suggest that light availability is not responsible for the low rates of primary productivity.

Chlorophyll and primary productivity data are not available for other lakes and reservoirs for 2011 thus preventing a direct comparison of production in Kinbasket and Revelstoke in 2011 with other systems. Data are available for earlier years for some lakes and reservoir which allows us to put the low rates in context to values commonly measured in BC lakes and reservoirs. Kinbasket Reservoir is similar to nearby oligotrophic Slocan Lake and Okanagan in terms of chlorophyll and productivity where biomass is ~ 30 mg/m^2 and where primary productivity is less than 100 mg C/m^2/d (Table 4). The lower biomass and primary productivity rates measured in Revelstoke Reservoir is similar to Elsie Lake and Williston Reservoir, two ultra-oligotrophic systems. Although not surprising, Kinbasket and Revelstoke primary productivity are an order of magnitude lower than Alouette Reservoir and Kootenay and Arrow Lake, all systems with nutrient restoration programs (Table 4).

Table 4. Depth integrated chlorophyll *a* and daily primary productivity for various lakes and reservoirs in BC. The shaded cells indicate fertilized systems.

	Chlorophyll *a* (mg m^{-2})	Primary Productivity (mg C m^{-2} d^{-1})	Reference
Kinbasket Forebay	25.8	32.1	Current study
Slocan	26.3	59.3	Harris 2002
Okanagan	27.2	72.2	Andrusak et al. 2004
Revelstoke Middle	14.5	32.6	Current study
Revelstoke Forebay	14.7	36.4	Current study
Elsie Reservoir, BC	8.1	13.9	Perrin and Harris 2006
Williston, embayment	10.3	32.6	Harris et al. 2005
Williston, pelagic	7.6	34.3	Stockner & Langston 2000
Alouette Reservoir	36.8	139.6	Wilson et al. 2003
Arrow Reservoir	48.8	196.5	Pieters et al. 2003
Kootenay Lake	90.5	353.3	Wright et al. 2002

Wetzel (2001) uses ranges of primary productivity and related characteristics such as chlorophyll concentrations to classify different trophic categories ranging from ultraoligotrophic to hypereutrophic types. Using this approach, the chlorophyll and primary productivity data classify Kinbasket and Revelstoke Reservoirs as ultraoligotrophic. This study confirms the low productivity status of Kinbasket and Revelstoke Reservoirs and provides a clearer understanding of the size structure of the phytoplankton communities which will aid in our understanding of trophic web dynamics and the sustainability of the fish communities.

Literature Cited

Andrusak, H, S. Matthews, I. McGregor, K. Ashley, R. Rae, A. Wilson, D. Sebastian, G. Scholten, P. Woodruff, L. Vidmanic, J. Stockner, G. Wilson, B. Jantz, J. Webster, H. Wright, C. Walters, and J. Korman. 2004. Okanagan Lake Action Plan Year 8 (2004). RD 108. Biodiversity Branch, Ministry of Water, Land and Air Protection, Province of British Columbia.

APHA. 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. American Public Health Association, Washington, DC.

Harris, S.L. 2002. Slocan Lake Primary Productivity Monitoring Program, 2000 & 2001. Report prepared for Redfish Consulting Ltd. Nelson, B.C. 32p

Harris, S.L. 2010. Primary productivity in Kinbasket and Revelstoke Reservoirs, 2010. Report prepared for BC Hydro. 21p

Ichimura, S., T.R. Parsons, M.Takahashi and H.Seki. 1980. A comparison of four methods for integrating ^{14}C-primary productivity measurements per unit area. J. Oceanogr. Soc. Jap. 36: 259-262.

Joint, I.R. and A.J. Pomroy.1983. Production of picoplankton and small nanoplankton in the Celtic Sea. Mar. Biol. 77(1): 19-27.

Parsons, T.K., Y. Maita and C.M. Lalli. 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, Oxford. 173 pp.

Perrin, C.J. and S. Harris. 2006. Trophic status of Elsie Lake Reservoir, 2005. Report prepared by Limnotek Research and Development Inc. and Hupacasath First Nation for Bridge Coastal Restoration Program. 41p.

Pieters, R. S. Harris, L.C. Thompson, J.G. Stockner, H. Andrusak, K.I Ashley, B. Lindsay, K. Hall, and D. Lombard. 2003. Restoration of Kokanee Salmon in the Arrow Lakes Reservoir, British Columbia: Preliminary results of a fertilization experiment, p. 177–196. In Stockner J.G. [ed.], Nutrients in salmonid ecosystems: Sustaining production and biodiversity. American Fisheries Society.

Price, N.M., P.J. Harrison, M.R Landry, F. Azam, and K.J.F. Hall. 1986. Toxic effects of latex and Tygon tubing on marine phytoplankton, zooplankton and bacteria. Mar. Ecol. Prog. Ser. 34: 41-49.

Stockner J.G., and A.R. Langston. 2000. The Limnology of Williston Reservoir: 1999 monitoring program. Peace/Williston Fish and Wildlife Compensation Program Report No. 214. 19 pp +appendices.

Stockner, J.G. and J. Korman. 2002. Pelagic carbon production in Kinbasket, Revelstoke and Arrow Lakes Reservoirs. Report prepared for BC Hydro

Wetzel, R.G. 2001. Limnology. 3rd Ed, Academic Press, San Diego.

Wilson, G., K. Ashley, M. McCusker, R. Land, J. Stockner, D. Dolecki, G. Scholten and D. Sebastian. 2003. The Alouette Reservoir Fertilization Project: Years 2000 and 2001 Experiment, Whole Reservoir Fertilization. Fisheries Project Report No. RD 99.

Wright, M.E., K.I. Ashley, H. Andrusak, H. Manson, R. Lindsay, R.J. Hammond, F.R. Pick, L.M. Ley, P.B. Hamilton, S.L. Harris, L.C. Thompson, L. Vidmanic, D. Sebastian, G. Scholten, M. Young and D. Miller. 2002. Kootenay Lake Fertilization Experiment Year 9 (2000/2001) Report, Fisheries Project Report No. 105, Ministry of Water, Land and Air Protection, Province of British Columbia.

Yentsch, C.S. and V.W. Menzel. 1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. Deep-Sea Res. 10: 221-231.

Appendix A. Raw Chlorophyll a and primary productivity in 2011.

Station	Date	Fraction (µm)	Depth (m)	Chl (mg/m^3)	PP mg/C/m^3/hr	PP mgC/m^3/day
KB	20 June 2011	0.2	0	2.43	0.40	0.36
KB	20 June 2011	0.2	1	2.03	0.99	0.89
KB	20 June 2011	0.2	2	2.23	0.07	0.06
KB	20 June 2011	0.2	5	1.96	0.37	0.33
KB	20 June 2011	0.2	10	1.86	2.91	2.62
KB	20 June 2011	0.2	15	3.00	3.19	2.87
KB	20 June 2011	2	0	1.42	-	-
KB	20 June 2011	2	1	1.45	-	-
KB	20 June 2011	2	2	1.31	-	-
KB	20 June 2011	2	5	1.40	-	-
KB	20 June 2011	2	10	1.10	-	-
KB	20 June 2011	2	15	1.60	-	-
KB	20 June 2011	20	0	0.68	-	-
KB	20 June 2011	20	1	0.48	-	-
KB	20 June 2011	20	2	0.53	-	-
KB	20 June 2011	20	5	0.62	-	-
KB	20 June 2011	20	10	0.54	-	-
KB	20 June 2011	20	15	0.98	-	-
KB	19 July 2011	0.2	0	0.94	4.60	6.83
KB	19 July 2011	0.2	1	1.59	4.77	7.07
KB	19 July 2011	0.2	2	1.46	4.93	7.32
KB	19 July 2011	0.2	5	1.49	1.65	2.44
KB	19 July 2011	0.2	10	1.75	0.79	1.18
KB	19 July 2011	0.2	15	1.34	0.17	0.26
KB	19 July 2011	2	0	0.95	2.25	3.33
KB	19 July 2011	2	1	0.75	1.53	2.27
KB	19 July 2011	2	2	0.89	2.65	3.93
KB	19 July 2011	2	5	0.79	1.10	1.63
KB	19 July 2011	2	10	0.90	0.54	0.80
KB	19 July 2011	2	15	0.82	0.24	0.35
KB	19 July 2011	20	0	0.09	0.66	0.98
KB	19 July 2011	20	1	0.16	0.42	0.62
KB	19 July 2011	20	2	0.16	0.68	1.01
KB	19 July 2011	20	5	0.18	0.60	0.89
KB	19 July 2011	20	10	0.16	0.02	0.03
KB	19 July 2011	20	15	0.19	0.03	0.04
KB	20 Aug 2011	0.2	0	1.13	-	-
KB	20 Aug 2011	0.2	1	1.51	-	-
KB	20 Aug 2011	0.2	2	1.37	-	-
KB	20 Aug 2011	0.2	5	1.49	-	-
KB	20 Aug 2011	0.2	10	1.31	-	-
KB	20 Aug 2011	0.2	15	1.28	-	-
KB	20 Aug 2011	0.2	20	0.54	-	-
KB	20 Aug 2011	2	0	0.76	-	-
KB	20 Aug 2011	2	1	0.55	-	-
KB	20 Aug 2011	2	2	0.52	-	-
KB	20 Aug 2011	2	5	0.55	-	-
KB	20 Aug 2011	2	10	0.84	-	-
KB	20 Aug 2011	2	15	0.76	-	-
KB	20 Aug 2011	2	20	0.42	-	-
KB	20 Aug 2011	20	0	0.09	-	-
KB	20 Aug 2011	20	1	0.09	-	-
KB	20 Aug 2011	20	2	0.09	-	-
KB	20 Aug 2011	20	5	0.08	-	-
KB	20 Aug 2011	20	10	0.19	-	-
KB	20 Aug 2011	20	15	0.16	-	-

Appendix A. Raw Chlorophyll a and primary productivity in 2011.

KB	20 Aug 2011	20	20	0.12	-	-
RD	21 June 2011	0.2	0	2.14	1.33	1.04
RD	21 June 2011	0.2	1	1.34	1.29	1.00
RD	21 June 2011	0.2	2	2.35	3.53	2.74
RD	21 June 2011	0.2	5	1.38	3.91	3.03
RD	21 June 2011	0.2	10	1.95	1.63	1.26
RD	21 June 2011	0.2	12	1.03	0.67	0.52
RD	21 June 2011	2	0	1.09	1.21	0.94
RD	21 June 2011	2	1	1.08	1.67	1.29
RD	21 June 2011	2	2	1.31	2.33	1.81
RD	21 June 2011	2	5	1.10	2.93	2.28
RD	21 June 2011	2	10	0.62	1.44	1.11
RD	21 June 2011	2	12	0.36	0.26	0.20
RD	21 June 2011	20	0	0.22	0.41	0.31
RD	21 June 2011	20	1	0.33	0.57	0.44
RD	21 June 2011	20	2	0.29	0.99	0.77
RD	21 June 2011	20	5	0.48	1.16	0.90
RD	21 June 2011	20	10	0.39	0.59	0.45
RD	21 June 2011	20	12	0.20	0.10	0.08
RD	19 July 2011	0.2	0	0.49	3.14	5.50
RD	19 July 2011	0.2	1	0.34	4.47	7.81
RD	19 July 2011	0.2	2	0.49	2.50	4.37
RD	19 July 2011	0.2	5	0.59	1.29	2.25
RD	19 July 2011	0.2	10	0.15	1.20	2.11
RD	19 July 2011	0.2	12	0.30	0.33	0.58
RD	19 July 2011	2	0	0.20	1.22	2.13
RD	19 July 2011	2	1	0.19	1.27	2.22
RD	19 July 2011	2	2	0.05	0.79	1.39
RD	19 July 2011	2	5	0.11	1.06	1.85
RD	19 July 2011	2	10	0.12	0.11	0.19
RD	19 July 2011	2	12	0.08	0.04	0.07
RD	19 July 2011	20	0	0.07	1.03	1.80
RD	19 July 2011	20	1	0.03	0.64	1.13
RD	19 July 2011	20	2	0.06	0.26	0.45
RD	19 July 2011	20	5	0.11	0.32	0.56
RD	19 July 2011	20	10	0.05	0.03	0.05
RD	19 July 2011	20	12	0.05	0.03	0.06
RD	23 Aug 2011	0.2	0	0.88	2.87	2.56
RD	23 Aug 2011	0.2	1	1.08	1.09	0.97
RD	23 Aug 2011	0.2	2	1.01	0.40	0.36
RD	23 Aug 2011	0.2	5	1.38	1.79	1.60
RD	23 Aug 2011	0.2	10	1.41	2.67	2.38
RD	23 Aug 2011	0.2	15	0.92	2.04	1.81
RD	23 Aug 2011	2	0	0.46	1.08	0.96
RD	23 Aug 2011	2	1	0.40	1.76	1.57
RD	23 Aug 2011	2	2	0.19	1.33	1.18
RD	23 Aug 2011	2	5	0.60	2.49	2.21
RD	23 Aug 2011	2	10	1.10	0.75	0.67
RD	23 Aug 2011	2	15	0.84	0.17	0.15
RD	23 Aug 2011	20	0	0.10	0.40	0.36
RD	23 Aug 2011	20	1	0.12	0.37	0.33
RD	23 Aug 2011	20	2	0.12	0.51	0.45
RD	23 Aug 2011	20	5	0.17	0.71	0.63
RD	23 Aug 2011	20	10	0.23	0.52	0.46
RD	23 Aug 2011	20	15	0.29	0.13	0.11
RD	19 Sept 2011	0.2	0	-	2.06	2.24
RD	19 Sept 2011	0.2	1	-	4.43	4.82
RD	19 Sept 2011	0.2	2	-	3.01	3.28
RD	19 Sept 2011	0.2	5	-	2.31	2.51

Appendix A. Raw Chlorophyll a and primary productivity in 2011.

RD	19 Sept 2011	0.2	10	-	3.00	3.26
RD	19 Sept 2011	0.2	15	-	0.98	1.06
RD	19 Sept 2011	0.2	17	-	1.51	1.64
RD	19 Sept 2011	2	0	0.45	0.74	0.80
RD	19 Sept 2011	2	1	0.43	1.29	1.40
RD	19 Sept 2011	2	2	0.44	0.82	0.90
RD	19 Sept 2011	2	5	0.41	2.17	2.36
RD	19 Sept 2011	2	10	0.49	1.35	1.47
RD	19 Sept 2011	2	15	0.54	0.97	1.06
RD	19 Sept 2011	2	17	0.42	0.35	0.38
RD	19 Sept 2011	20	0	0.08	0.13	0.14
RD	19 Sept 2011	20	1	0.09	0.22	0.24
RD	19 Sept 2011	20	2	0.11	0.48	0.53
RD	19 Sept 2011	20	5	0.09	0.35	0.39
RD	19 Sept 2011	20	10	0.09	0.54	0.59
RD	19 Sept 2011	20	15	0.10	0.26	0.28
RD	19 Sept 2011	20	17	0.08	0.03	0.04
RF	22 June 2011	0.2	0	2.34	1.88	1.27
RF	22 June 2011	0.2	1	1.97	3.09	2.10
RF	22 June 2011	0.2	2	1.64	4.40	2.99
RF	22 June 2011	0.2	5	2.56	2.85	1.94
RF	22 June 2011	0.2	10	1.19	1.97	1.34
RF	22 June 2011	0.2	12	3.03	0.66	0.45
RF	22 June 2011	2	0	1.21	0.75	0.51
RF	22 June 2011	2	1	1.39	1.63	1.11
RF	22 June 2011	2	2	1.47	2.16	1.47
RF	22 June 2011	2	5	1.41	1.77	1.20
RF	22 June 2011	2	10	1.86	1.15	0.78
RF	22 June 2011	2	12	2.14	0.44	0.30
RF	22 June 2011	20	0	0.49	0.31	0.21
RF	22 June 2011	20	1	0.53	0.87	0.59
RF	22 June 2011	20	2	0.60	0.78	0.53
RF	22 June 2011	20	5	0.54	1.18	0.80
RF	22 June 2011	20	10	0.91	0.59	0.40
RF	22 June 2011	20	12	0.81	0.30	0.20
RF	20 July 2011	0.2	0	0.96	2.56	2.88
RF	20 July 2011	0.2	1	0.77	1.96	2.20
RF	20 July 2011	0.2	2	0.84	2.38	2.67
RF	20 July 2011	0.2	5	0.85	1.06	1.19
RF	20 July 2011	0.2	10	0.82	1.85	2.07
RF	20 July 2011	0.2	12	0.40	0.63	0.71
RF	20 July 2011	2	0	0.49	0.66	0.75
RF	20 July 2011	2	1	0.46	0.52	0.58
RF	20 July 2011	2	2	0.49	1.12	1.26
RF	20 July 2011	2	5	0.47	0.51	0.57
RF	20 July 2011	2	10	0.50	0.18	0.20
RF	20 July 2011	2	12	0.35	0.05	0.06
RF	20 July 2011	20	0	0.16	0.40	0.45
RF	20 July 2011	20	1	0.14	0.44	0.50
RF	20 July 2011	20	2	0.16	0.48	0.54
RF	20 July 2011	20	5	0.14	0.39	0.43
RF	20 July 2011	20	10	0.15	0.23	0.26
RF	20 July 2011	20	12	0.08	0.04	0.05
RF	24 Aug 2011	0.2	0	0.95	1.82	1.61
RF	24 Aug 2011	0.2	1	1.16	2.76	2.43
RF	24 Aug 2011	0.2	2	1.00	2.14	1.89
RF	24 Aug 2011	0.2	5	0.70	1.74	1.54
RF	24 Aug 2011	0.2	10	0.39	0.90	0.80
RF	24 Aug 2011	0.2	15	0.22	1.52	1.34

Appendix A. Raw Chlorophyll a and primary productivity in 2011.

RF	24 Aug 2011	2	0	0.46	0.31	0.27
RF	24 Aug 2011	2	1	0.48	1.67	1.47
RF	24 Aug 2011	2	2	0.43	1.20	1.06
RF	24 Aug 2011	2	5	0.57	0.85	0.75
RF	24 Aug 2011	2	10	0.30	0.16	0.14
RF	24 Aug 2011	2	15	0.21	0.05	0.04
RF	24 Aug 2011	20	0	0.13	0.11	0.10
RF	24 Aug 2011	20	1	0.13	0.23	0.21
RF	24 Aug 2011	20	2	0.15	0.56	0.49
RF	24 Aug 2011	20	5	0.18	0.27	0.24
RF	24 Aug 2011	20	10	0.16	0.17	0.15
RF	24 Aug 2011	20	15	0.09	0.01	0.01
RF	20 Sept 2011	0.2	0	-	3.70	2.97
RF	20 Sept 2011	0.2	1	-	2.88	2.31
RF	20 Sept 2011	0.2	2	-	2.46	1.97
RF	20 Sept 2011	0.2	5	-	1.87	1.50
RF	20 Sept 2011	0.2	10	-	2.72	2.18
RF	20 Sept 2011	0.2	15	-	1.22	0.98
RF	20 Sept 2011	0.2	17	-	4.03	3.23
RF	20 Sept 2011	2	0	0.39	1.66	1.33
RF	20 Sept 2011	2	1	0.56	1.56	1.25
RF	20 Sept 2011	2	2	0.54	2.80	2.25
RF	20 Sept 2011	2	5	0.59	0.64	0.52
RF	20 Sept 2011	2	10	0.58	1.44	1.16
RF	20 Sept 2011	2	15	0.86	0.40	0.32
RF	20 Sept 2011	2	17	0.30	0.48	0.38
RF	20 Sept 2011	20	0	0.08	0.50	0.40
RF	20 Sept 2011	20	1	0.11	0.34	0.27
RF	20 Sept 2011	20	2	0.09	0.44	0.35
RF	20 Sept 2011	20	5	0.09	0.42	0.34
RF	20 Sept 2011	20	10	0.16	0.20	0.16
RF	20 Sept 2011	20	15	0.06	0.31	0.25
RF	20 Sept 2011	20	17	0.08	0.04	0.03

Appendix 6

Phytoplankton
Kinbasket and Revelstoke Reservoirs, 2011

Darren Brandt
Advanced Eco-Solutions

PHYTOPLANKTON POPULATIONS IN KINBASKET AND REVELSTOKE RESERVOIRS, UPPER COLUMBIA BASIN, BRITISH COLUMBIA – 2011

PREPARED FOR:

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January 2013

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SECTION 1.0 INTRODUCTION

1.1 Background & Study Purpose

Kinbasket is the first of 3 large reservoirs on the upper reaches of the Columbia River Basin in Canada. It was created upon completion of the Mica Dam over 30 years ago and its discharge flows directly to the upper reaches of Revelstoke Reservoir, the second in the series. Revelstoke Reservoir discharges to the Columbia River and Upper Arrow Lakes Reservoir, the third in the series at the city of Revelstoke, BC. Both Kinbasket and Revelstoke Reservoirs are assumed to be oligotrophic, with low concentrations of total dissolved phosphorus (TDP), low phytoplankton and zooplankton biomass, and low fish production, as is the case in the Arrow Lakes Reservoir which is immediately downstream of Kinbasket and Revelstoke Reservoirs (Pieters et al., 1998). It is hypothesized that one of the factors leading to the low production status of both ecosystems is ‘oligotrophication,’ or ‘nutrient depletion’, caused by reservoir aging; i.e. increased water retention increases rates of nutrient utilization within the reservoir as well as increased rates of sedimentation of organic and inorganic particulate carbon (C), i.e. nutrient trapping (Stockner et al. 2000, Pieters et al. 1998, 1999).

This study is part of CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring under BC Hydro’s Columbia River Water Use Plan. Results from 2008, 2009, 2010 and 2011 in addition to the data from previous studies will permit further commentary on observed changes in phytoplankton density and biomass among depths, stations (sectors) and between years.

SECTION 2.0 METHODS

2.1 Sampling Protocol and Station Locations

Samples were collected from discrete depths at four stations in Kinbasket Reservoir (Canoe, Columbia, Wood, and Forebay) in May, July, August, and October. June sampling was not completed due to a staff injury and September was not done because high water and debris prevented launching on Kinbasket. Samples from three stations in Revelstoke Reservoir (Revelstoke-Forebay, Revelstoke-Mid and Revelstoke-Upper) were taken monthly from May to October in 2011. Phytoplankton communities and density change with depth. Due to this characteristic, discrete samples were taken at depths of 2, 5, 10, 15, and 25 meters. An aliquot of each of these samples was preserved with Lugols for identification and enumeration.

Two depth strata: the epilimnion and hypolimnion were assessed by creating composites of discrete samples. The mean of the densities of taxa from samples collected at 2, 5, and 10 meters were used to determine epilimnetic density and biovolume while samples from 15 and, 25 meters were used to determine the hypolimnetic density and biovolumes. In 2009 and 2008, samples taken at various depths were composited in the field and then identified and enumerated in the laboratory. The change in methodology in 2010 and 2011 is compatible with the previous year's sampling methodology; however, the taxa richness could be higher in the composited samples from 2010 and 2011 since counting multiple samples and then compositing them after identification and enumeration will result in an increase in the fraction of the sample counted than counting a single field composited sample.

At each station an aliquot of composited water from the epilimnion (0-10 meters) and hypolimnion (15-25 meters) was taken for bacterial and pico-cyanobacterial enumeration. Bacteria samples were preserved with three drops of 25% glutaraldehyde and placed in a small, brown polyethylene bottle. Bacterial and pico-cyanobacterial densities from composited water samples

2.2 Enumeration Protocol

2.2.1 Phytoplankton

Phytoplankton samples were preserved in the field in acid Lugol's iodine preservative and shipped to Advanced Eco-Solutions Inc. in Newman Lake, WA for enumeration. The samples were gently shaken for 60 seconds and poured into 25 mL settling chambers and allowed to settle for a minimum of 3 hrs prior to quantitative enumeration using the Utermohl Method (Utermohl 1958). Counts were done using a plankton microscope. All cells within a random transect ranging from 3.5 to 7 mm were counted at high power (900X magnification) that permitted a semi-quantitative enumeration of minute (<2 μ) autotrophic pico-cyanobacteria cells (1.0-2.0 μ) [Class Cyanophyceae], and of small, delicate auto-, mixo- and heterotrophic nano-flagellates (2.0-20.0 μ) [Classes Chrysophyceae and Cryptophyceae]. Comments on the relative density of ciliates in each sample were also noted on count sheets. Where feasible, from 250-300 cells were enumerated in each sample to assure counting consistency and statistical accuracy (Lund et al. 1958). The compendium of Canter-Lund and Lund (1995) was used as a taxonomic reference. The primary taxonomist was Nichole Manley of Advanced Eco-Solutions Inc. and quality assurance was performed by John Stockner, Ph.D., Eco-Logic Ltd,

2.2.2 Bacteria and Pico-cyanobacteria

Fifteen milliliters of sample water was filtered for pico-cyano bacteria density determination. A second aliquot of 5 mL was inoculated with a fluorescent dye (DAPI) for autotrophic picoplankton (heterotrophic bacteria) determination. Both of these sub-samples were then filtered through black 0.2 polycarbonate Nucleopore filters. The bacteria become trapped on the surface of the filters. The number of cells in a given filter area was then used to determine bacteria densities. Pico-cyano bacteria densities were determined using direct count epiflourescence method described by MacIsaac et al. (1993 and heterotrophic bacteria was enumerated using the epiflourescence method described by MacIsaac and Stockner (1993). Eight to 32 random fields on each of the filters were counted at 1000x magnification using either blue-band excitation filter (450-490nm) for pico-cyano bacteria or a UV wide-band excitation filter (397-560nm) for heterotrophic bacteria density determination. Heterotrophic bacteria and pico-cyanobacterial densities are reported as cells/mL. Pico-plankton enumeration is an emerging plankton technique and is not yet commonly used in other lake systems. To facilitate comparison of phytoplankton densities in Revelstoke and Kinbasket to other systems and to previous data from the reservoirs the densities of picoplankton were not added to the total phytoplankton counts. The total density of autotrophs can be calculated by summing the phytoplankton and picoplankton if so desired.

SECTION 3.0 RESULTS

3.1 Study Limitations

As a caveat, it should be noted that the number of stations sampled (four in Kinbasket and three in Revelstoke), and sampling frequency (monthly) provide only an approximation of phytoplankton population density, biomass, diversity, and spatiotemporal variability in two of the largest Upper Columbia Basin's reservoirs. Interpretations in this report are made on observed patterns of only two variables, ***Density*** (cells/mL) of groups and their respective taxonomic Classes, and ***Biovolume*** (mm^3/L) or biomass of groups and Classes. Thus, this report should essentially be considered more as an 'overview' of the current status of phytoplankton populations in Kinbasket and Revelstoke rather than a comprehensive 'synthesis' of phytoplankton community dynamics.

3.2 Phytoplankton Density and Biovolume by Class – 2011

A complete list of the taxa identified in Kinbasket and Revelstoke Reservoirs in 2011 can be found in Appendix A. The taxa are organized into major taxonomic groups that are used throughout the report.

3.2.1 Epilimnion

Kinbasket

In Kinbasket Reservoir flagellates (chryso/cryptophytes) were the most abundant group in the epilimnion, followed by blue-Greens (cyanophytes), and diatoms (bacillariophytes) with greens (chlorophytes) and dinoflagellates (dinophytes) the least numerous (Table 1 and Figure 1). In terms of density, the major taxa contributing to the high density of the flagellates were microflagellates. The cyanophytes were dominated by Synechococcus (coccoids).
In terms of biovolume, the major contributors throughout the season were flagellates followed by diatoms, greens, blue-greens and dinoflagellates (Figure 2). Peak phytoplankton density occurred at the Wood Arm Station in July (8586 cells/mL) (Figure 3). The Forebay Station had the lowest phytoplankton density at 1675 cells/mL during October. On a seasonal average the Wood and Columbia Stations had the highest mean phytoplankton density. The Wood Station had the highest seasonal mean biomass of the four stations (Table 2 and Figure 4).

Table 1 Kinbasket Reservoir mean phytoplankton density (Cells/mL) by group and month from the 2, 5 and 10 meter laboratory composites in 2011

Station	Group	May	July	August	October	Seasonal Average
Kin-Forebay	Blue-greens	1195	1764	1268	740	1242
	Coccoid Greens, Desmids, etc.	114	122	171	146	138
	Diatoms	49	163	187	24	106
	Dinoflagellates	8	33	49	33	30
	Flagellates	1138	1984	1659	732	1378
	Sum of All Groups	**2504**	**4065**	**3333**	**1675**	**2894**
Kin-Canoe	Blue-greens	1504	2146	1415	846	1478
	Coccoid Greens, Desmids, etc.	24	228	163	106	130
	Diatoms	33	187	252	98	142
	Dinoflagellates	33	33	24	33	30
	Flagellates	1472	1935	2041	764	1553
	Sum of All Groups	**3065**	**4529**	**3894**	**1846**	**3333**
Kin-Wood	Blue-greens	1309	4293	2163	618	2096
	Coccoid Greens, Desmids, etc.	366	423	390	122	325
	Diatoms	49	285	195	81	152
	Dinoflagellates	49	16	65	8	35
	Flagellates	1764	3569	1789	2423	2386
	Sum of All Groups	**3537**	**8586**	**4602**	**3252**	**4994**
Kin-Columbia	Blue-greens	1724	4000	1504	732	1990
	Coccoid Greens, Desmids, etc.	138	98	244	138	154
	Diatoms	488	203	89	98	220
	Dinoflagellates	49	33	24	8	28
	Flagellates	2049	2651	1699	756	1789
	Sum of All Groups	**4447**	**6984**	**3561**	**1732**	**4181**

Table 2 Kinbasket Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2011

Station	Group	May	July	August	October	Seasonal Average
Kin-Forebay	Blue-greens	0.0085	0.0080	0.0110	0.0046	0.0080
	Coccoid Greens, Desmids, etc.	0.0094	0.0111	0.0201	0.0082	0.0122
	Diatoms	0.0078	0.0323	0.0279	0.0175	0.0214
	Dinoflagellates	0.0033	0.0130	0.0138	0.0081	0.0096
	Flagellates	0.0289	0.0617	0.0470	0.0204	0.0395
	Sum of All Groups	**0.0579**	**0.1260**	**0.1198**	**0.0589**	**0.0906**
Kin-Canoe	Blue-greens	0.0077	0.0185	0.0076	0.0070	0.0102
	Coccoid Greens, Desmids, etc.	0.0067	0.0230	0.0170	0.0173	0.0160
	Diatoms	0.0048	0.0214	0.0352	0.0622	0.0309
	Dinoflagellates	0.0114	0.0098	0.0098	0.0106	0.0104
	Flagellates	0.0383	0.0464	0.0500	0.0252	0.0400
	Sum of All Groups	**0.0688**	**0.1191**	**0.1195**	**0.1222**	**0.1074**
Kin-Wood	Blue-greens	0.0150	0.0400	0.0101	0.0045	0.0174
	Coccoid Greens, Desmids, etc.	0.0437	0.0339	0.0221	0.0056	0.0263
	Diatoms	0.0085	0.0609	0.0184	0.0557	0.0359
	Dinoflagellates	0.0163	0.0065	0.0260	0.0028	0.0129
	Flagellates	0.0483	0.1299	0.0424	0.0247	0.0613
	Sum of All Groups	**0.1317**	**0.2712**	**0.1190**	**0.0933**	**0.1538**
Kin-Columbia	Blue-greens	0.0148	0.0280	0.0061	0.0049	0.0135
	Coccoid Greens, Desmids, etc.	0.0123	0.0082	0.0239	0.0067	0.0128
	Diatoms	0.0447	0.0431	0.0155	0.0280	0.0328
	Dinoflagellates	0.0179	0.0114	0.0053	0.0033	0.0095
	Flagellates	0.0308	0.0373	0.0413	0.0216	0.0327
	Sum of All Groups	**0.1205**	**0.1279**	**0.0922**	**0.0645**	**0.1013**

Figure 1 Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between May - October 2011 derived from the 2, 5, 10 meter laboratory composites

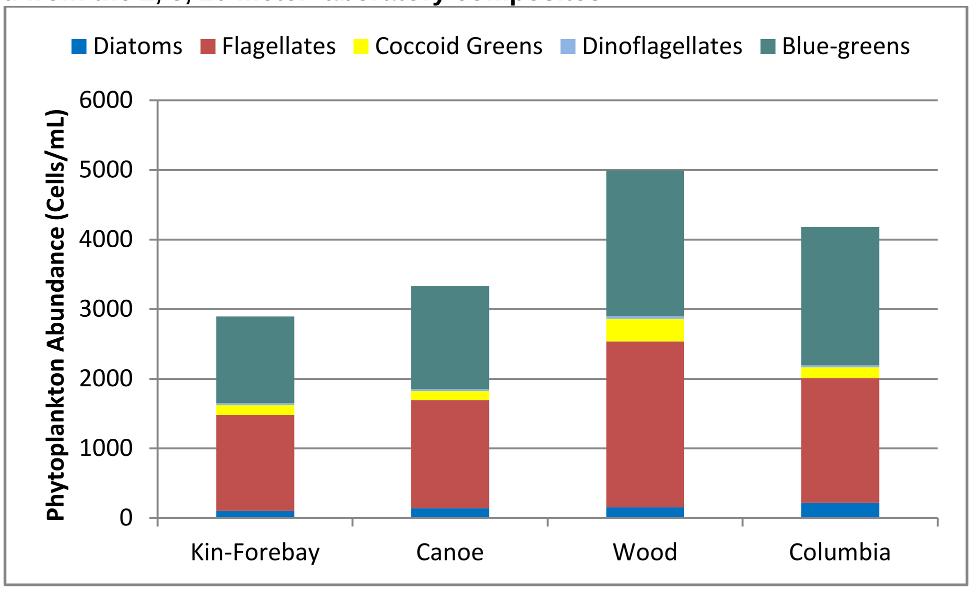


Figure 2 Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between May - October 2011 derived from the 2, 5, and 10 meter laboratory composites

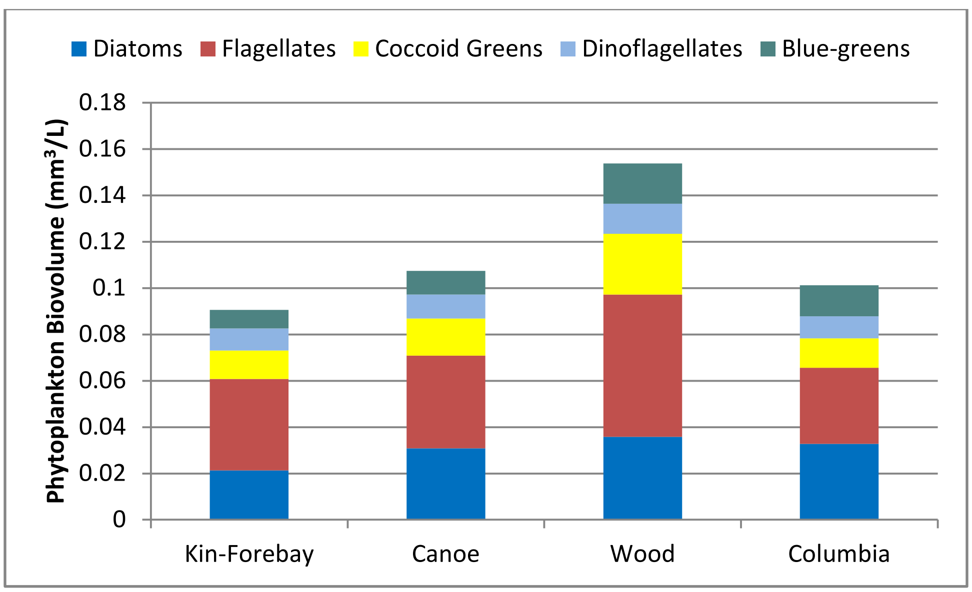


Figure 3 Kinbasket mean epilimnetic phytoplankton density by month

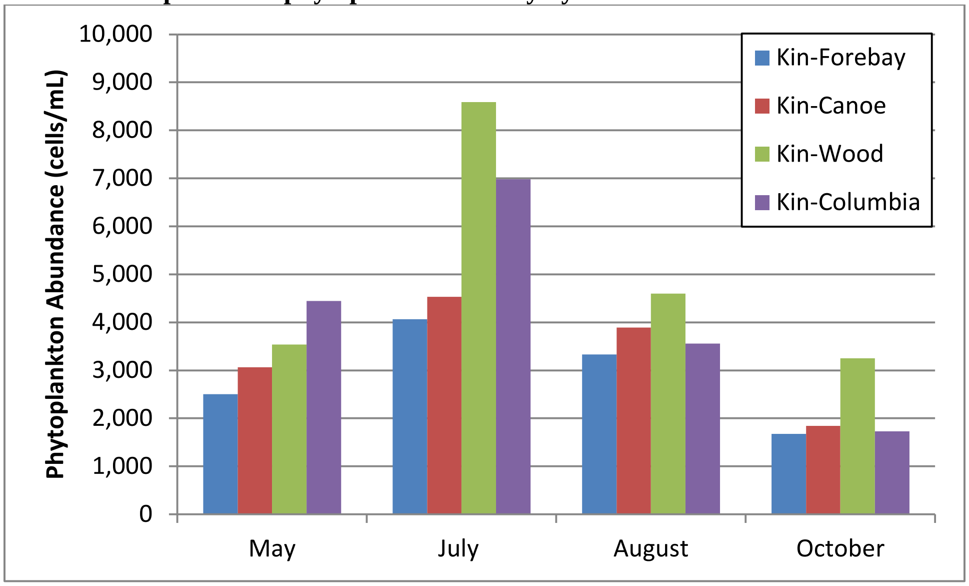
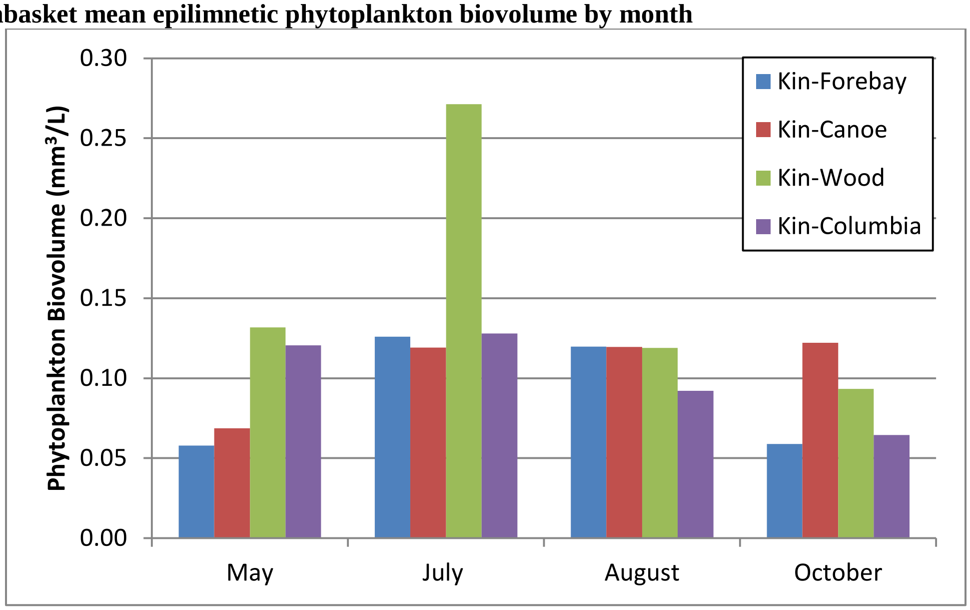


Figure 4 Kinbasket mean epilimnetic phytoplankton biovolume by month



Revelstoke

The dominant taxonomic groups in Revelstoke are the blue-greens and flagellates (Table 3 and Figure 5). The mean overall cell density is higher than those observed in Kinbasket (4,569 cells/mL compared to 3,851 cells/mL).The mean cell density is greater in 2011(4,201 cells/mL) than in 2010 (2634 cells/mL). Based on biovolume, the taxonomic group making up the greatest amount of the biovolume are the flagellates, with the other groups contributing significantly less (Table 4 and Figure 6).

Peak phytoplankton density and biovolume occurred at the Forebay Station in June (8025 cells/mL and 0.2421 mm^3/L) (Figure 7 and Figure 8). The Forebay Station also had the lowest phytoplankton density and biovolume at (1439 cells/mL) and (0.0372 mm^3/L) during October.

On a density basis, the three monitoring locations within Revelstoke Reservoir have similar total density with the Middle Reservoir Station having the greatest density on a seasonal basis followed by the Forebay Station and the Upper Reservoir Station (Table 3). When one looks at the data based on biovolume, there appears to be a gradient from higher productivity in the Forebay Station to the lowest productivity occurring in the Upper Reservoir Station (Table 4). This is due to the fact that the taxa making up the community in the Upper Reservoir Station have a greater proportion of small sized taxa such as chryso/cryptophytes and cyanophytes compared to the Forebay and Middle Reservoir Stations.

Table 3 Revelstoke Reservoir mean phytoplankton density (Cells/mL) by group and month from the 2, 5 and 10 meter laboratory composites 2011

Station	Group	May	June	July	August	September	October	Seasonal Average
Forebay	Blue-greens	1675	3472	2520	3675	1374	659	2229
	Coccoid Greens, Desmids, etc.	211	374	236	569	447	81	320
	Diatoms	33	407	49	130	89	33	123
	Dinoflagellates	8	106	24	49	24	8	37
	Flagellates	1602	3667	1781	2098	1358	659	1861
	Sum of All Groups	**3529**	**8025**	**4610**	**6521**	**3293**	**1439**	**4569**
Middle	Blue-greens	2683	2594	4610	1740	984	854	2244
	Coccoid Greens, Desmids, etc.	89	163	276	1675	1146	228	596
	Diatoms	163	268	24	122	24	33	106
	Dinoflagellates	8	33	8	81	33	24	31
	Flagellates	1959	2447	1821	1764	1244	870	1684
	Sum of All Groups	**4903**	**5504**	**6740**	**5382**	**3431**	**2008**	**4661**
Upper	Blue-greens	2504	2838	4455	1163	1716	715	2232
	Coccoid Greens, Desmids, etc.	228	154	33	33	146	16	102
	Diatoms	73	154	89	81	81	211	115
	Dinoflagellates	24	41	16	0	24	0	18
	Flagellates	2398	2984	2553	1187	1846	1098	2011
	Sum of All Groups	**5228**	**6171**	**7147**	**2464**	**3813**	**2041**	**4477**

Table 4 Revelstoke Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2011

Station	Group	May	June	July	August	September	October	Seasonal Average
Forebay	Blue-greens	0.0124	0.0258	0.0088	0.0137	0.0207	0.0021	0.0139
	Coccoid Greens, Desmids, etc.	0.0142	0.0288	0.0341	0.0270	0.0352	0.0059	0.0242
	Diatoms	0.0075	0.0340	0.0079	0.0298	0.0080	0.0046	0.0153
	Dinoflagellates	0.0016	0.0431	0.0098	0.0179	0.0098	0.0033	0.0142
	Flagellates	0.0201	0.1104	0.0396	0.0415	0.0513	0.0214	0.0474
	Sum of All Groups	0.0558	0.2421	0.1002	0.1299	0.1250	0.0372	0.1150
Middle	Blue-greens	0.0143	0.0182	0.0181	0.0078	0.0059	0.0070	0.0119
	Coccoid Greens, Desmids, etc.	0.0069	0.0169	0.0167	0.0423	0.0392	0.0142	0.0227
	Diatoms	0.0384	0.0213	0.0065	0.0162	0.0049	0.0030	0.0150
	Dinoflagellates	0.0033	0.0130	0.0033	0.0293	0.0130	0.0049	0.0111
	Flagellates	0.0388	0.0464	0.0239	0.0410	0.0185	0.0220	0.0318
	Sum of All Groups	0.1016	0.1159	0.0684	0.1365	0.0815	0.0511	0.0925
Upper	Blue-greens	0.0276	0.0134	0.0179	0.0040	0.0069	0.0030	0.0121
	Coccoid Greens, Desmids, etc.	0.0207	0.0099	0.0043	0.0059	0.0107	0.0013	0.0088
	Diatoms	0.0143	0.0121	0.0087	0.0052	0.0058	0.0308	0.0128
	Dinoflagellates	0.0065	0.0163	0.0049	0.0000	0.0081	0.0000	0.0060
	Flagellates	0.0548	0.0909	0.0394	0.0226	0.0336	0.0146	0.0427
	Sum of All Groups	0.1239	0.1426	0.0752	0.0377	0.0651	0.0497	0.0824

Figure 5 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between May - October 2011 derived from the 2, 5, and 10 meter laboratory composites

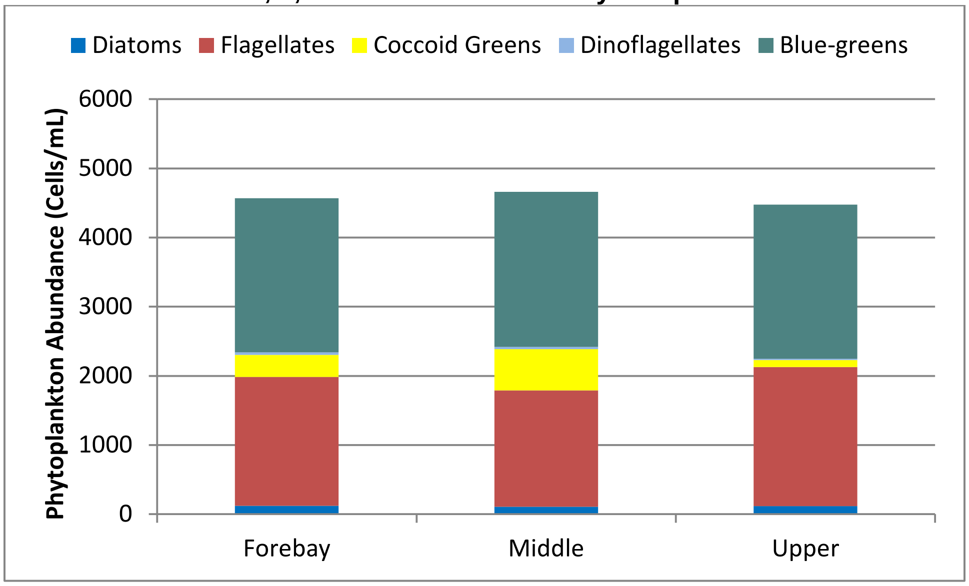


Figure 6 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2011 derived from the 2, 5, and 10 meter laboratory composites

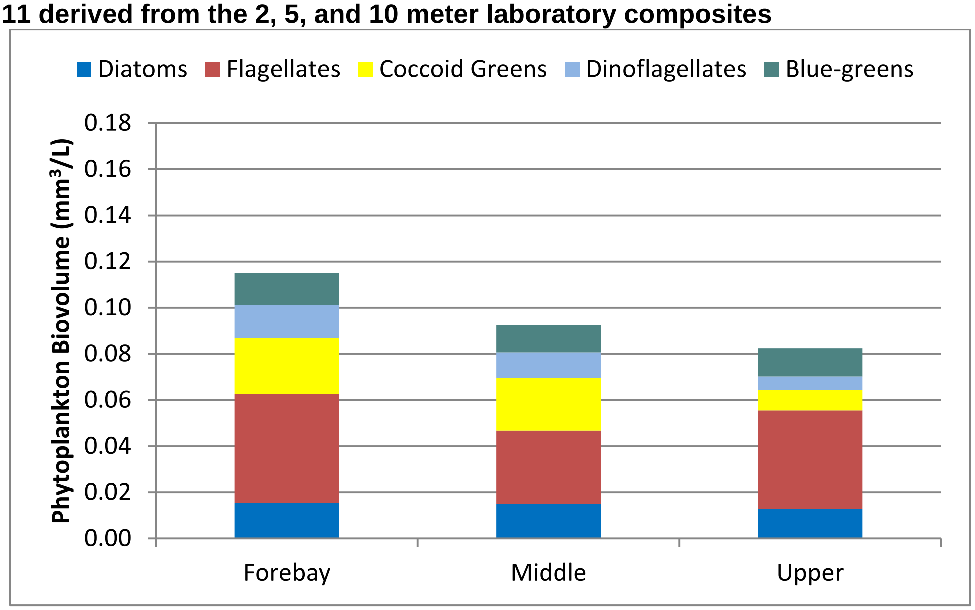


Figure 7 Revelstoke mean epilimnetic phytoplankton density by month

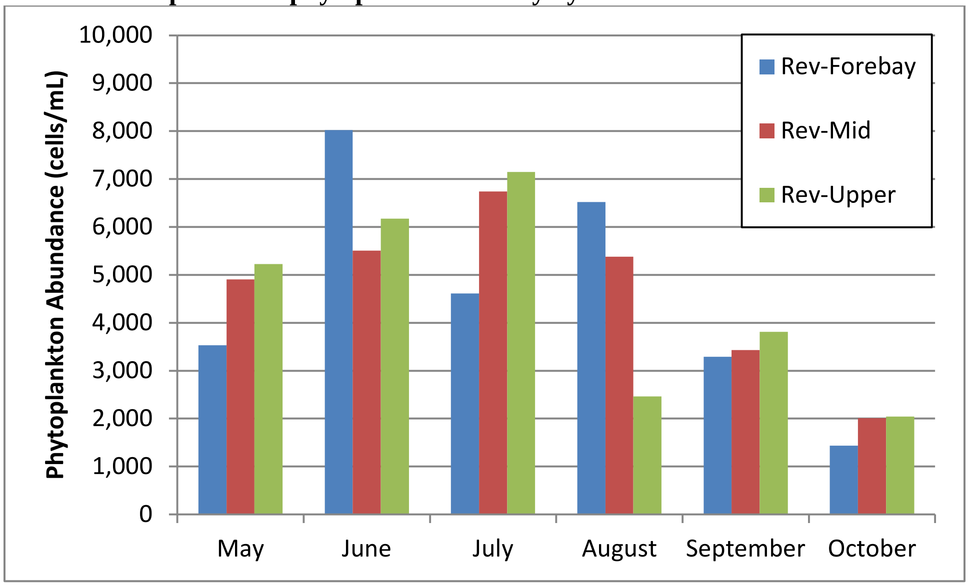
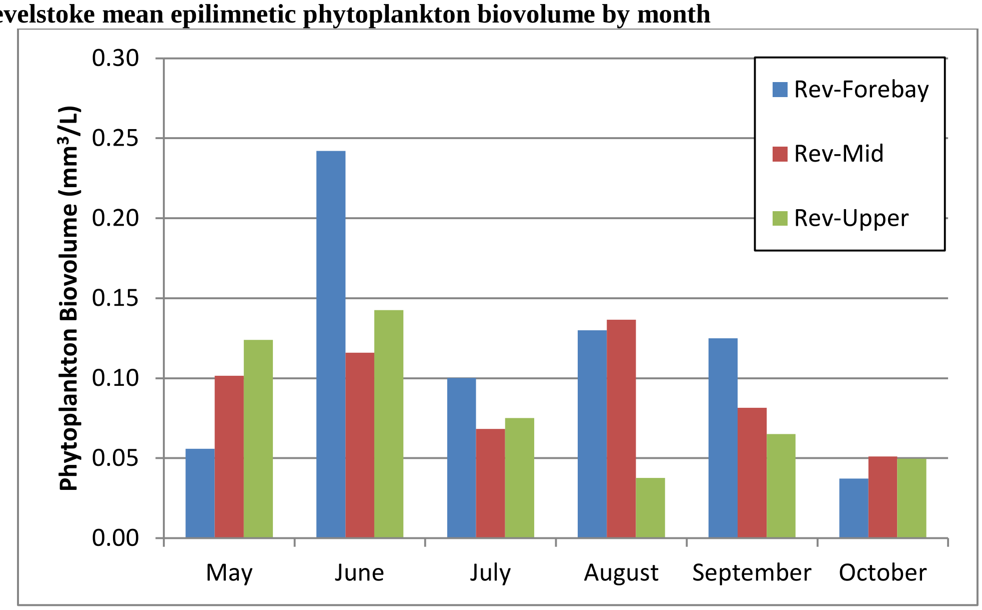


Figure 8 Revelstoke mean epilimnetic phytoplankton biovolume by month



3.2.2 Hypolimnion

Kinbasket

Hypolimnetic phytoplankton densities in Kinbasket Reservoir were comparable to epilimnetic densities, in terms of dominant groups. Blue-Greens were the most abundant group, followed by flagellates. Diatoms, greens and dinoflagellates were minor contributors to hypolimnetic phytoplankton density (Table 5 and Figure 9). In terms of biovolume, flagellates were the largest contributors followed by diatoms and green taxa. Dinoflagellates, and blue-green contributed the least to biovolume (Table 6 and Figure 10). The Wood Arm had the highest seasonal average phytoplankton density (5558 cells/mL); as well as the highest seasonal average of biovolume (0.097 mm^3/L), due to high blue-green densitiesThe month of July had the highest hypolimnetic phytoplankton cell density in all stations (Figure 11), with July and August having the highest biovolumes (Figure 12).

Table 5 Kinbasket Reservoir phytoplankton density (Cells/mL) by group and month from the 15, and 25 meter laboratory composites in 2011

Station	Group	May	July	August	October	Seasonal Average
Canoe	Blue-greens	1024	2037	1244	634	1235
	Coccoid Greens, Desmids, etc.	61	268	37	122	122
	Diatoms	24	134	134	61	88
	Dinoflagellates	37	0	24	12	18
	Flagellates	1183	1781	1354	695	1253
	Sum of All Groups	**2329**	**4220**	**2793**	**1524**	**2717**
Columbia	Blue-greens	1281	4000	1683	768	1933
	Coccoid Greens, Desmids, etc.	37	12	49	195	73
	Diatoms	329	73	61	122	146
	Dinoflagellates	49	12	37	12	27
	Flagellates	1451	2073	1329	768	1406
	Sum of All Groups	**3146**	**6171**	**3159**	**1866**	**3586**
Kin-Forebay	Blue-greens	927	1171	1427	732	1064
	Coccoid Greens, Desmids, etc.	220	122	110	134	146
	Diatoms	49	195	171	61	119
	Dinoflagellates	37	12	49	12	27
	Flagellates	951	1305	1512	707	1119
	Sum of All Groups	**2183**	**2805**	**3268**	**1646**	**2476**
Wood	Blue-greens	1049	9208	2232	744	3308
	Coccoid Greens, Desmids, etc.	73	183	220	220	174
	Diatoms	98	159	134	110	125
	Dinoflagellates	12	24	12	0	12
	Flagellates	1049	4220	1805	683	1939
	Sum of All Groups	**2281**	**13793**	**4403**	**1756**	**5558**

Table 6 Kinbasket Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2011

Station	Group	May	July	August	October	Seasonal Average
Kin-Canoe	Blue-greens	0.0100	0.0111	0.0109	0.0056	0.0094
	Coccoid Greens, Desmids, etc.	0.0065	0.0237	0.0314	0.0067	0.0171
	Diatoms	0.0055	0.0143	0.0168	0.0067	0.0108
	Dinoflagellates	0.0122	0.0000	0.0098	0.0043	0.0066
	Flagellates	0.0284	0.0361	0.0333	0.0185	0.0291
	Sum of All Groups	**0.0626**	**0.0852**	**0.1022**	**0.0419**	**0.0730**
Kin-Columbia	Blue-greens	0.0082	0.0190	0.0067	0.0032	0.0093
	Coccoid Greens, Desmids, etc.	0.0049	0.0004	0.0110	0.0098	0.0065
	Diatoms	0.0259	0.0049	0.0082	0.0616	0.0251
	Dinoflagellates	0.0171	0.0024	0.0146	0.0043	0.0096
	Flagellates	0.0219	0.0331	0.0170	0.0160	0.0220
	Sum of All Groups	**0.0780**	**0.0598**	**0.0575**	**0.0948**	**0.0725**
Kin-Forebay	Blue-greens	0.0036	0.0045	0.0087	0.0030	0.0049
	Coccoid Greens, Desmids, etc.	0.0201	0.0064	0.0365	0.0101	0.0183
	Diatoms	0.0070	0.0204	0.0211	0.0268	0.0188
	Dinoflagellates	0.0146	0.0049	0.0195	0.0049	0.0110
	Flagellates	0.0190	0.0404	0.0468	0.0215	0.0319
	Sum of All Groups	**0.0642**	**0.0766**	**0.1325**	**0.0663**	**0.0849**
Kin-Wood	Blue-greens	0.0071	0.0427	0.0090	0.0030	0.0154
	Coccoid Greens, Desmids, etc.	0.0077	0.0149	0.0099	0.0172	0.0124
	Diatoms	0.0166	0.0163	0.0230	0.0796	0.0339
	Dinoflagellates	0.0024	0.0098	0.0049	0.0000	0.0043
	Flagellates	0.0205	0.0506	0.0384	0.0137	0.0308
	Sum of All Groups	**0.0544**	**0.1342**	**0.0852**	**0.1134**	**0.0968**

Figure 9 Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between May - October 2011 derived from the 15, and 25 meter laboratory composites

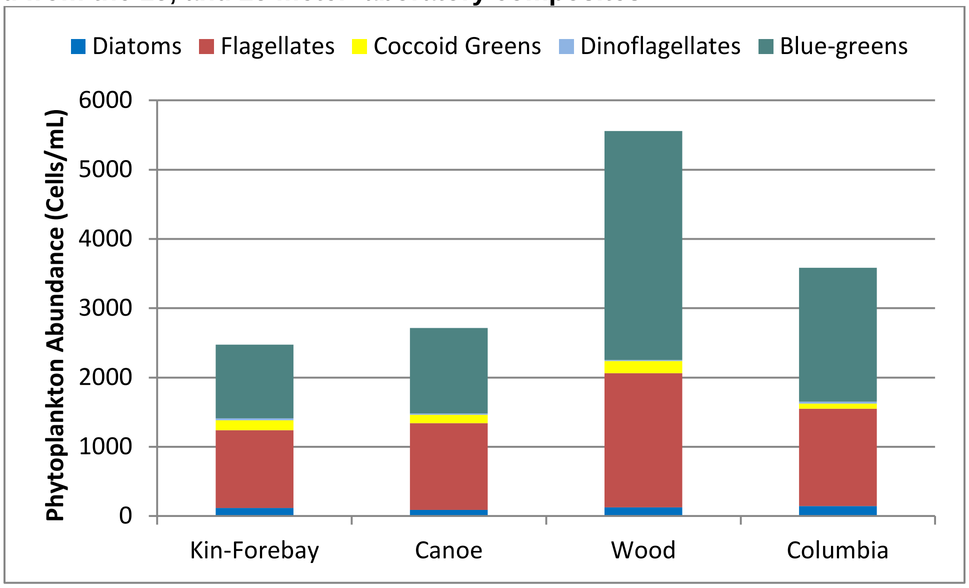


Figure 10 Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between May - October 2011 derived from the 15, and 25 meter laboratory composites

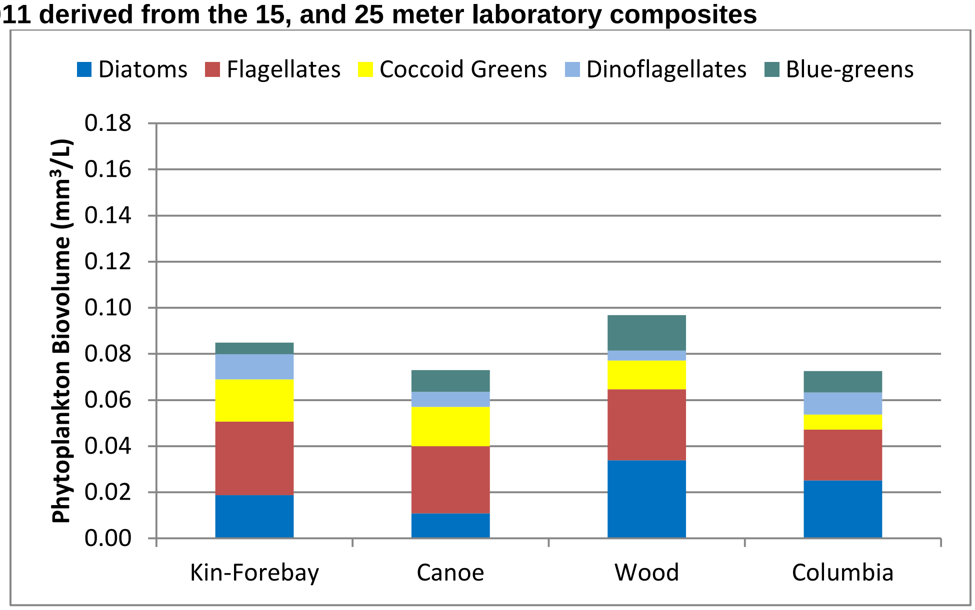


Figure 11 Kinbasket mean hypolimnetic phytoplankton density by month

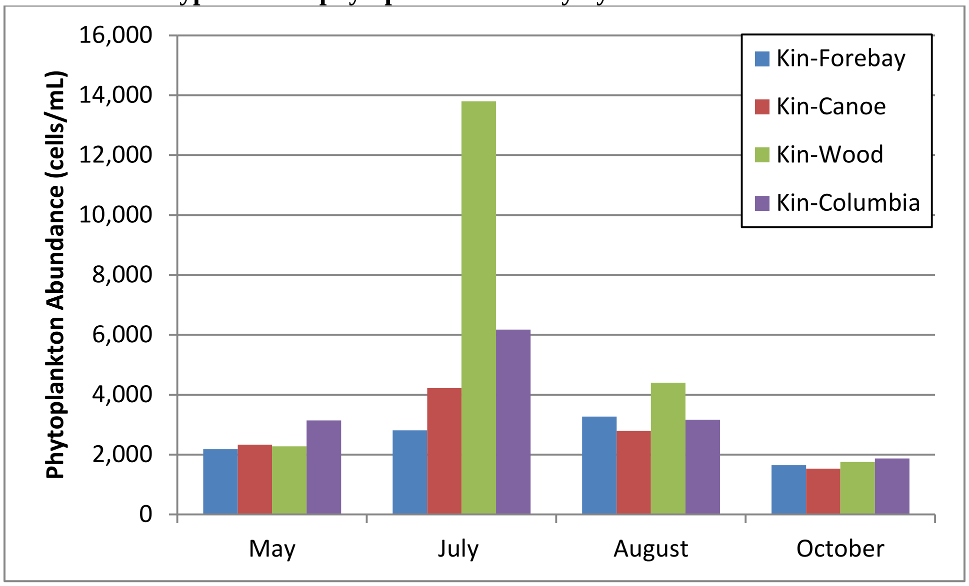
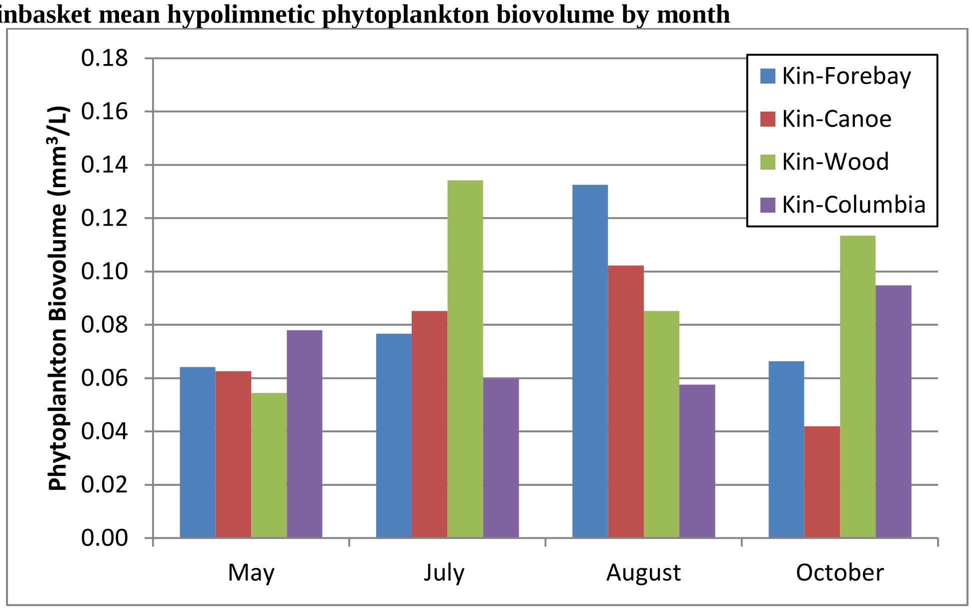


Figure 12 Kinbasket mean hypolimnetic phytoplankton biovolume by month



Revelstoke

The most abundant groups in the hypolimnion of Revelstoke Reservoir in 2011 were blue-greens and flagellates. The least abundant groups present were dinoflagellates and diatoms (Table 7 and Figure 13). The greatest contributors to biovolume at all stations were flagellates and the greens. Diatoms, blue-greens and dinoflagellates contributed the least to biovolume (Table 8 and Figure 14). The middle station had the highest mean cell density of the three Revelstoke stations, followed by the upper and forebay stations, respectively. The seasonal mean biovolume for the entire phytoplankton community was similar at all three stations during 2011. The gradient in biovolume as one moves upstream within the reservoir that was observed in the eiplimnion samples was not evident in the hypolimnion samples.

June and July had the highest phytoplankton density in the hypolimnion, followed by a steep reduction in density from August through October (Figure 15).Hypolimnetic biovolume was variable throughout the sampling season (Figure 16).

Table 7 Revelstoke Reservoir phytoplankton density (Cells/mL) by group and month from the 15, and 25 meter laboratory composites in 2011

Station	Group	May	June	July	August	September	October	Seasonal Average
Forebay	Blue-greens	1220	3768	2695	1366	1305	793	1858
	Coccoid Greens, Desmids, etc.	146	402	37	12	110	134	140
	Diatoms	24	195	98	49	73	37	79
	Dinoflagellates	24	24	12	24	24	0	18
	Flagellates	1134	3134	2671	1342	1293	793	1728
	Sum of All Groups	**2549**	**7525**	**5512**	**2793**	**2805**	**1756**	**3823**
Middle	Blue-greens	3183	4378	5171	1159	1732	683	2718
	Coccoid Greens, Desmids, etc.	220	146	49	110	1000	134	276
	Diatoms	122	122	12	98	183	61	100
	Dinoflagellates	24	24	0	0	12	0	10
	Flagellates	1854	3293	2951	1500	1744	890	2039
	Sum of All Groups	5403	7964	8183	2866	4671	1768	5143
Upper	Blue-greens	**2195**	**3403**	**5939**	**1281**	**915**	**634**	**2394**
	Coccoid Greens, Desmids, etc.	73	37	146	37	12	122	71
	Diatoms	134	49	122	98	73	61	89
	Dinoflagellates	37	24	0	12	12	0	14
	Flagellates	1829	2768	2988	1281	1146	939	1825
	Sum of All Groups	**4268**	**6281**	**9196**	**2707**	**2159**	**1756**	**4395**

Table 8 Revelstoke Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2011

Station	Group	May	June	July	August	September	October	Seasonal Average
Rev-Forebay	Blue-greens	0.0078	0.0151	0.0108	0.0085	0.0074	0.0061	0.0093
	Coccoid Greens, Desmids, etc.	0.0093	0.0294	0.0035	0.0004	0.0369	0.0101	0.0149
	Diatoms	0.0021	0.0276	0.0101	0.0098	0.0050	0.0060	0.0101
	Dinoflagellates	0.0049	0.0098	0.0049	0.0098	0.0098	0.0000	0.0065
	Flagellates	0.0170	0.0556	0.0454	0.0258	0.0213	0.0149	0.0300
	Sum of All Groups	**0.0410**	**0.1375**	**0.0746**	**0.0541**	**0.0803**	**0.0372**	**0.0708**
Rev-Mid	Blue-greens	0.0176	0.0205	0.0207	0.0047	0.0070	0.0029	0.0122
	Coccoid Greens, Desmids, etc.	0.0156	0.0103	0.0159	0.0241	0.0176	0.0063	0.0149
	Diatoms	0.0140	0.0079	0.0012	0.0167	0.0159	0.0044	0.0100
	Dinoflagellates	0.0098	0.0098	0.0000	0.0000	0.0006	0.0000	0.0034
	Flagellates	0.0254	0.0570	0.0335	0.0224	0.0263	0.0171	0.0303
	Sum of All Groups	**0.0823**	**0.1054**	**0.0713**	**0.0679**	**0.0674**	**0.0308**	**0.0708**
Rev-Upper	Blue-greens	0.0113	0.0136	0.0238	0.0107	0.0038	0.0055	0.0114
	Coccoid Greens, Desmids, etc.	0.0128	0.0040	0.0309	0.0065	0.0015	0.0115	0.0112
	Diatoms	0.0130	0.0042	0.0235	0.0102	0.0098	0.0125	0.0122
	Dinoflagellates	0.0146	0.0098	0.0000	0.0049	0.0024	0.0000	0.0053
	Flagellates	0.0389	0.0313	0.0307	0.0163	0.0106	0.0145	0.0237
	Sum of All Groups	**0.0907**	**0.0628**	**0.1089**	**0.0487**	**0.0281**	**0.0440**	**0.0639**

Figure 13 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between May - October 2011 derived from the 15, and 25 meter laboratory composites

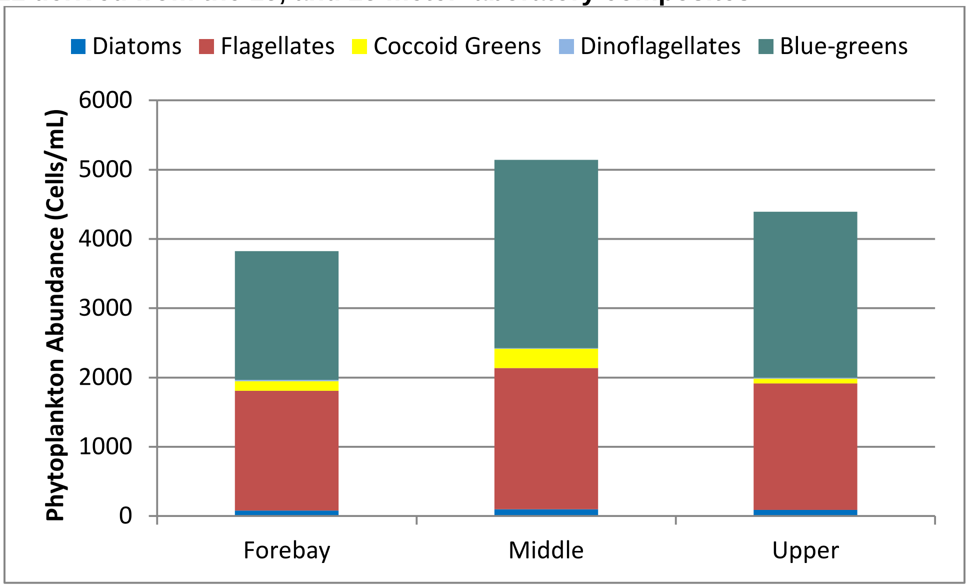


Figure 14 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2011 derived from the 15, and 25 meter laboratory composites

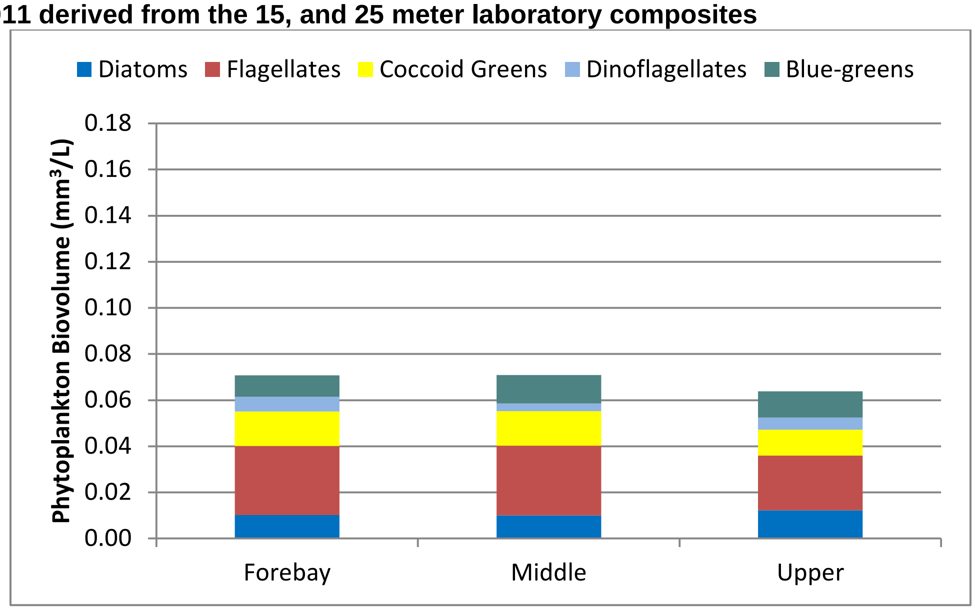


Figure 15 Revelstoke mean hypolimnetic phytoplankton density by month

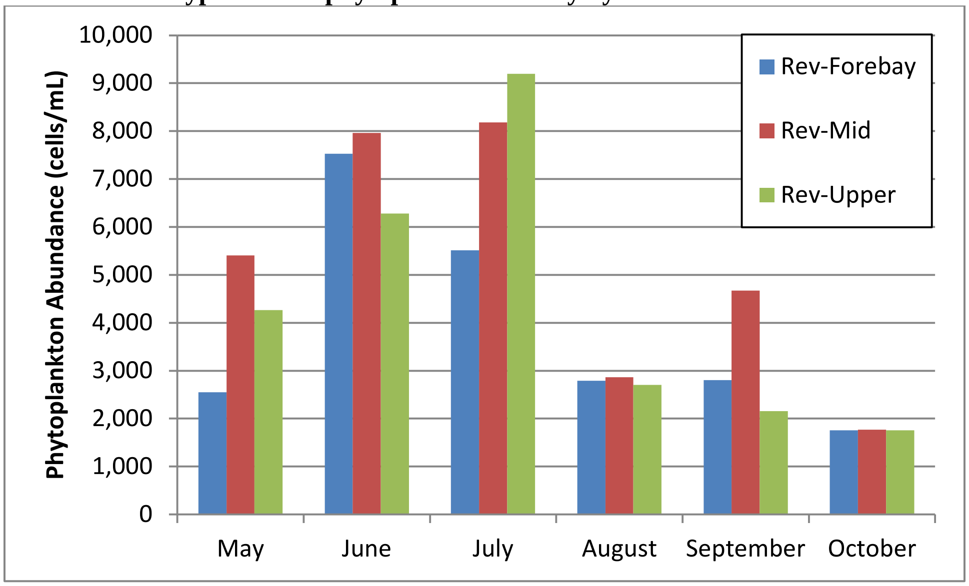
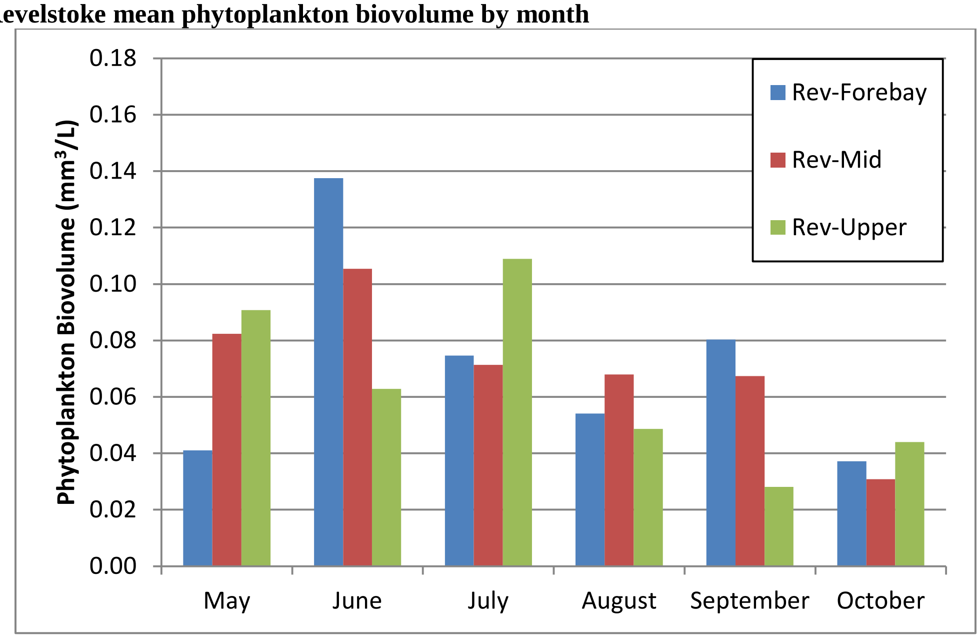


Figure 16 Revelstoke mean phytoplankton biovolume by month



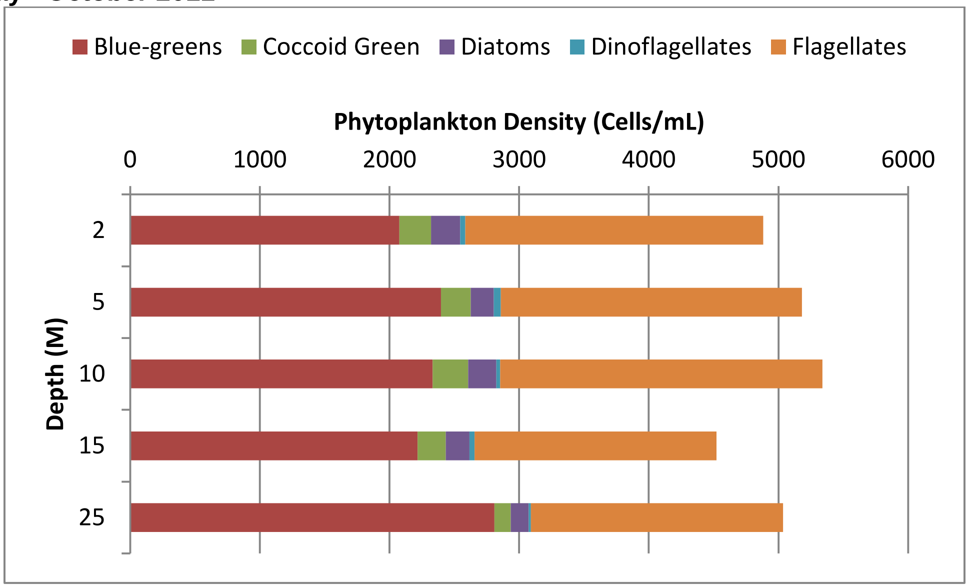
3.3 Vertical Distribution- Phytoplankton Density and Biovolume – 2011

Average density (cells/mL) and average biovolume (mm^3/L) of phytoplankton groups were calculated for individual depth strata for both Kinbasket and Revelstoke Reservoirs. The averages were based on every sample collected at each station within the respective reservoirs during the 2011 sampling season.

Kinbasket

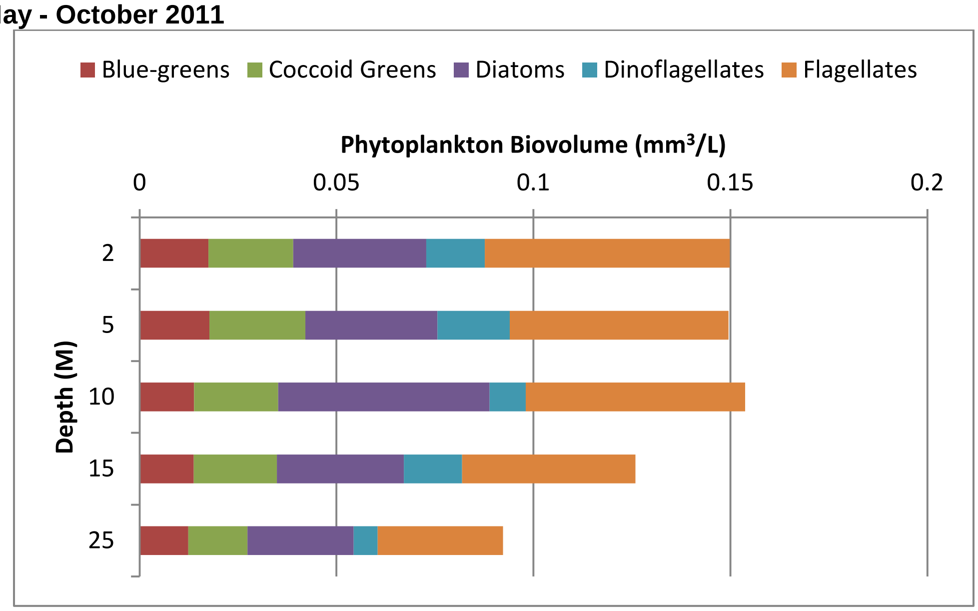
In Kinbasket Reservoir, between May and October, the 10 meter depth category had marginally greater community density than the other depths sampled. There was little change in phytoplankton density with depth in 2011. Blue-Greens and flagellates dominated the community at all depths (Figure 17).

Figure 17 Average phytoplankton density (Cells/mL), by depth and group, in Kinbasket Reservoir between May - October 2011



The biovolume of the phytoplankton community is relatively similar in the upper 10 meters and then decreases at the 15 and 25 meter sample depths. The reduction in biovolume in samples greater than 10 meters in depth is consistent across groups but most pronounced in the diatoms and flagellate communities (Figure 18).

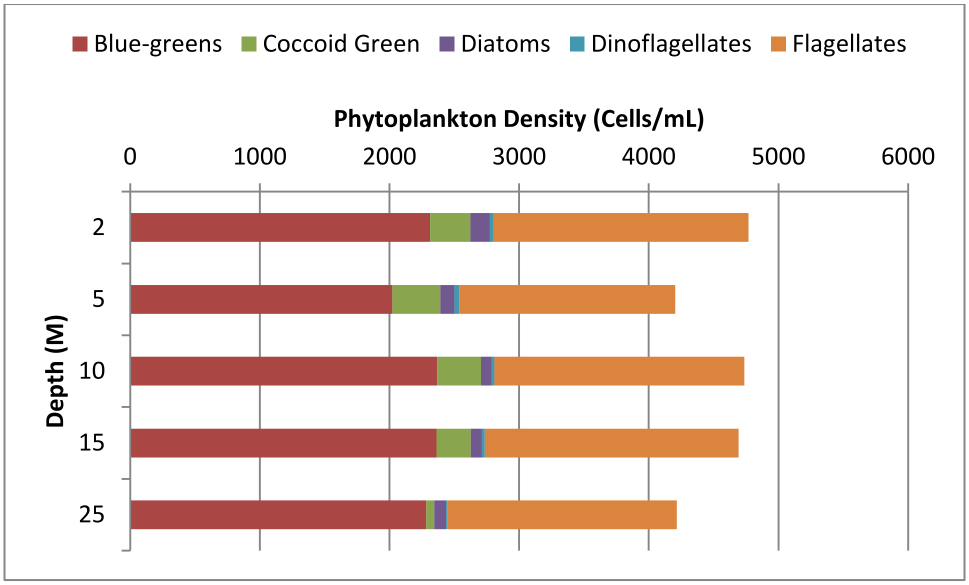
Figure 18 Average phytoplankton biovolume (mm^3/L), by depth and group, in Kinbasket Reservoir between May - October 2011



Revelstoke

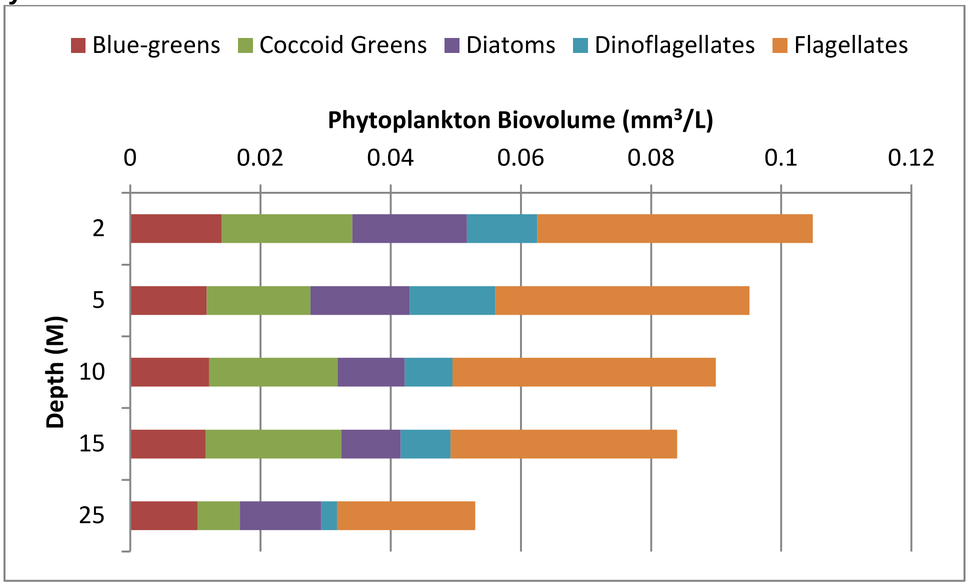
As with Kinbasket, there was little difference in phytoplankton density with depth in Revelstoke Reservoir. The only taxa that seemed to decrease in density with depth were the greens. The most abundant group at all depths were the blue-greens and flagellates. Dinoflagellate and diatoms were the least abundant groups (Figure 19).

Figure 19 Average phytoplankton density (Cells/mL), by depth, in Revelstoke Reservoir between May - October 2011



The greatest average biovolume in Revelstoke Reservoir was at 2 meters. The trend of decreasing biovolume with increased depth observed in Kinbasket Reservoir was also evident in Revelstoke. Flagellates had the highest average biovolume at all depths. Dinoflagellates and diatoms were the groups with the lowest average biovolumes, respectively (Figure 20).

Figure 20 Average phytoplankton biovolume (mm^3/L), by depth and group, in Revelstoke Reservoir between May - October 2011



3.4 Phytoplankton in 2008, 2009, 2010,and 2011

To compare the 2008 through 2011 sampling seasons, phytoplankton cell counts and biovolume data from every sampling event at each station for the epilimnion samples were compiled.

Kinbasket

Inter-annual comparison of the average total density and total biovolume of phytoplankton suggests that there has been an increase in phytoplankton density since 2008. The reservoir average has increased in every year since 2008. There has been some variability between stations but there is a general trend of increasing density through time. Biovolume is exhibiting a trend opposite of density (Figure 21). This indicates that the taxa present in the system is made up of taxa with smaller biovolumes. As mentioned previously the dominant taxa were micro-flagellates members of the Chryso-Cryptophyte group and Synechococcus (coccoids) a member of the Cyanophyte group. Both of these taxa are very small taxa with low biovolume estimates (Table 9).

Table 9 Average seasonal phytoplankton density and biomass in Kinbasket Reservoir

Kinbasket	Year	Kin-Forebay	Canoe	Wood	Columbia	Reservoir Average
Average Density (Cells/mL)	2008*	1672	1284	1276	1238	1368
	2009	2215	2066	2208	2110	2150
	2010	2797	3133	3075	2569	2893
	2011ŧ	2476	2717	5558	3586	3584
Biovolume (mm^3/L)	2008	0.19	0.13	0.16	0.16	0.16
	2009	0.26	0.22	0.23	0.18	0.22
	2010	0.14	0.14	0.16	0.12	0.14
	2011	0.09	0.07	0.10	0.07	0.08

* samples were not collected in May or June of 2008 so the averages is only based on July through October values.
ŧ samples were not collected in June or September of 2011 so the averages do not include the values from those months

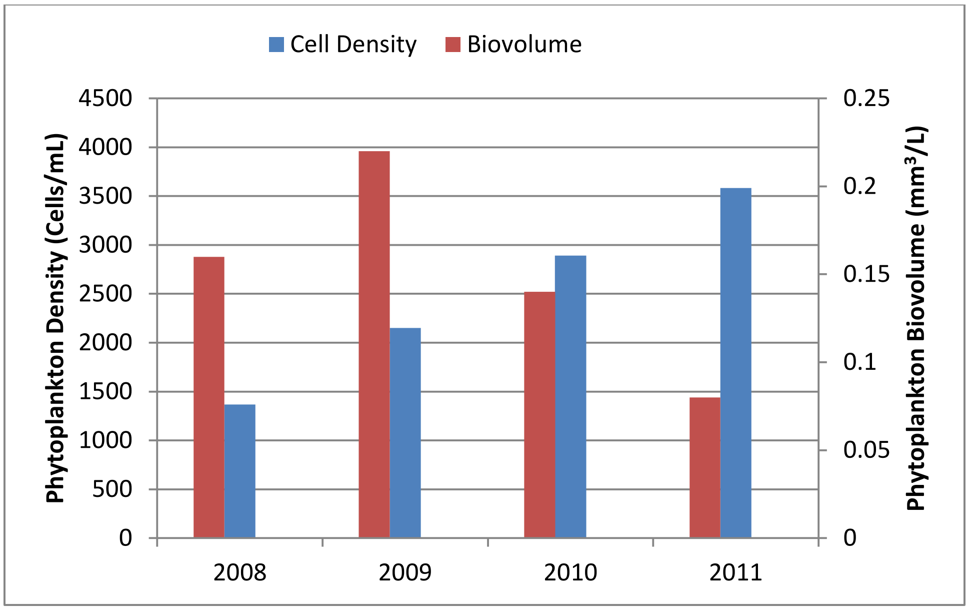


Figure 21 Mean reservoir phytoplankton density and biovolume by year for Kinbasket

Revelstoke

As observed in Kinbasket the mean epilimnetic phytoplankton density has been increasing since 2008. The largest increase in density occurred between 2010 and 2011, primarily due to the high densities of small flagellates and Synechococcus sp. observed in these stations in 2011 (Table 10).

The total biovolume has decreased considerably since 2008. As with Kinbasket Reservoir, this indicates that the taxa present within the reservoir are smaller in recent years compared to 2008 Table 10 and Figure 22).

Table 10 Average seasonal phytoplankton density and biomass in Revelstoke Reservoir

Revelstoke	Year	Forebay	Mid	Upper	Reservoir Average
Average Density (Cells/mL)	2008*	2604	1829	1544	1992
	2009	2416	1901	1683	2000
	2010	1940	2502	1684	2375
	2011	3823	5143	4395	4154
Biovolume (mm^3/L)	2008	0.16	0.15	0.13	0.15
	2009	0.20	0.13	0.12	0.15
	2010	0.10	0.09	0.08	0.09
	2011	0.07	0.07	0.06	0.07

* samples were not collected in May or June of 2008 so the averages is only based on July through October values.

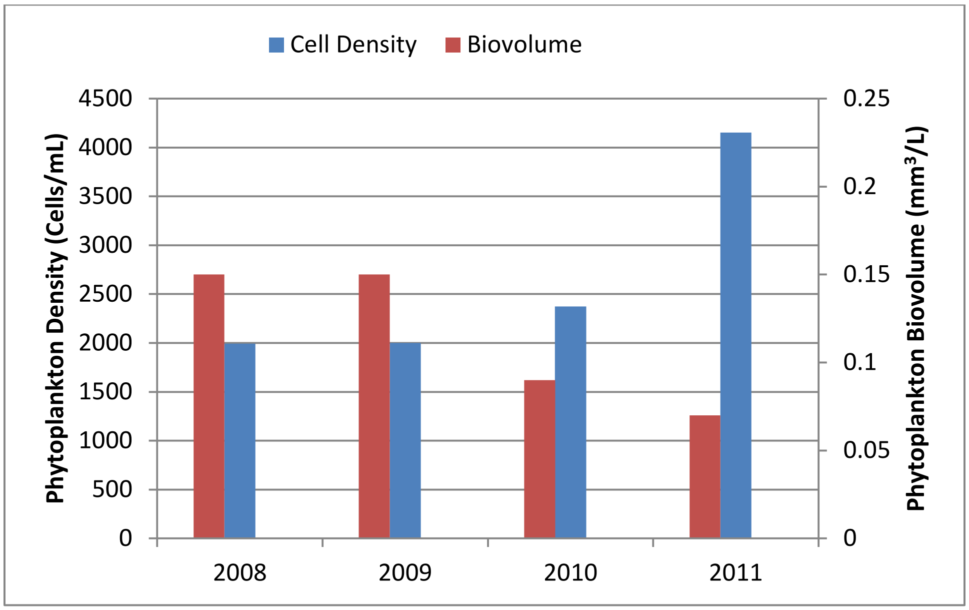


Figure 22 Mean reservoir phytoplankton density and biovolume by year for Revelstoke

3.5 Bacteria and Pico-cyanobacteria Density in 2011

3.5.1 Bacteria.

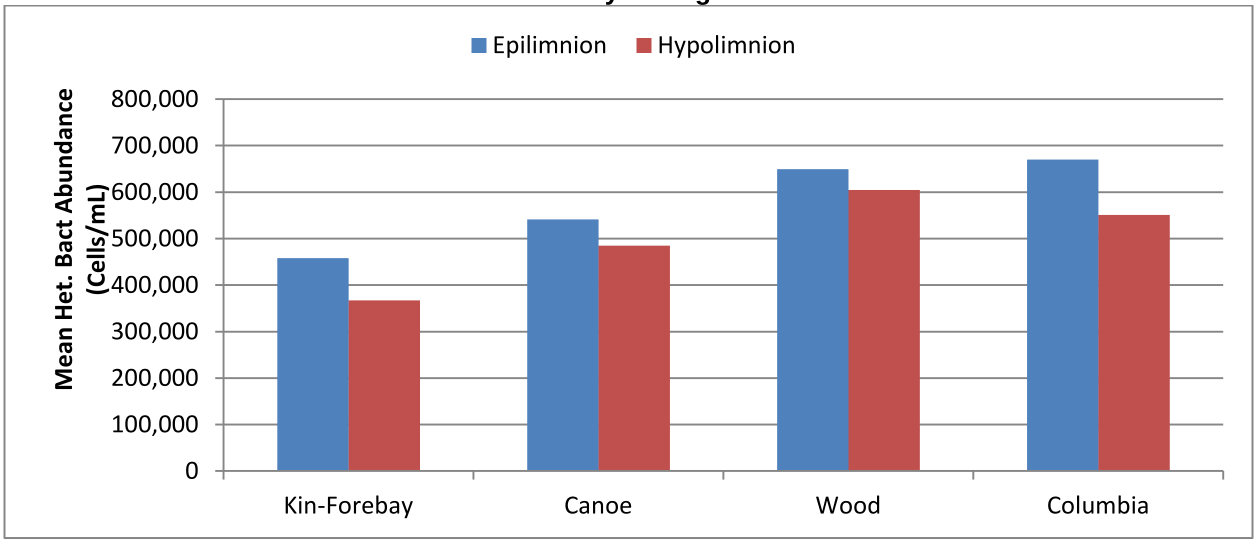
Kinbasket

Of the four stations, the Columbia (670,000 cells/mL) and Wood Arm (650,000 cells/mL)stations had the highest average epilimnetic densities. The Forebay, and Canoe stations had mean epilimnetic densities of 458,000 cells/mL and 541,000 cells/mL respectively (Table 9 and Figure 23). The epilimnion had slightly higher densities than the hypolimnion at all stations (Table 9 and Figure 23).

Table 9 2011 Picoplankton densities

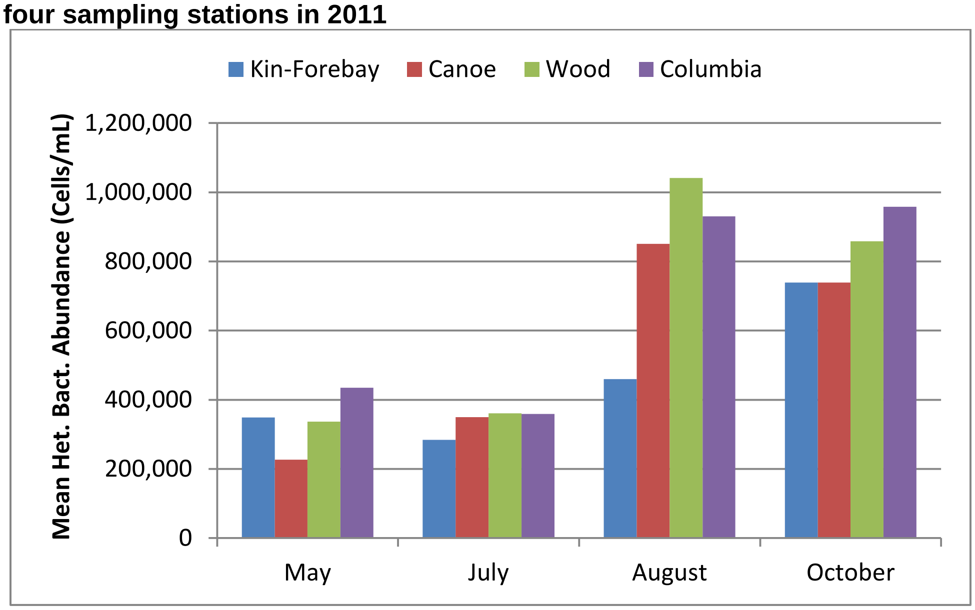
		Heterotrophic Bacteria (Cells/mL)						
		May	June	July	August	Sept.	Oct.	Avg.
Epilimnion	Kin-Canoe	226,522		349,718	850,449		739,176	541,466
	Kin-Columbia	435,160		358,659	929,931		957,749	670,375
	Kin-Forebay	348,724		284,145	459,998		739,176	458,011
	Kin-Wood	336,802		360,646	1,041,204		858,398	649,262
	Rev-Forebay	301,035	250,366	220,561	818,657	255,334	687,513	422,244
	Rev-Middle	363,627	241,424	347,730	691,487	363,627	643,798	441,949
	Rev-Upper	299,048	302,029	246,392	564,317	324,880	592,135	388,133
Hypolimnion	Kin-Canoe	306,996		412,309	735,202			484,836
	Kin-Columbia	314,944		385,484	778,916		723,279	550,656
	Kin-Forebay	256,327		318,919	184,794		707,383	366,856
	Kin-Wood	372,568		503,712	806,735		735,202	604,554
	Rev-Forebay	333,821	200,690	275,204	600,083	282,158	560,343	375,383
	Rev-Middle		271,230	322,893	548,421	341,769	755,072	447,877
	Rev-Upper		362,633	507,686	584,187	350,711	631,876	487,419
		Pico-cyano Bacteria (Cells/mL)						
		May	June	July	August	Sept.	Oct.	Avg.
Epilimnion	Kin-Canoe	28,978		99,352	54,312		16,227	49,717
	Kin-Columbia	57,955		117,566	52,988		12,805	60,328
	Kin-Forebay	39,078		74,845	70,540		19,208	50,918
	Kin-Wood	37,754		107,631	71,202		15,518	58,026
	Rev-Forebay	17,552	43,715	361,640	81,799	50,073	33,448	98,038
	Rev-Middle	41,396	31,351	385,484	57,293	33,338	33,780	97,107
	Rev-Upper	63,916	59,280	29,640	99,683	50,338	15,896	53,125
Hypolimnion	Kin-Canoe	40,403		74,514	53,650			56,189
	Kin-Columbia	16,338		91,072	27,156		17,221	37,947
	Kin-Forebay	17,883		75,507	49,676		20,533	40,900
	Kin-Wood	47,358		99,352	53,981		21,952	55,661
	Rev-Forebay	22,851	35,104	42,390	87,429	25,169	22,189	39,189
	Rev-Middle		28,150	48,020	75,176	26,163	18,214	39,145
	Rev-Upper		80,144	57,955	105,644	28,812	22,520	59,015

Figure 23 Average density (Cells/mL) of heterotrophic bacteria at four sampling stations in Kinbasket Reservoir between the months of May through October 2011



Monthly average density of epilimnetic heterotrophic bacteria in Kinbasket Reservoir exhibited a significant increase between the July and August sampling event. The high densities persisted into October in 2011 (Figure 24). The highest densities observed were in the Wood station. The increase in heterotrophic bacteria densities was less pronounced in the Forebay than the stations located within the arms of the reservoir.

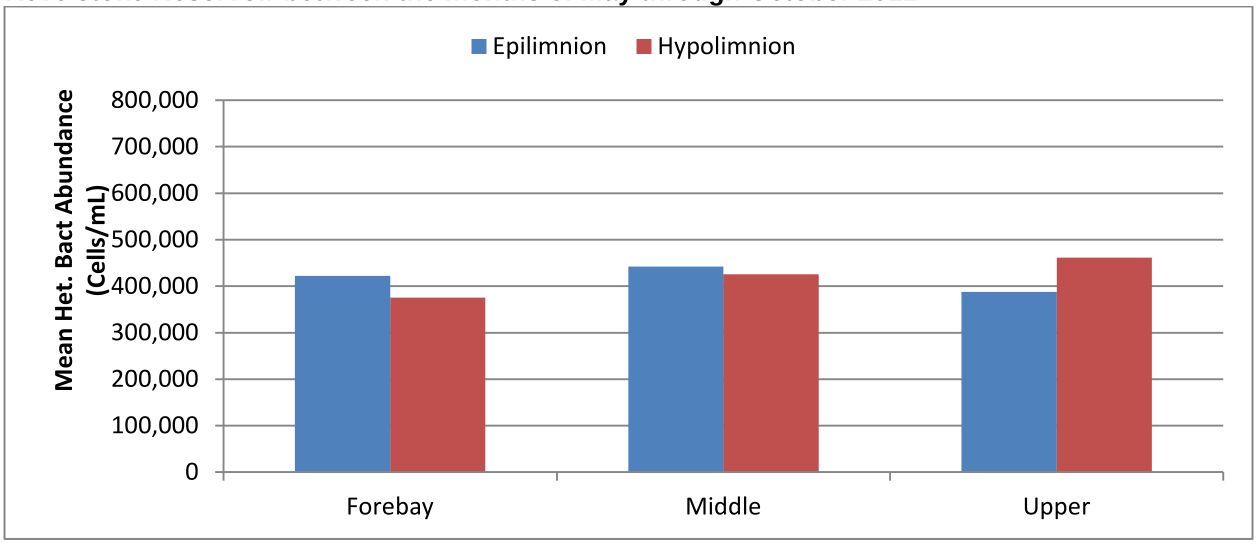
Figure 24 Kinbasket Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at four sampling stations in 2011



Revelstoke

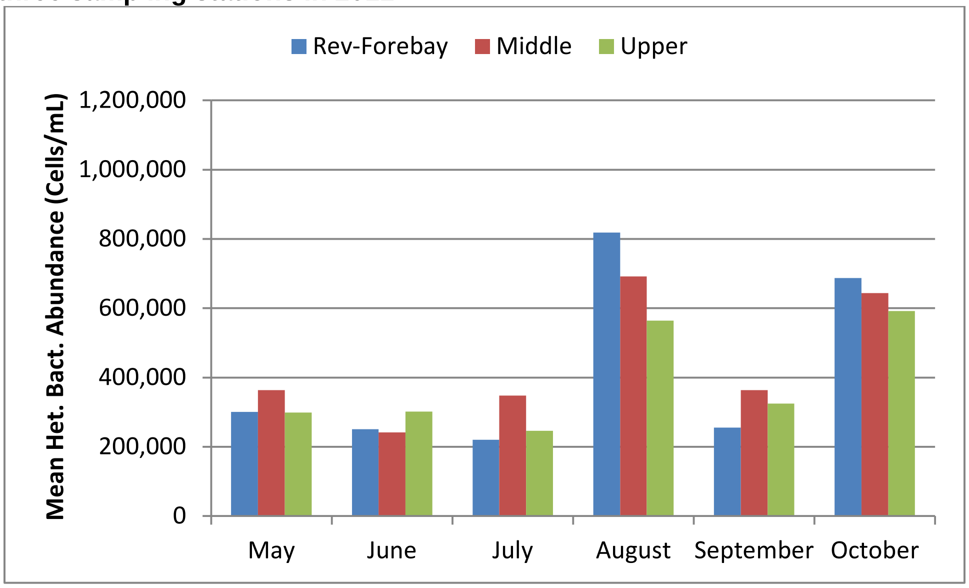
The epilimnetic average of heterotrophic bacteria ranged from 388,000 to 442,000 cells/mL (Table 9). These values are slightly lower than those observed in Kinbasket in 2011 and almost identical to the densities observed in Revelstoke in 2010. The Middle Station had the highest epilmnion density and the Upper Station had the greatest hypolimnion density and overall density for any depth or station. (Figure 25).

Figure 25 Average density (Cells/mL) of heterotrophic bacteria at three sampling stations in Revelstoke Reservoir between the months of May through October 2011



The heterotrophic bacteria densities in May through July were relatively stable with a substantial increase in heterotrophic bacteria density in August. This is similar to the conditions observed in Kinbasket Reservoir. The densities dropped considerably in September and then recovered in October (Figure 26). There does not appear to be a pattern regarding density versus station.

Figure 26 Revelstoke Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at three sampling stations in 2011



3.5.2 Pico-cyanobacteria.

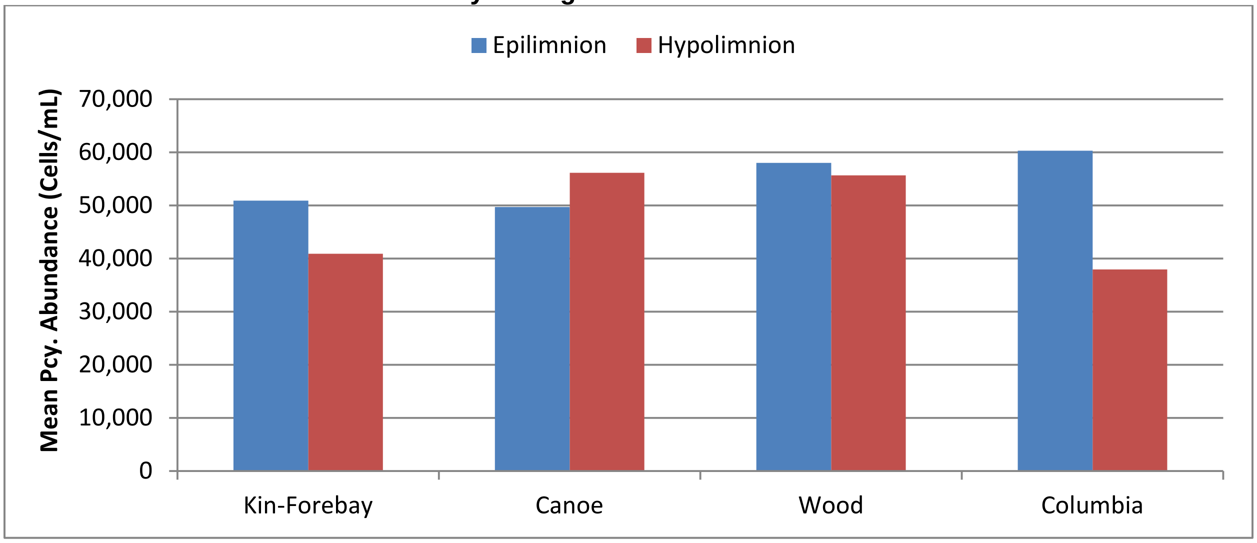
Kinbasket

Total seasonal average density of epilimnetic pico-cyanobacteria in Kinbasket Reservoir was just under 55,000 cells/mL. The stations had relatively similar average epilimnetic densities (Table 9 and Figure 27). The densities observed in 2011 were more than double the densities observed in 2010.

Hypolimnetic total seasonal average density of pico-cyanobacteria averaged just over 47,000 cells/mL. The Columbia sampling station had the lowest average density out of the four stations (Figure 27).

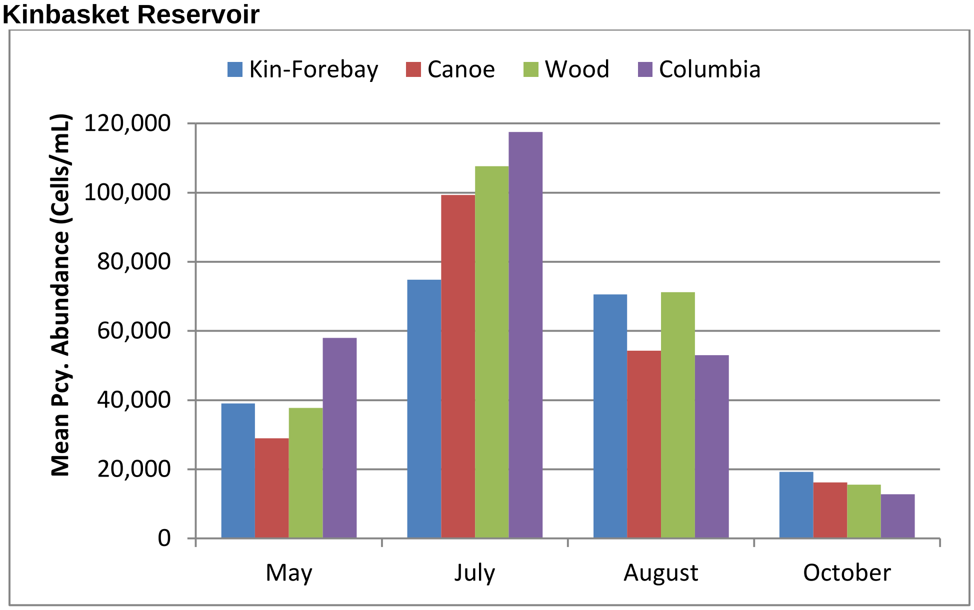
Average pico-cyanobactera density varied between the epilimnion and hypolimnion. At three of the stations the epilimnion had higher average densities than the hypolimnion, the only station where this did not occur was the Canoe Station.

Figure 27 Average density (Cells/mL) of pico-cyanobacteria at four sampling stations in Kinbasket Reservoir between the months of May through October 2011



All sites in Kinbasket Reservoir showed a similar seasonal trend of pico-cyanobacterial density. Average density increased May through July followed by a decline in August through October (8).

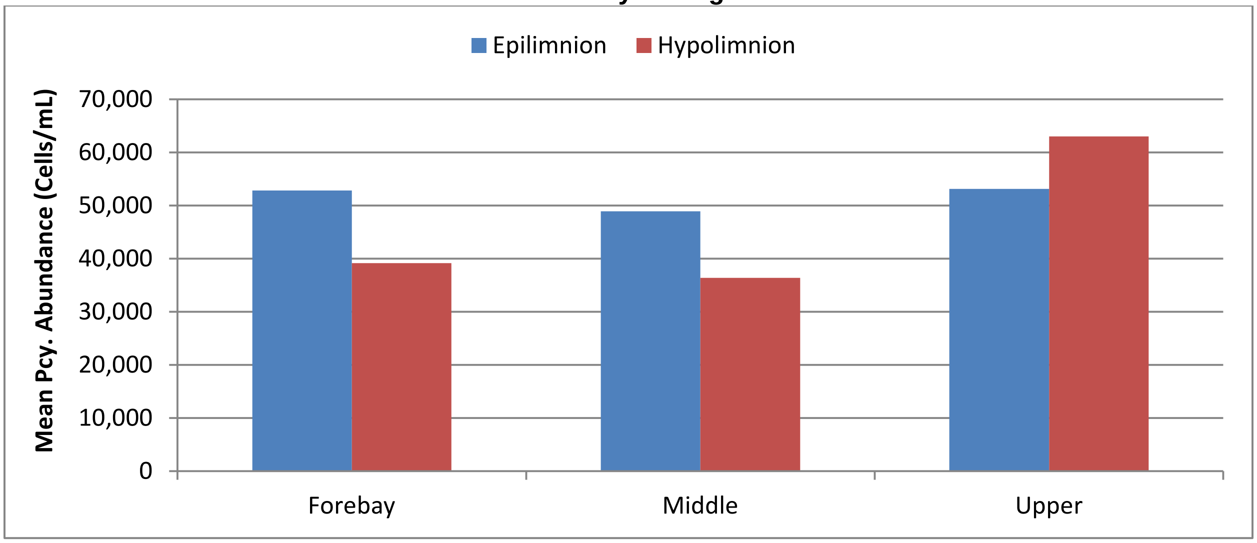
Figure 28 Average monthly density (Cells/mL) of epilimnetic pico-cyanobacteria at four sampling stations in Kinbasket Reservoir



Revelstoke

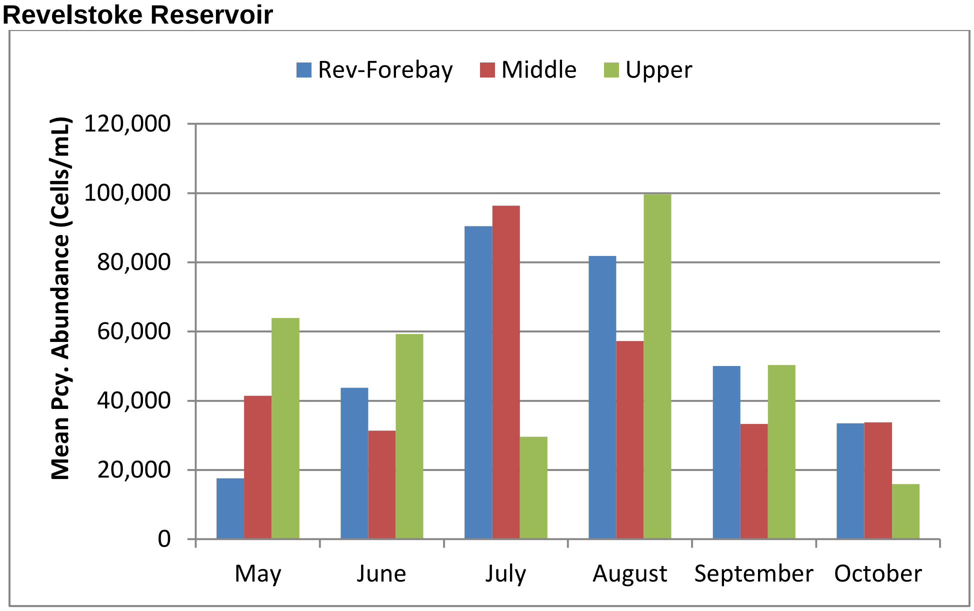
The average density in the epilimnion was approximately 51,600 cells/mL in Revelstoke Reservoir (Table 9). In the hypolimnion the average density was 46,000 cells/mL. The Upper Station had the highest average density in both the hypolimnion and epilimnion, followed by the Forebay and Middle Station (Figure 29).

Figure 29 Average density (Cells/mL) of pico-cyanobacteria at three sampling stations in Revelstoke Reservoir between the months of May through October 2011



The Forebay and Middle Reservoir stations exhibited a general trend of increasing densities from May through July, when densities peaked. The densities declined in August through October for these two stations. The Upper station experienced a decline in picocyanobacteria density between May and July before peaking in August (Figure 30).

Figure 30 Average monthly density (Cells/mL) of epilimnetic pico-cyanobacteria at three sampling stations in Revelstoke Reservoir



SECTION 4.0 SUMMARY

Based on phytoplankton density and biovolume, Kinbasket and Revelstoke Reservoirs fall within the oligotrophic classification. They both exhibit a typical temperate zone pattern of low phytoplankton density in the spring followed by a significant increase in mid-summer and a subsequent decline. The rapid decline of the phytoplankton density between July and August may be a result of nutrient depletion within the system

The increase in phytoplankton density with the concomitant decrease in biovolume indicates that the systems are becoming increasingly dominated by smaller taxa. This is a further indication that the systems are nutrient poor and that the total productivity of the system is likely declining. As the last of the organic material from the inundation of the terrestrial environment decay one can expect the phytoplankton productivity of the system to continue to decline.

To better ascertain the trends within the system regarding productivity a comprehensive assessment of the nutrient concentrations, phytoplankton, zooplankton, and fish communities should be conducted. This information, in addition to the primary productivity measurements taken over the past few years, would provide an adequate set of data to determine overall system condition and allow for short term predictions of future conditions.

REFERENCES

Canter-Lund, H. and J.W.G. Lund. 1995. Freshwater Algae – their microscopic world explored. BioPress Ltd., Bristol, UK, 360p.

Lund J.G., C. Kipling, and E.D. LeCren. 1958. The Inverted Microscope Method of Estimating Algal Numbers and the Statistical Basis of Estimations by Counting. Hydrobiologia. 11: 143-170.

MacIsaac, E.R. and J.G. Stockner. 1993. Enumeration of phototrophic picoplankton by auto-fluorescence microscopy, p. 187-197. In: B. Sherr and E. Sherr [Eds.], The handbook of methods in aquatic microbial ecology, CRC Press, Boca Raton, Fl..

Pieters, R., L.C. Thompson, L. Vidmanic, S. Pond, J. Stockner, P. Hamblin, M. Young, K. Ashley, B. Lindsay, G. Lawrence, D. Sebastian, G. Scholten and D.L. Lombard. 1998. Arrow Reservoir Limnology and Trophic Status - Year 1 (1997/98) Report. Fisheries Project Report No. RD 67. Ministry of Environment, Lands and Parks, Province of British Columbia.

Pieters, R., L.C. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, M. Derham, K. Ashley, B. Lindsay, G. Lawrence, D. Sebastian, G. Scholten, F. McLaughlin, A. Wüest, A. Matzinger and E. Carmack. 1999. Arrow Reservoir Limnology and Trophic Status Report, Year 2 (1998/99). RD 72, Fisheries Branch, Ministry of Environment, Lands and Parks, Province of British Columbia.

Stockner, J. G., E. Rydin, and P. Hyehstrand. 2000. Cultural oligotrophication: Causes and consequences for fisheries resources. Fisheries 25(5):7-14.

Utermohl, H. 1958. Zur Vervollkommnung der Quantitativen Phytoplankton Methodik. Int. Verein. theor. angew. Limnologie, Mitteilung 9.

Appendix A.

Kinbasket and Revelstoke 2011 Taxa List and Number of Occurrences

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
Bacillariophyte	Diatoms	Achnanthidium sp.	2	4
		Asterionella formosa	7	6
		Cyclotella comta	42	19
		Cyclotella glomerata	37	26
		Cyclotella stelligera	3	
		Cymbella sp. (large)	1	1
		Cymbella sp. (medium)		3
		Diatoma sp.		3
		Fragilaria capucina	18	18
		Fragilaria crotonensis	45	48
		Gomphonema sp. (medium)	2	1
		Nitzschia sp. (medium)	1	1
		Nitzschia sp. (small)	1	1
		Staurosia construens		1
		Stephanodiscus sp. (large)	21	2
		Stephanodiscus sp. (small)	11	2
		Synedra acus	34	38
		Synedra acus var. angustissima	3	8
		Synedra nana	7	4
		Synedra sp.		1
		Synedra ulna	4	4
		Tabellaria flocculosa		1
Chlorophyte	Coccoid Greens, Desmids, etc.	Acanthosphaera sp.	4	4
		Aulomonas sp.	1	1
		Chlamydocapsa sp.	14	3
		Chlamydomonas	12	6
		Coelastrum sp. (cells)	30	23
		Cosmarium sp.	17	7
		Crucigenia sp.	1	2
		Dichtyosphaerium (cells)		1
		Distigma sp.		1
		Elakatothrix sp.	6	7
		Euglena	2	2
		Gleotila sp.	10	10
		Gloeococcus sp.	6	3
		Golenkinia sp.	1	4
		Monomastix sp.	5	12
		Monoraphidium		2
		Nephroselmis	23	25

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
		Oocystis sp. (cells)	5	12
		Paramastix		2
		Phacus (medium)		6
		Planctosphaeria	10	25
		Scenedesmus sp.	3	7
		Scourfieldia	30	28
		Sphaerocystis sp.	1	
		Stichococcus minutissimus		8
		Tetraedron	19	25
Chryso- & Cryptophyte	Flagellates	Bitrichia sp.	3	2
		Chilomonas sp.	5	7
		Chromulina sp.	34	27
		Chroomonas acuta	49	38
		Chroomonas sp.	20	23
		Chrysochromulina sp.	2	3
		Chrysococcus	66	73
		Cryptomonas sp. (large)	1	1
		Cryptomonas sp. (medium)	41	42
		Cryptomonas sp. (small)	9	12
		Dinobryon sp. (large)	1	
		Dinobryon sp. (medium)	53	63
		Gyromitus sp.	14	10
		Kephyrion sp.	52	52
		Kephyriopsis sp.	1	
		Komma sp.	45	47
		Mallomonas sp. (medium)	1	2
		Mallonomopsis sp.	2	2
		Ochromonas sp.	53	52
		Pseudokephrion sp.	12	9
		Small microflagellates	80	89
		Trachelomonas sp.	3	2
Cyanophyte	Blue-greens	Chroococcus sp. (cells)	33	29
		Gomphosphaeria sp. (cells)	1	
		Lyngbya sp. (cells)	1	2
		Merismopedia sp. (cells)	25	24
		Microcystis sp. (cells)	3	13
		Planktothrix sp.	1	
		Synechococcus sp. (coccoid)	80	89
		Synechococcus sp. (rod)	66	70

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
		Synechocystis	48	37
		Unknown Cyanophyte 1		1
		Dinophyte	65	55
		Dinoflagellates	65	55
		Amphidinium	2	1
		Gloeodinium sp.	4	
		Gymnodinium sp. (large)	1	1
		Gymnodinium sp. (medium)	42	39
		Gymnodinium sp. (small)	16	13
		Peridinium spp.		1

Appendix 7

Zooplankton
Kinbasket and Revelstoke Reservoirs, 2011

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Kinbasket and Revelstoke Reservoirs
Zooplankton, 2011

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March 2012

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1. Introduction

This report summarises the zooplankton data collected in 2011, with comparisons to available data from previous years and some historical data. The study of Kinbasket and Revelstoke Reservoirs macrozooplankton (length >150 m), including their composition, abundance and biomass help to determine the current status of the reservoir. These results are a component of the study CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity conducted by BC Hydro under the Columbia Water Use Plan.

2. Methods

Samples were collected monthly at four stations in Kinbasket Reservoir during the highest production season. The Kinbasket sampling stations are located at Mica Forebay, Canoe Reach, Wood Arm and Columbia Reach.

Samples were collected at three stations in Revelstoke Reservoir. The stations Rev Upper, Rev Middle, and Rev Forebay are located along the length of the main body in Revelstoke Reservoir.

Samples were collected from May to October in 2011, with a vertically hauled 153 µm mesh Wisconsin net with a 0.2 m throat diameter. The depth of each haul was 30 m. Duplicate samples were taken at each site of the reservoir. Due to a technical problems samples could not be collected from Kinbasket reservoir in June and September 2011 sampling season.

Collected zooplankton samples were rinsed from the dolphin bucket and preserved in 70% ethanol. Zooplankton samples were analyzed for species density, biomass, and fecundity. Samples were re-suspended in tap water filtered through a 74 µm mesh and sub-sampled using a four-chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope (at up to 400X magnification). For each replicate, organisms were identified to species level and counted until up to 200 organisms of the predominant species were recorded. If 150 organisms were counted by the end of a split, a new split was not started. The lengths of up to 30 organisms of each species were measured for use in biomass calculations, using a mouse cursor on a live television image of each organism. Lengths were converted to biomass (µg dry-weight) using empirical length-weight regression from McCauley (1984). The number of eggs carried by gravid females and the lengths of these individuals were recorded for use in fecundity estimations. Zooplankton species were identified with reference to taxonomic keys (Sandercock and Scudder 1996, Pennak 1989, Wilson 1959, Brooks 1959).

3. Results – Kinbasket Reservoir

3.1 Species Present

Four calanoid copepod species were identified in the samples from the Kinbasket Reservoir (Tab. 1). *Leptodiaptomus sicilis* (Forbes) and *Epischura nevadensis* (Lillj.) were present in samples during each sampling season, while *Leptodiaptomus ashlandi* (Marsh) and *Aglaodiaptomus leptopus* (Forbes) were observed rarely. One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was seen in samples during the studied period.

Table 1. List of zooplankton species identified in Kinbasket Reservoir in 2003-2011. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2004	2005	2008	2009	2010	2011
Cladocera							
Alona sp.						r	
Bosmina longirostris	+	+	+	+	+	+	+
Chydorus sphaericus			+		+	+	
Daphnia galeata mendotae	+	+	+	+	+	+	+
Daphnia rosea	+	+	+	+	+	+	+
Daphnia schoedleri	+	+	+	+	+	+	+
Diaphanosoma brachiurum		+	+		+	+	
Holopedium gibberum	r			r	r	r	
Leptodora kindtii	+	+	+	+		+	+
Macrothrix sp.					r		
Scapholeberis mucronata	+	+	+	+	+	+	+
Copepoda							
Aglaodiaptomus leptopus		r		r			
Diacyclops bicuspidatus	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+
Leptodiaptomus ashlandi		r	r+		r	r	r
Leptodiaptomus sicilis	+	+	+	+	+	+	+

Six species of Cladocera were present in 2011 (Tab. 1). *Daphnia galeata mendotae* (Birge), *Daphnia schoedleri* (Sars), *Daphnia rosea* (Sars) and *Bosmina longirostris* (O.F.M.) were common, while other species such as *Scapholeberis mucronata* (O.F.M.) and *Leptodora kindtii* (Focke), were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

The predominant copepods *D. bicuspidatus thomasi* and *E. nevadensis*, and cladocerans *Daphnia* spp., and *B. longirostris* were common during studied years.

3.2 Density and Biomass

For comparison with historical data the average at Mica Forebay station in Kinbasket was used. Zooplankton density values in 2003-2011 are significantly higher then those reported by the Division of Applied Biology, BC Research in 1977, Watson 1985 and Fleming and Smith 1988 (Fig. 1).

The seasonal average zooplankton density observed in Kinbasket Reservoir decreased in 2011 to 7.97 individuals/L from 14.86 individuals/L in 2010 (Fig. 2). The zooplankton density was numerically dominated by copepods, which averaged 79% of the 2011 community. *Daphnia* spp comprised 7%, and cladocerans other than *Daphnia* 14%. Copepods were the most abundant zooplankton at all four stations. They numerically prevailed during the whole sampling season, with populations peaking during the summer (Fig. 3). The number of Cladocerans varied by season as well as along the reservoir. Cladocerans other than *Daphnia* were the most numerous in August at each sampling station. The highest density was found in August at Columbia Reach with 9.55 individuals/L. *Daphnia* was present during the whole sampling season at each station. Monthly averaged density of *Daphnia* for the whole reservoir increased gradually during the sampling season reaching its peak in October with 1.68 individuals/L (Fig.4). The highest density of *Daphnia* was found in October at Mica Forebay with 2.77 individuals/L. The proportion of *Daphnia* density was the highest at Mica Forebay (10%), while at other stations it varied between 3 and 8%. (Fig. 5, Tab. 2)

Table 2. Seasonal average zooplankton density at four sampling stations in Kinbasket Reservoir in 2011. Density is in units of individuals/L; biomass is in units of µg/L.

		Canoe Reach	Mica Forebay	Columbia Reach	Wood Arm
Density	Copepoda	5.99	6.80	5.69	6.87
	Daphnia	0.42	0.81	0.71	0.20
	Other Cladocera	0.52	0.64	2.63	0.59
	Total	**6.93**	**8.26**	**9.04**	**7.66**
Biomass	Copepoda	9.75	11.31	9.56	11.53
	Daphnia	7.49	11.36	8.31	3.97
	Other Cladocera	0.67	0.86	3.33	0.82
	Total	**17.91**	**23.53**	**21.20**	**16.32**

Seasonal average total zooplankton biomass in 2011 was 19.74 µg/L (Fig.6). Copepods had the highest proportion of the total biomass in the whole reservoir 53% with 10.54 µg/L. *Daphnia* spp made up 39% with 7.78 µg/L, while Cladocerans other than *Daphnia* comprised only 7% of the total zooplankton biomass with 1.42 µg/L. The highest total zooplankton biomass 45.26 µg/L was found at Mica Forebay in October, when *Daphnia* comprised 86% of total biomass with 38.79 µg/L (Fig. 7). Although *Daphnia* spp. was present in samples during the entire season, it made up a great proportion of the biomass in October 77%. Among the stations the highest *Daphnia* biomass was found at Mica Forebay where *Daphnia* contributed to 86% of the zooplankton biomass. The proportion of seasonal average *Daphnia* biomass at Canoe Reach was 77%, at Columbia Reach 71%, while at Wood Arm proportion of *Daphnia* biomass was 67% (Fig. 8). The most stable zooplankton community was at Canoe Reach, where both density and biomass of all three zooplankton groups did not change much during the study years 2003-2011. Contrary to that, zooplankton composition, density, and biomass fluctuated along a great range during the study period at the other three stations (Fig. 9).

In 2011 peak total zooplankton density occurred in August at 12.88 individuals/L while highest biomass was found in October at 32.79 µg/L (Tab. 3, Fig. 4). *Daphnia* was the most numerous in October with 1.68 individuals/L and the highest biomass in the season with 25.22 µg/L.

Table 3. Monthly average density and biomass of zooplankton in Kinbasket Reservoir in 2011. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
	Copepoda	3.51		9.18	8.70		3.96
	Daphnia	0.02		0.06	0.39		1.68
	Other Cladocera*	0.01		0.12	3.79		0.47
	Total Zooplankton	**3.54**		**9.35**	**12.88**		**6.10**
Biomass		**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
	Copepoda	5.67		13.22	16.38		6.88
	Daphnia	0.18		0.86	4.88		25.22
	Other Cladocera**	0.02		0.31	4.68		0.68
	Total Zooplankton	**5.86**		**14.38**	**25.93**		**32.79**

*Values do not include *Daphnia* spp. density.
**Values do not include *Daphnia* spp. biomass.

In comparison to data from previous years, total zooplankton density and biomass decreased in 2011, as a result of decreased numbers of all three zooplankton groups. *Daphnia* did not develop strong and numerous populations as in 2005, which would be mirrored in significant biomass increase (Fig. 2, 6).

3.3 Zooplankton Fecundity

Fecundity features of two most common zooplankton species *D. bicuspidatus thomasi* and *Daphnia* spp. were studied during the sampling season.

In Kinbasket Reservoir *D. bicuspidatus thomasi* females were gravid throughout the sampling period (Fig. 10). From May to October 2011 the proportion of gravid females averaged 0.15. The highest proportions have been found at Canoe Reach 0.47 in May. On average, gravid female carry 14.83 eggs. The number of eggs per water volume averaged 1.28 eggs/L, and the number of eggs per capita averaged 0.40 eggs/individual (Tab. 4).

Table 4. Fecundity data for *D. bicuspidatus thomasi* in Kinbasket Reservoir in 2003-2011. Values are seasonal averages, calculated for samples collected between May - October 2003, 2005, 2009, 2010 and 2011, May – December 2004 and July – October 2008.

	2003	2004	2005	2008	2009	2010	2011
Proportion of gravid females	0.12	0.05	0.08	0.11	0.17	0.13	0.15
# Eggs per gravid Female	12.42	12.42	9.67	11.17	13.86	14.31	14.83
# Eggs per Litre	1.42	0.29	0.47	2.58	1.68	1.25	1.28
# Eggs per Capita	0.25	0.25	0.1	0.18	0.48	0.25	0.40

In Kinbasket Reservoir *Daphnia* gravid females were present from July to October in 2011 (Fig. 11). The proportion of gravid females averaged 0.09 (Tab. 5). The seasonal average number of eggs per gravid female was 2.08. Across the sampling season the number of eggs per water volume averaged 0.07 eggs/L and the number of eggs per capita averaged 0.25 eggs/individual.

Table 5. Fecundity data for *Daphnia* spp. in Kinbasket Reservoir in 2003-2011. Values are seasonal averages, calculated for samples collected between May - October 2003, 2005, 2009, 2010 and 2011, May – December 2004 and July – October 2008.

	2003	2004	2005	2008	2009	2010	2011
Proportion of gravid females	0.07	0.03	0.03	0.19	0.19	0.12	0.09
# Eggs per gravid Female	1.80	2.11	1.59	1.91	2.04	1.52	2.08
# Eggs per Litre	0.16	0.03	0.1	0.13	0.18	1.14	0.07
# Eggs per Capita	0.15	0.05	0.05	0.37	0.48	0.23	0.25

4. Results – Revelstoke Reservoir

4.1 Species Present

Three calanoid copepod species were identified in the samples from Revelstoke Reservoir (Tab. 6). *Leptodiaptomus sicilis* (Forbes) and *Epischura nevadensis* (Lillj.) were present in samples during the whole season while *Leptodiaptomus ashlandi* (Marsh) were observed occasionally. One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was seen in samples from the Revelstoke Reservoirs.

Nine species of Cladocera were present in Revelstoke Reservoir during the study period in 2010 (Tab. 6). *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia longispina* (O.F.M.), *Bosmina longirostris* (O.F.M.), *Holopedium gibberum* (Zaddach) and *Leptodora kindtii* (Focke) were common. Other species such as *Scapholeberis mucronata* (O.F.M.), and *Diaphanosoma brachiurum* (Lievin) were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

The predominant copepod was *D. bicuspidatus thomasi*, and among the cladocerans *Daphnia* spp., and *B. longirostris.*

Table 6. List of zooplankton species identified in Revelstoke Reservoir in 2003-2010. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2008	2009	2010	2011
Cladocera					
Acroperus harpae	r				
Alona sp.	r			r	r
Alonella nana				r	
Biapertura affinis	r	r			
Bosmina longirostris	+	+	+	+	+
Ceriodaphnia sp.		r			
Chydorus sp.	r				
Chydorus sphaericus	r	r		r	r
Daphnia galeata	+	+	+	+	+
Daphnia rosea	+	+	+	+	+
Daphnia pulex	+	+	+	+	+
Diaphanosoma brachiurum			r		
Holopedium gibberum	+	+	+	+	+
Leptodora kindtii	+	+	+	+	+
Scapholeberis mucronata	r	r	r	r	r
Copepoda					
Diacyclops bicuspidatus	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+	+
Leptodiaptomus sicilis	+	+	+	+	+

4.2 Density and Biomass

The seasonal mean zooplankton densities observed in 2003, 2008- 2011 were much higher then those reported for years 1984 and 1986 by Watson 1985 and Fleming and Smith 1988 (Fig. 12). For comparison with historical data the average at Rev Forebay in Revelstoke was used.

The zooplankton community was primarily composed of copepods, which made up 77% of the zooplankton density and 33% of the zooplankton biomass during the studied period in 2011. *Daphnia* accounted for 5% of the density and 26% of the biomass during the same time period, while other cladocerans comprised 18% of density and 40% of zooplankton biomass (Fig. 13 and 14).

The seasonal average zooplankton density in 2011 (May to October) was 4.59 individuals/L. Copepods were the most abundant with 3.53 individuals/L. Annual average density of *Daphnia* was 0.25 individuals/L, while density of other Cladocerans (mainly *Bosmina* and *Holopedium*) was 0.81 individual/L. (Tab. 7, Fig. 13). Total zooplankton biomass, averaged for the whole reservoir was 16.05 µg/L. Copepods contributed 33% of the total zooplankton biomass with annual average biomass of 5.35 µg/L. *Daphnia* and other cladocerans made up 26% and 40%, with 4.23 µg/L, and 6.47 µg/L of the total zooplankton biomass (Tab. 7; Fig. 14).

Table 7. Annual average zooplankton abundance and biomass in Revelstoke Reservoir 2003-2011. Data are averaged for May to October in 2003, 2009, 2010 and 2011, and July to October in 2008.

		2003	2008	2009	2010	2011
Density	Copepoda	5.49	7.08	4.96	6.63	3.53
	Daphnia	2.64	0.77	0.72	0.47	0.25
	other Cladocera	2.12	1.00	0.73	1.17	0.81
	Total	**10.25**	**8.85**	**6.41**	**8.27**	**4.59**

		2003	2008	2009	2010	2011
Biomass	Copepoda	10.79	17.32	8.02	9.83	5.35
	Daphnia	51.56	14.75	12.30	7.56	4.23
	other Cladocera	6.61	4.69	4.22	7.37	6.47
	Total	**68.96**	**36.76**	**24.54**	**24.76**	**16.05**

The seasonal average zooplankton densities in Revelstoke Reservoir decreased in comparison to the previous year, from 8.27 individuals/L in 2010 to 4.59 individuals/L in 2011. Zooplankton density had two peaks during the study season in 2011, first in June and the second one in September (Fig. 15). Densities averaged 0.95 individuals/L at the beginning of the season in May, and then increased to 6.86 individuals/L by June. After a gradual decrease during the summer, density increased again in September to 7.01 individuals/L (Fig. 15). Seasonal average zooplankton biomass in 2011 decreased in comparison to the previous year (Tab. 7). During the sampling season in 2011 zooplankton biomass increased from 2.05 µg/L in May to 29.42 µg/L in July, sharply decreased in August and than increased again in September to 26.56 µg/L, (Fig. 15). The highest total zooplankton density was seen in June at Rev Middle station (13.96 individuals/L), while biomass was the highest at the same station in July with 65.64 µg/L (Fig. 16 and 17).

An increase of copepod density was observed in May and September 2011. The number of Copepoda in that period averaged 5.65 individuals/L consisting mainly of *D. bicuspidatus thomasi.* They numerically prevailed during the whole sampling season, with the most numerous populations found at station Rev Middle (Fig. 16).

The pattern of seasonal changes of zooplankton density and biomass was similar to the pattern in the previous sampling season. In both years number of Copepoda increased at the beginning of the season, than decreased in July, and increased again in the late summer. *Daphnia* increased in numbers at the end of the sampling season, while number of other Cladocera changed during the season. After a peak in July a decrease of cladoceran density was recorded in August, followed by a slight increase in September (Fig. 15). Other Cladocerans were composed mainly of *Holopedium* and *Bosmina*, averaging 0.59 and 0.21 individuals/L respectively, in the whole reservoir. In July 2011, at station Mid Lake the number of other cladocerans was the highest in the season due to a peak of *Holopedium* with 5.10 individuals/L. In terms of biomass, regardless to their small size, other cladocerans contributed 40% to the total zooplankton biomass. Their biomass was less then 10 µg/L at each station during the whole sampling season, except in June and July at Mid Lake when the biomass of other cladocerans was 20.39 µg/L and 58.28 µg/L (Fig. 17).

Number of *Daphnia* was low during the entire sampling season in 2011. It was less than 1 individual/L at each station except in September at station Mid Lake when *Daphnia* density increased to 2.00 individuals/L. Although *Daphnia* were present in samples during the entire season, they accounted for 0.2 to 17% of the zooplankton community from May to October. Its density was relatively low averaging 0.01 to 2.00 individual/L at all three stations from May to October (Fig. 16). *Daphnia* biomass was also low averaging 4.23 µg/L (Fig. 14). The highest *Daphnia* biomass during the study season was found at Rev Middle station with 32.39 µg/L in September, when *Daphnia* accounted for 54% of the total zooplankton biomass (Fig. 17).

4.3 Seasonal and Along-Lake Patterns

The seasonal development of zooplankton density and biomass in Revelstoke Reservoir follow the usual pattern of increasing copepods in spring and summer, and a cladoceran increase in the spring and early fall (Fig. 15). Copepods dominated numerically from May to October. Cladocerans were present in significant numbers in June and July, while *Daphnia* spp., although was present in samples during the whole season, it made up the majority of the biomass in September.

During 2011 peak total zooplankton density occurred in September with 7.01 individuals/L (Tab. 8, Fig. 15). The peak total zooplankton biomass occurred in July with 29.42 µg/L, when other cladocerans biomass reached its peak with 23.03 µg/L comprising 78% of the total zooplankton biomass.

Along the length of Revelstoke Reservoir zooplankton densities as well as biomass tended to be higher in the middle part of the basin (Fig. 16 and 17).

Table 8. Monthly average density and biomass of zooplankton in Revelstoke Reservoir in 2011. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
	Copepoda	0.78	5.65	2.46	3.33	5.65	3.30
	Daphnia	0.02	0.02	0.15	0.26	0.90	0.17
	Other Cladocera*	0.15	1.19	2.70	0.16	0.46	0.21
	Total Zooplankton	**0.95**	**6.86**	**5.31**	**3.75**	**7.01**	**3.68**
Biomass		**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
	Copepoda	1.22	8.79	4.05	4.30	8.82	4.92
	Daphnia	0.26	0.12	2.34	2.80	14.16	5.71
	Other Cladocera**	0.58	9.89	23.03	0.77	3.58	0.99
	Total Zooplankton	**2.05**	**18.80**	**29.42**	**7.87**	**26.56**	**11.62**

*Values do not include *Daphnia* spp. density.
**Values do not include *Daphnia* spp. biomass.

4.4 Zooplankton Fecundity

Fecundity features of two most common zooplankton species *D. bicuspidatus thomasi* and *Daphnia* spp. were studied during the sampling season.

D. bicuspidatus thomasi females were gravid throughout the sampling period in 2011. Gravid females in Revelstoke Reservoir comprise 0-42% of the female population in 2011 (Fig. 18). From May to October the proportion of gravid females averaged 0.16. The highest proportions have been found in May at the Rev Upper station 0.42. On average, gravid female carry up to about 18.51 eggs (Tab. 9). Across the sampling season the number of eggs per water volume averaged 0.65 eggs/L. The number of eggs per capita averaged 0.60 eggs/individual.

Table 9. Fecundity data for *D. bicuspidatus thomasi* in Revelstoke Reservoir in 2003-2011. Values are seasonal averages, calculated for samples collected between July and October in 2008 and May to October in 2003, 2009 - 2011.

	2003	2008	2009	2010	2011
Proportion of gravid females	0.19	0.18	0.15	0.13	0.16
# Eggs per gravid Female	15.64	11.18	15.17	17.36	18.51
# Eggs per Litre	3.18	1.54	1.06	1.18	0.65
# Eggs per Capita	0.88	0.54	0.89	0.31	0.60

Daphnia spp. gravid females were observed in Revelstoke Reservoir throughout the sampling season. The proportion of females that were gravid was variable across the season and along the reservoir (Fig. 19). The proportion of gravid females averaged 0.09 in 2011 (Tab. 10). The seasonal average number of eggs per gravid female was 2.41. Across the sampling season the number of eggs per water volume averaged 0.05 eggs/L, and the number of eggs per capita averaged 0.27 eggs/individual over the study period in 2011.

Table 10. Fecundity data for *Daphnia* spp. in Revelstoke Reservoir 2003-2011. Values are seasonal averages, calculated for samples collected between May and October in 2008 and May to October in 2003, 2009 - 2011.

	2003	2008	2009	2010	2011
Proportion of gravid females	0.11	0.20	0.13	0.09	0.09
# Eggs per gravid Female	2.67	2.66	2.00	1.76	2.41
# Eggs per Litre	0.32	0.16	1.15	0.07	0.05
# Eggs per Capita	0.35	0.46	0.28	0.18	0.27

5. Conclusions

Kinbasket Reservoir is oligotrophic with a moderate zooplankton density. The zooplankton community is diverse and has a relatively stable cladoceran population with a moderate proportion of *Daphnia* spp., considered as a favourable food for kokanee. Density and biomass of *Daphnia* spp. decreased in 2011 in comparison to the previous year. Zooplankton composition is more or less uniform and overall total zooplankton density and biomass, as well as that of copepods, cladocerans, and *Daphnia* do not differ much from station to station.

Revelstoke Reservoir is also oligotrophic with a moderate zooplankton density, and a relatively stable cladoceran population. Density and biomass of *Daphnia* spp. decreased in the 2011 season in comparison to the previous year.

In comparison to historical data it is notable that zooplankton abundance in both reservoirs, Kinbasket and Revelstoke has increased over the time period. These changes have likely been due to combination of climatic changes, predation, nutrients availability, grazeable algae and especially of shifting from riverine (before impoundment) toward lake habitat.

6. References

Brooks, J.L. 1959. Cladocera. pp. 586-656. In Edmondson, W.T. (Ed.) Fresh-Water Biology, 2nd Ed. John Wiley and Sons, New York.

Division of Applied Biology, BC Research, 1977. Limnology of Arrow, McNaughton, Upper Campbell and Williston Lakes. BC Hydro, Project No. 1-05-807.

Fleming, J.O. and H.A. Smith, 1988. Revelstoke Reservoir Aquatic Monitoring Program, 1986 Progress Report. BC Hydro, Report No. ER 88-03.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. In: A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters.

Downing, J.A. and F.H. Rigler (eds.), Blackwell Scientific Publications, Boston.

Pennak, R.W. 1989. Fresh-Water Invertebrates of the United States: Protozoa to Mollusca. 3rd Ed., John Wiley and Sons, New York, 628 p.

Sandercock, G.A. and Scudder, G.G.E. 1996. Key to the Species of Freshwater Calanoid Copepods of British Columbia. Department of Zoology, UBC Vancouver, BC.

Schindler, E.U., H. Andrusak, K.I. Ashley, G.F. Andrusak, L. Vidmanic, D. Sebastian, G. Scholten, P. Woodruff, J. Stockner, F. Pick, L.M. Ley and P.B. Hamilton. 2007a. Kootenay Lake Fertilization Experiment, Year 14 (North Arm) and Year 2 (South Arm) (2005) Report. Fisheries Project Report No. RD 122, Ministry of Environment, Province of British Columbia.

Schindler, E.U., L. Vidmanic, D. Sebastian, H. Andrusak, G. Scholten, P. Woodruff, J. Stockner, K.I. Ashley and G.F. Andrusak. 2007b. Arrow Lakes Reservoir Fertilization Experiment, Year 6 and 7 (2004 and 2005) Report. Fisheries Project Report No. RD 121, Ministry of Environment, Province of British Columbia.

Watson, T.A. 1985. Revelstoke Project, Water Quality Studies 1978-1984. BC Hydro, Report No. ESS-108.

Wilson, M.S. 1959. Free-living copepoda: Calanoida. pp. 738-794. In Edmondson, W.T. (Ed.) Fresh-Water Biology, 2nd Ed. John Wiley and Sons, New York.

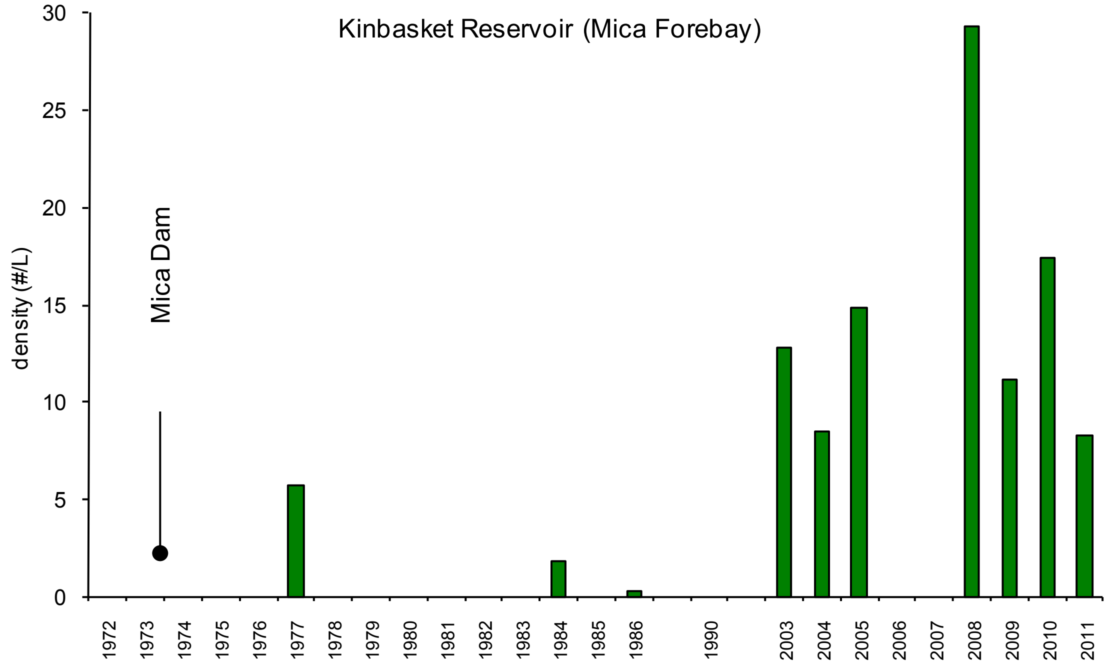


Figure 1. Zooplankton density 1977-2011 at Mica Forebay in Kinbasket Reservoir.

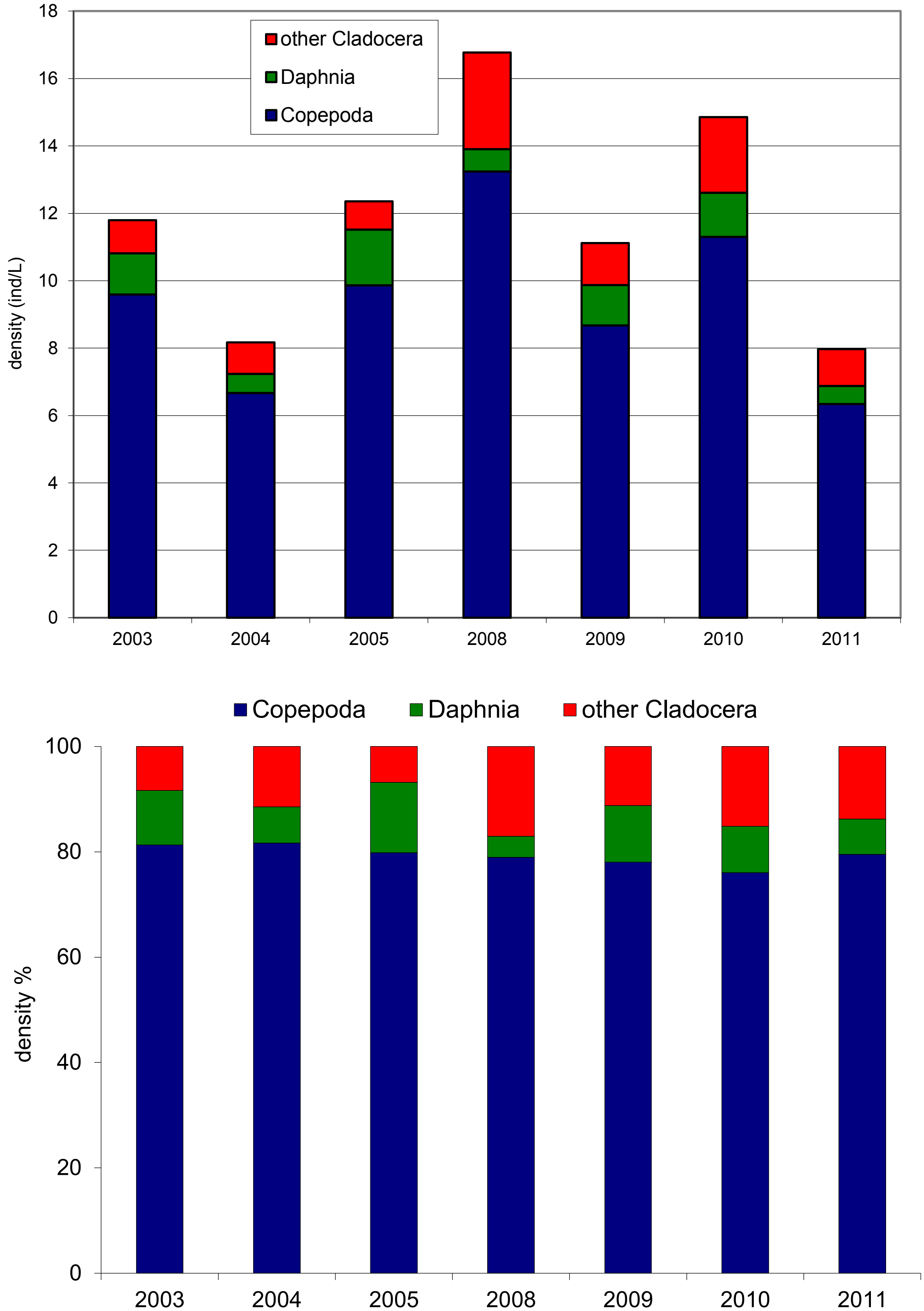


Figure 2. Seasonal average zooplankton density in Kinbasket Reservoir 2003-2011.

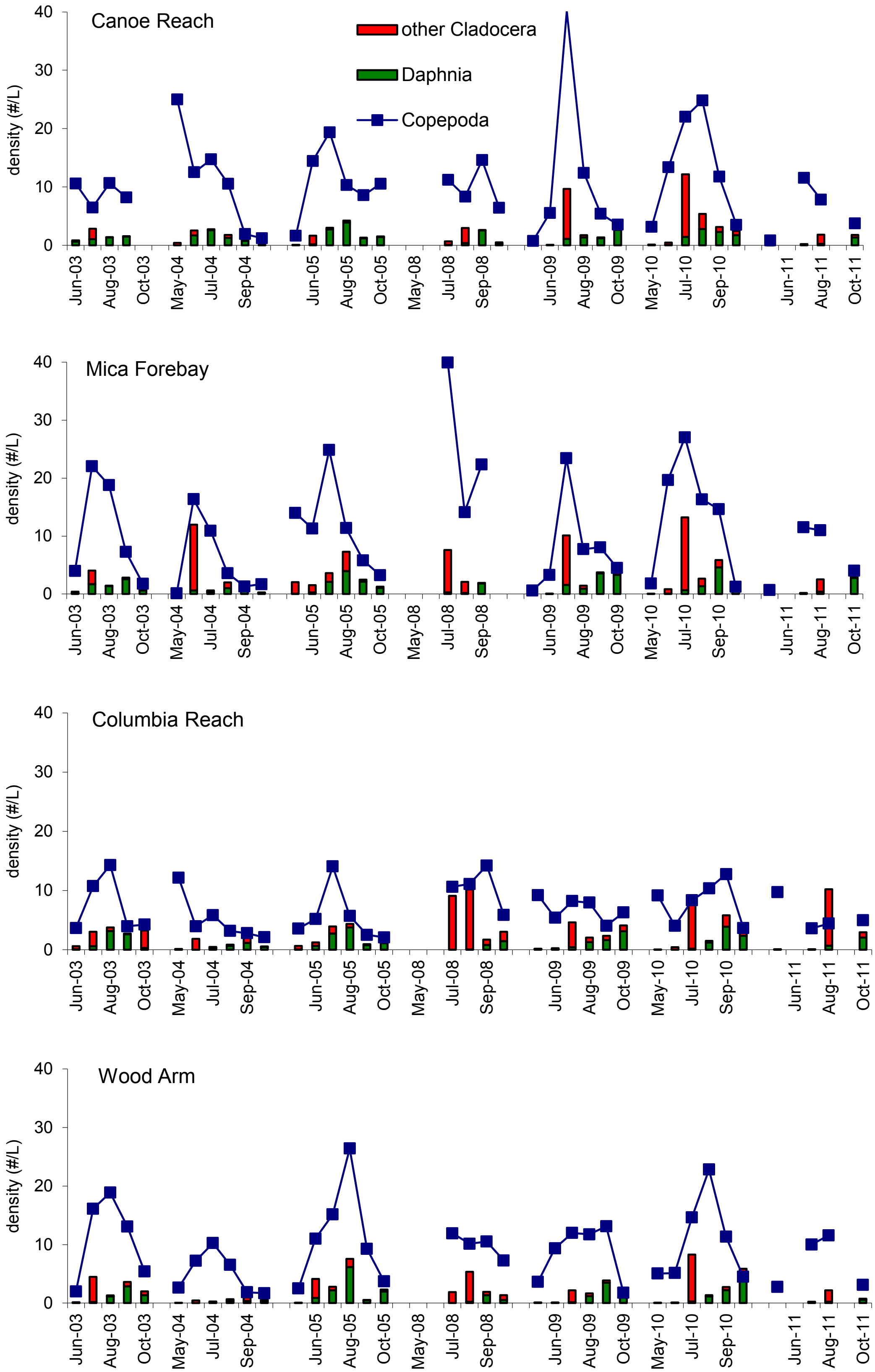


Figure 3. Density of cladoceran and copepod zooplankton in Kinbasket Reservoir in 2003-2011.

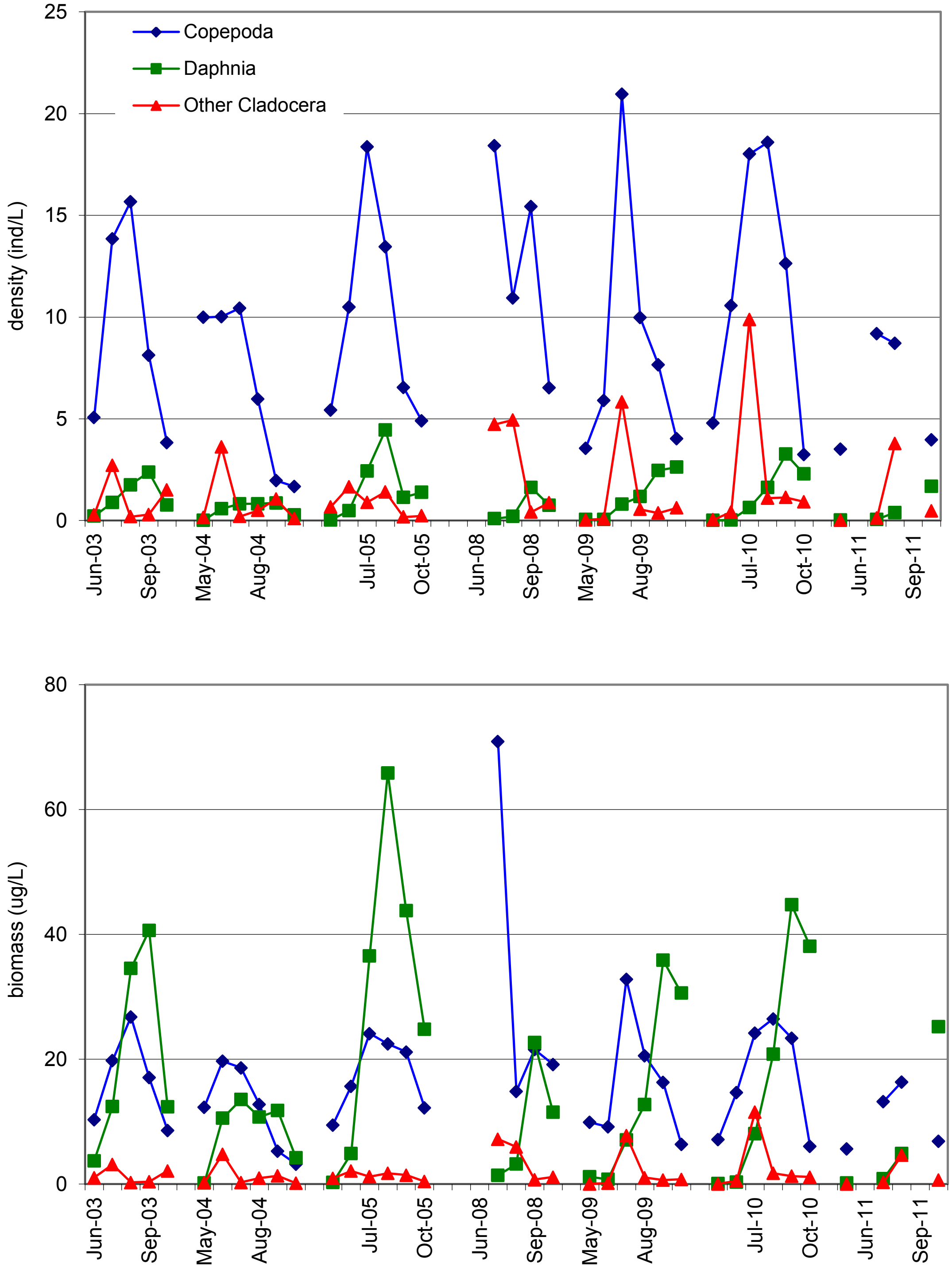


Figure 4. Monthly zooplankton density averaged for the whole Kinbasket Reservoir in 2003-2011.

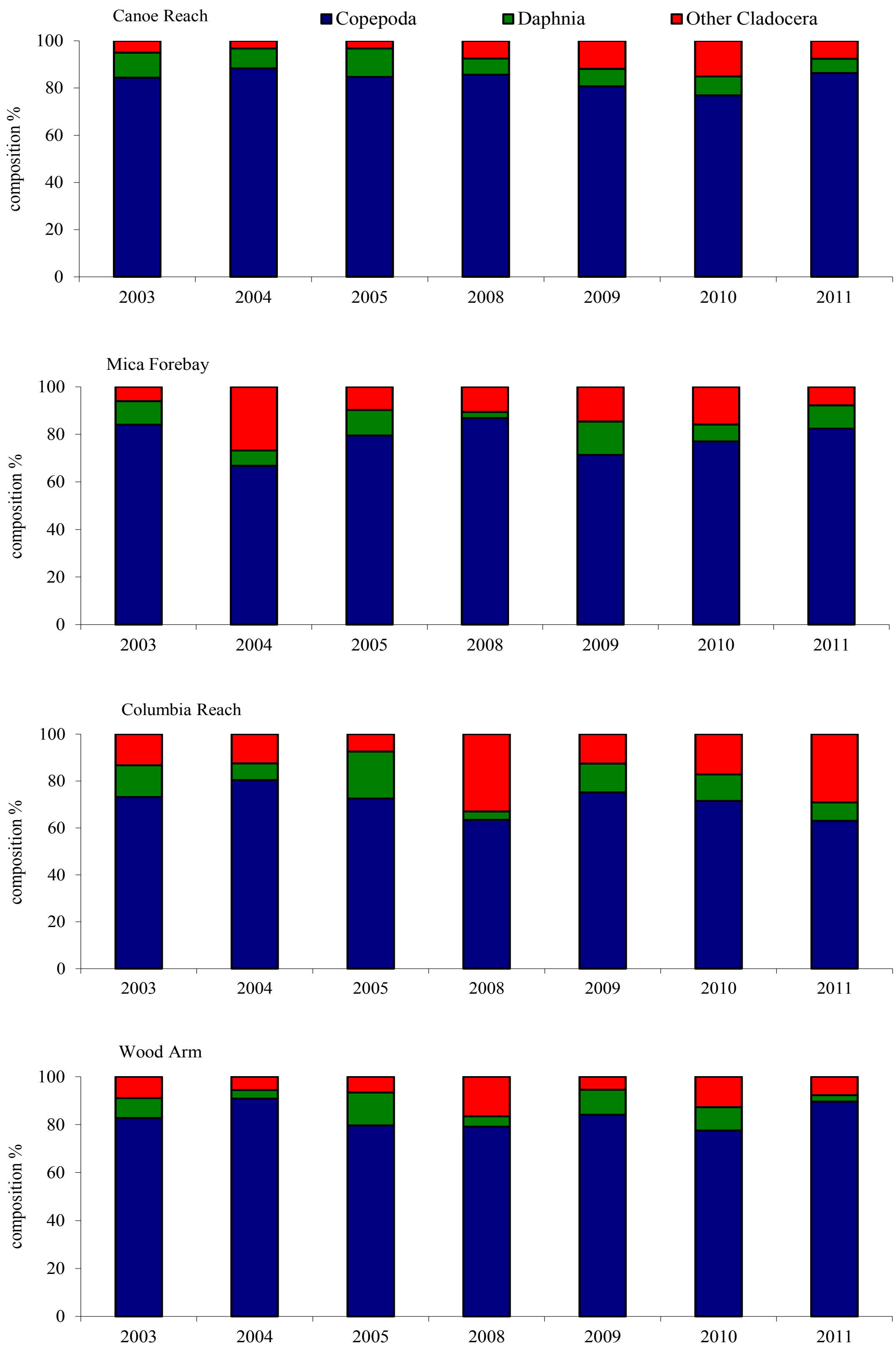


Figure 5. Seasonal average % of zooplankton density composition at four stations in Kinbasket.

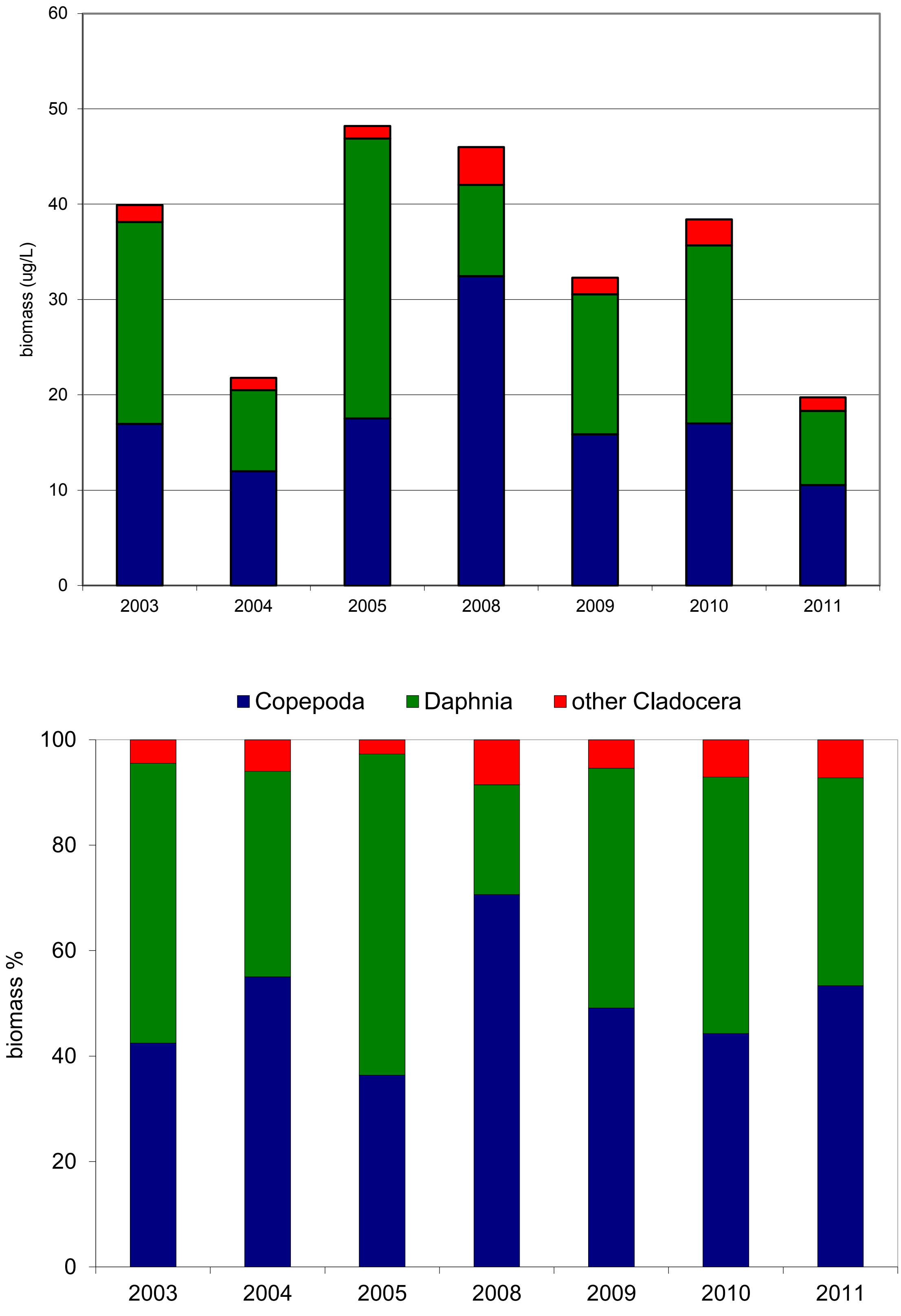


Figure 6. Seasonal average zooplankton biomass in Kinbasket Reservoir 2003-2011.

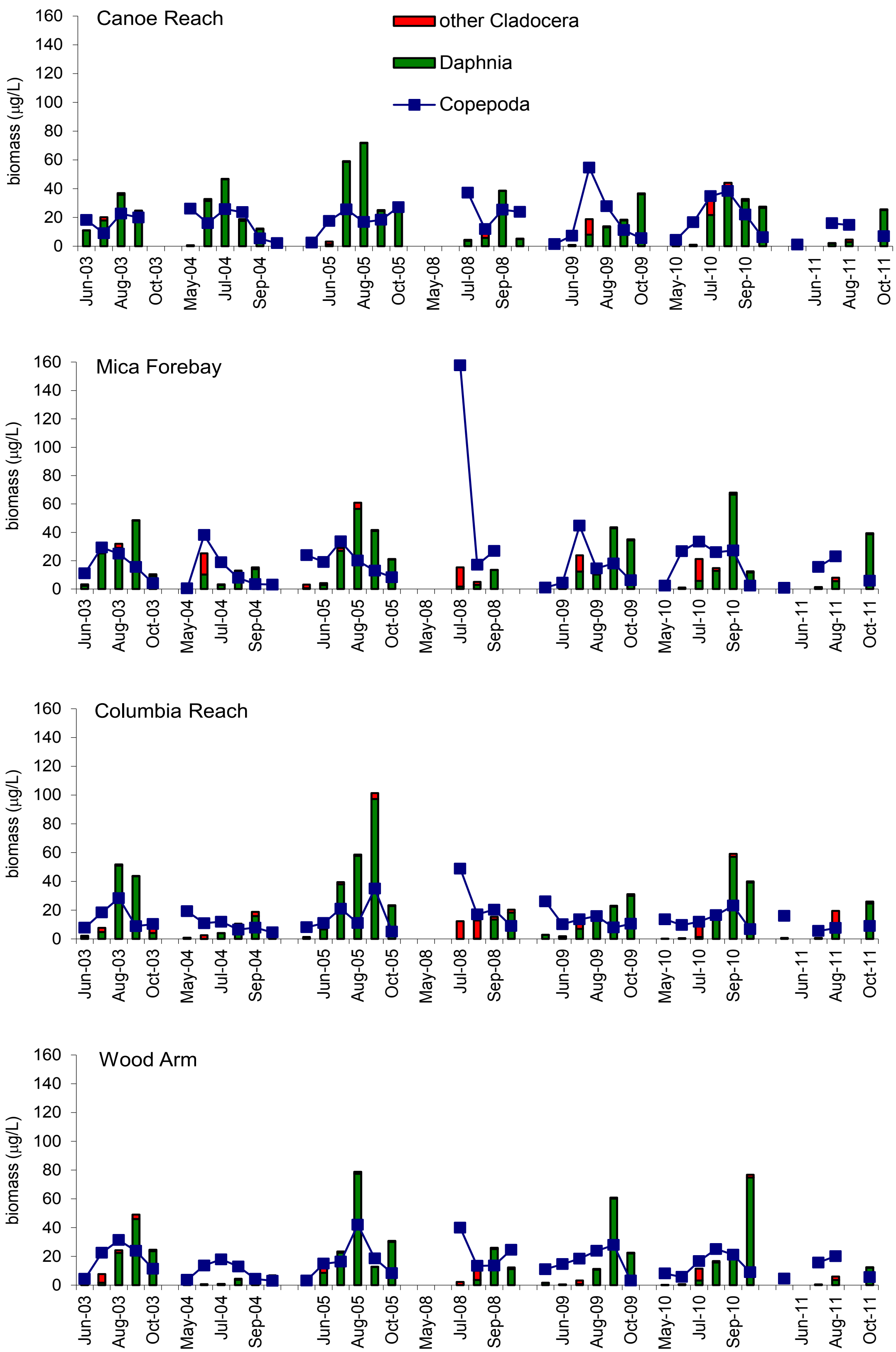


Figure 7. Biomass of cladoceran and copepod zooplankton in Kinbasket Reservoir in 2003-2011.

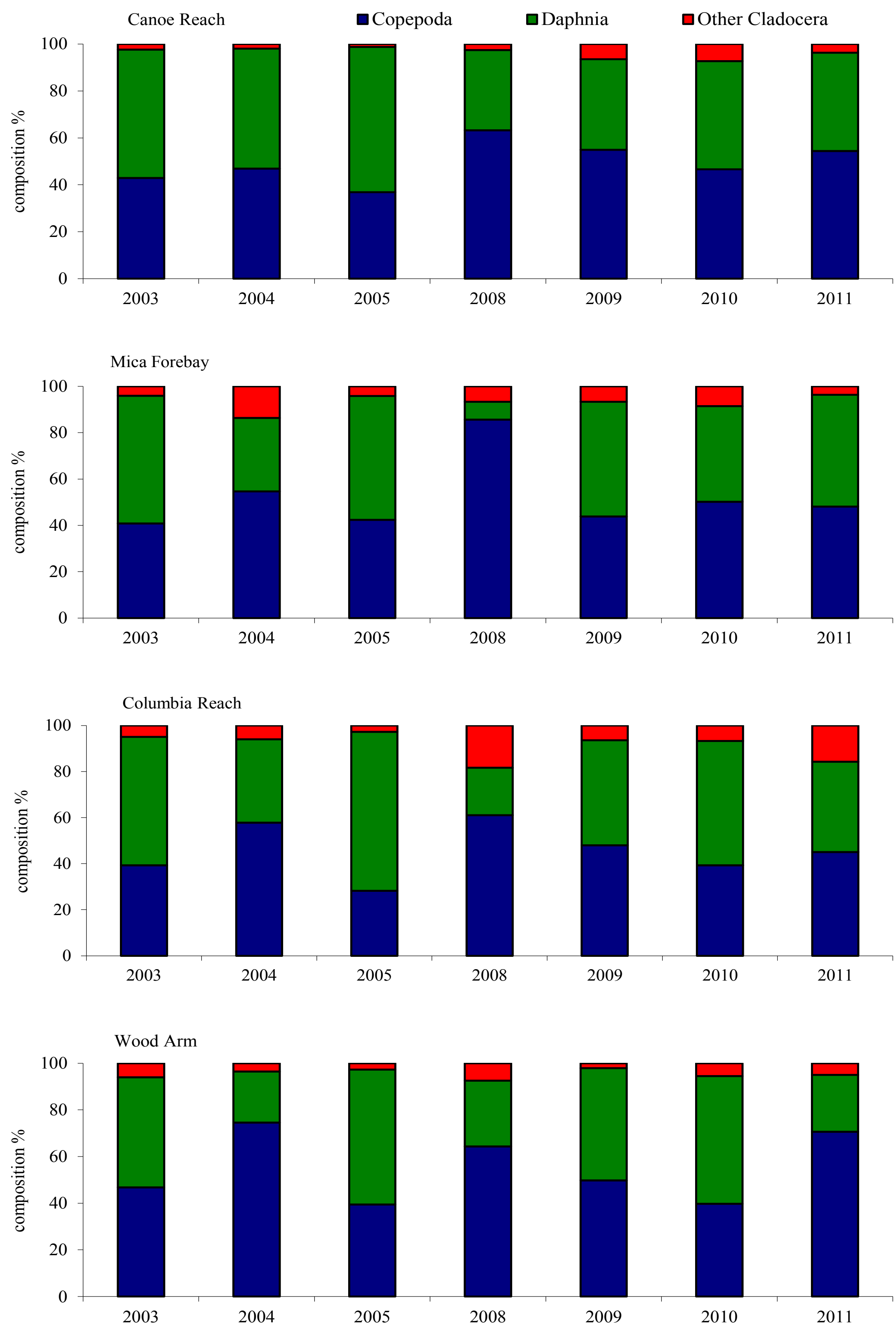


Figure 8. Seasonal average % of zooplankton biomass composition at four stations in Kinbasket.

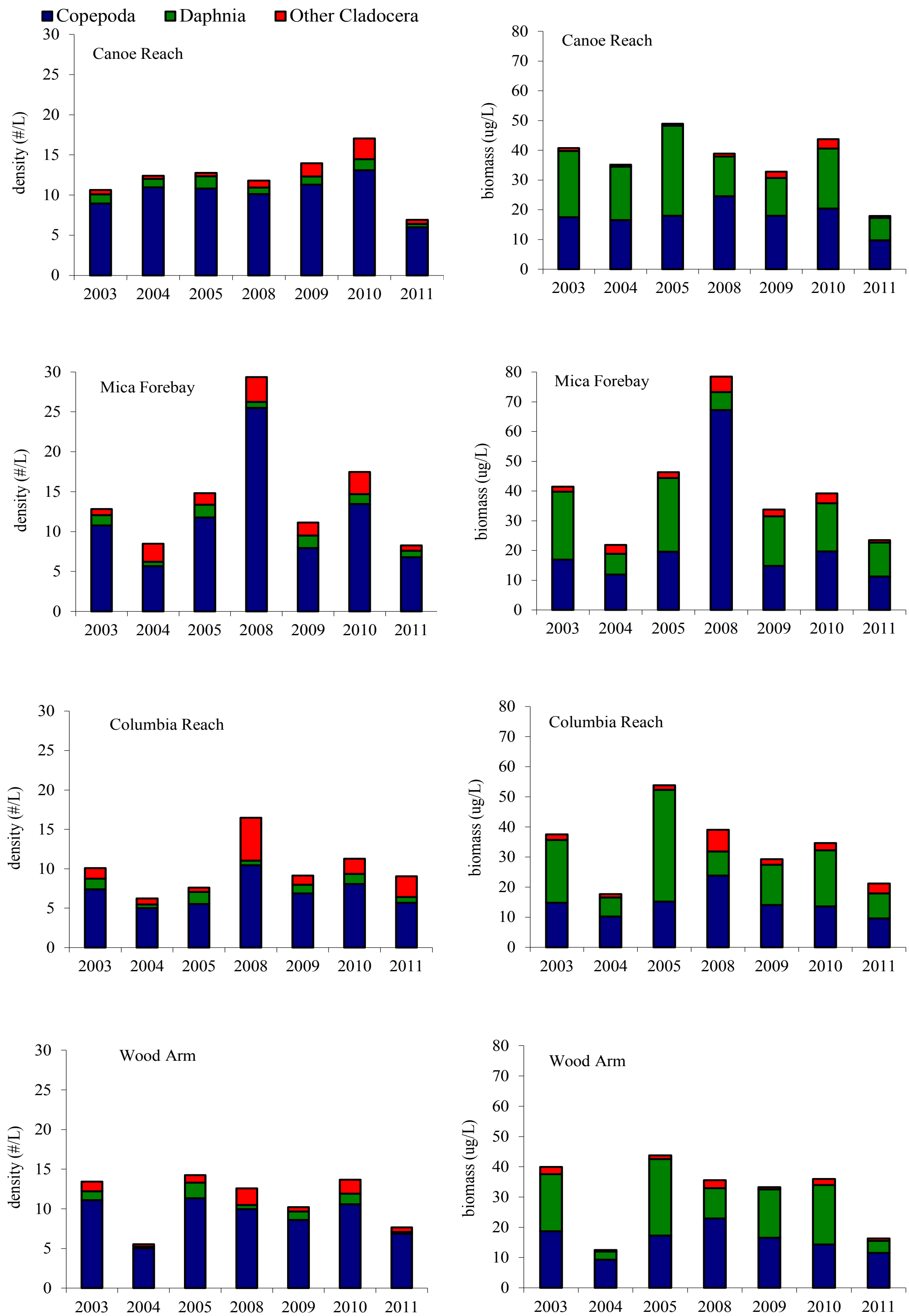


Figure 9. Annual average zooplankton density (left) and biomass (right) at four stations in Kinbasket.

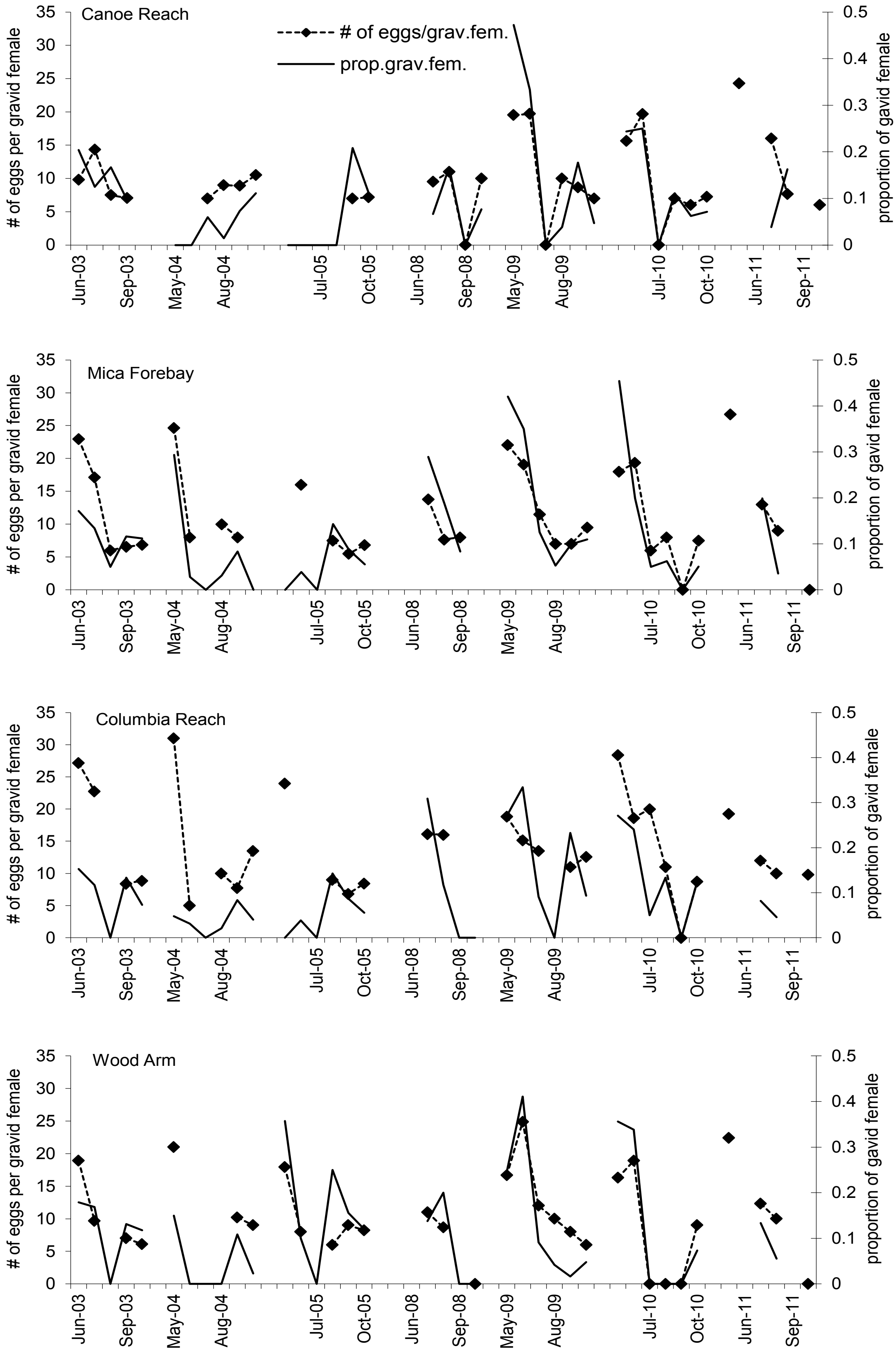


Figure 10. Fecundity features of Diacyclops bicuspidatus in Kinbasket Reservoir in 2003-2011.

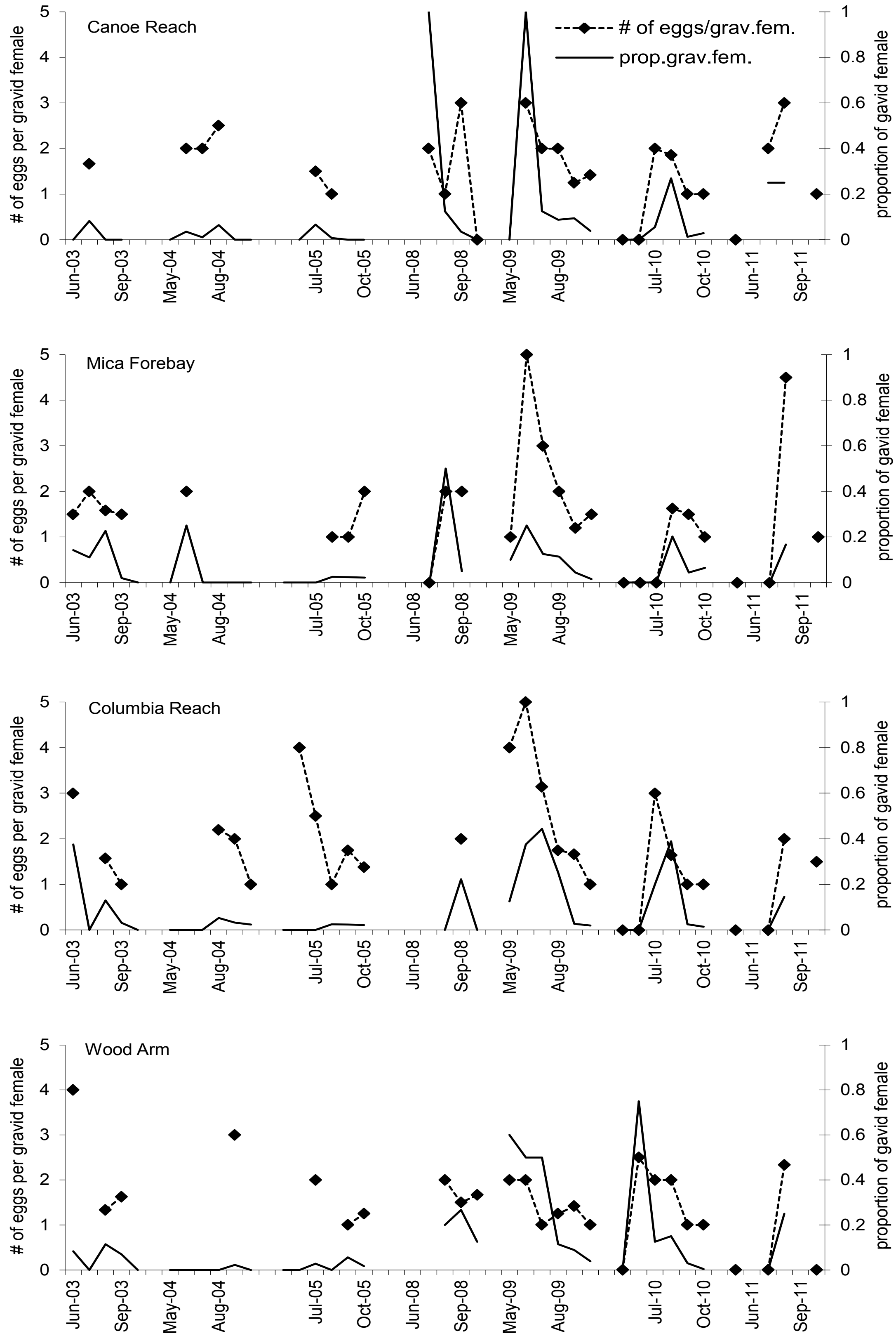


Figure 11. Fecundity features of Daphnia spp. in Kinbasket Reservoir in 2003-2011.

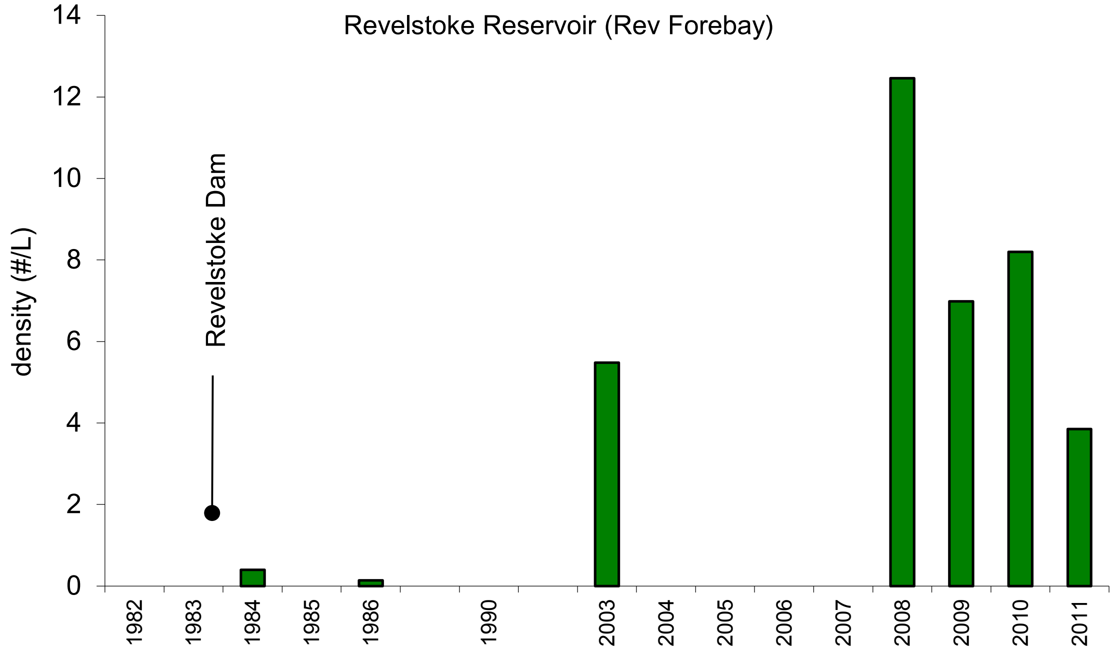


Figure 12. Zooplankton density 1984-2011 at Rev Forebay in Revelstoke Reservoir.

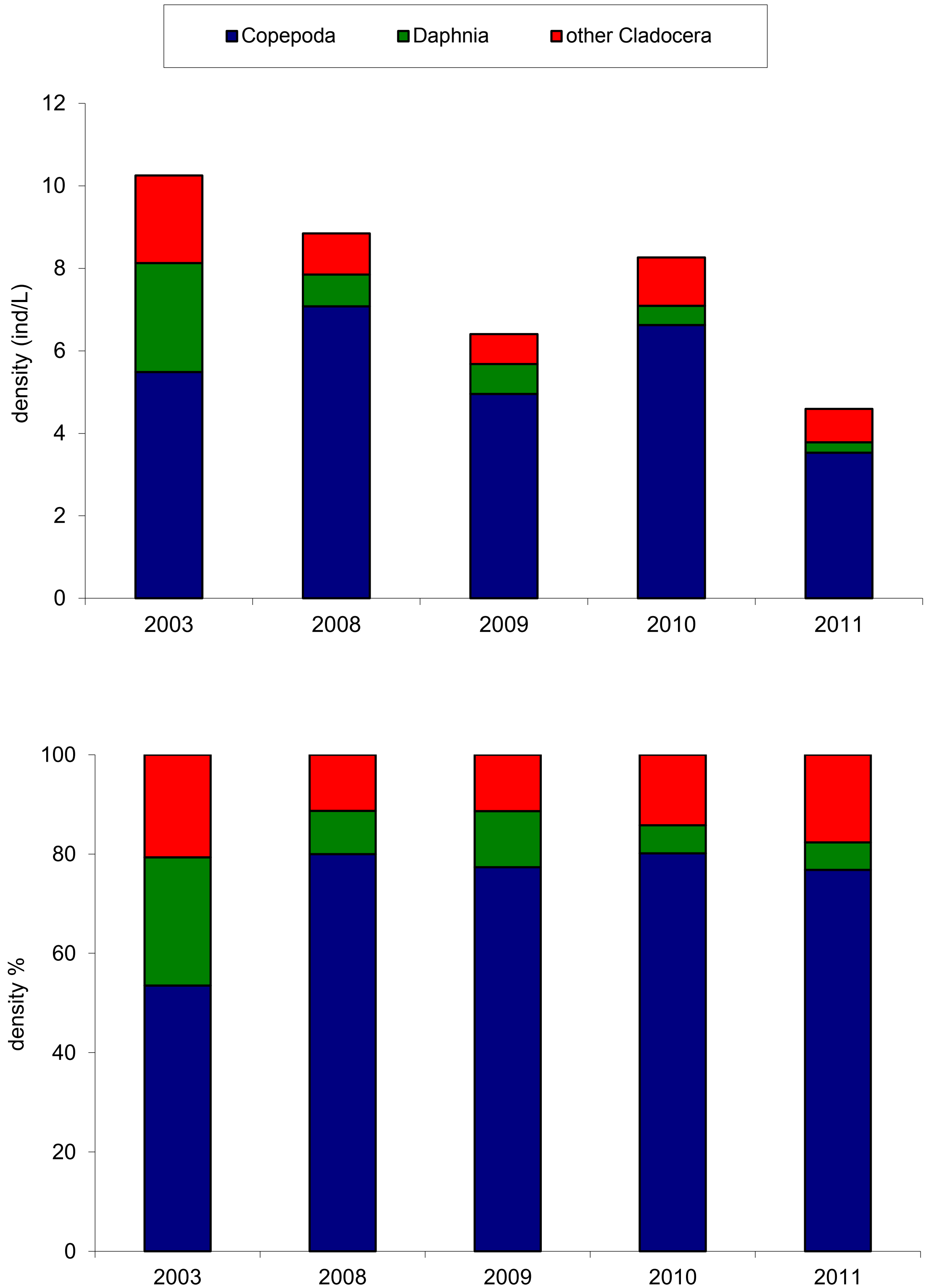


Figure 13. Seasonal average composition of zooplankton density in Revelstoke Reservoir in 2003, 2008 - 2011.

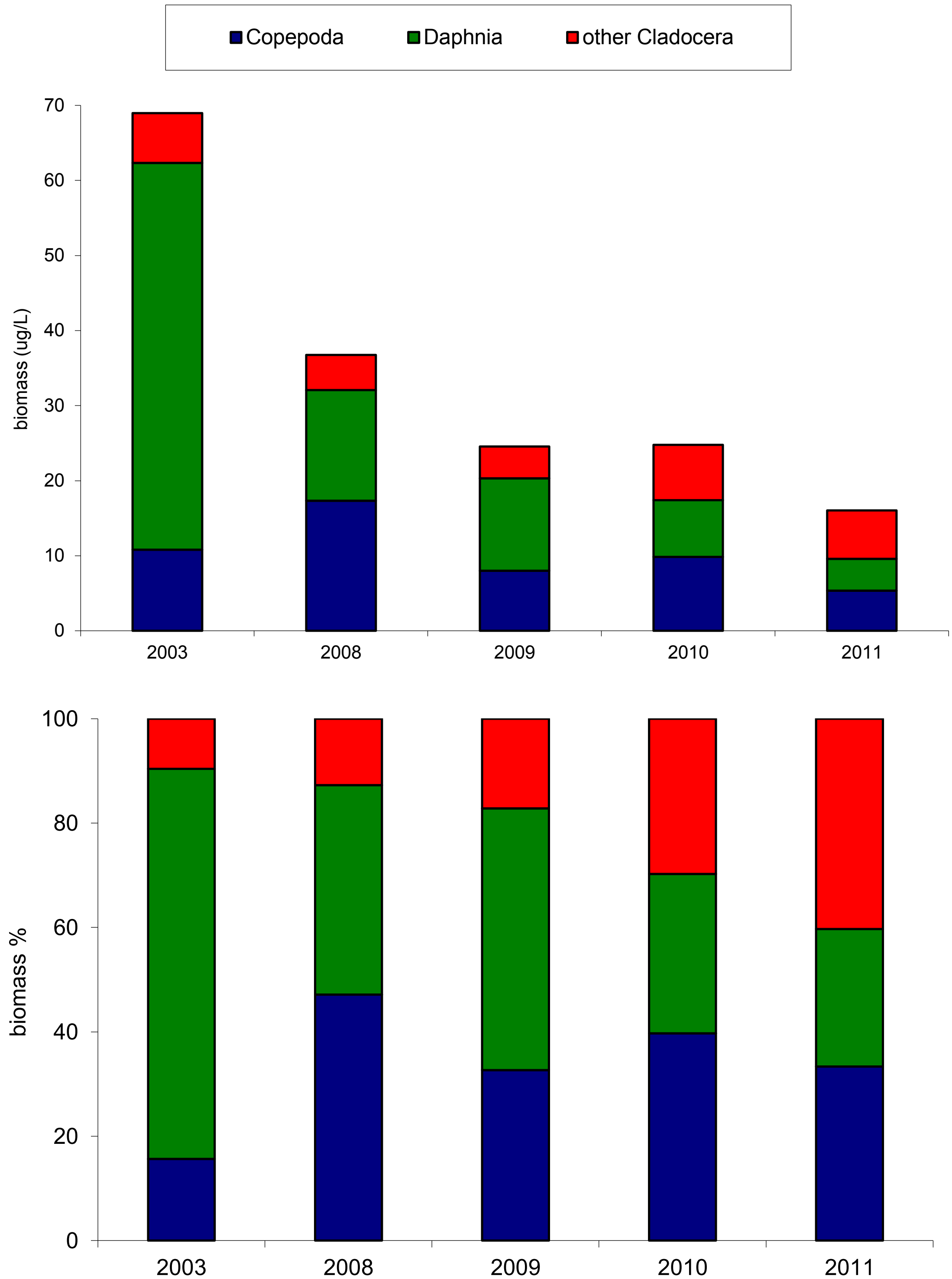
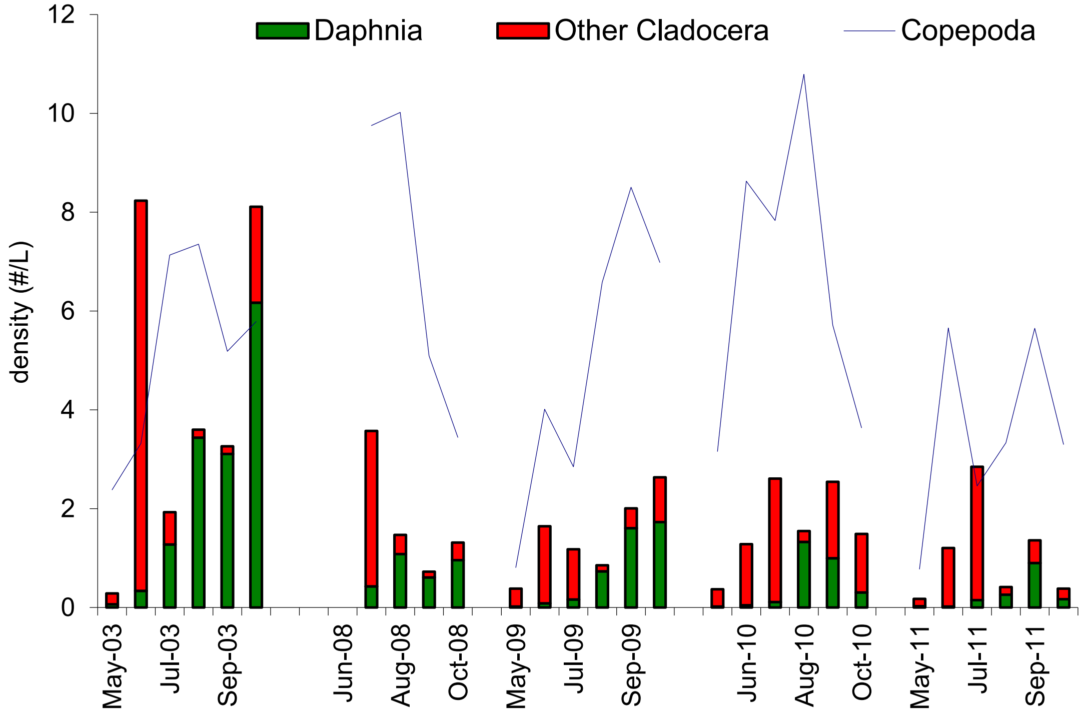


Figure 14. Seasonal average composition of zooplankton biomass in Revelstoke Reservoir in 2003, 2008 - 2011.



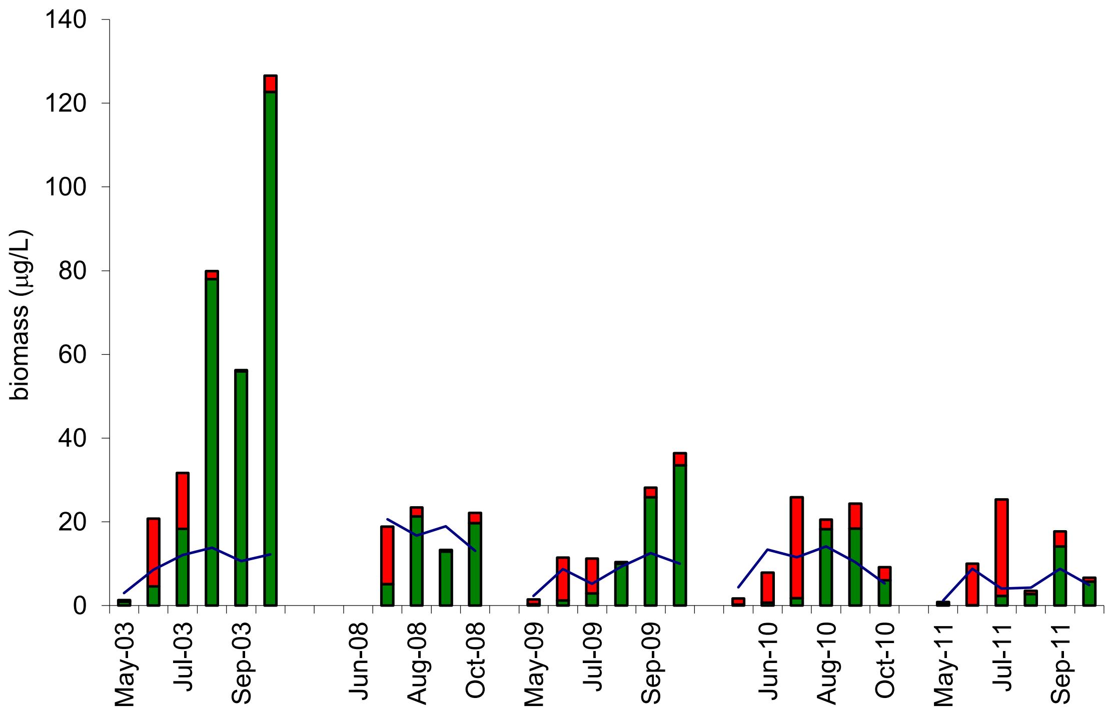


Figure 15. Monthly average zooplankton density (top) and biomass (bottom) in Revelstoke Reservoir.

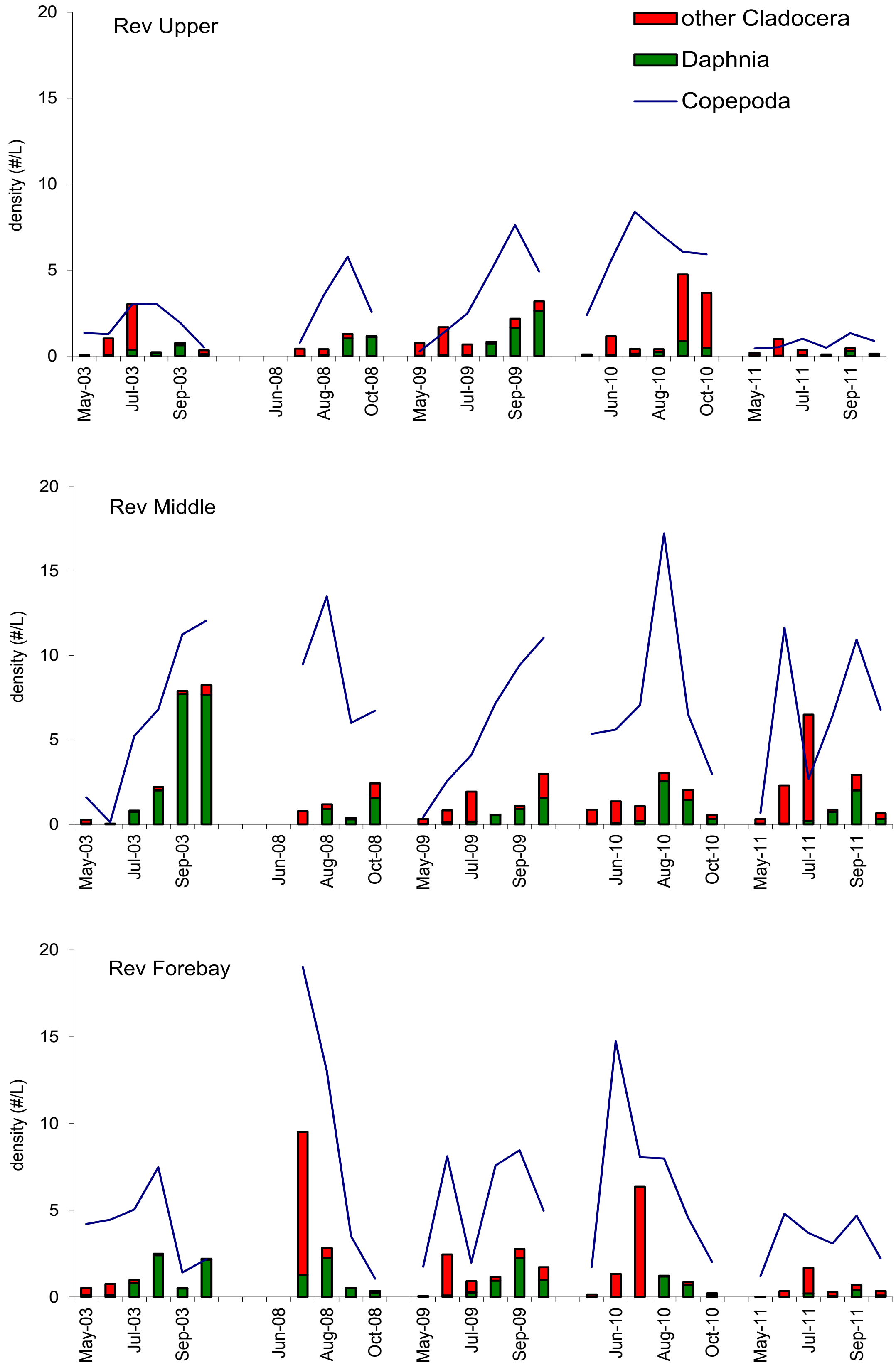


Figure 16. Zooplankton density at 3 stations in Revelstoke Reservoir 2003, 2008 - 2011.

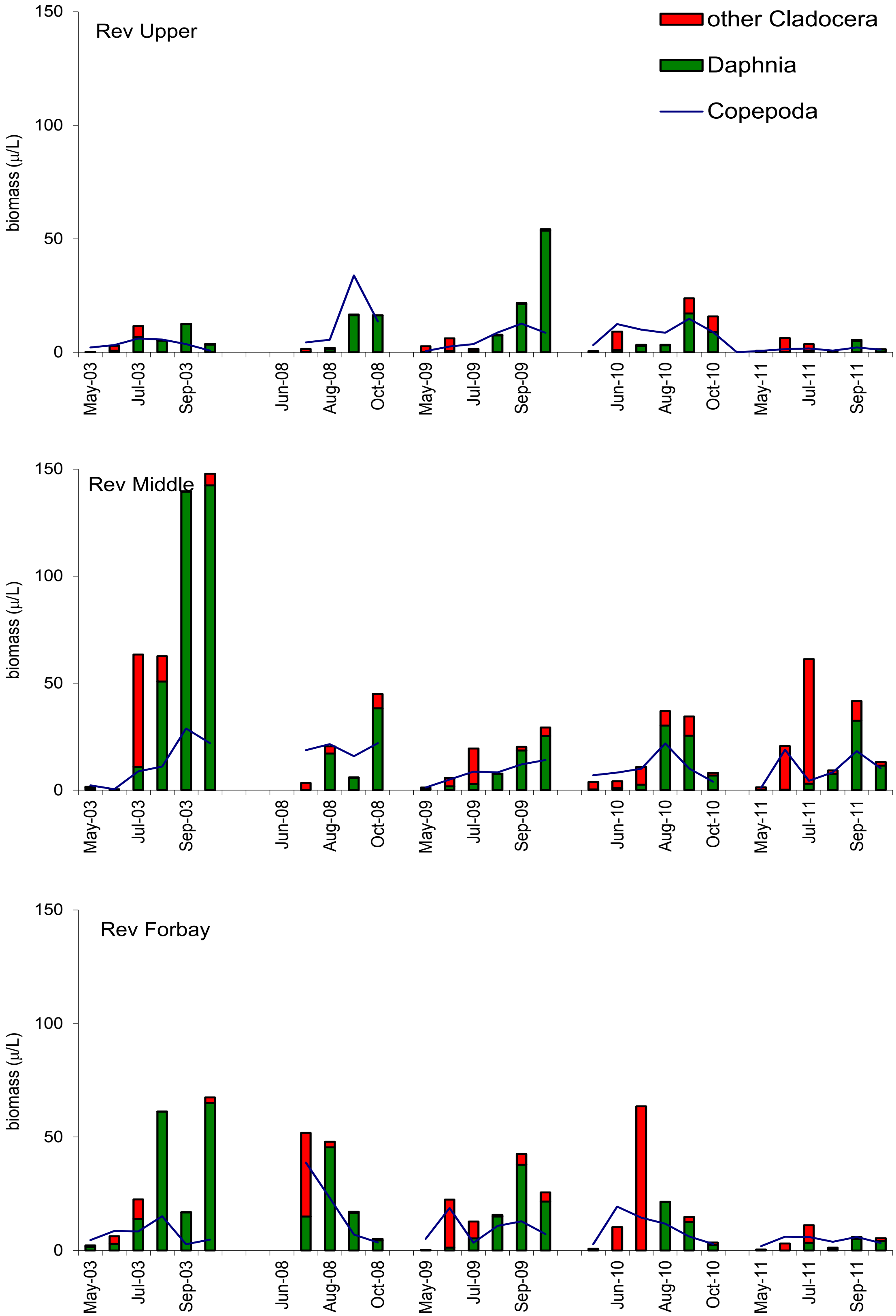


Figure 17. Zooplankton biomass at 3 stations in Revelstoke Reservoir 2003, 2008 – 2011.

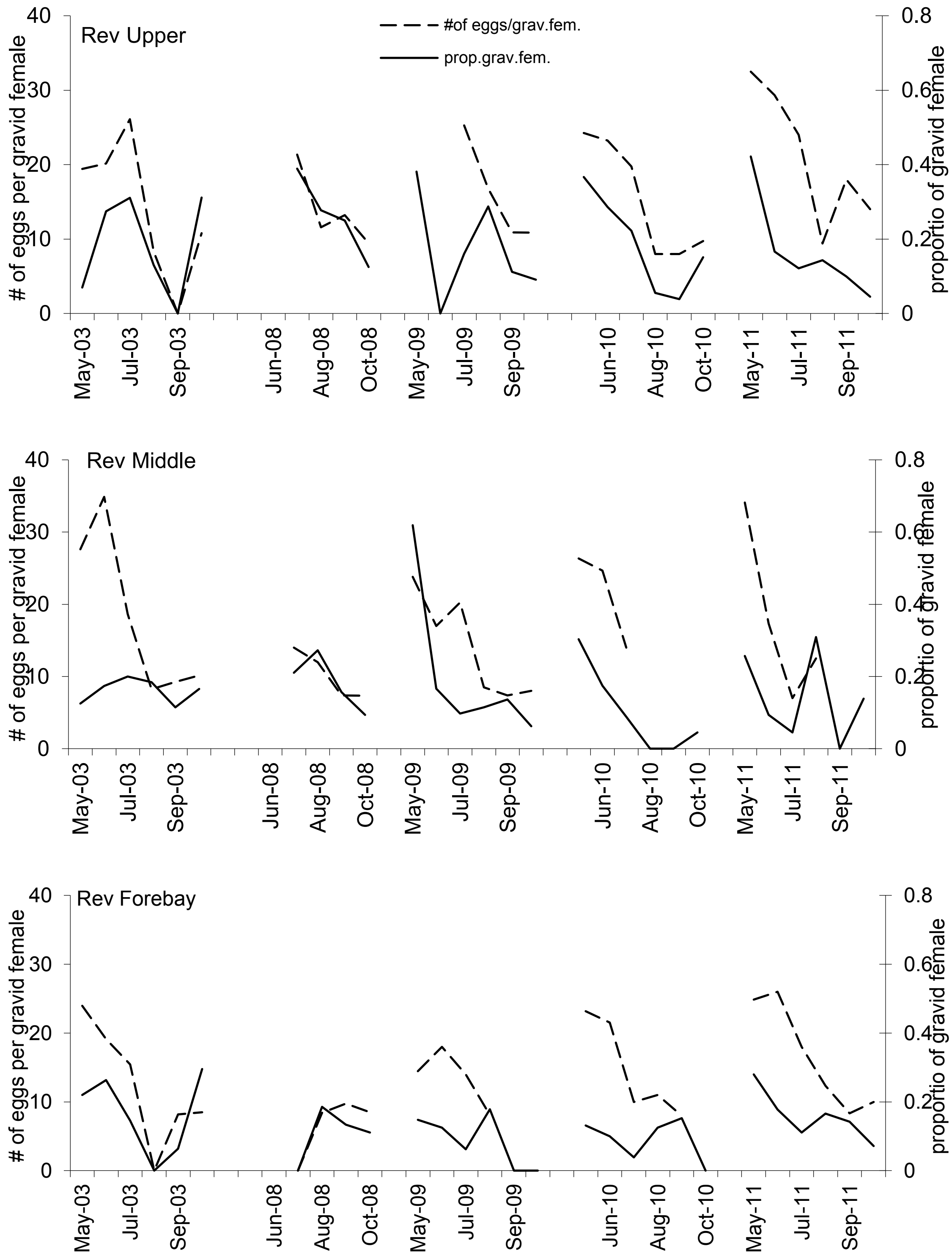


Figure 18. Fecundity features of Diacyclops bicuspidatus in Revelstoke Reservoir in 2003, 2008-2011.

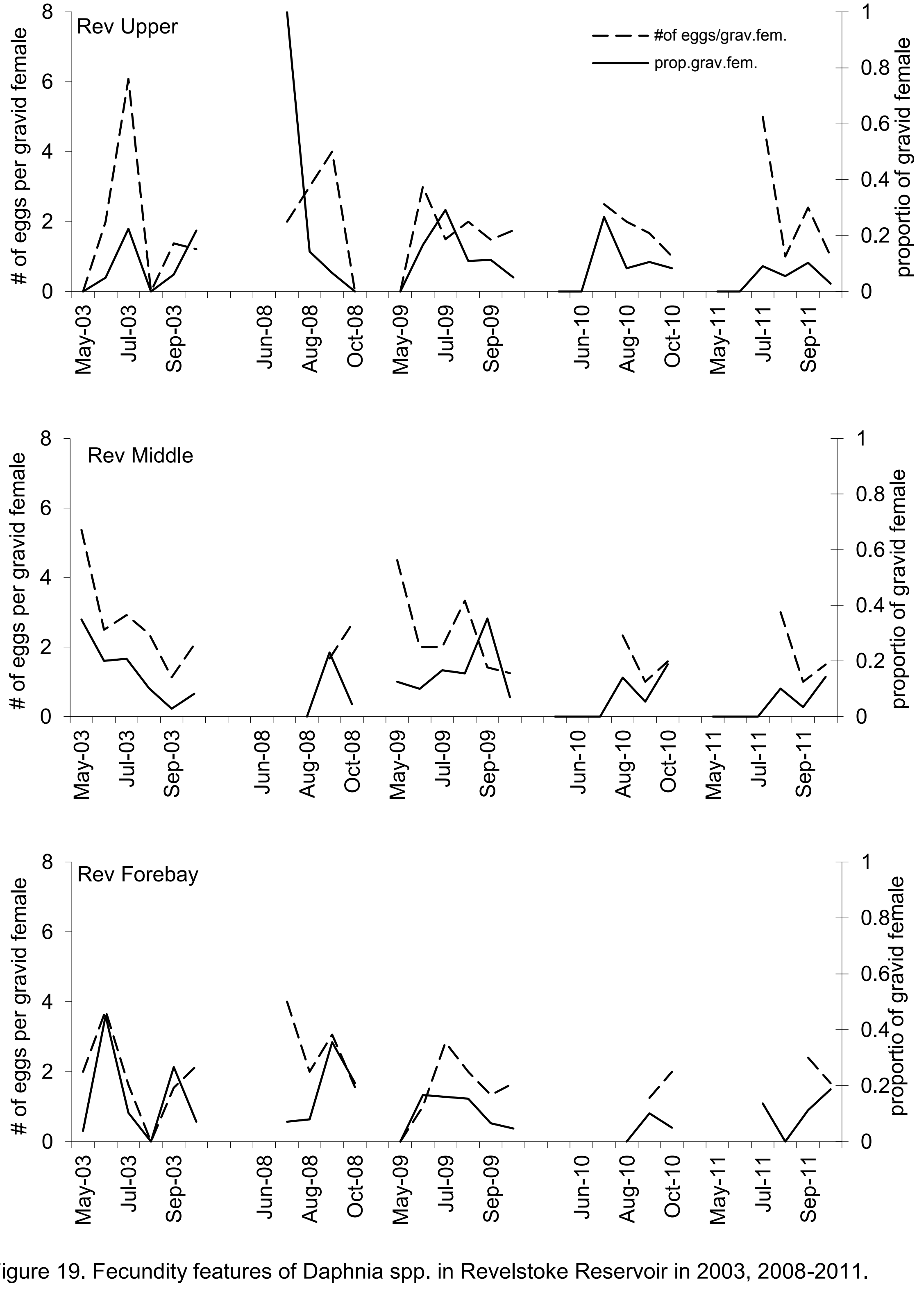


Figure 19. Fecundity features of Daphnia spp. in Revelstoke Reservoir in 2003, 2008-2011.