Columbia River Project Water Use Plan

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring

Implementation Year 5

Reference: CLBMON-3 and CLBMON-56 (Year 1)

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring – Year 5 (2012) Progress Report

Study Period: 2012

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Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring
Year 5 (2012) Progress Report

Spilling 40kcfs at Revelstoke Dam, July 15, 2012

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Revelstoke, B.C.

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.

Suggested Citation for Progress Report:

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Suggested citation for individual reports contained within:

Harris, S. 2014. Primary Productivity in Kinbasket and Revelstoke Reservoirs, 2012. Prepared for BC Hydro, Water Licence Requirements. 21 pp.. Appendix 5 *in* Bray, K.E. 2014. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 5 (2012). BC Hydro, Environment. Study No. CLBMON-3 and CLBMON-56

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1.0 Introduction

This report summarises the Year 5 (2012) 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).

As a result of the Environmental Assessment for the addition of two turbines at the Mica Generating Station (Units 5 and 6), the Terms of Reference for this study was amended to include a component for addressing the potential influence of the new units on reservoir productivity. This component, CLBMON-56, is a nine year study focussing on fine scale measurement of temperature in Kinbasket and Revelstoke Reservoirs to further refine data on circulation, and thus, production. The first year of this study was implemented in 2012 and results are included in this annual report (Appendix 8).

1.1 Management Questions

A Terms of Reference (TOR) (BC Hydro 2007b) for this study and revised in 2011 to include an addendum for Mica 5/6 (BC Hydro 2011b) 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, and Williston Reservoir)?
vii) Does the addition of Mica Units 5 and 6 influence pelagic productivity? (added in 2011)
viii) 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 Study Implementation

The study team (Table 1) met on February 7-8, 2012, to discuss progress on the management questions, evaluate the sampling program to date, and set 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; an annual progress report is prepared in intervening years. The first phase synthesis report covering 2008-2011 has been completed (Bray, et al. 2013).

Table 1: Study team members (CLBMON-3/56 and CLBMON-2), 2012.

Study Team Member	Affiliation
Karen Bray, Project Manager/Biologist	BC Hydro
Dr. Roger Pieters, Associate Researcher	University of British Columbia, Dept. of Earth and Ocean Sciences
Dale Sebastian	BCCF
Tyler Weir, Ecosystems Biologist	Ministry of Forests, Lands and Natural Resources Operations
Shannon Harris, Limnologist	Ministry of Environment, Ecosystems Branch
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Dr. Ken Ashley, Professor	BCIT

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 field sampling, analyses, and reporting for specific components

This fifth annual report presents a study overview followed by individual progress reports for the physical processes and biological components of the 2012 sampling year as per previous progress reports (Bray 2013; Bray 2012; BC Hydro 2011a; BC Hydro 2010). Also included is the first annual report for CLBMON-56. More specific information pertaining to individual year monitoring results is contained in these reports.

In Year 5 (2012) regular reservoir monthly sampling began in June and concluded in October (Figure 1). The regular May sampling session was missed due to administrative delays. Sampling protocols remained mostly unchanged from the previous year with only minor alterations to hypolimnetic depths sampled in Kinbasket Reservoir (Table 2).

2.1 Reservoir Operations in 2012

Kinbasket Reservoir reached its minimum level (722m) for the year on April 22, 2012, and its maximum level (754.7m) on August 29, 2012. Kinbasket Reservoir was surcharged by 0.3m in August 2012 due to an unusually high inflow year and operational constraints at Mica Dam. A very wet June resulted in the highest inflows in 40 years that were 140% of normal.

Completion of a new switchgear building in preparation for Mica Units 5 and 6 necessitated unit outages, thereby placing constraints on the ability of the generating station to generate power. Low level outlets at Mica Dam were operated in July to pass additional non-power discharge and manage reservoir levels (cf. Appendix 1). The total range of elevation in 2012 was 32.7m whereas the maximum range is normally 47m without surcharge. The average reservoir elevation range between 1977 and 2012 has been 25.4m.

Revelstoke Reservoir operation was also unusual in 2012. Spilling at the Revelstoke Generating Station occurred on 18 separate occasions between May and July 2012 to manage high inflow volumes and storage capacity. Spill volumes ranged from 6kcfs to 40kcfs and the total discharge from generation and spillway volumes peaked on July 21 at 2573 m^3/s.

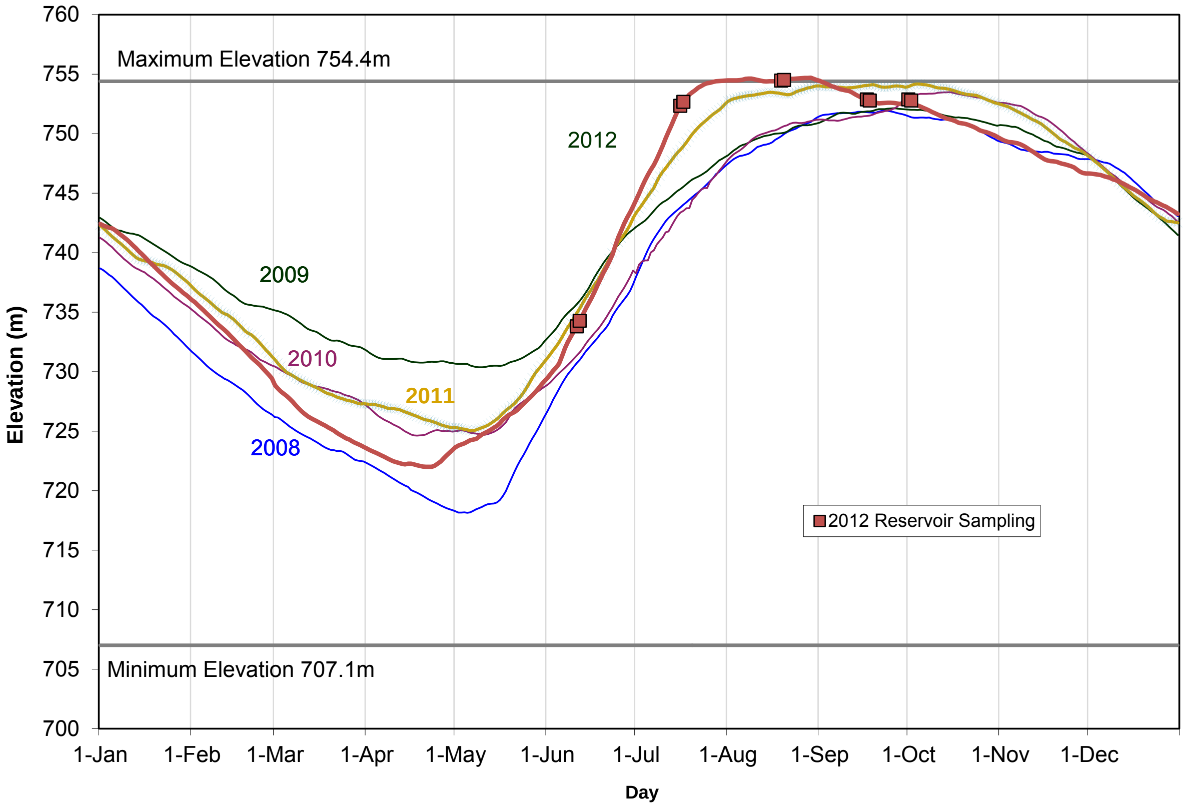

Figure 1. Kinbasket Reservoir elevation and sampling dates, 2012. Elevations for 2008-2011 are shown for comparison.

Table 2. Summary of Kinbasket and Revelstoke Reservoirs field sampling program 2012.

Parameter (Analysis/Provider)	**Sampling Frequency**	**Sampling 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, RH, PAR, wind) (BCH)	Hourly/daily	Fixed Data logger		Mica dam crest							Rev Dam crest	
Profile (DO, temp, cond, chl a, PAR, turbidity) +Secchi (BCH)	**Jun-Oct** Monthly (5)	Seabird Profiler	0 to 60m+ (to within 5 m of bottom) Longitudinal profile in spring/fall	√	√	√	√	√	√	√	√	
Water Chem – Reservoir TP, SRP, TDP, cond, NO2+NO3, alk, pH, turb, Si,Secchi disk Cultus Lake-DFO	**Jun-Oct** Monthly (6)	Bottle, tube	2,5,10,15,20, 40, 60, 80m 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 Cultus Lake-DFO	5 reference tribs once in A/S/O/N and twice in M/J/J	Bucket	Surface grab									√
Temperature (BCH)	Tidbits, hourly	Reference trib sites*										√
Chl a (MOE)	**Jun-Oct** Monthly (5)	Integrated tube	0-20m	√	√	√	√		√	√	√	
Phytoplankton (Advanced E-S)	**Jun-Oct** Monthly (5)	Niskin bottle	2, 5, 10, 15, 25 m	√	√	√	√		√	√	√	
Bacteria (Advanced E-S)	**Jun-Oct** Monthly (5)	Niskin bottle	Composites of 2,5,10m and 15,20,25m	√	√	√	√		√	√	√	
Zooplankton (Limno Lab)	**Jun-Oct** Monthly (5)	Wisconsin net 2 hauls per site	0-30m	√	√	√	√		√	√	√	
C^{14} (MOE)	**June-Sep** Monthly (4)	Niskin bottle	0,1,2,5,10,12,15	√**						√	√	

* Columbia River at Donald, Mica outflow, Goldstream River

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

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Appendix 1

Hydrology of Kinbasket and Revelstoke Reservoirs, 2012

Roger Pieters, Aleicia Sharp, and Greg Lawrence
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Hydrology of Kinbasket and Revelstoke Reservoirs, 2012

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Kinbasket Reservoir, 30 Aug 2013

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Contents

List of Figures

1. Introduction

The hydrology of Kinbasket and Revelstoke Reservoirs is described, focusing on flow in 2012. This report updates Pieters et al (2013) 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. As shown in Table 1.1, 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 Drainage area, mean flow and yield of selected regions of the Columbia River

	Drainage area (km^2)	**Flow (m^3/s)**	**Yield* (m/yr)**
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

*Annual water yield gives the total volume of river water leaving a catchment. Rather than express the volume in m^3, the yield is commonly given as the average depth of water spread over the entire catchment area, here given in m. The yield can be thought of as the average precipitation minus evapotranspiration over the catchment.

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 lengths 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.

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 inflow (71%) 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/yr)	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 1944-2012 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 1944-2012. 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 1944-2012 was 171 m^3/s.

The daily flows are shown in Figure 3.2 for selected years (1993-1994, 1999-2012) which include the years with hydroacoustic surveys of kokanee abundance (1993, 1994, 2003-2012). Also shown for comparison in each panel is the daily mean flow for 1944-2012. 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 3.2.2f). In 2012, flow from June until mid-August was much higher than average (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 1971-2012 from BC Hydro. The data from “Columbia River above Nagle Creek” were used for 1947-1975 and the BC Hydro data were used for 1976-2012.

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 (1993-1994, 1999-2012) 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. In 2012, water was retained in Kinbasket Reservoir with almost no outflow from late June until mid-July, and then from mid-July to mid-August flow far exceeded average.

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 1986-2012, data were available from WSC station 08ND025, entitled “Revelstoke Project Outflow”.

Results

The daily discharge for 1955-2012 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 daily 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 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 (1993-1994, 1999-2012) is shown in Figure 5.2, and generally follows the mean post-impoundment hydrograph. Two particular exceptions were July to September 2010 when outflow was below average, and mid-July to mid-August 2012 when outflow was far greater than average, including spill.

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 2012 are compared in Figures 6.5 to 6.9, 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 that above average flows in June and July 2012 occurred at all sites.

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 1974-2012 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 1980-2012 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 1974-2012. 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 1977-2012.

The water level in Kinbasket Reservoir for selected years (1993-1994, 1999-2012) 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 mid-October. In 2012, water levels were slightly below average from March to June, but rose to above average (including surcharge) for July to September.

Figure 7.3 shows the annual minimum and maximum water level for Kinbasket Reservoir, 1977-2012. While the difference between the normal maximum and normal minimum water level is 47 m (754.38 to 707.41 m ASL), drawdown in any given year averages 25 m. There are periods of time when the water level is relatively low throughout the year (e.g. 1994-1996) and at other times it is relatively high (e.g. during the study period 2008-2012). The minimum and maximum water levels are shown in Figure 7.3b, along with the corresponding dates in Figure 7.3c. During the study period, the minimum water level occurred significantly later than average, in early May, and the area of the reservoir at minimum water level was 240 to 320 km^3, only 55-75% of the area at maximum water level later in the year.

8. Revelstoke Water Level

Data

Daily water level data were available for 1984-2012 from the BC Hydro station located in the Revelstoke forebay.

Results

Figure 8.1a shows the water level of Revelstoke Reservoir for 1984-2012. 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 1988-2012. The water level varies by only a few meters, as the reservoir is operated run of the river.

The water level for selected years (1993-1994, 1999-2012) is shown in Figure 8.2, together with the mean post-impoundment level averaged from 1988-2012. The water levels generally followed the post-impoundment mean levels. The largest change in water level was a decrease of about 2 m in May 2012, and twice in October 2012.

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 forebay 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 1976-2012. 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 (1993-1994, 1999-2012) is shown without smoothing in Figure 9.2. The flow in recent years, 2008 to 2012, generally followed the mean, although flow in 2012 was above average from June to July.

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 net 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 1989-2012. 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 (1993-1994, 1999-2012). 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. 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 the Columbia at Donald (Figure 10.3.2d), and in July 2012 the local flow to Revelstoke Reservoir declined before the others (Figure 10.3.2h).

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 to 2012

The El-Nino/Southern Oscillation ENSO index (Wolter, 2012) and the size of winter snow packs (BCRFC, 2012) 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
2012	Weak El Nino (Apr-Jul 2012) Columbia Region Snow Basin Index (April 1st), 125% Flow average

* ‘Strong’ being defined as one of the top 6 bi-months since 1950.

The summer, including those of 2008 to 2012, 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 7.2.2d,e,f,g,h) and little outflow (Figure 4.2.2d,e,f,g,h). In 2010, this low outflow period extended to the end of July (Figure 4.2.2f). 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 8.2.2d,e,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). In 2012, freshet peaked in late June and again in mid-July (Figure 6.9).

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 4.2.2d,e,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 5.2.2d,e,f,g,h; Figure10.4.2d,e,f,g,h).

Acknowledgements

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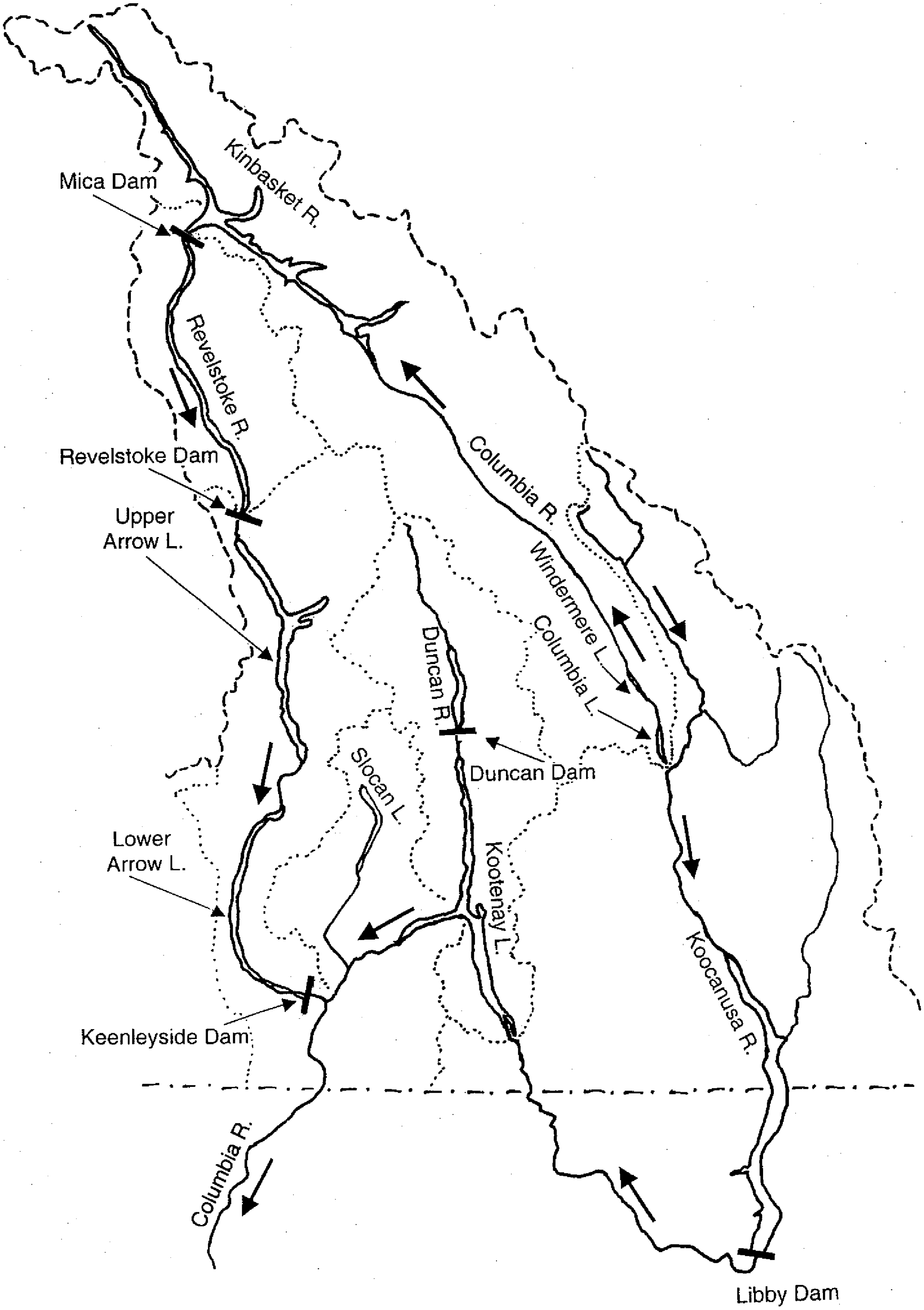


Figure 1.1. Upper Columbia River Basin

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

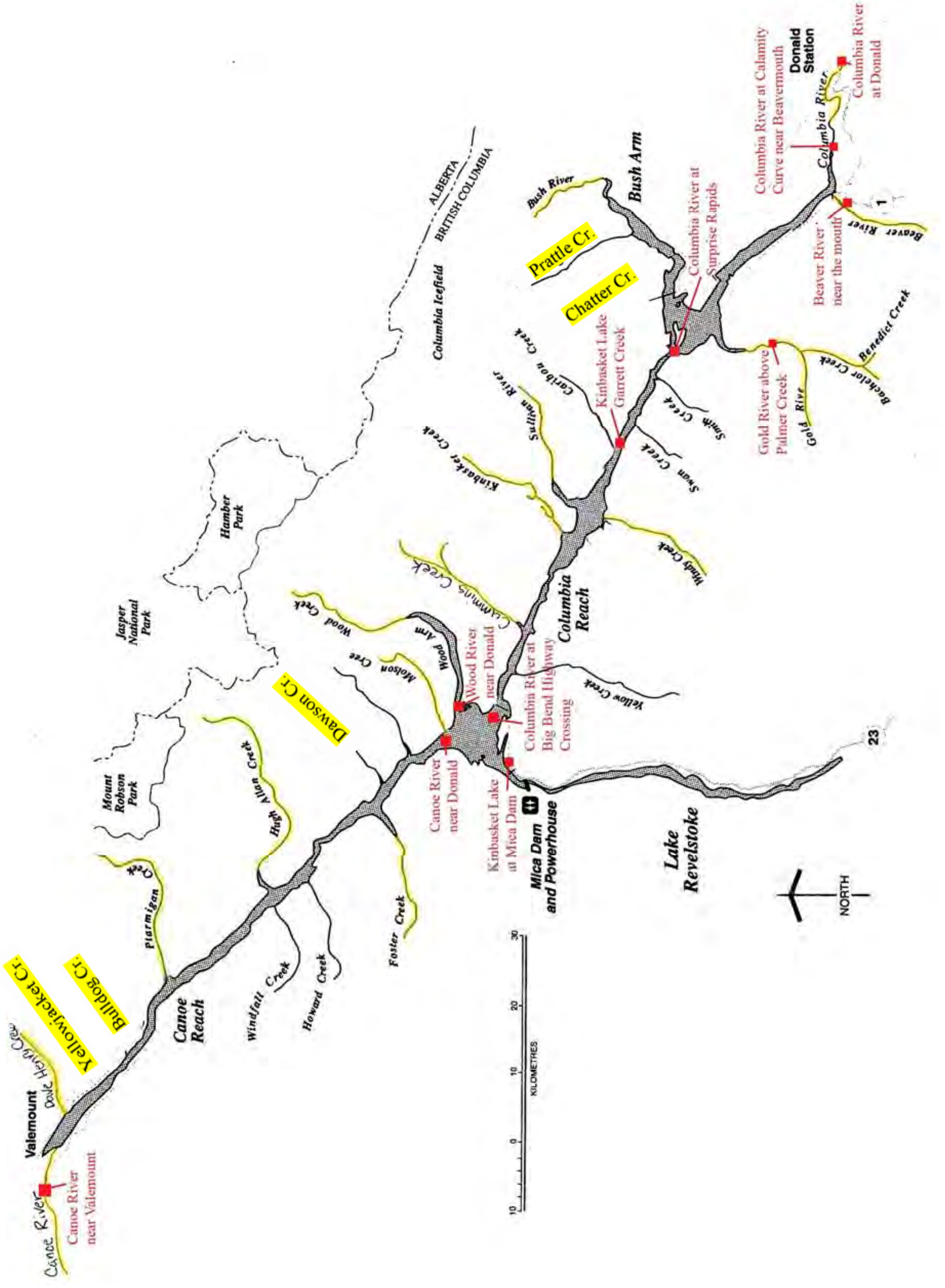
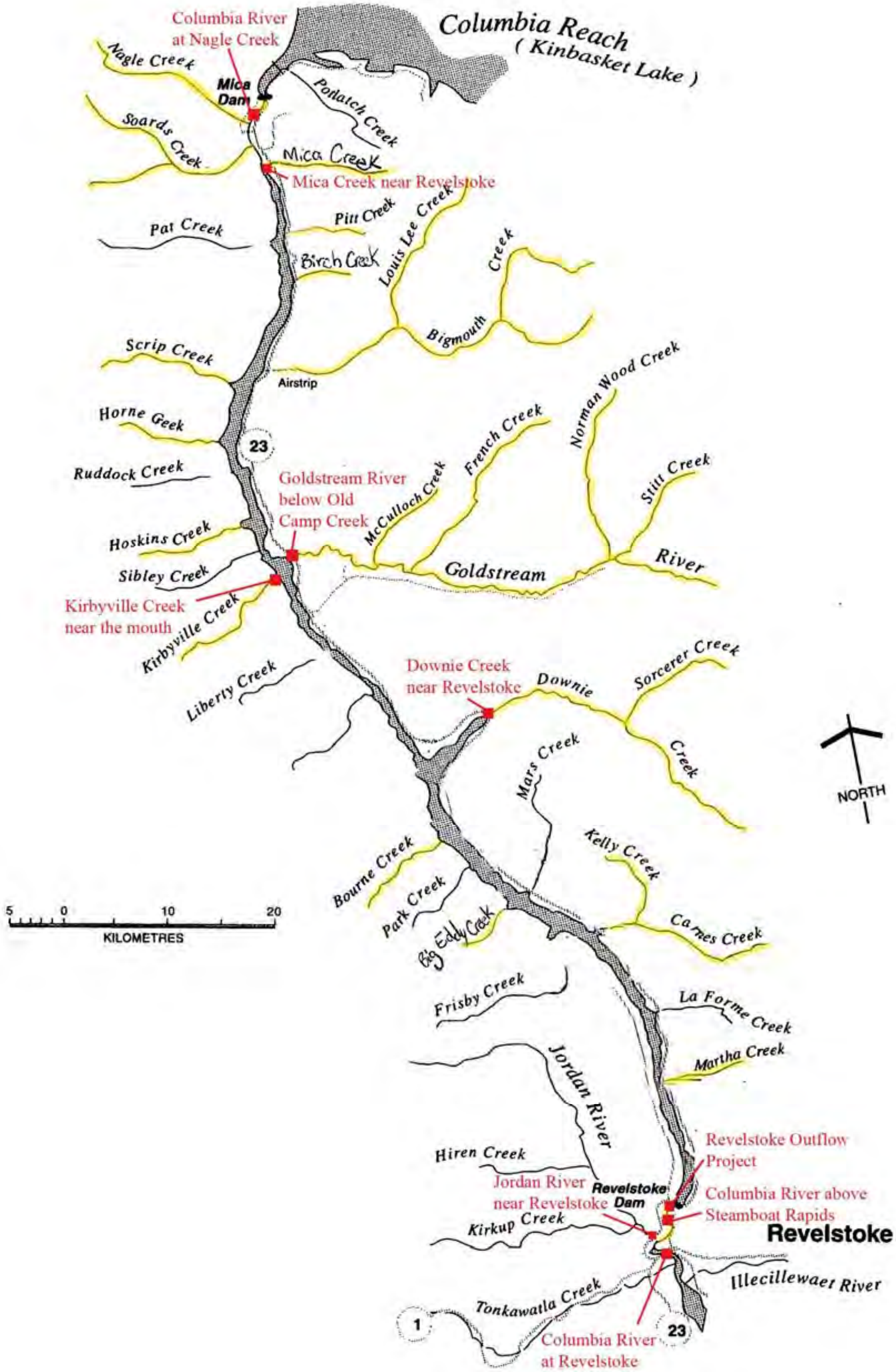


Figure 1.3 Revelstoke Reservoir with gauging stations (RED) and sampled tributaries (YELLOW).



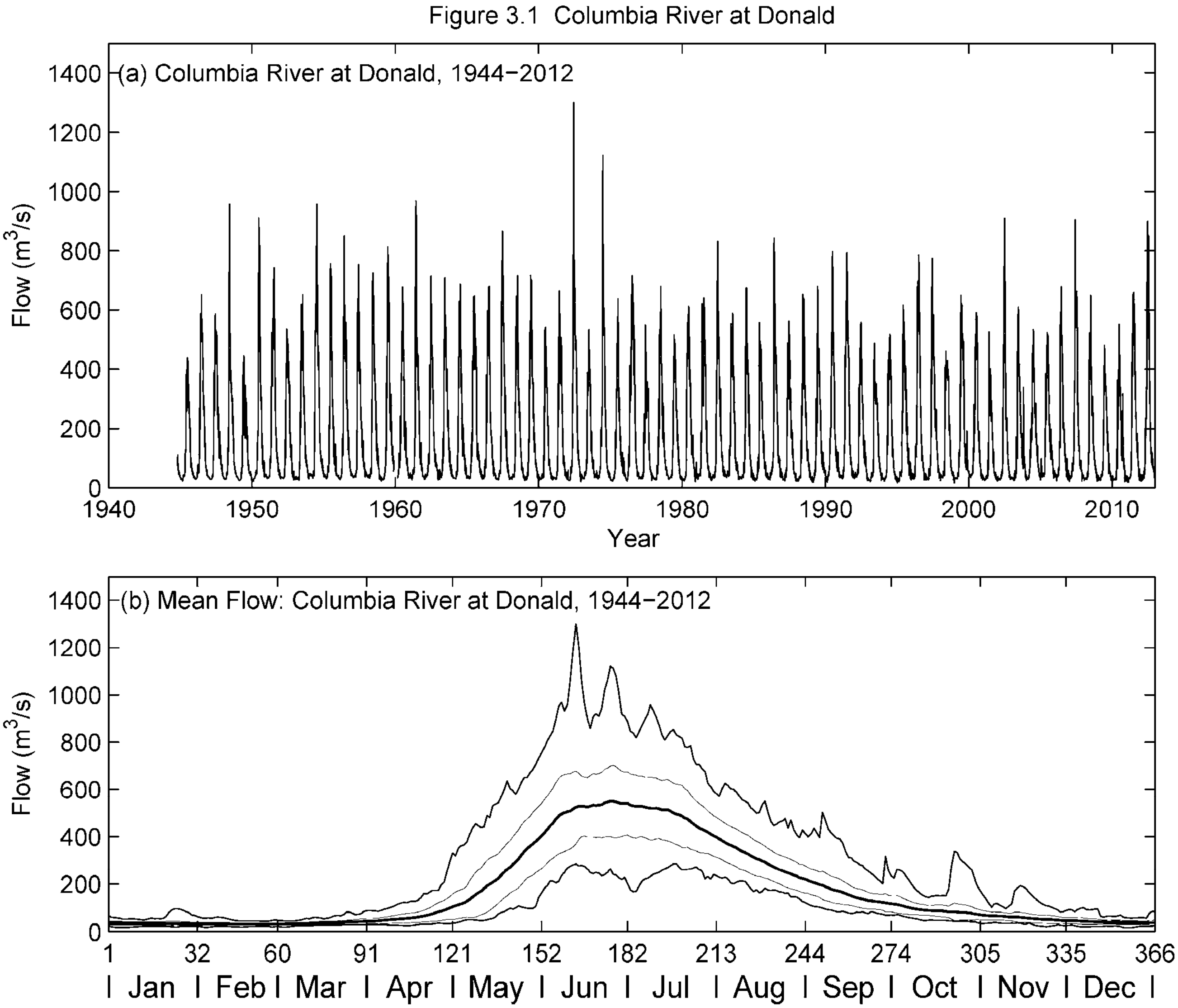


Figure 3.1. **(a)** WSC station 08NB005, "Columbia River at Donald", 1944-2012. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

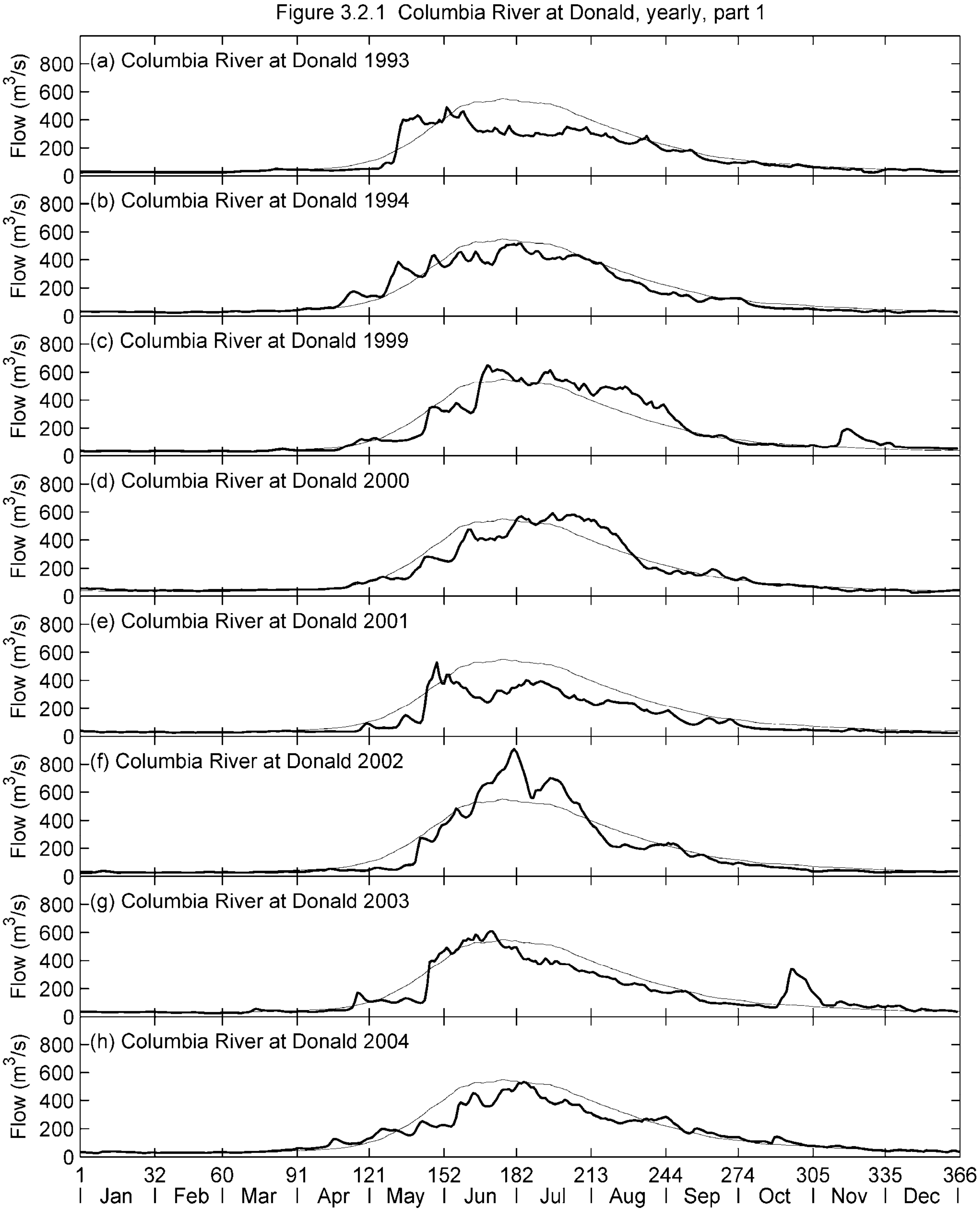


Figure 3.2.1. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2012 (light line) is shown for comparison.

Figure 3.2.2 Columbia River at Donald, yearly, part 2

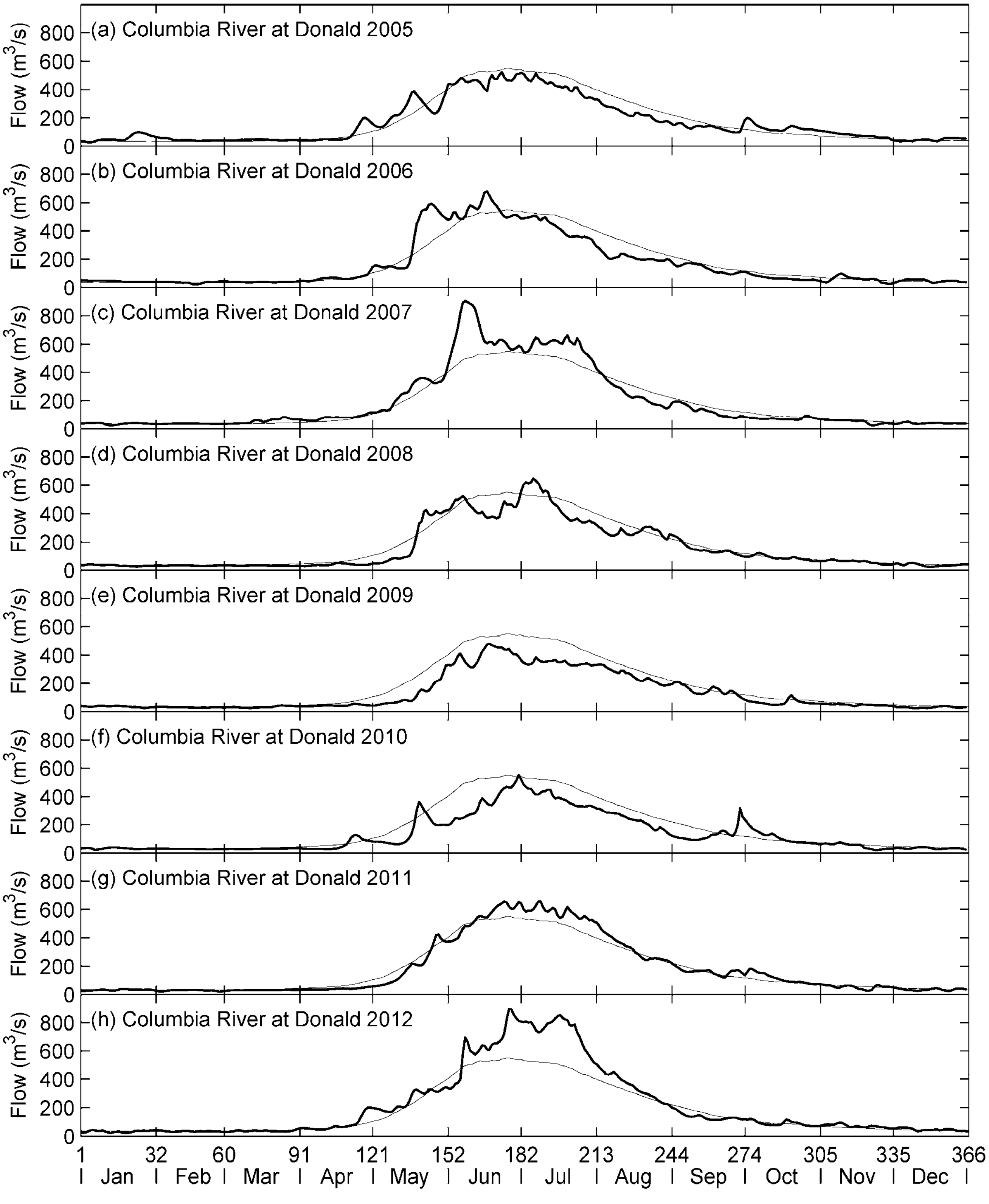


Figure 3.2.2. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2012 (light line) is shown for comparison.

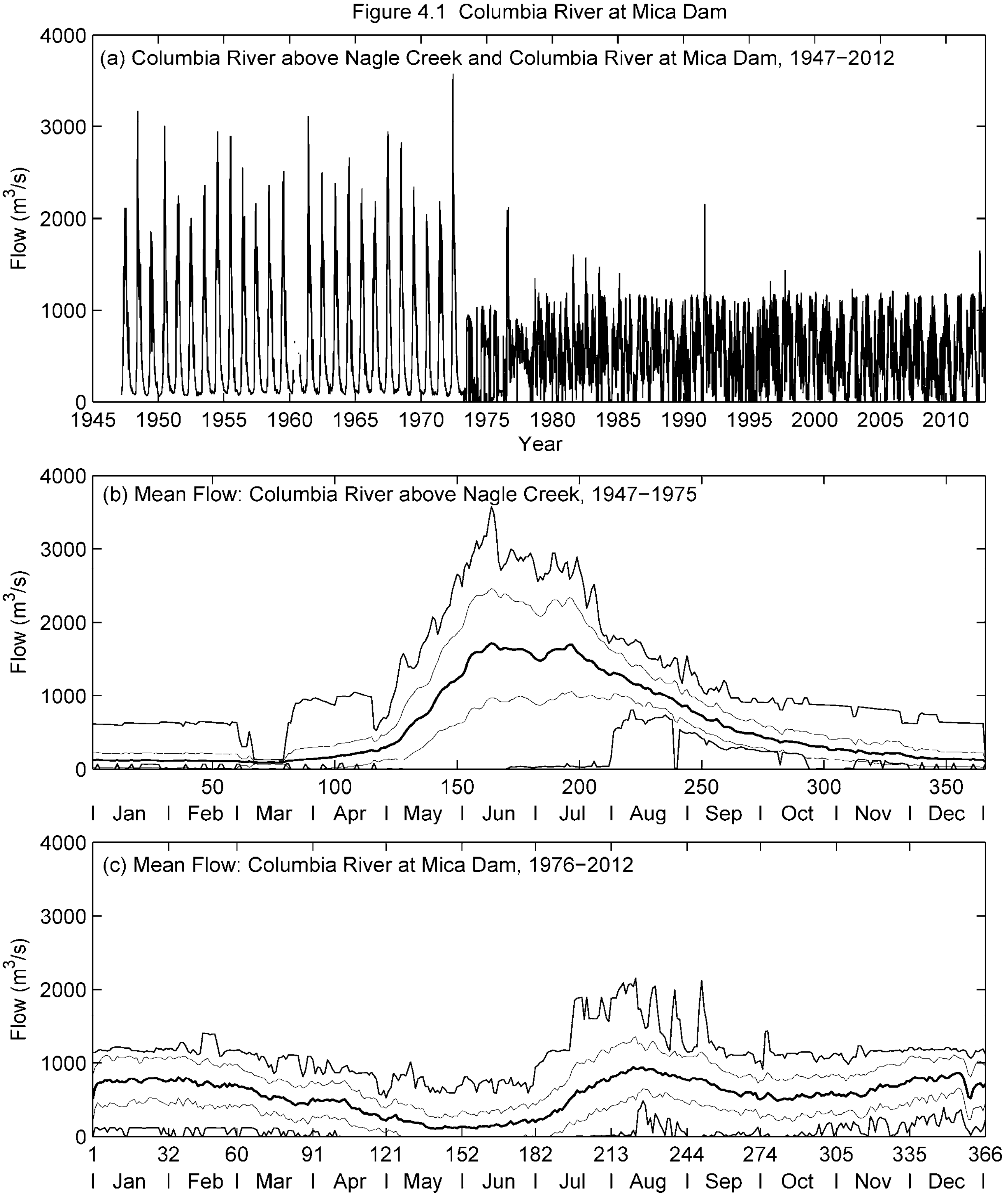


Figure 4.1. **(a)** WSC station 08ND007, “Columbia River above Nagle Creek”, 1947-1975 and BC Hydro station “Columbia River at Mica Dam Outflow”, 1976-2012. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

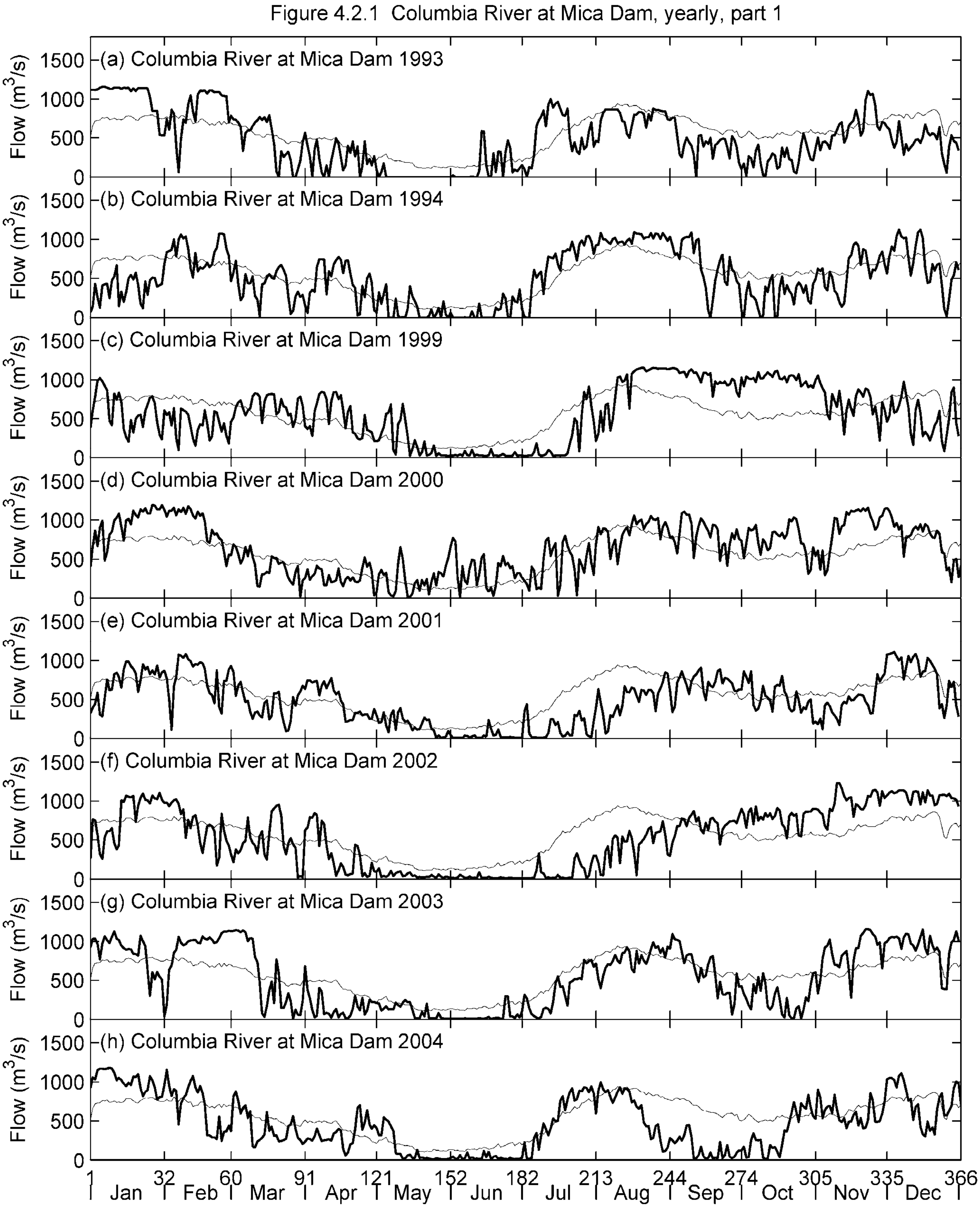


Figure 4.2.1. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2012 (light line) is shown for comparison.

Figure 4.2.2 Columbia River at Mica Dam, yearly, part 2

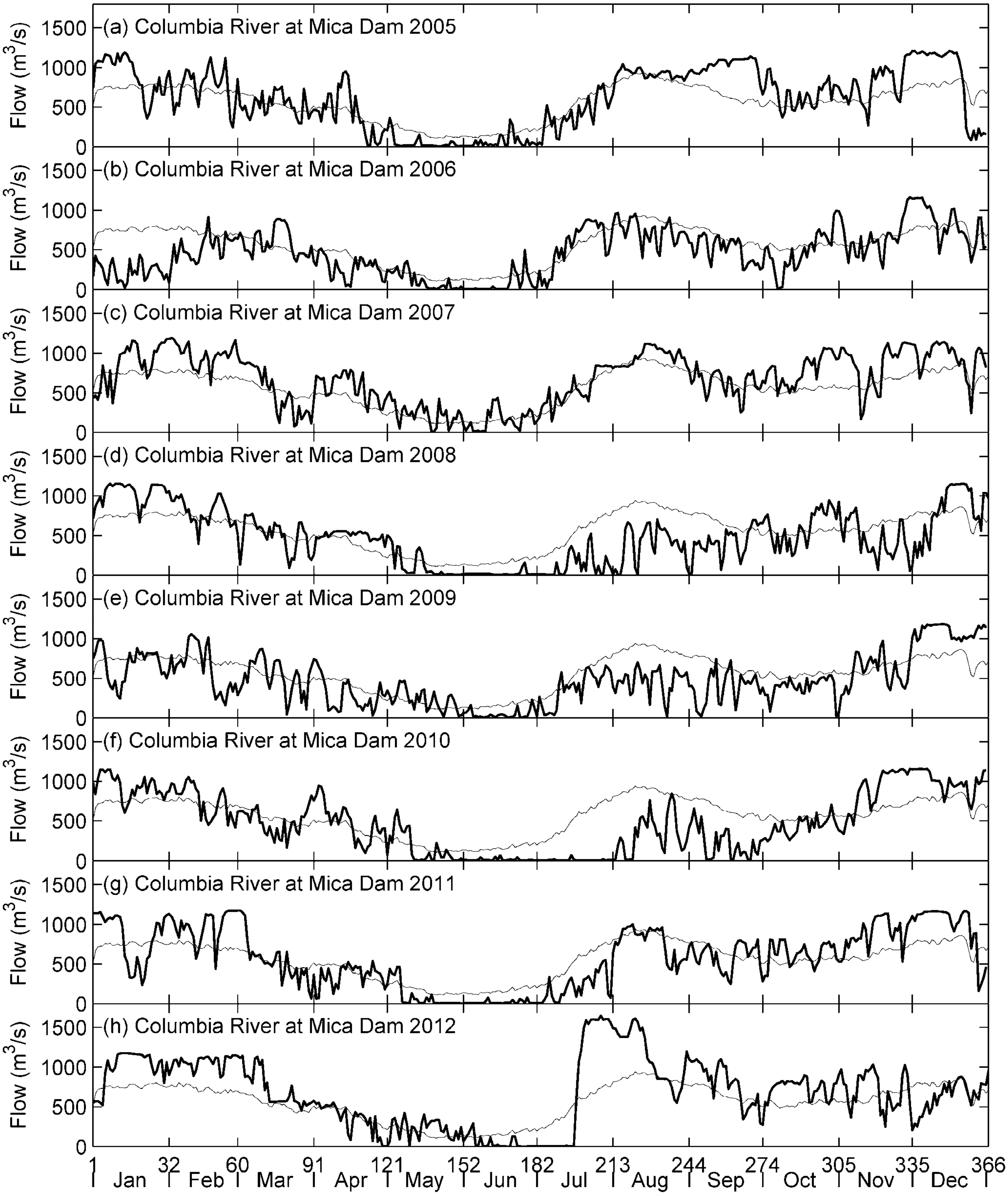


Figure 4.2.2. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2012 (light line) is shown for comparison.

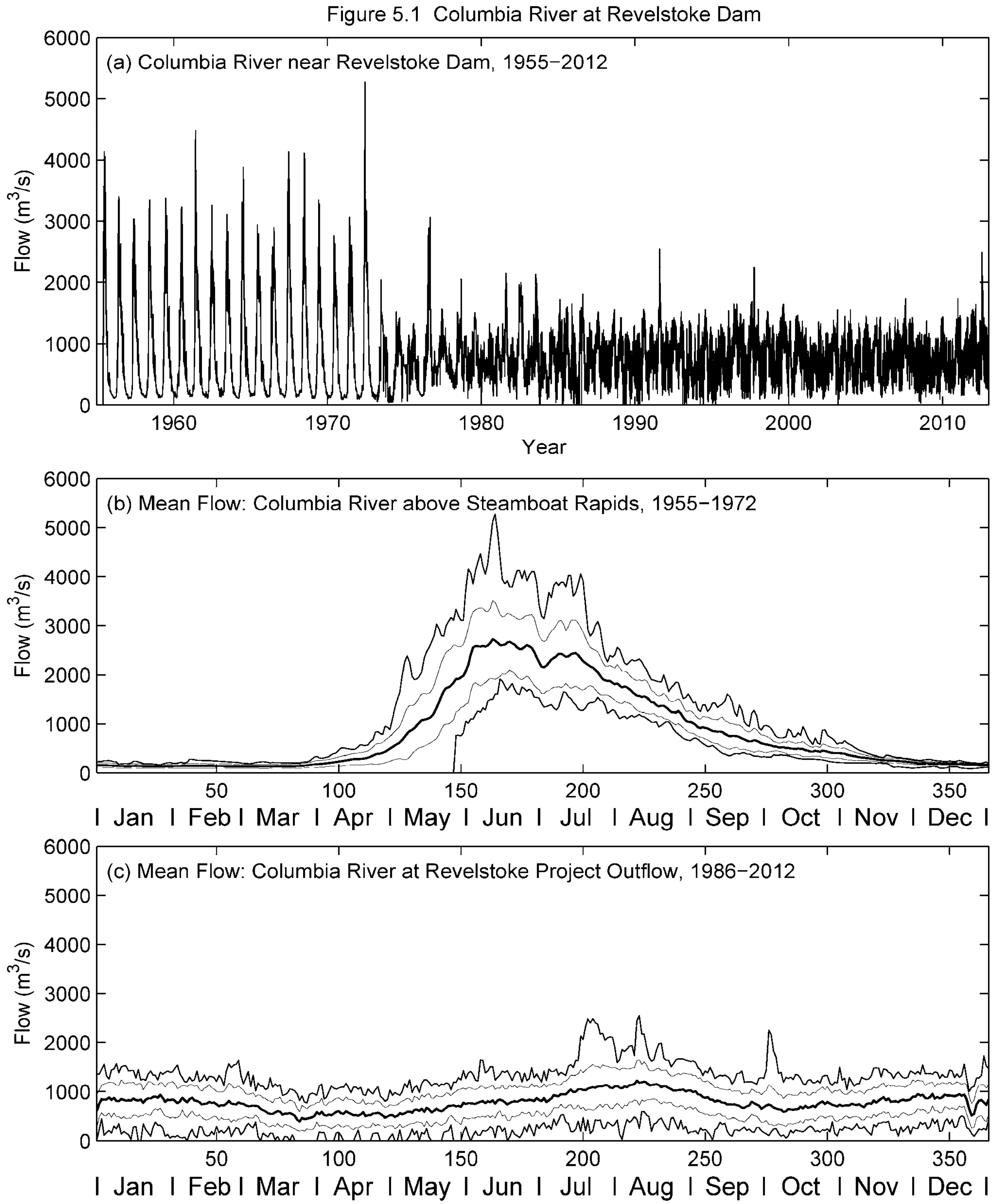


Figure 5.1. **(a)** WSC station 08ND011, "Columbia River above Steamboat Rapids", 1955-1985 and WSC station 08ND025, "Revelstoke Project Outflow", 1986-2012. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

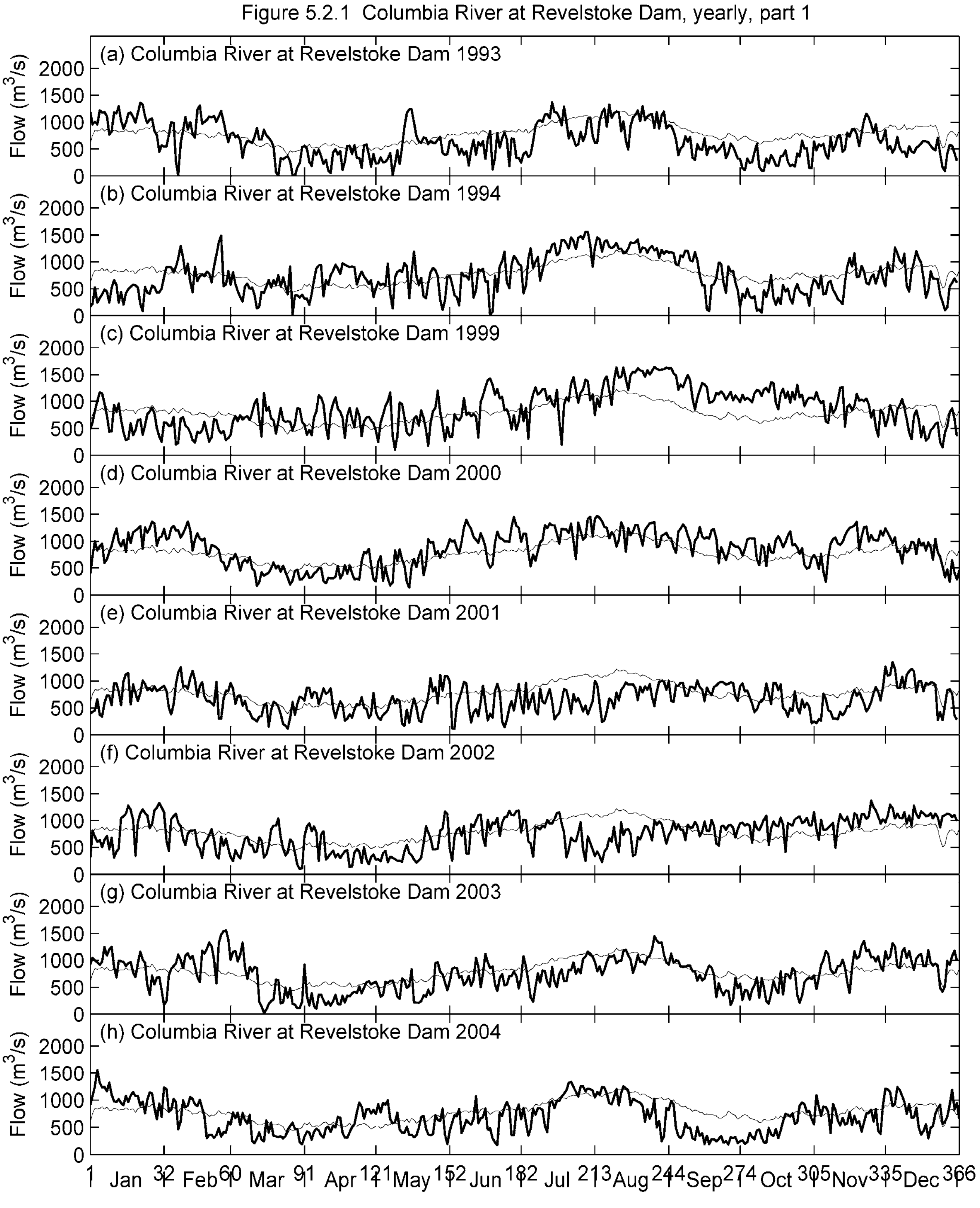


Figure 5.2.1. WSC station 08ND025, “Revelstoke Project Outflow”, selected years (heavy line). Mean flow for 1986-2012 (light line) is shown for comparison.

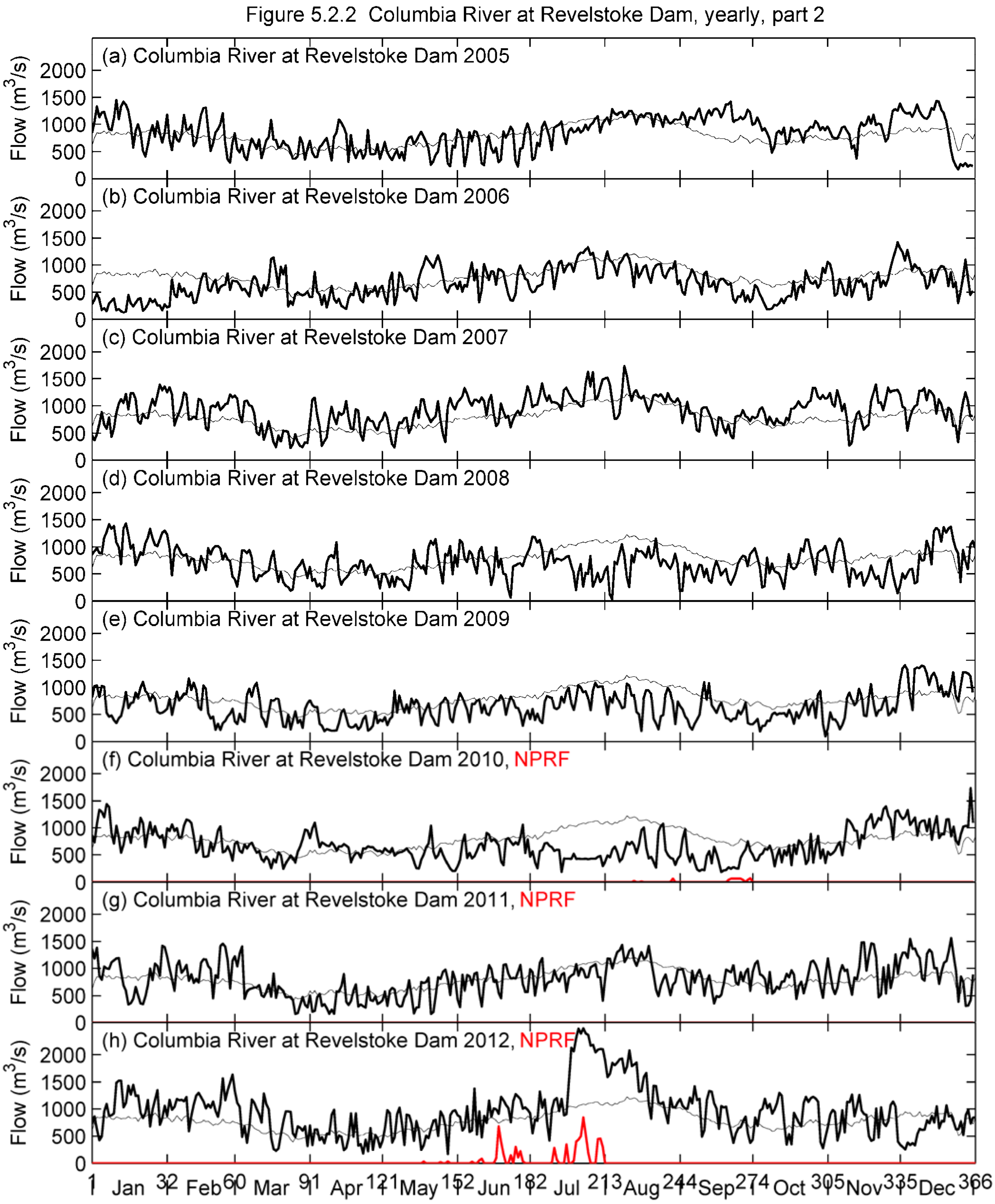


Figure 5.2.2. WSC station 08ND025, “Revelstoke Project Outflow”, selected years (heavy line). Mean flow for 1986-2012 (light line) is shown for comparison. NPRF (RED) marks non-power flow (spill).

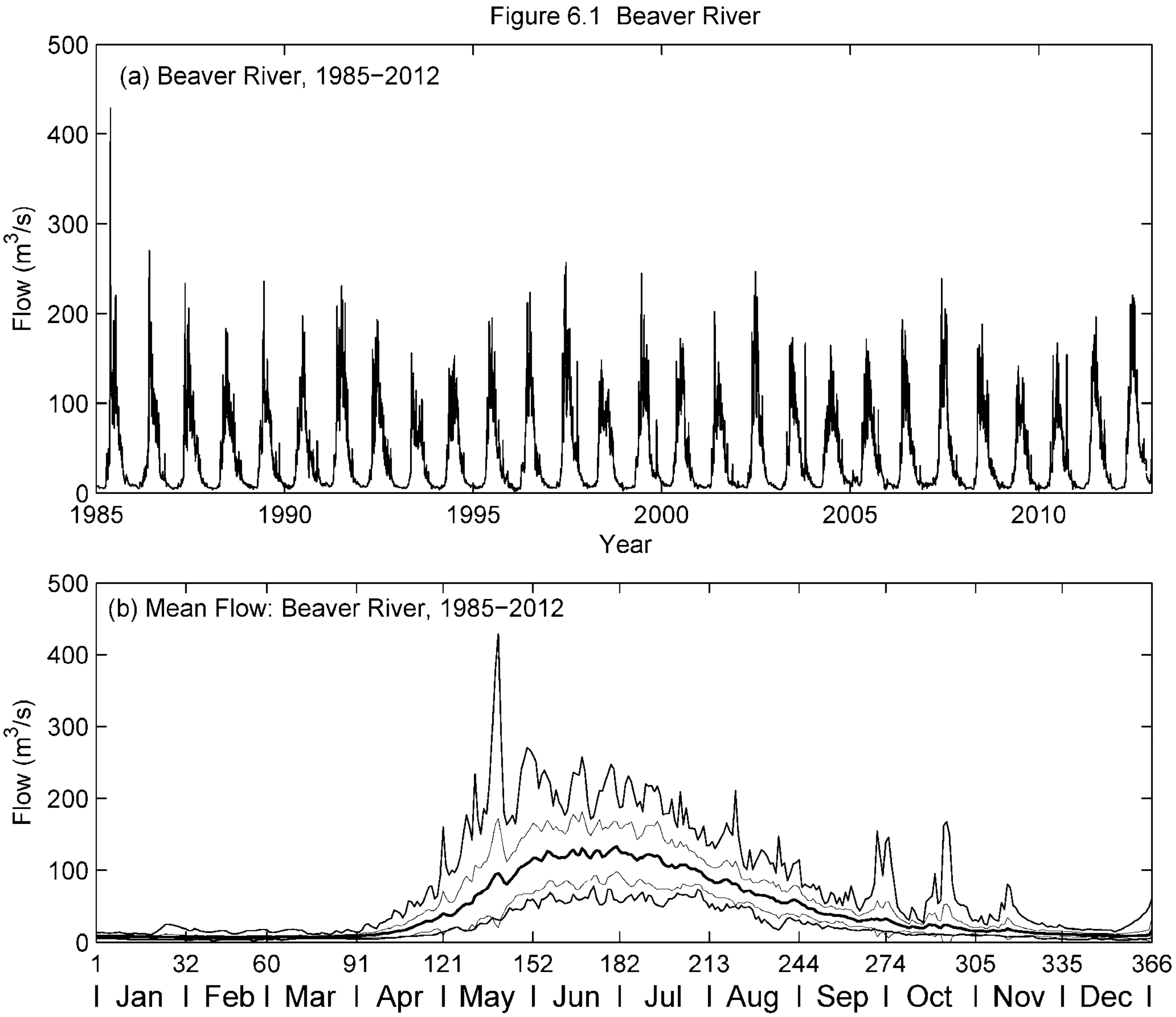


Figure 6.1. **(a)** WSC station 08NB019, "'Beaver River near the Mouth", 1985-2012. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

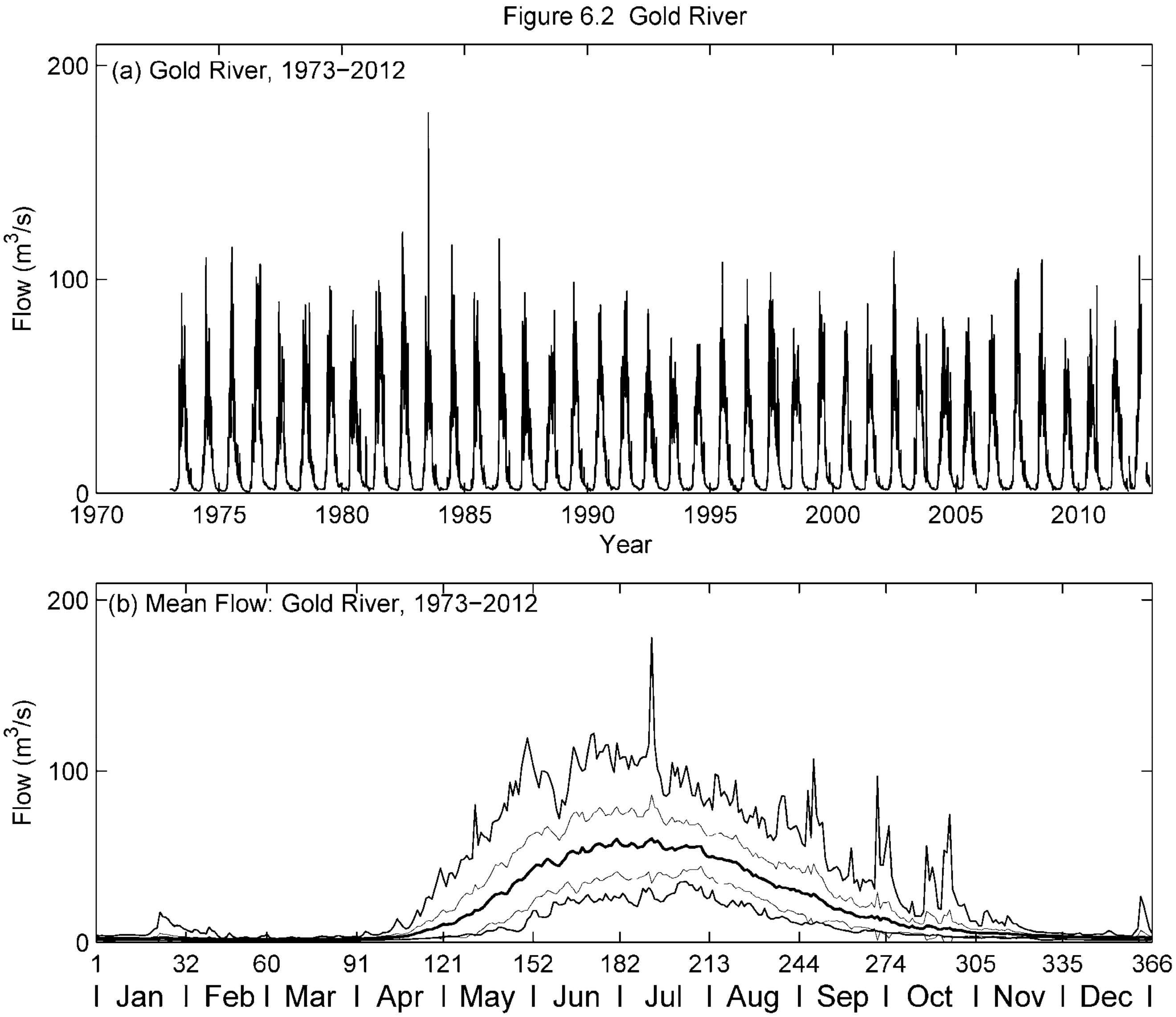


Figure 6.2. **(a)** WSC station 08NB014, "Gold River above Palmer Creek", 1973-2012. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

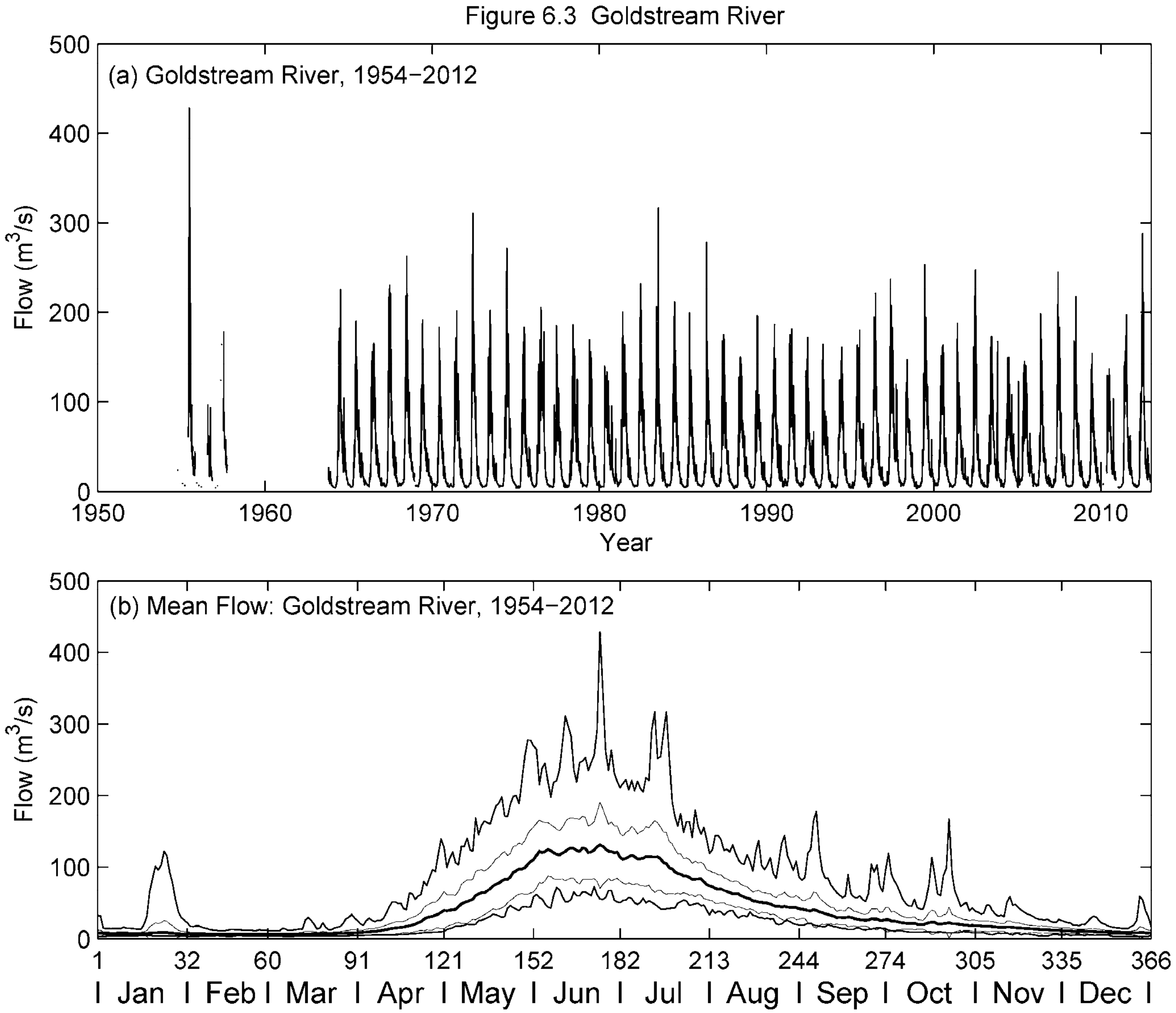


Figure 6.3. **(a)** WSC station 08ND012, "Goldstream River below Old Camp Creek", 1954-2012. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

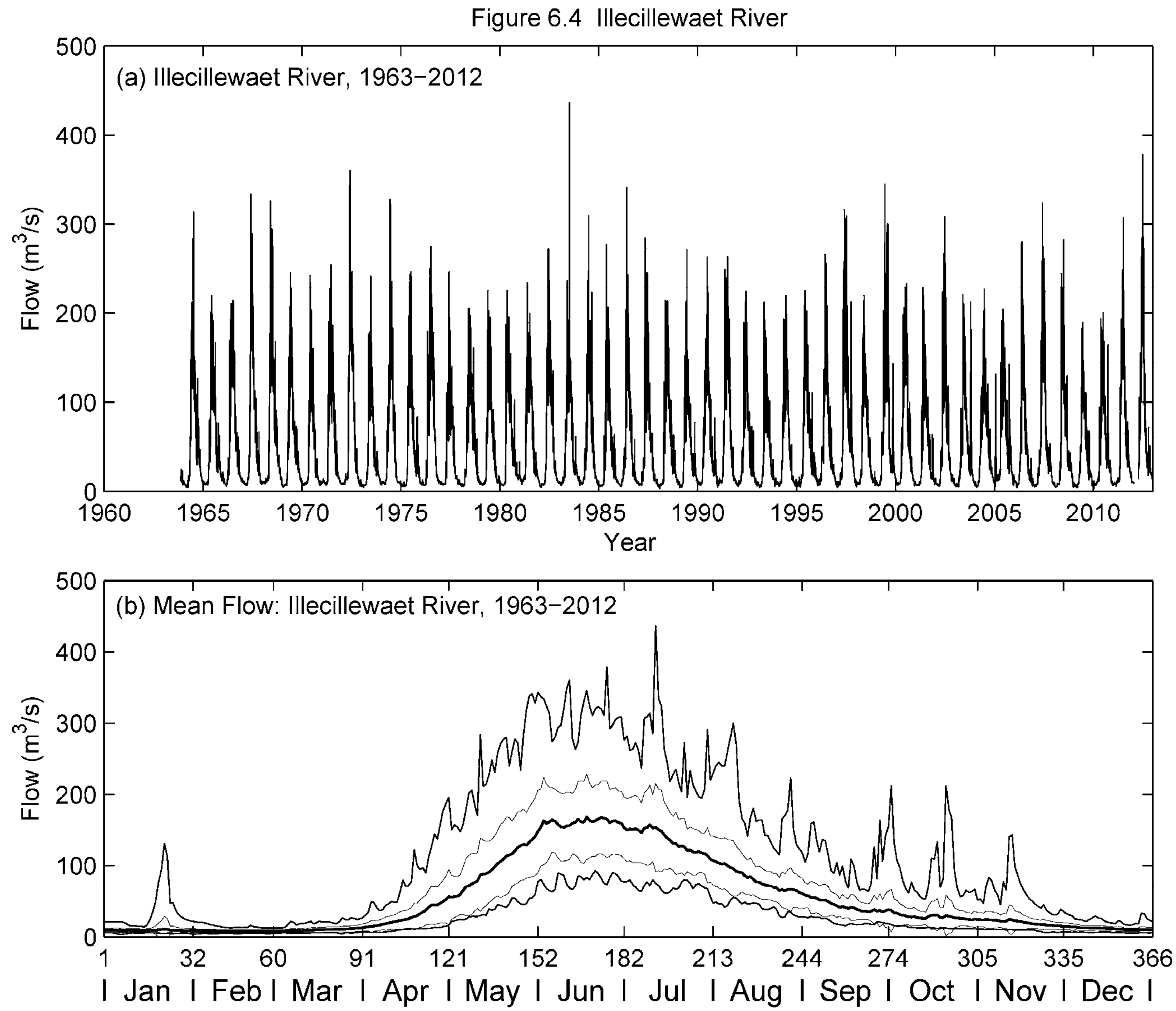


Figure 6.4. **(a)** WSC station 08ND013, "Illecillewaet River at Greeley", 1963-2012. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

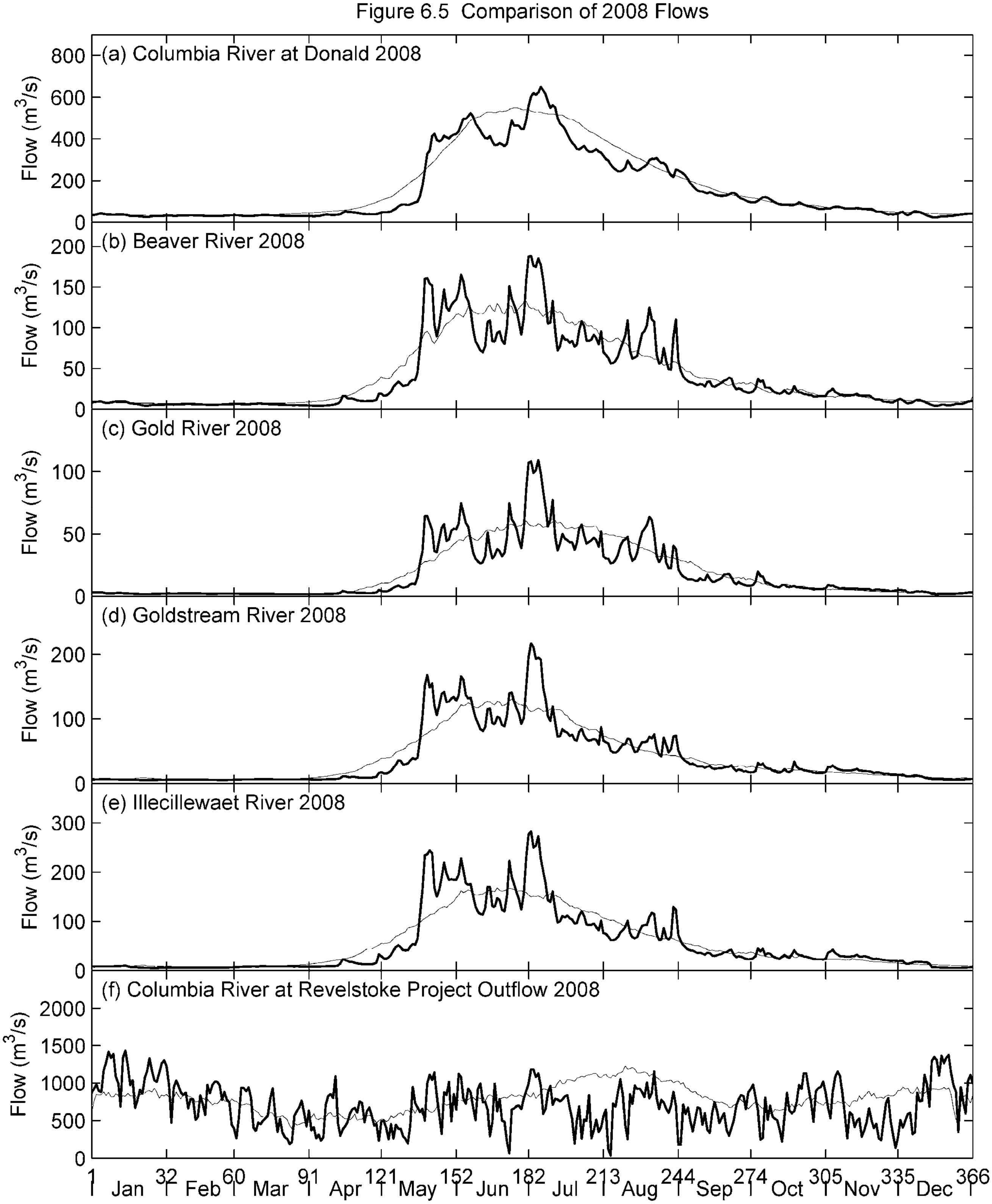


Figure 6.5. Comparison of flows in 2008 for the stations indicated (heavy line). Mean flows for **a)** 1944-2012 **b)** 1985-2012 **c)** 1973-2012 **d)** 1954-2012 **e)** 1963-2012 **f**) 1986-2012 (light line).

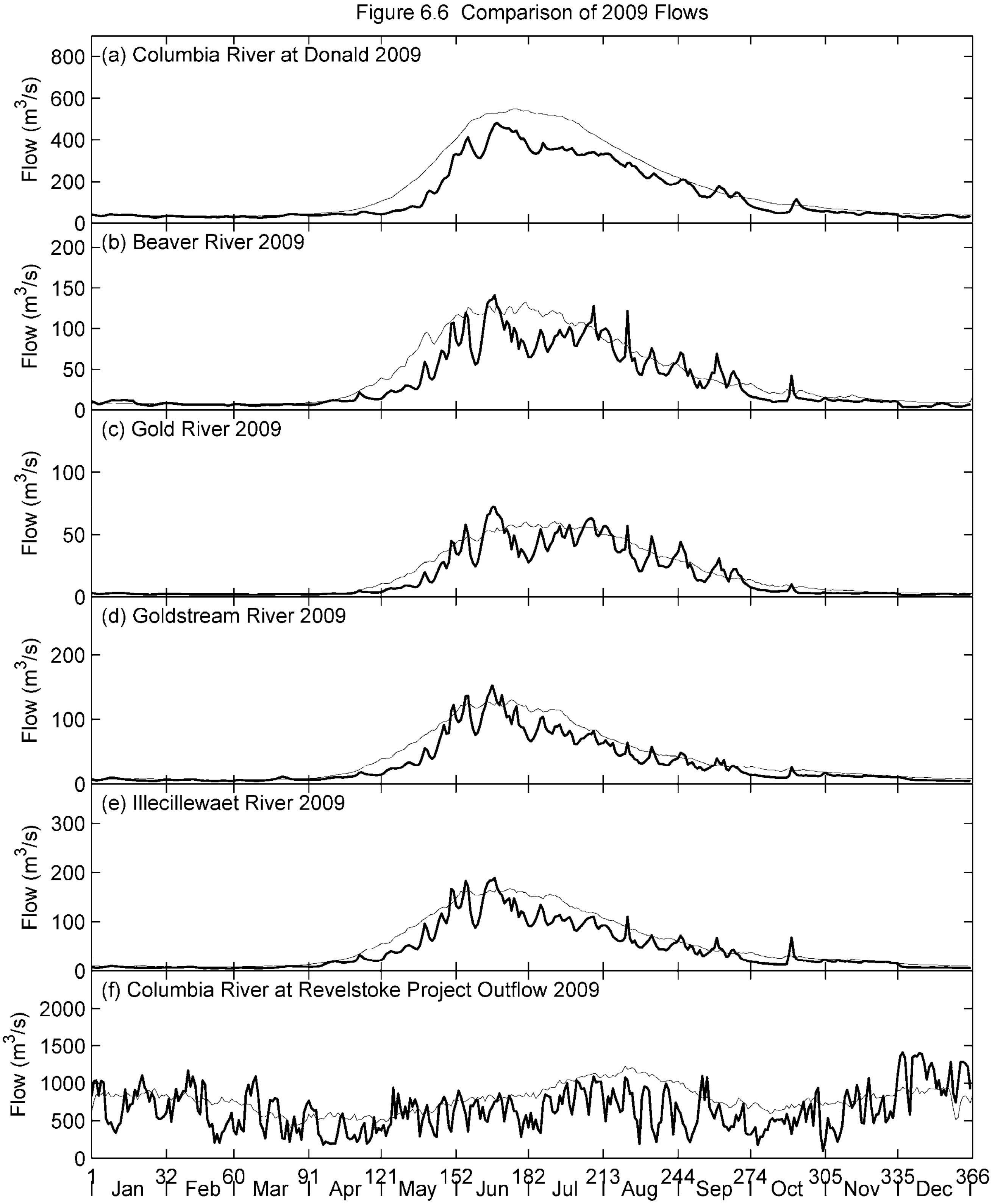


Figure 6.6. Comparison of flows in 2009 for the stations indicated (heavy line). Mean flows for **a)** 1944-2012 **b)** 1985-2012 **c)** 1973-2012 **d)** 1954-2012 **e)** 1963-2012 **f**) 1986-2012 (light line).

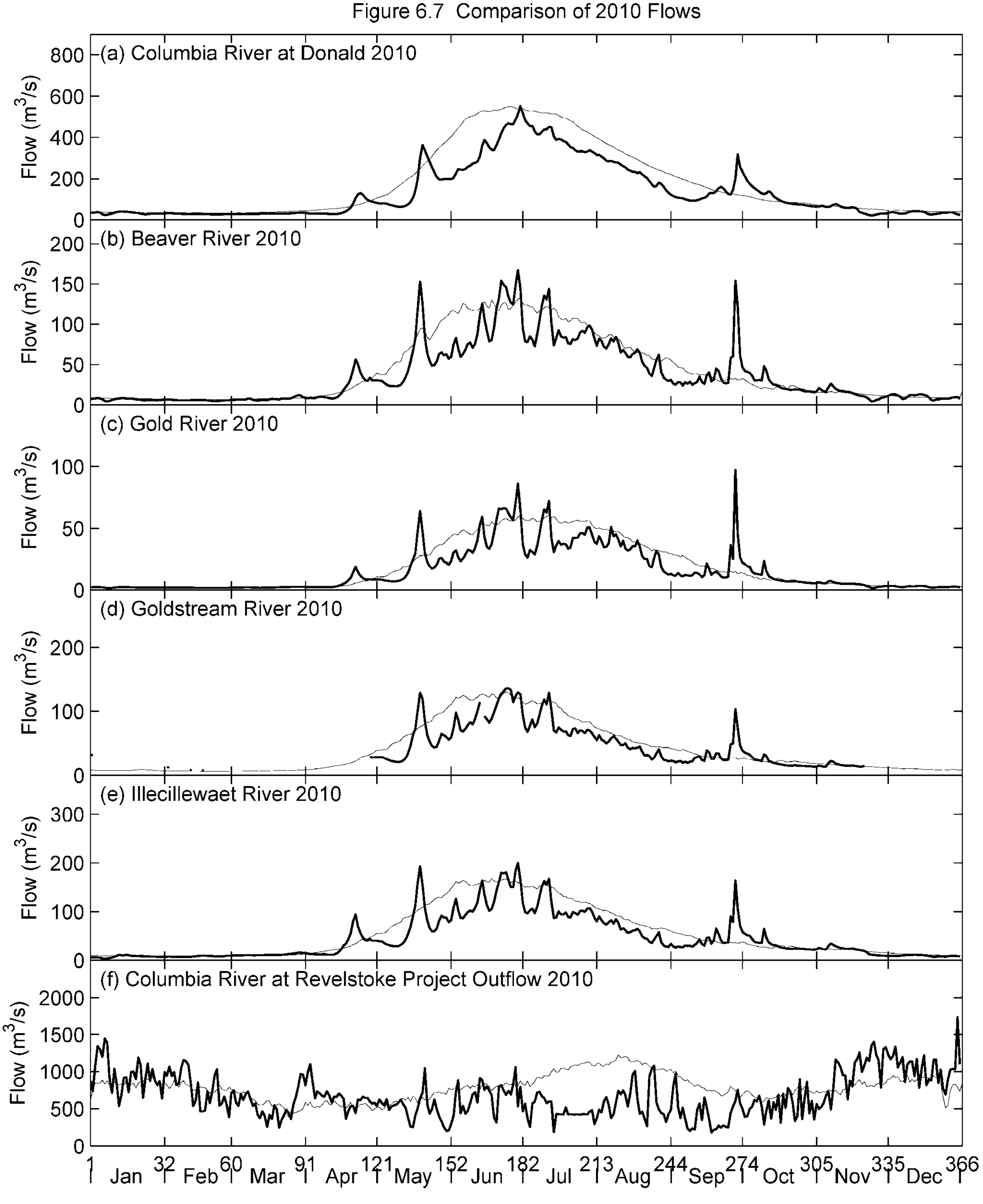


Figure 6.7. Comparison of flows in 2010 for the stations indicated (heavy line). Mean flows for **a)** 1944-2012 **b)** 1985-2012 **c)** 1973-2012 **d)** 1954-2012 **e)** 1963-2012 **f**) 1986-2012 (light line).

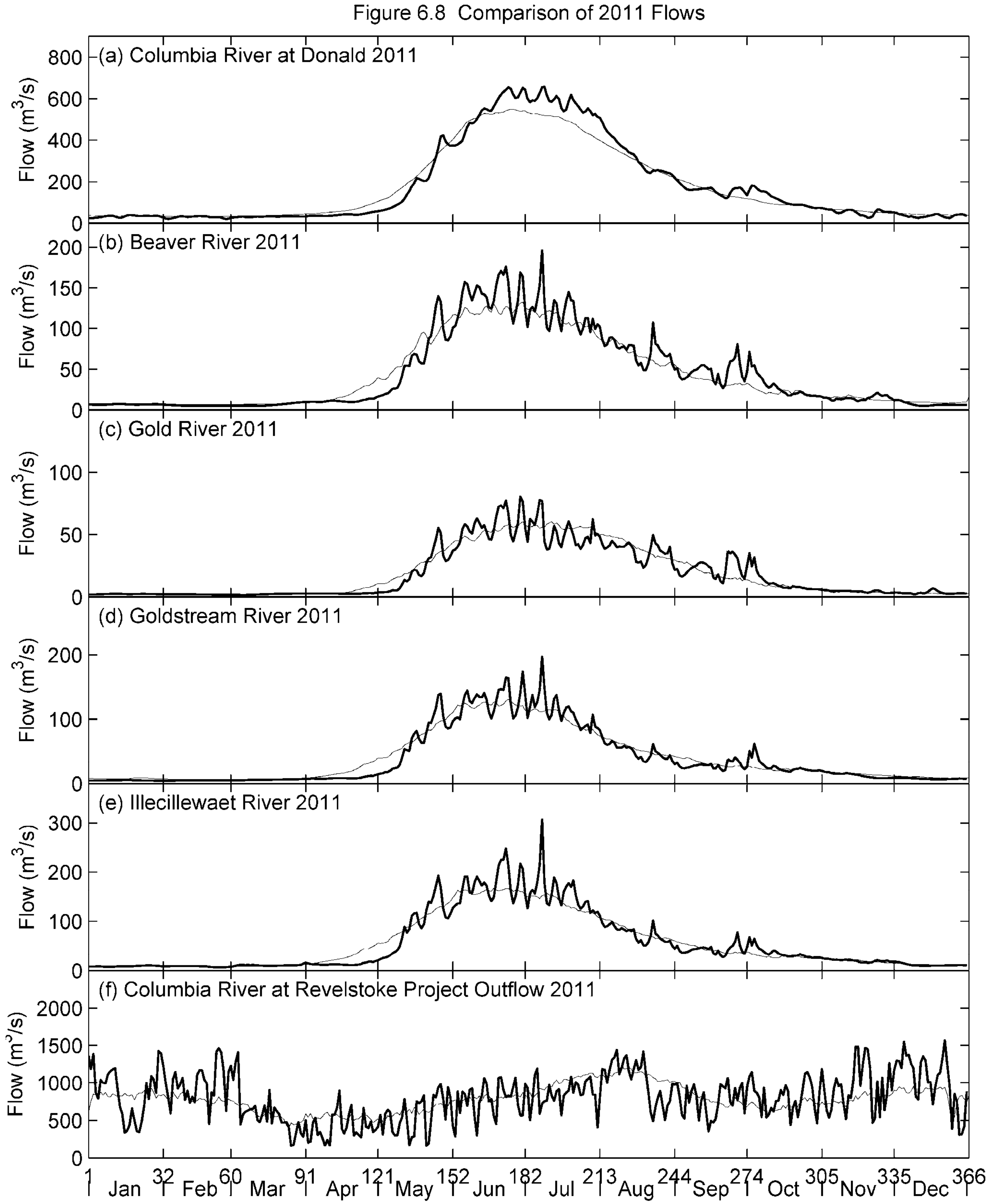


Figure 6.8. Comparison of flows in 2011 for the stations indicated (heavy line). Mean flows for **a)** 1944-2012 **b)** 1985-2012 **c)** 1973-2012 **d)** 1954-2012 **e)** 1963-2012 **f)** 1986-2012 (light line).

Figure 6.9 Comparison of 2012 Flows

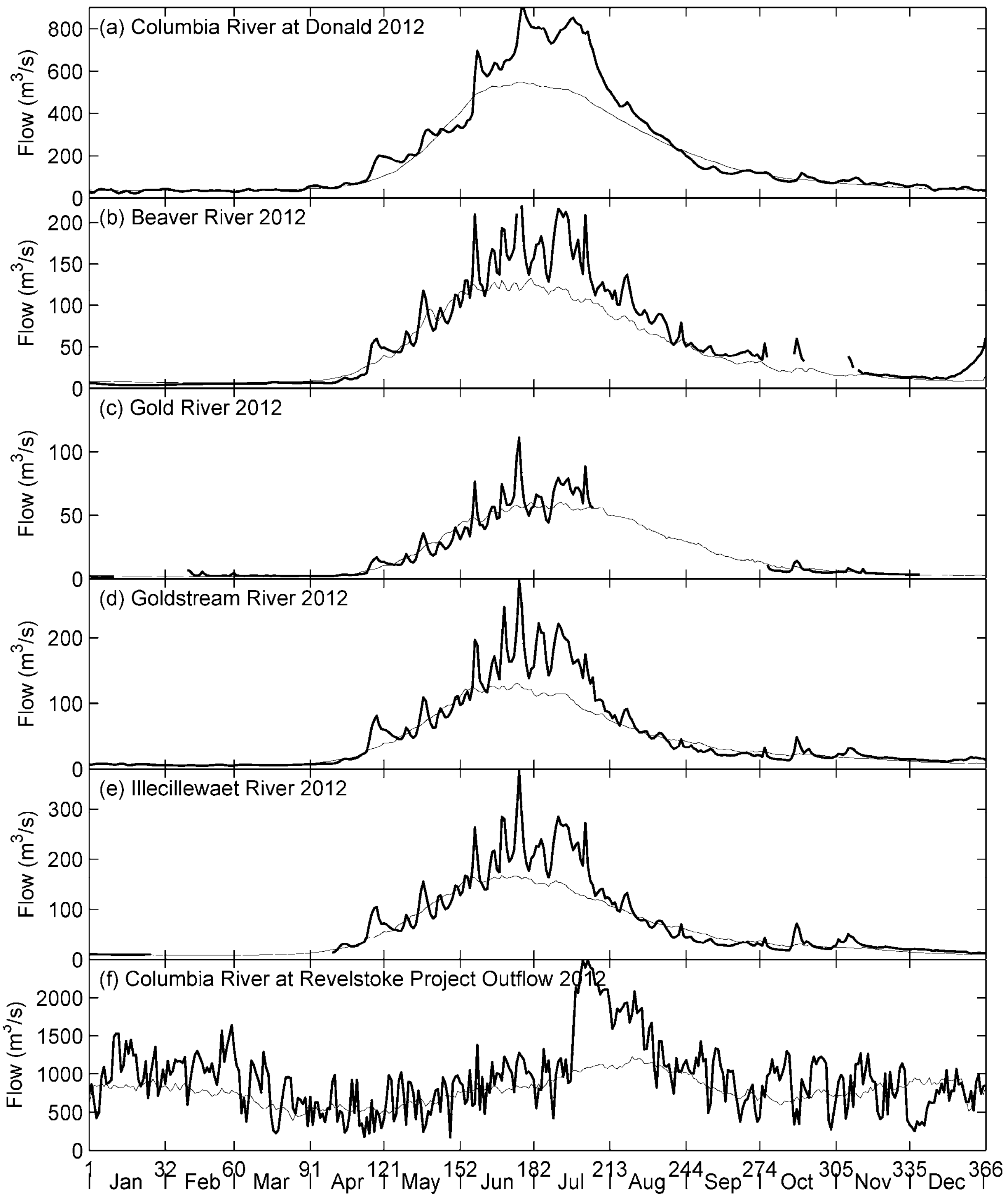


Figure 6.9. Comparison of flows in 2012 for the stations indicated (heavy line). Mean flows for **a)** 1944-2012 **b)** 1985-2012 **c)** 1973-2012 **d)** 1954-2012 **e)** 1963-2012 **f**) 1986-2012 (light line).

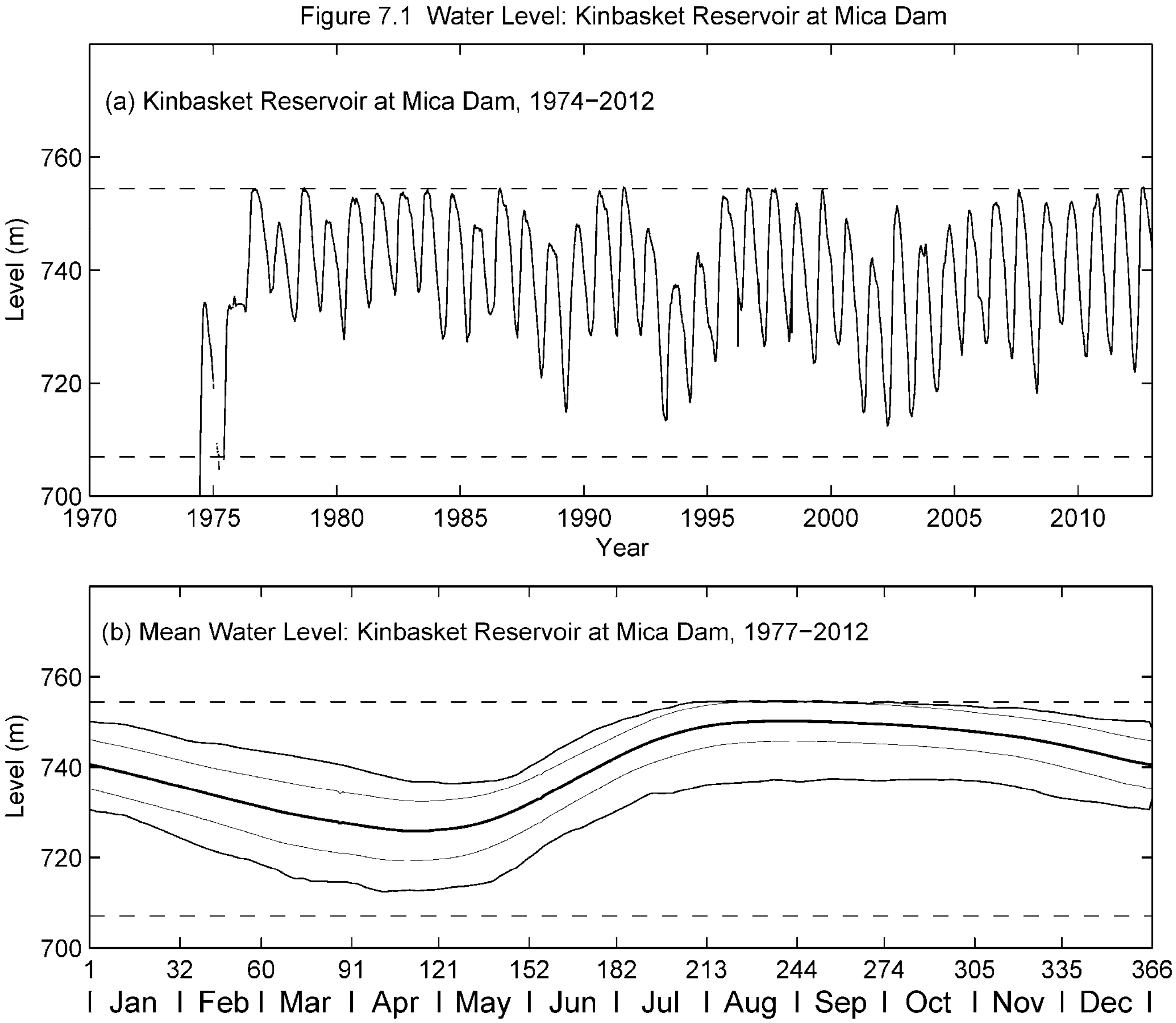


Figure 7.1. **(a)** WSC station 08ND017 “Kinbasket Lake at Mica Dam”, 1974-2012. **(b)** Mean daily water level for 1977-2012. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

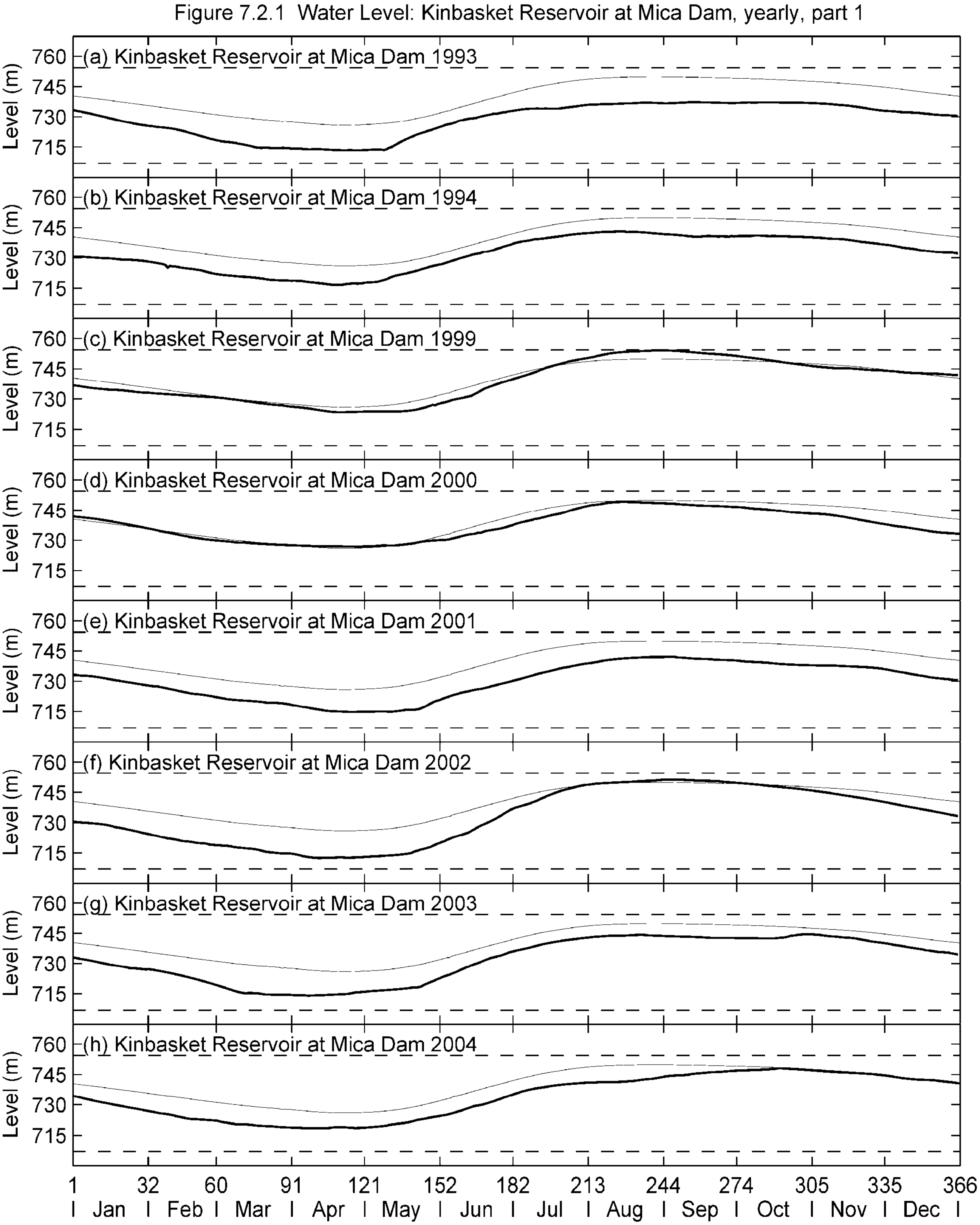


Figure 7.2.1. Water levels for WSC station 08ND017 “Kinbasket Lake at Mica Dam”, selected years (heavy line). Mean daily water level for 1977-2012 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

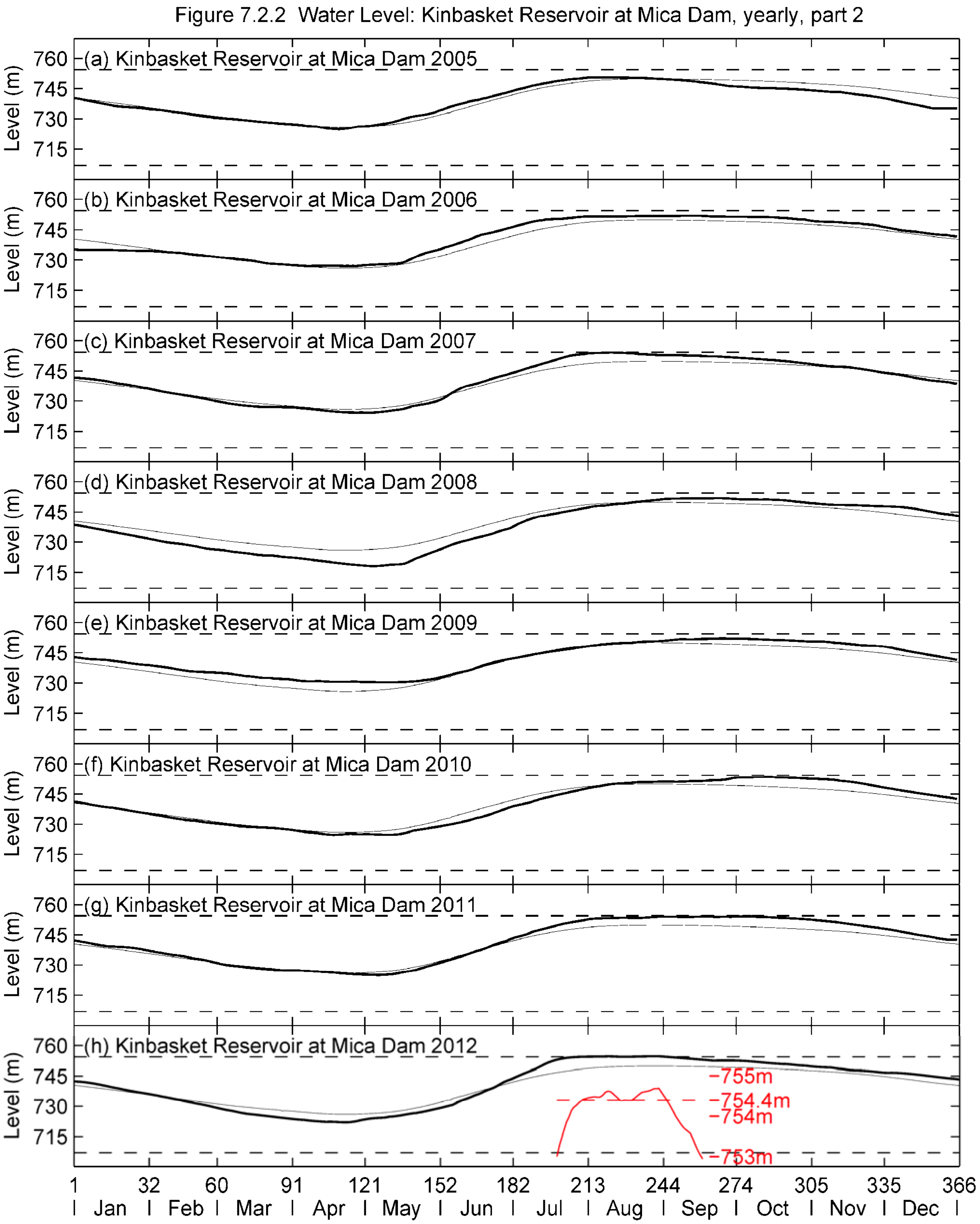


Figure 7.2.2. Water levels for WSC station 08ND017 "Kinbasket Lake at Mica Dam", selected years (heavy line). Mean daily water level for 1977-2012 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

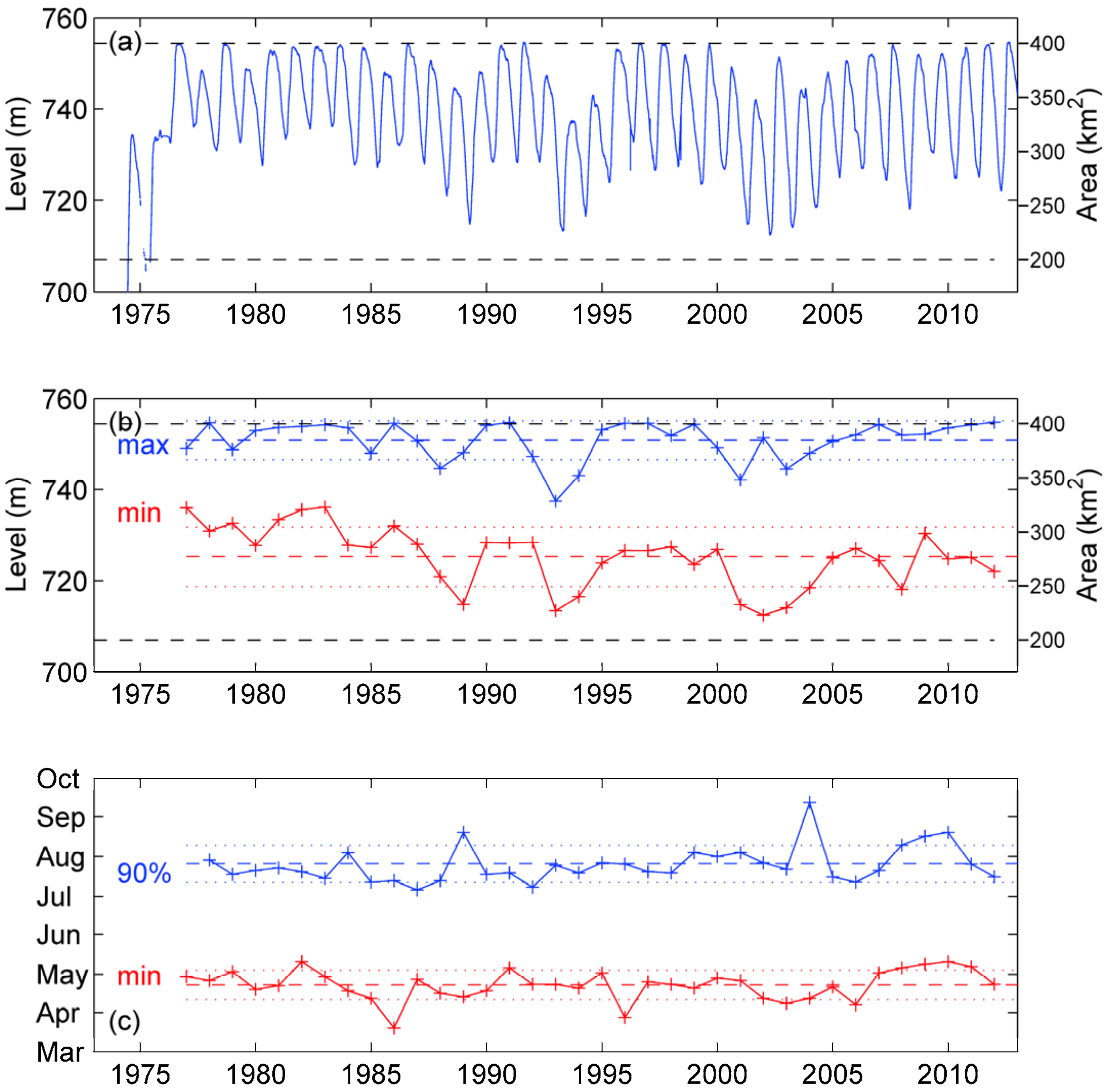


Figure 7.3 (a) Water level in Kinbasket Reservoir, 1973-2012. Black dash lines mark normal minimum and maximum water level. (b) Minimum (red) and maximum (blue) water level for 1977-2012. (c) Date of minimum (red), 90% maximum (blue) water level for 1977-2012. The time to 90% full is shown because the time to the maximum water level can occur later in some years. Red and blue dash lines mark the average, and dotted lines mark ± 1 standard deviation.

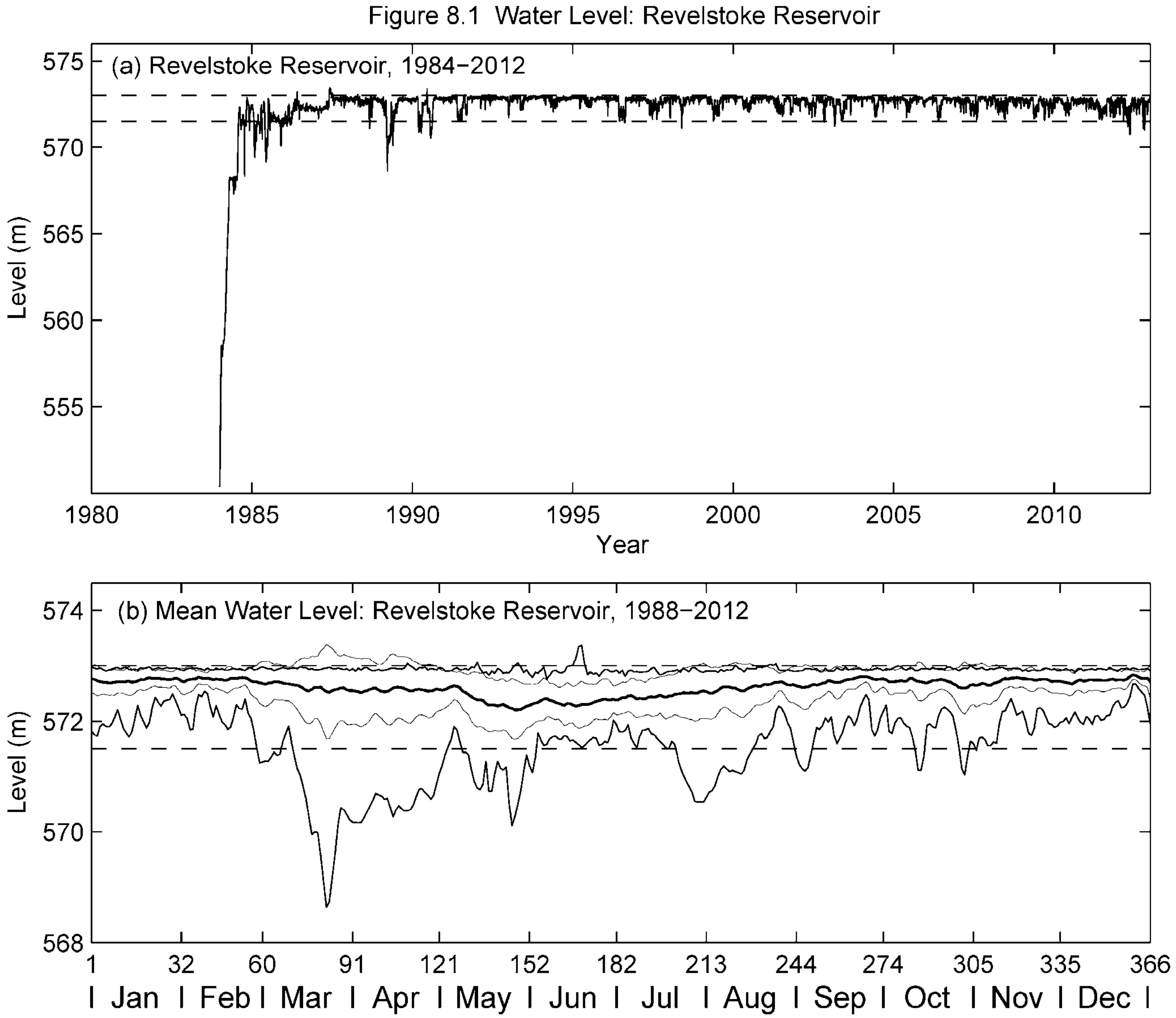


Figure 8.1. (a) BC Hydro station "Revelstoke Lake Forebay", 1984-2012. **(b)** Mean daily water level for 1988-2012. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

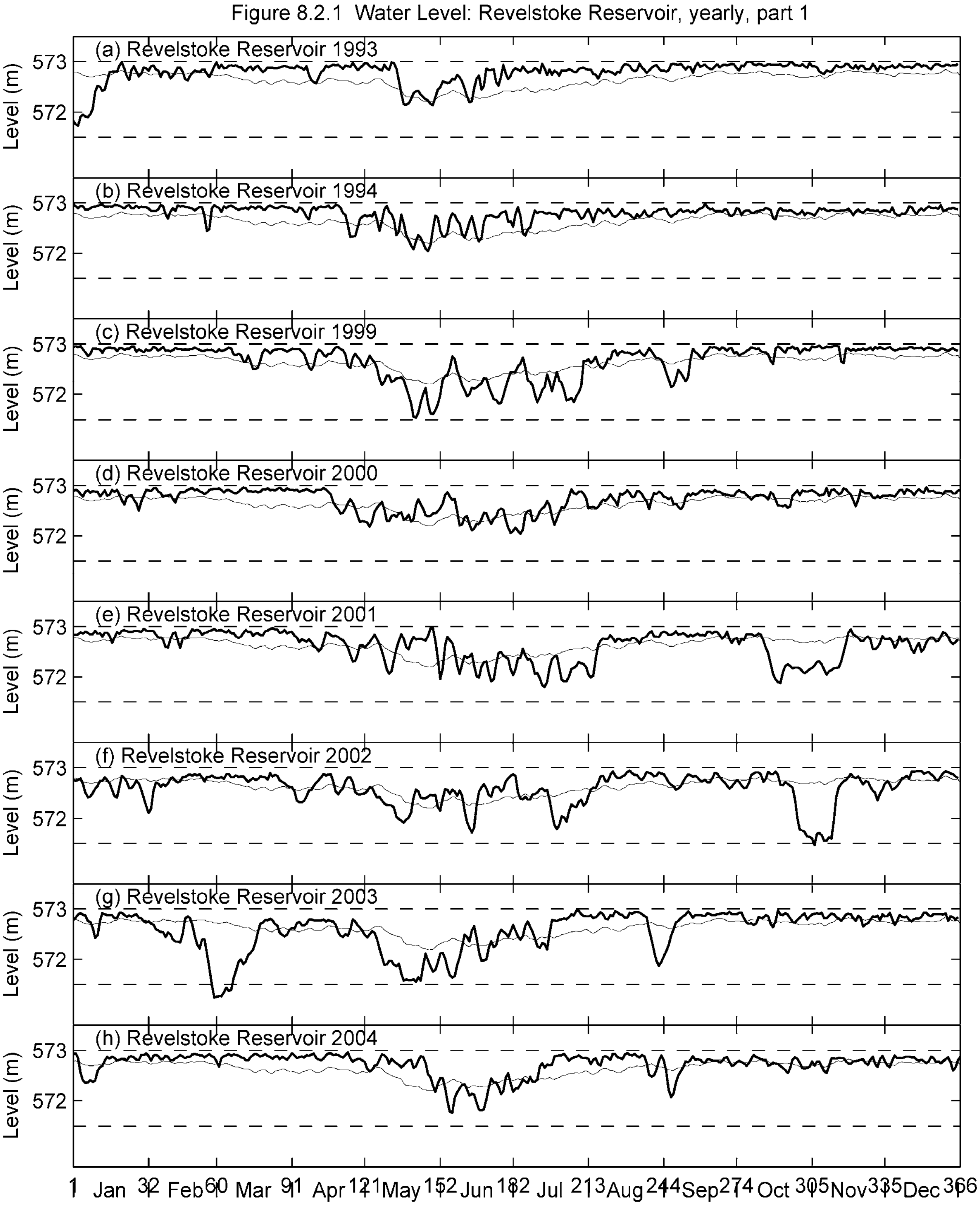


Figure 8.2.1. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2012 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

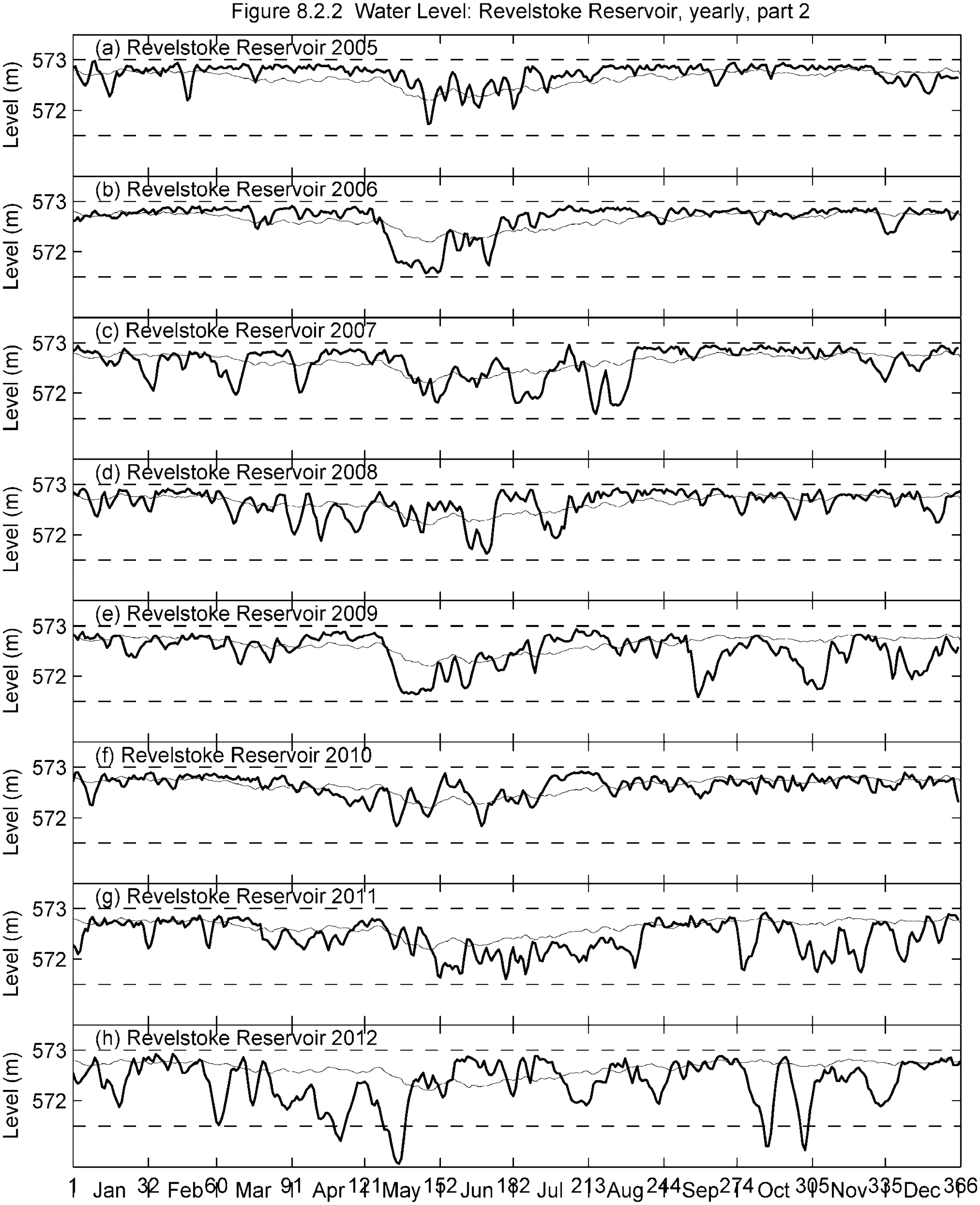


Figure 8.2.2. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2012 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

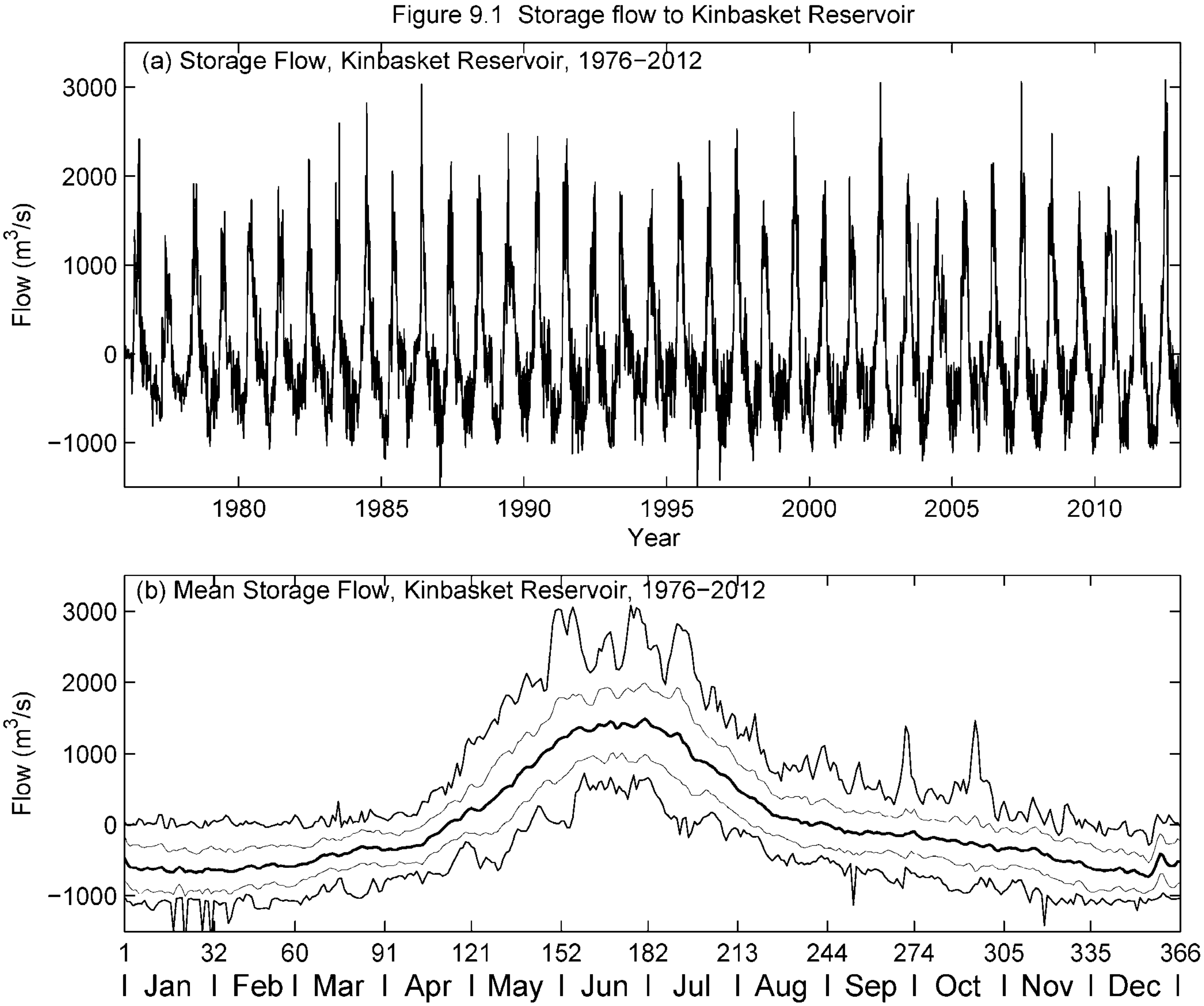


Figure 9.1. **(a)** Storage flow to Kinbasket Reservoir, 1976-2012. **(b)** Mean daily storage flow for 1976-2012. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

Figure 9.2.1 Kinbasket storage flow, yearly, part 1

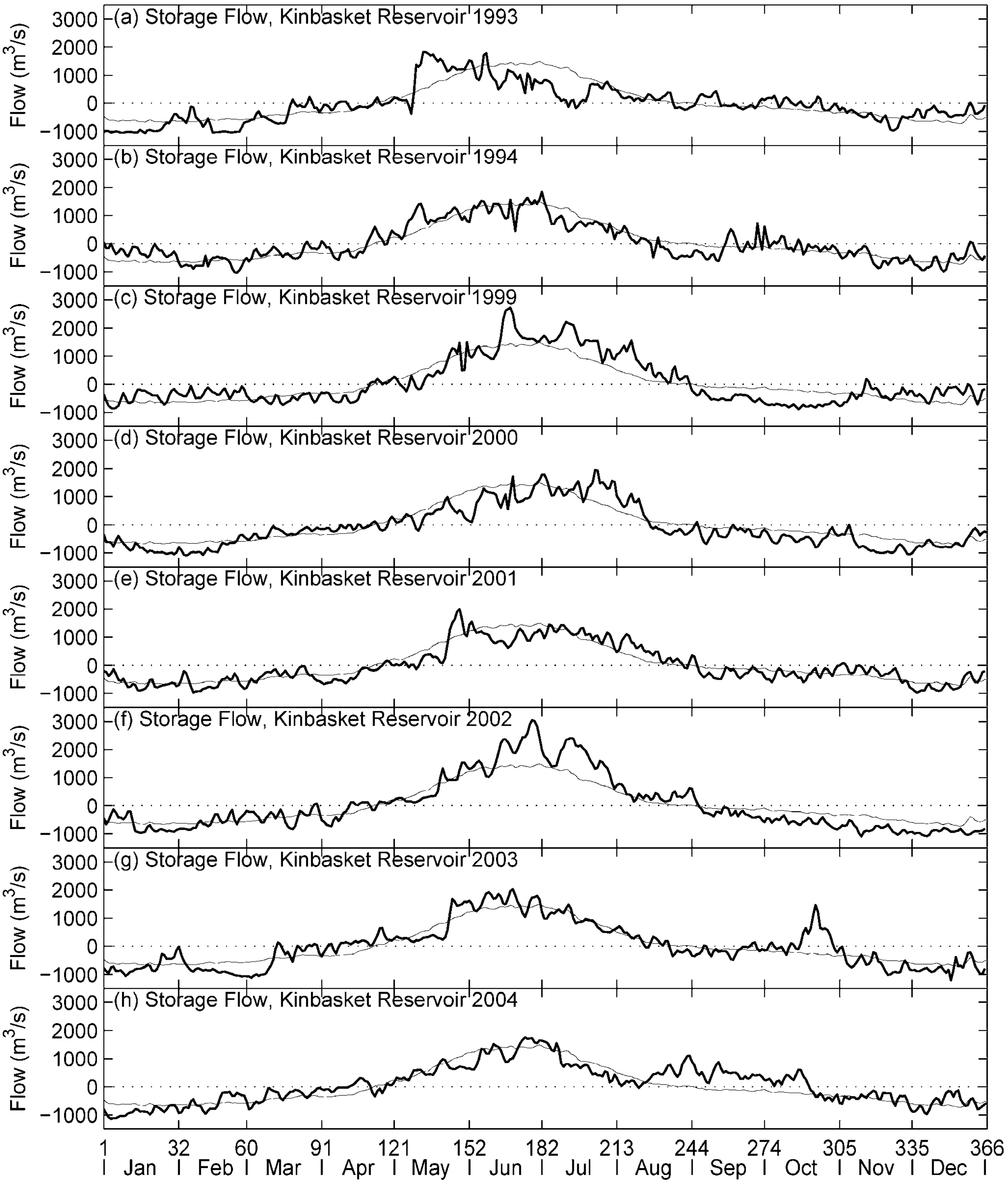


Figure 9.2.1. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2012 (light line) is shown for comparison.

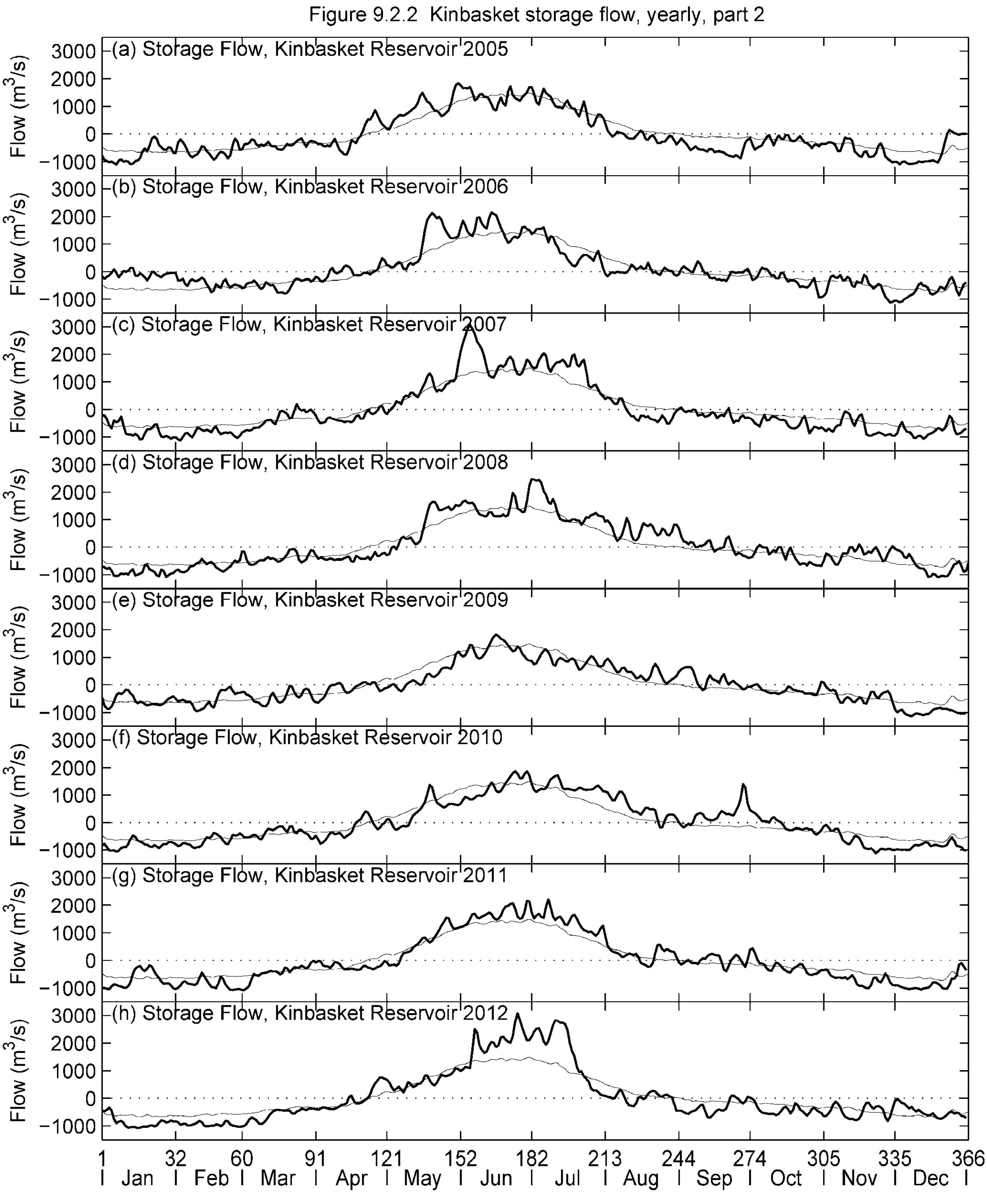


Figure 9.2.2. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2012 (light line) is shown for comparison.

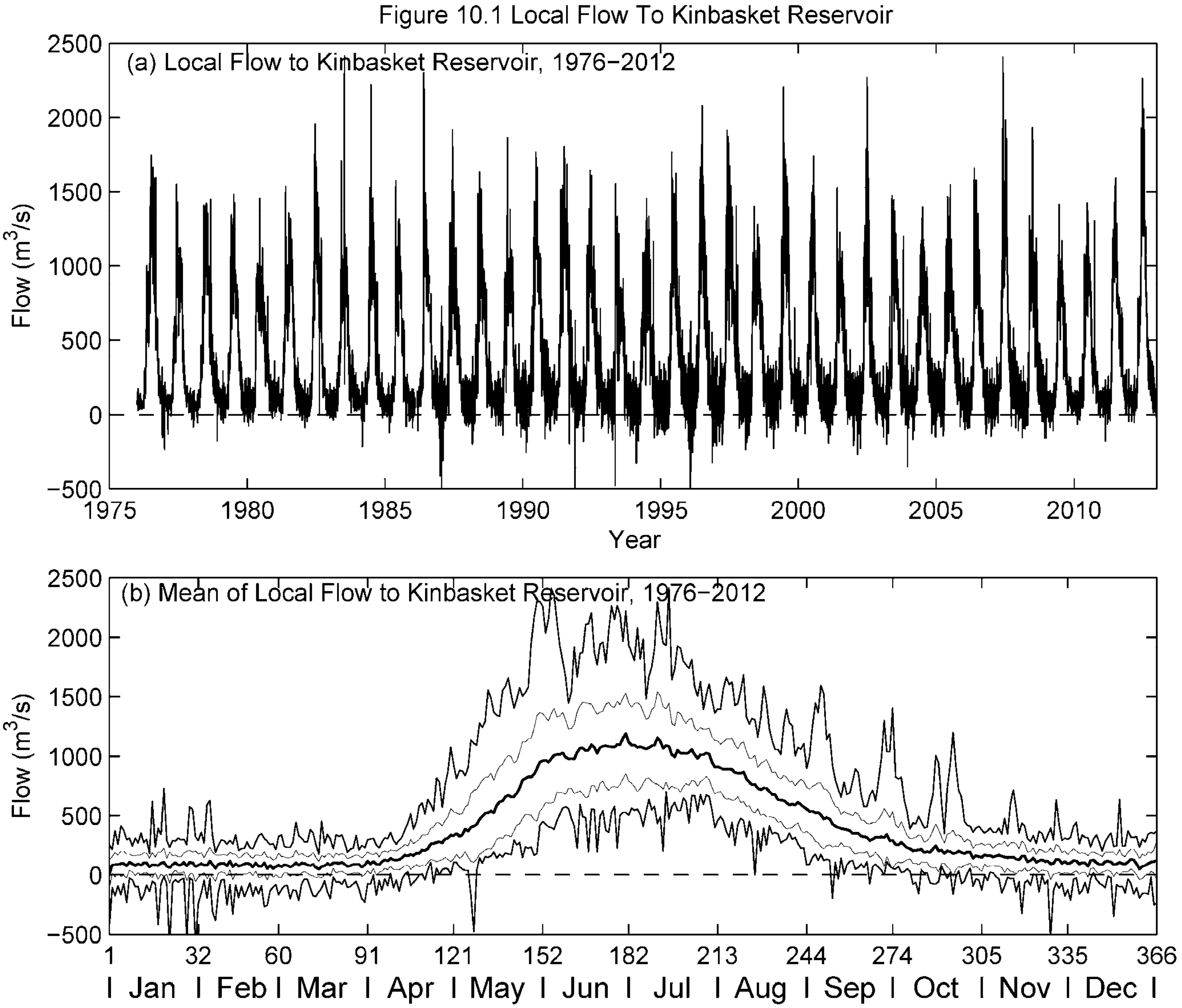


Figure 10.1. **(a)** Local flow to Kinbasket Reservoir, 1976-2012. **(b)** Mean daily local flow for 1976-2012. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

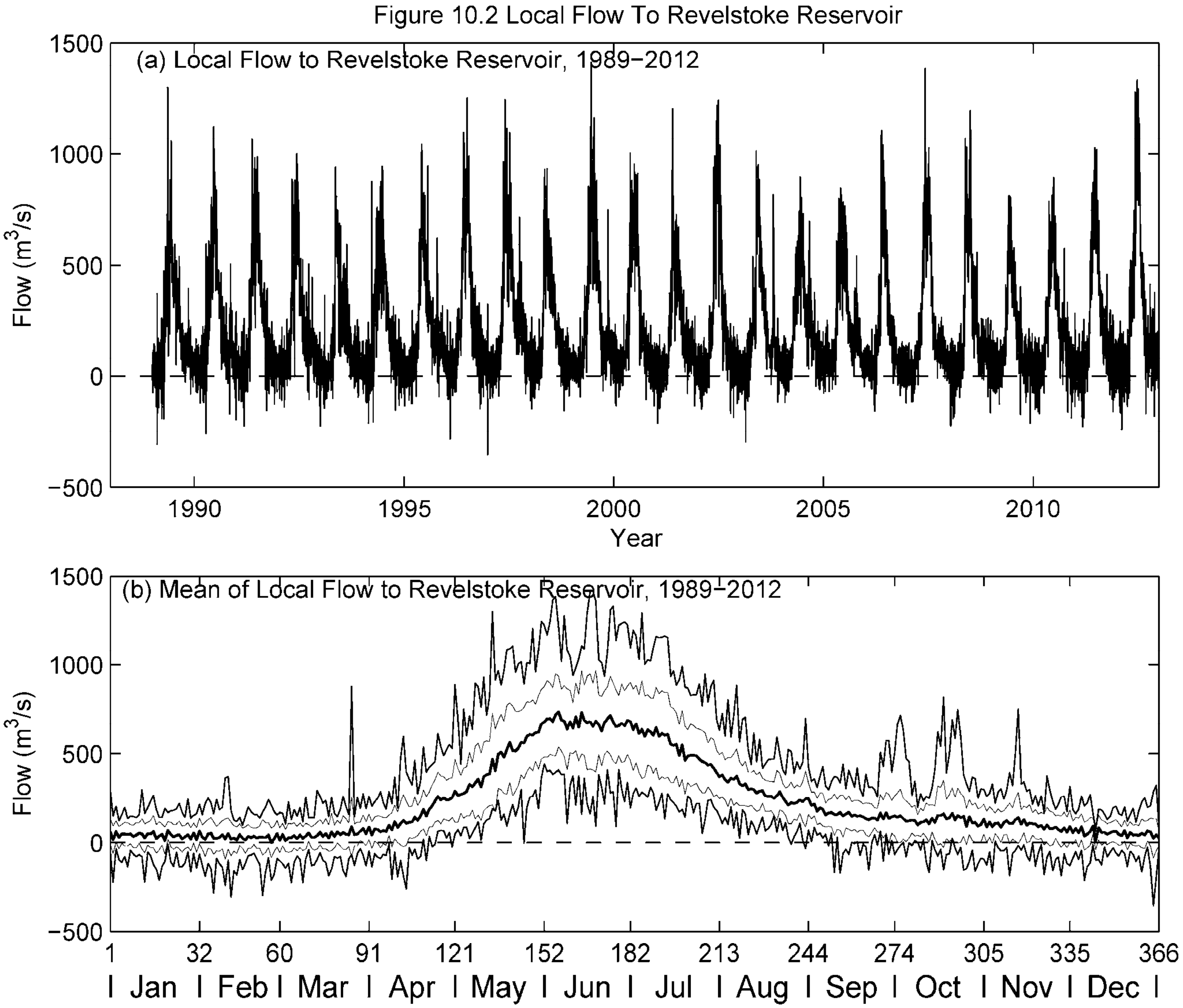


Figure 10.2. **(a)** Local flow to Revelstoke Reservoir, 1976-2012. **(b)** Mean daily local flow for 1976-2012. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

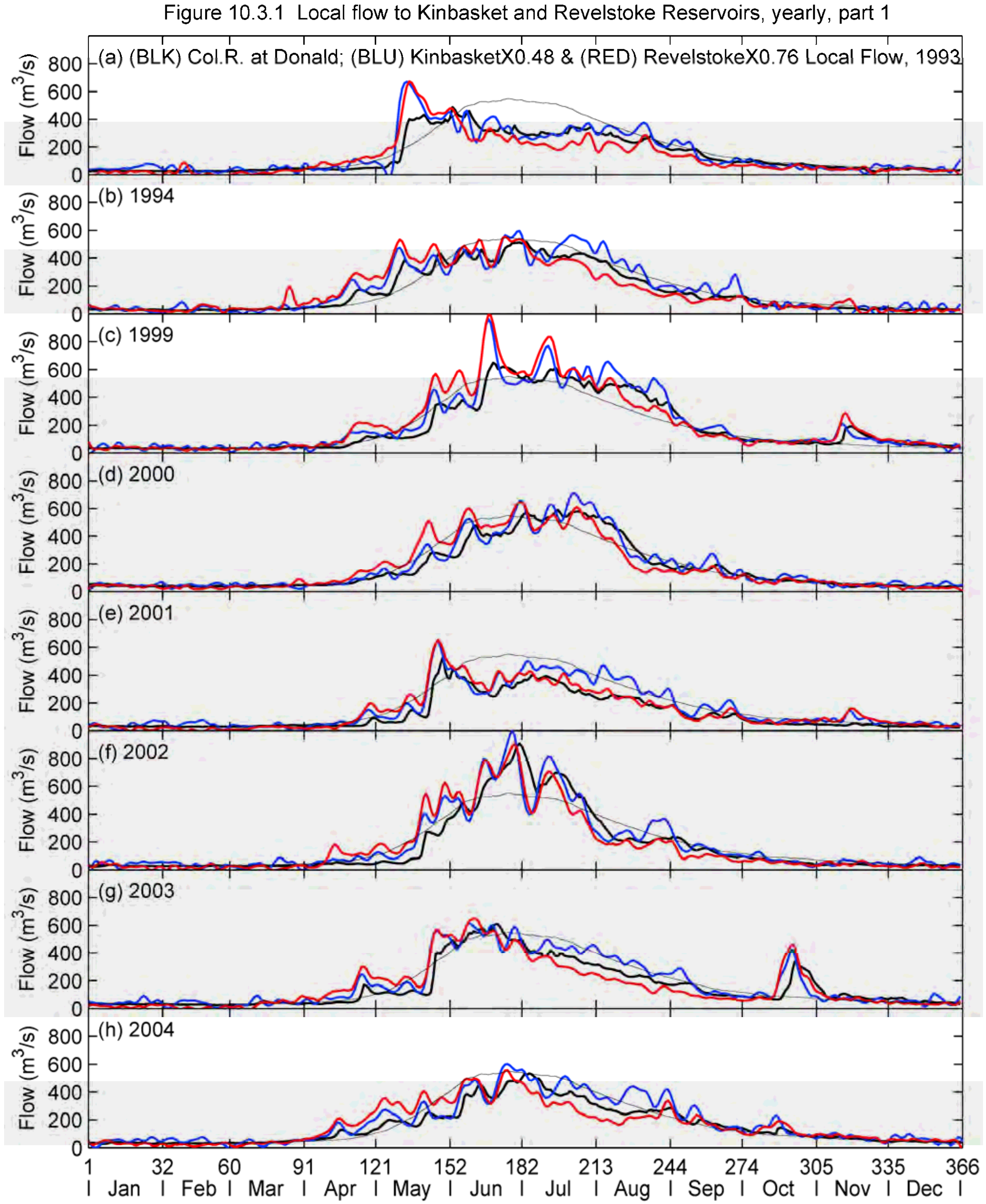


Figure 10.3.1. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2012 (light line) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

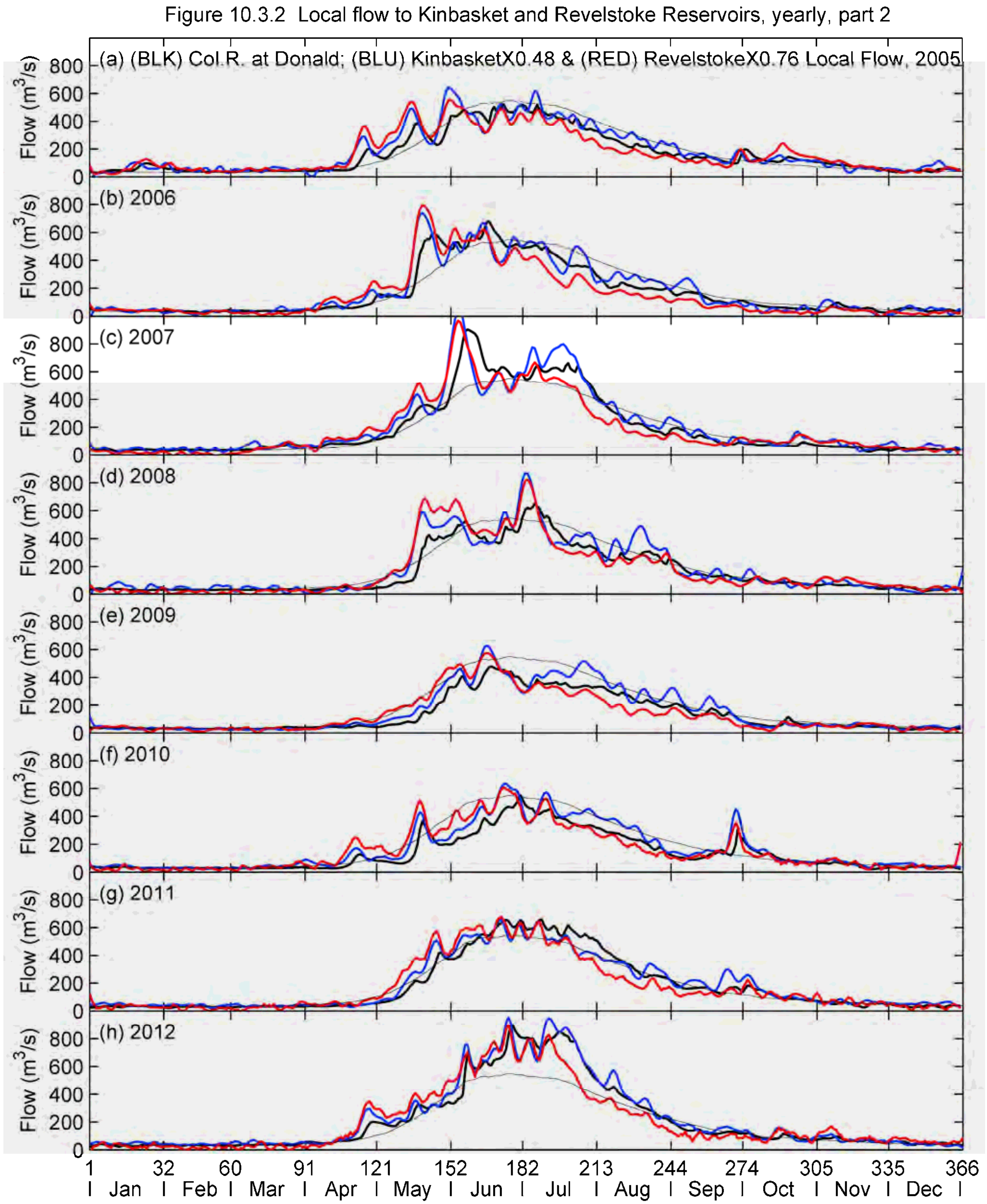


Figure 10.3.2. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2012 (light line) are shown for comparison.

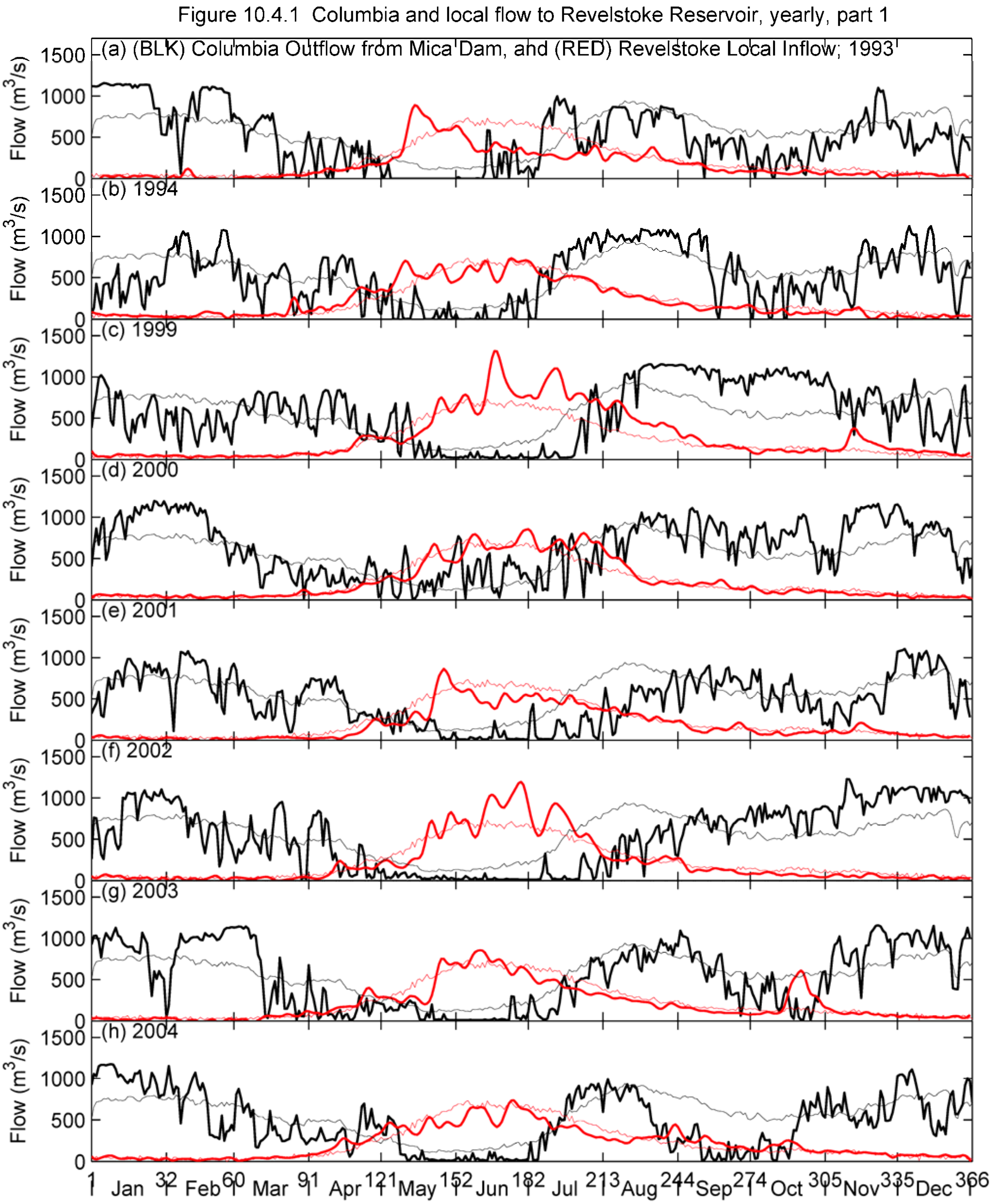


Figure 10.4.1. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison.

Figure 10.4.2 Columbia and local flow to Revelstoke Reservoir, yearly, part 2

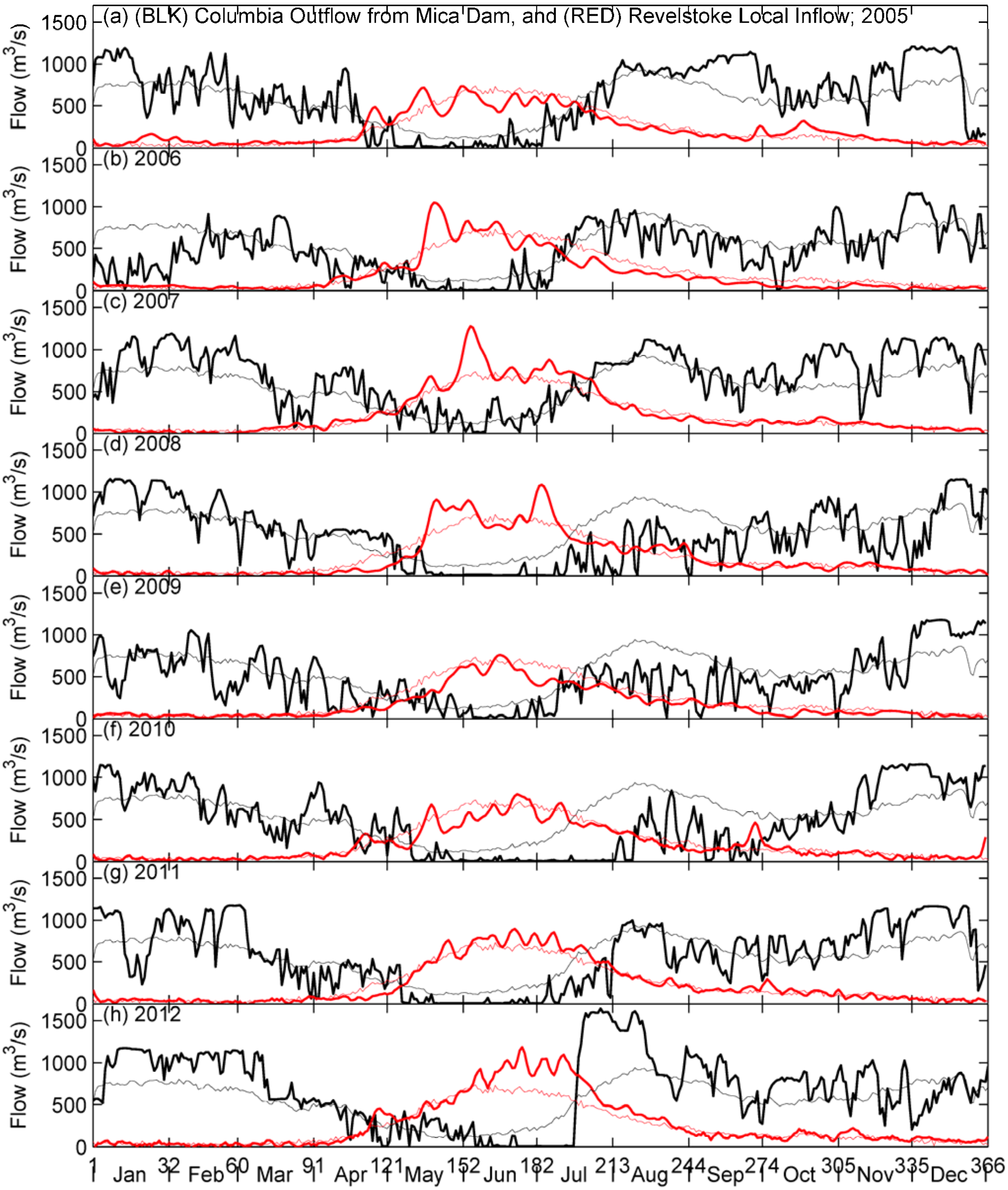


Figure 10.4.2. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

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)

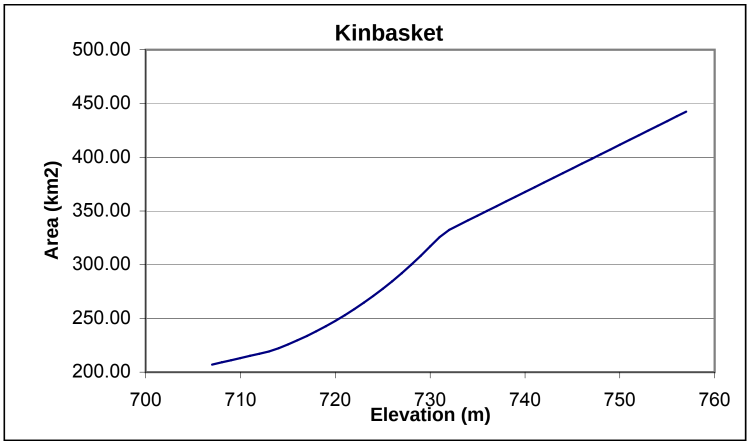
Appendix 3   Storage Elevation Curves

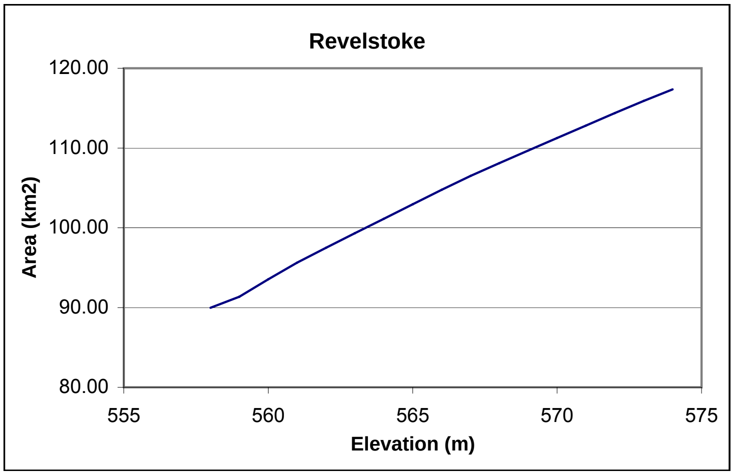
Kinbasket

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, 2012

Roger Pieters and Greg Lawrence
University of British Columbia

Tributary Water Quality
Kinbasket and Revelstoke Reservoirs, 2012

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Revelstoke Reservoir, 26 Apr 2013

Prepared for

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Revelstoke B.C. V0E 2S0

February 12, 2014

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List of Figures

1. Introduction

We report on water quality data collected from reference tributaries to Kinbasket and Revelstoke Reservoirs in 2012. This is the fifth 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, 2011 or 2012 due to lack of helicopter availability. Regular sampling of reference tributaries began in 2009 (Pieters et al. 2011, 2012 and 2013); here we report on the data from the reference tributaries in 2012.

2. Methods

Four reference tributaries – Columbia River at Donald, Goldstream River, Kinbasket Reservoir (Mica Dam) outflow, and Revelstoke Reservoir (Revelstoke Dam) outflow – were sampled twice monthly in May, June, and July, and once a month from August to November in 2012. There was no data for Columbia at Donald on 6 June 2012 due to a mudslide in Glacier Park blocking the Trans-Canada Highway between Revelstoke and Golden. 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 2012 are given in Appendix 3.

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[*] 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	mg$CaCO_3$/L	Alk	
Water Temperature	^{o}C	T	

3. Results

Consider first the natural flows: the Columbia River at Donald and the Beaver River which flow into Kinbasket Reservoir, and the Goldstream River which flows into Revelstoke Reservoir. Data for 2009 to 2012 are shown in Figures 1 through 4, respectively. River flow is shown in Figures 1-4a; the flow at all three locations is highly correlated in any given year. Flow is dominated by spring freshet which peaks from mid-June to early July.

River temperature is shown in Figures 1-4b. 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 1-4c, declined through the freshet to about half by mid-summer. Turbidity (Figures 1-4d) was highly variable while pH remained slightly alkaline (Figures 1-4e).

Even more than conductivity, nitrate and nitrite (NN) concentrations declined by 6 and 7 times from May to mid-summer in 2012 in Goldstream and in Columbia at Donald, respectively (Figures 4f). For example, on 14 May 2012, the Goldstream River had 382 µg/L NN which declined to 65 µg/L by 30 Jul 2012 (Figure 4f); there were similar declines in previous years (Figures 1f, 2f, and 3f). Nitrate in the Columbia River at Donald during summer 2012 was comparatively low, with values ranging from 19-38 µg/L (Figure 4f). As in previous years, the concentrations of SRP were low in 2012

(Figure 4g), 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 (3-8 µg/L) and relatively constant (Figure 4h). TP was highly variable (Figure 4i), 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 2012, with NN:TDP ratios < 10 persisting until late October (Figure 4j).

In Figures 5 to 8, 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 will be noted for different parameters below, the results for the Columbia River at Mica can be influenced by Revelstoke Reservoir when outflow is low, such as typically occurs during summer (Figure 5-8a).

As in previous years, the temperature of the outflows from the dams were cold as a result of the deep intakes (<10 ºC, Figure 8b). An exception was the Mica outflow in July and August 2010 when two temperature readings were warmer; at low flow, the temperature below Mica Dam may have been influenced by Revelstoke Reservoir (Figure 6b). Another exception was the Revelstoke outflow reaching 11 ˚C from late August to late September 2012 (Figure 8b), slightly higher than in previous years (Figures 5b, 6b and 7b).

The conductivity below Mica Dam showed some variation in 2012, with lower values during low outflow from Mica Dam as in previous years, while the conductivity of the outflow from Revelstoke was relatively steady (Figure 8c). 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. The average turbidity in 2012 was 1.1and 0.3 NTU, respectively (Figure 8d), similar to previous years. Like the tributaries, the pH was relatively constant and slightly alkaline, again with some lower values below Mica Dam from mid-May to mid-July, corresponding with low outflow (Figure 8e).

Nitrate and nitrite concentrations (NN) were variable in the outflow from Mica in the spring of 2012, peaking at 214 µg/L in mid-May, dropping to around 100 µg/L through the summer (Figure 8f). In the outflow from Revelstoke, NN was relatively constant, at approximately 85-150 µg/L (Figure 8f). For both Mica and Revelstoke outflows, SRP concentrations were close to the detection limit, generally below 4 µg/L (Figure 8g). TDP and TP were low and relatively constant (Figures 8h,i). The NN:TDP ratio for the Mica and Revelstoke outflows exceeded 10 throughout the year, suggesting nutrients from these sources are phosphorus limited (Figure 8j).

Intensive sampling of the reference tributaries began in 2009. Comparison of the 2009 through 2012 data is shown for May to November in Figure 9 (Columbia River at Donald), Figure 10 (Goldstream River), Figure 11 (Beaver River) Figure 12 (Mica Dam/Kinbasket Reservoir Outflow) and Figure 13 (Revelstoke Outflow). As data were available for Beaver River throughout the year, Figure 11 is plotted from January to December. Overall the water quality parameters show similar trends, the exception being TDP which shows slightly higher variability (Figures 9e, 10e, 12e, and 13e; no TDP available for Beaver). There was also higher variability for Kinbasket outflow from May through July, likely due to the effect of backwater during low outflow. Of particular interest is nitrate shown over the whole year for Beaver River; nitrate had a steady winter value of just under 200 µg/L, increases rapidly at the start of freshet to double the winter value, 400 µg/L, but then dropped dramatically as freshet peaked to a low of approximately 50 µg/L in summer, and then gradually returned to winter levels by December (Figure 11d).

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 14. Also shown in grey is the flow from WSC Station 08ND013, Illecillewaet at Greeley. Similar to that observed in the reference tributaries, there is a clear seasonal cycle in C25 and nitrate, 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 15 compares the seasonal evolution of the flow, C25 and NN during these 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 15b). The decline in NN occurs more gradually through May and June to very low values in July and August (Figure 15c). 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. In the presence of 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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Figure 1 Flow and water quality of reference tributaries, 2009

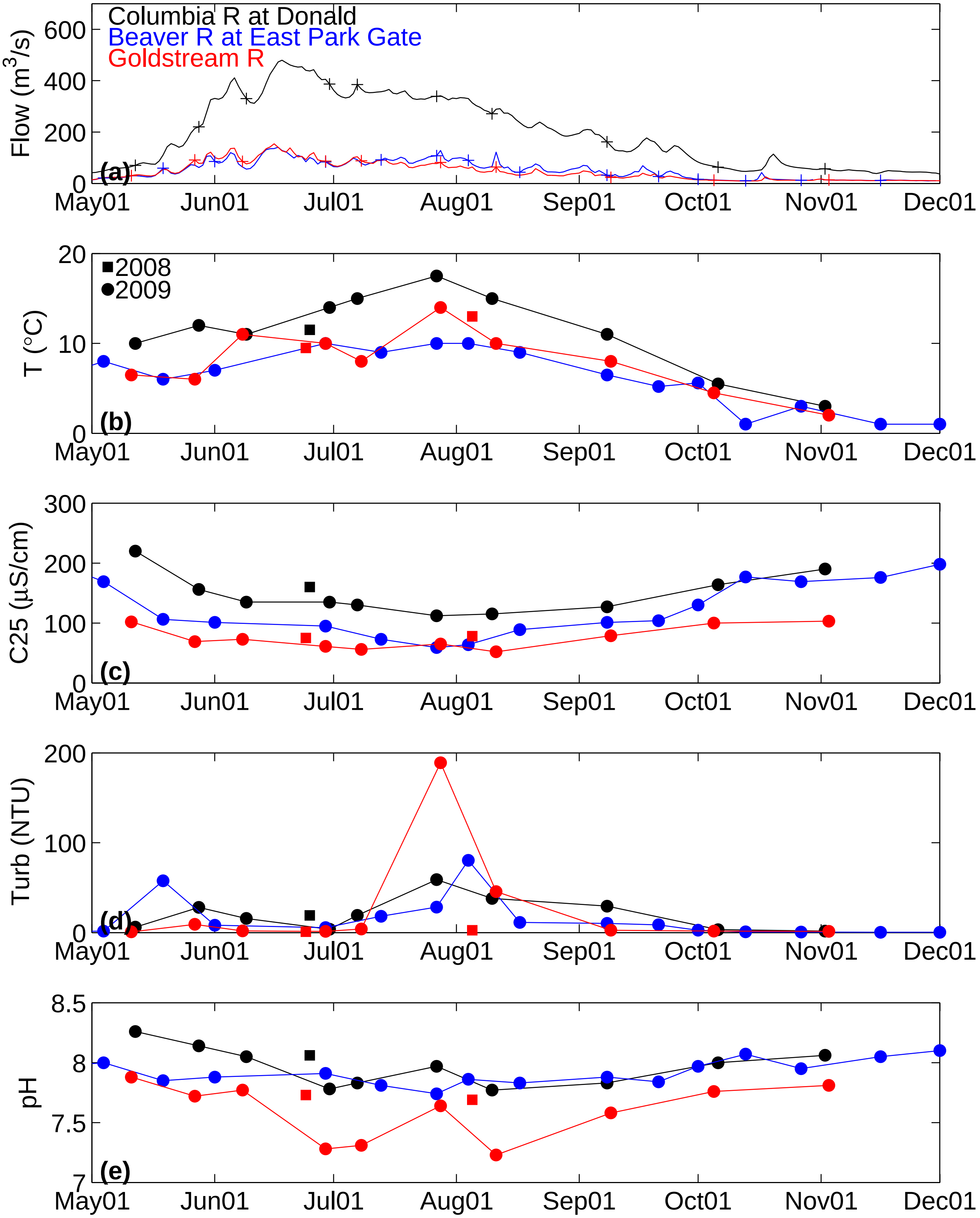

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Figure 1 con't Flow and water quality of reference tributaries, 2009

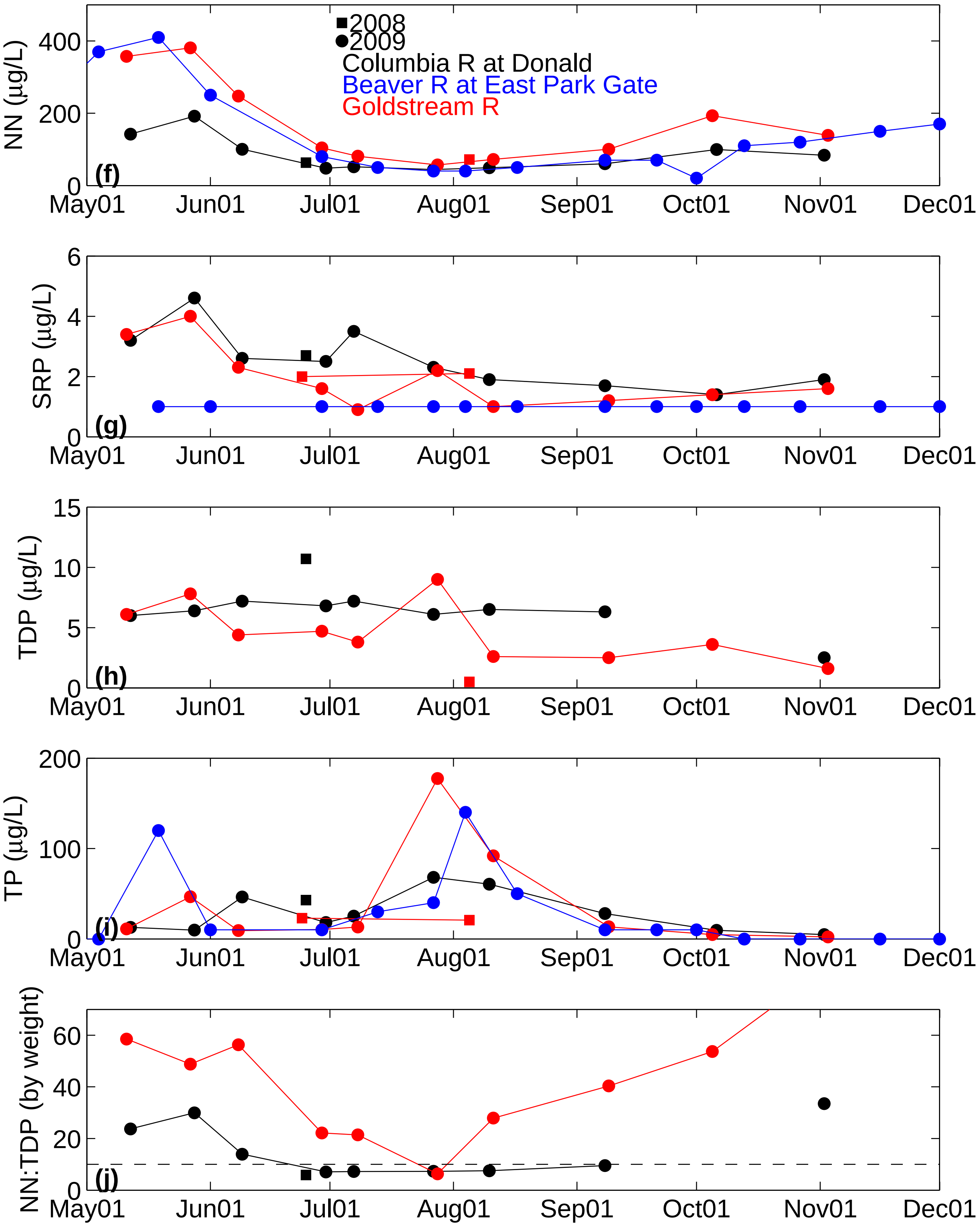

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Figure 2 Flow and water quality of reference tributaries, 2010

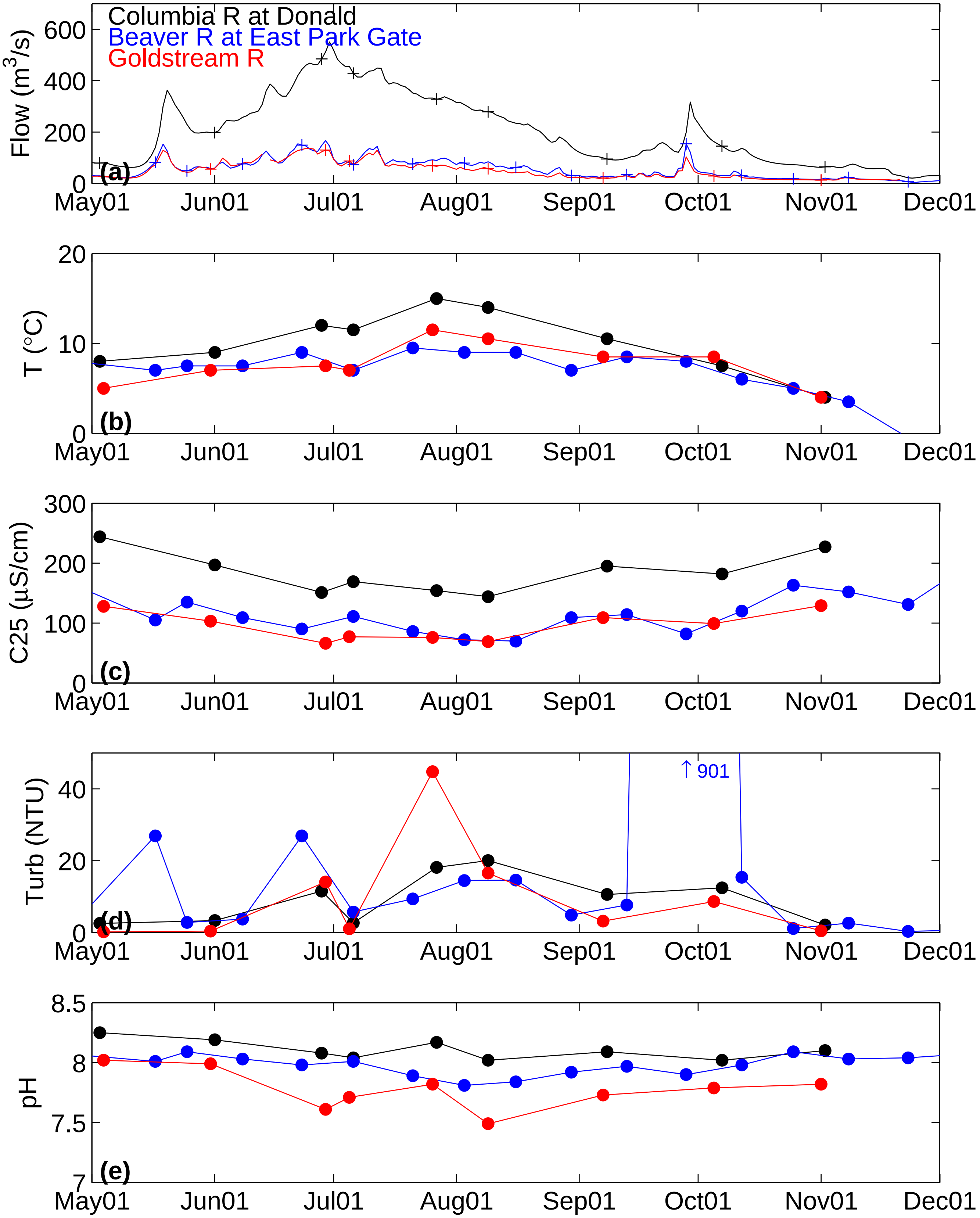

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Figure 2 con't Flow and water quality of reference tributaries, 2010

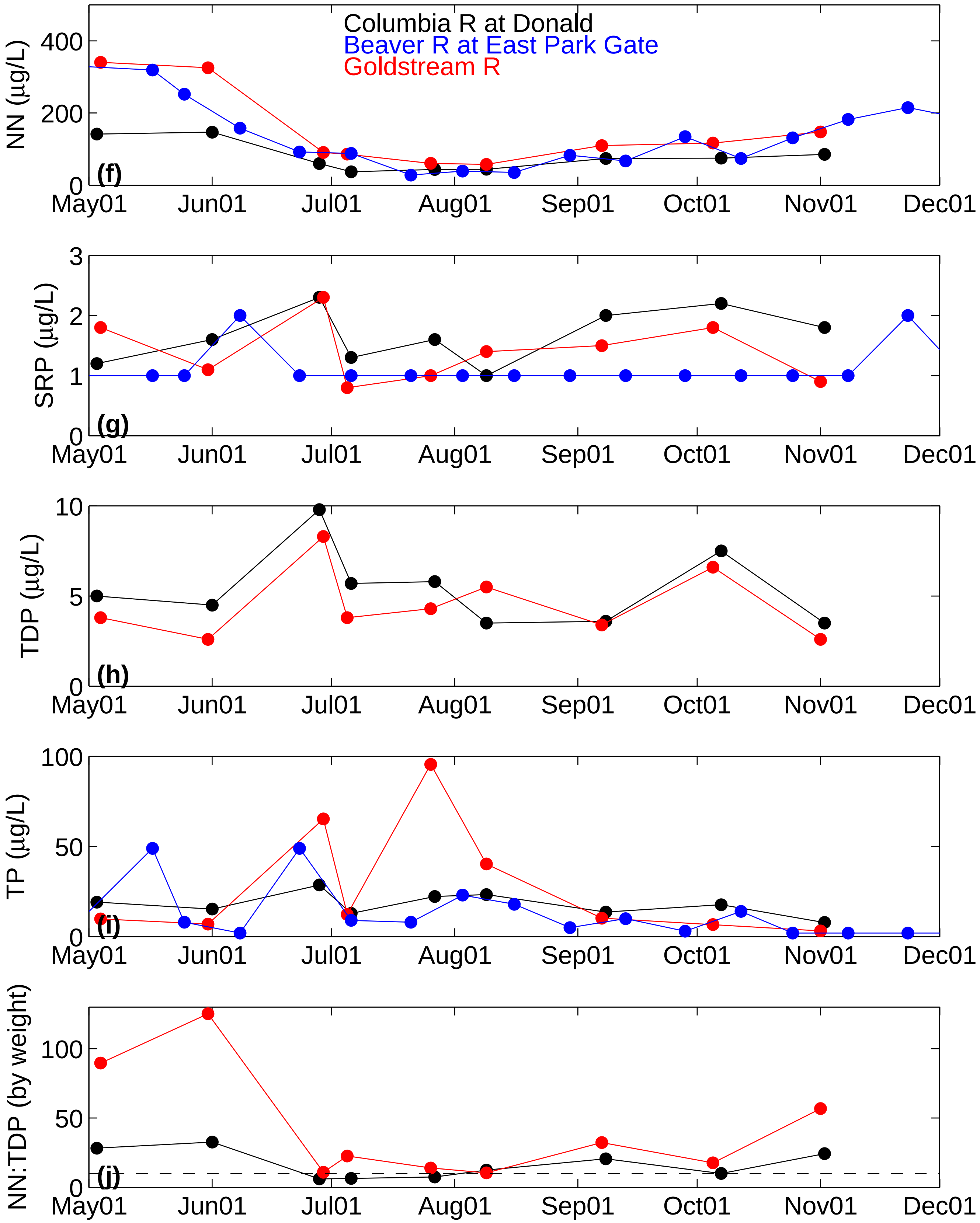

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Figure 3 Flow and water quality of reference tributaries, 2011

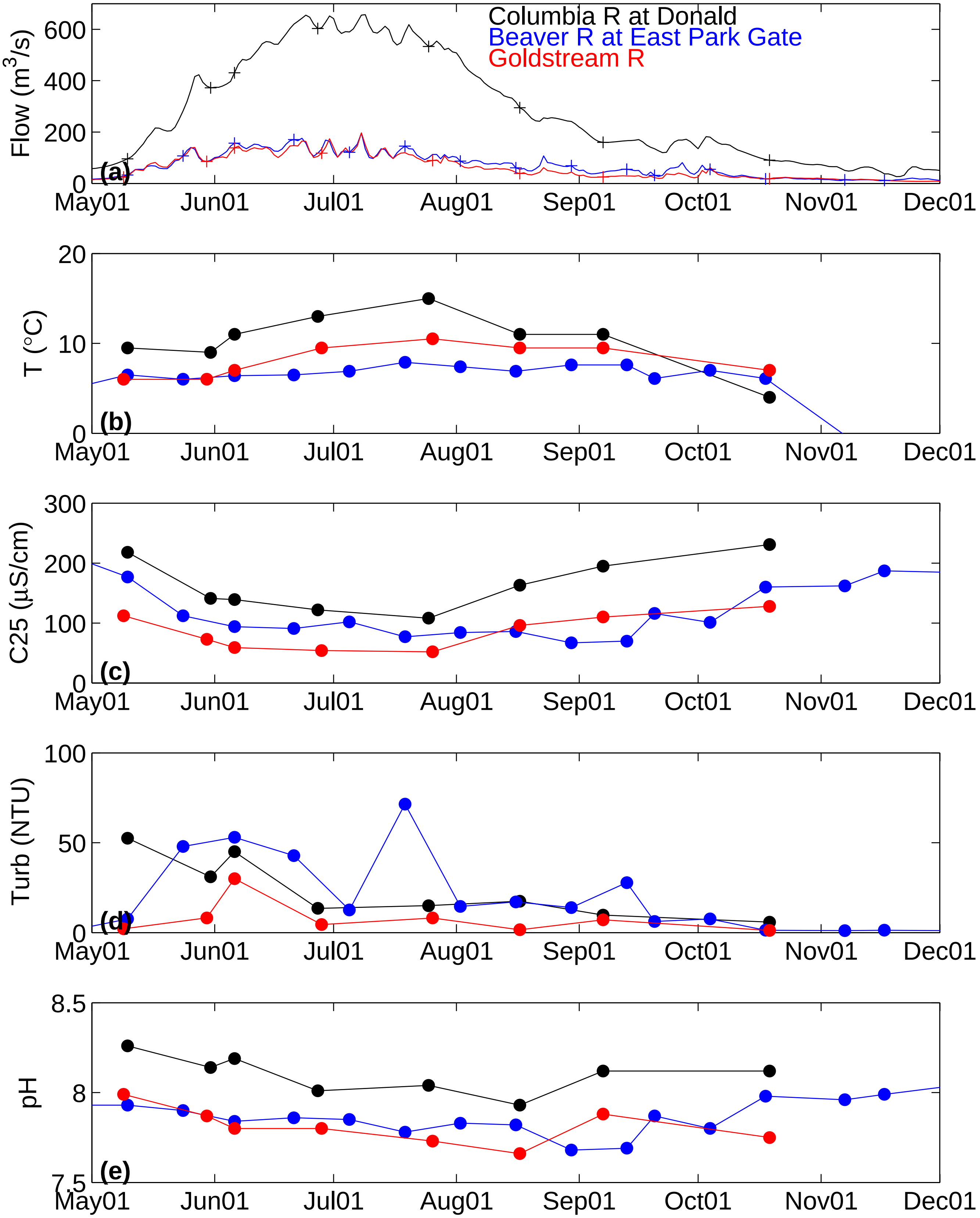

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Figure 3 con't Flow and water quality of reference tributaries, 2011

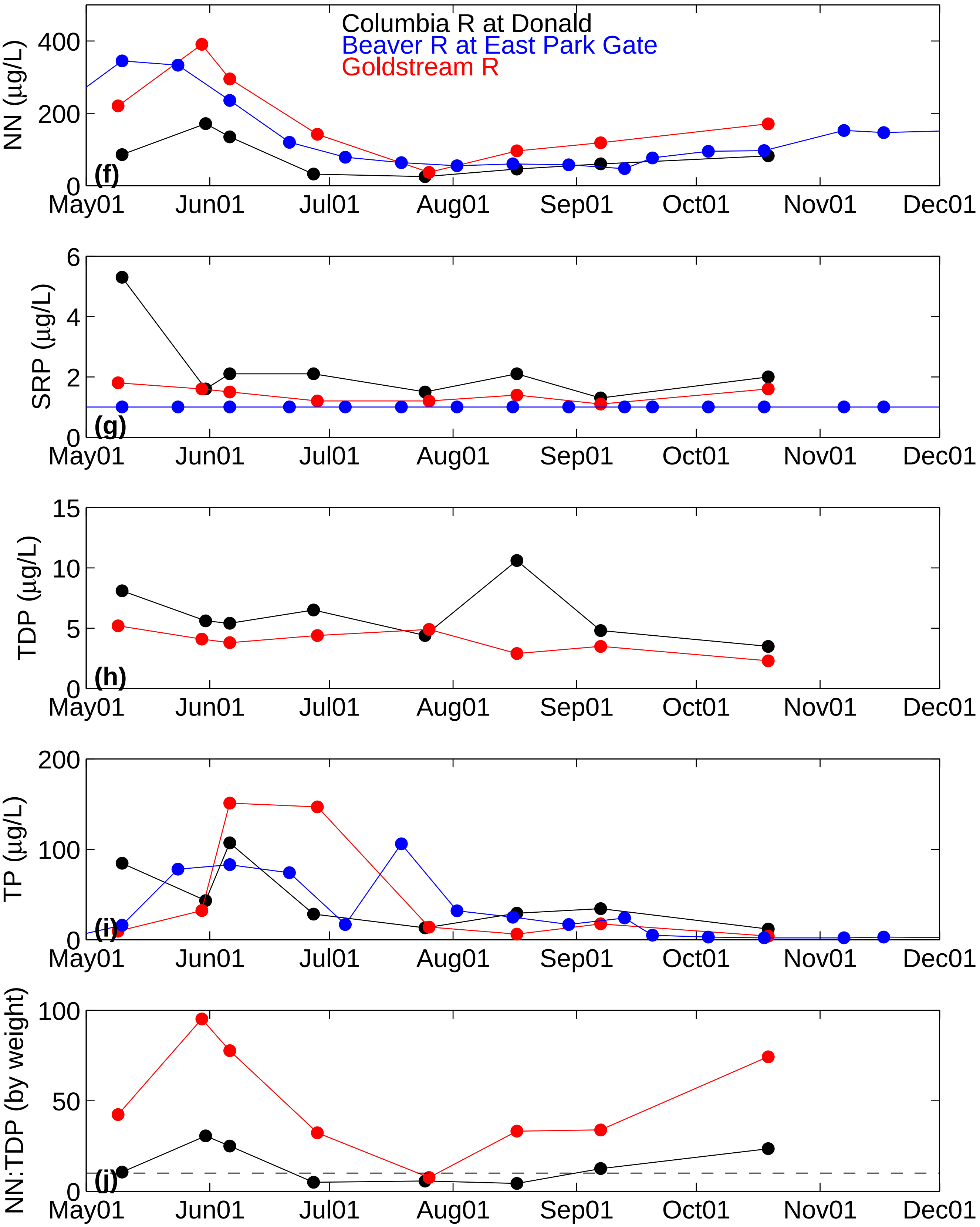

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Figure 4 Flow and water quality of reference tributaries, 2012

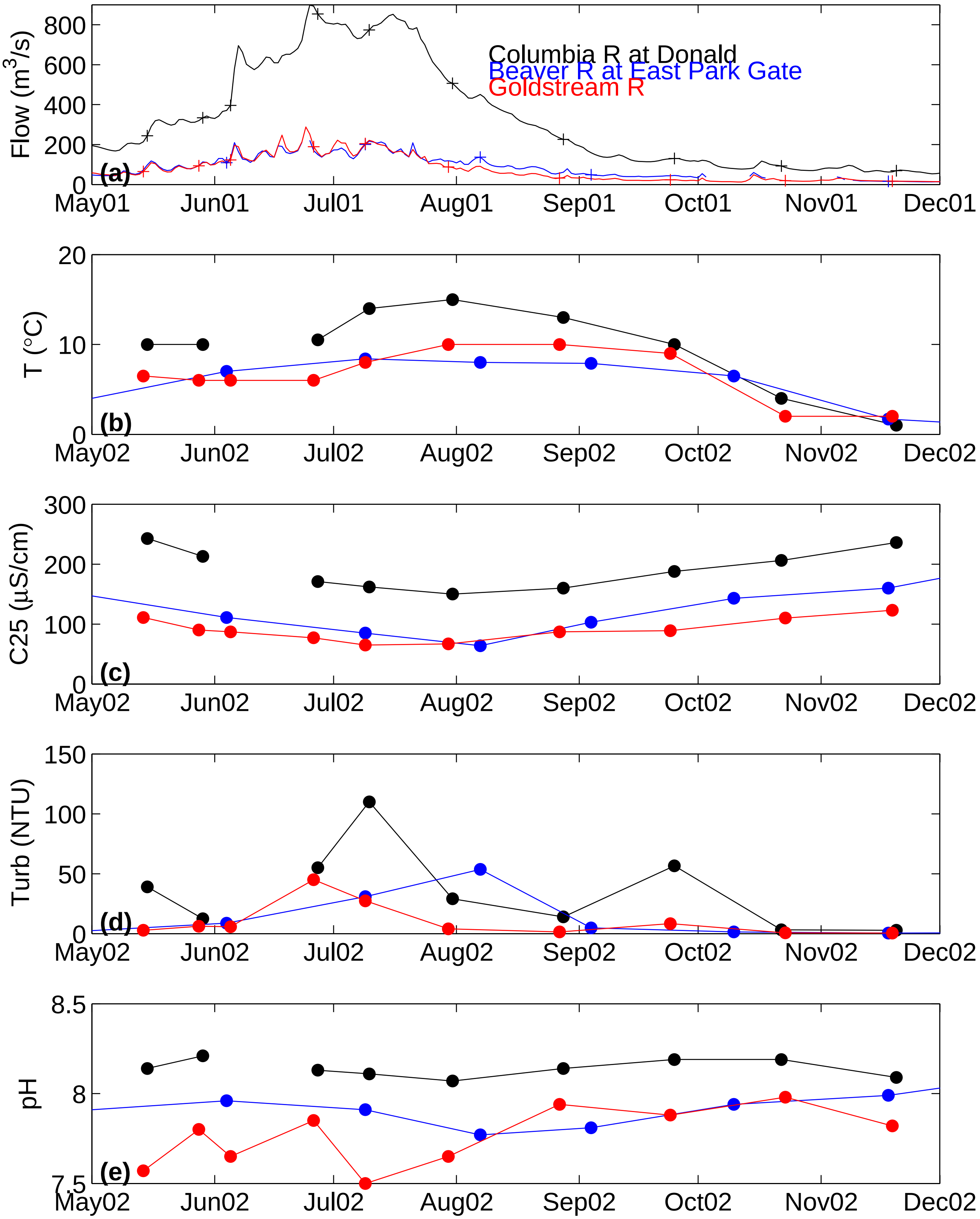

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Figure 4 con't Flow and water quality of reference tributaries, 2012

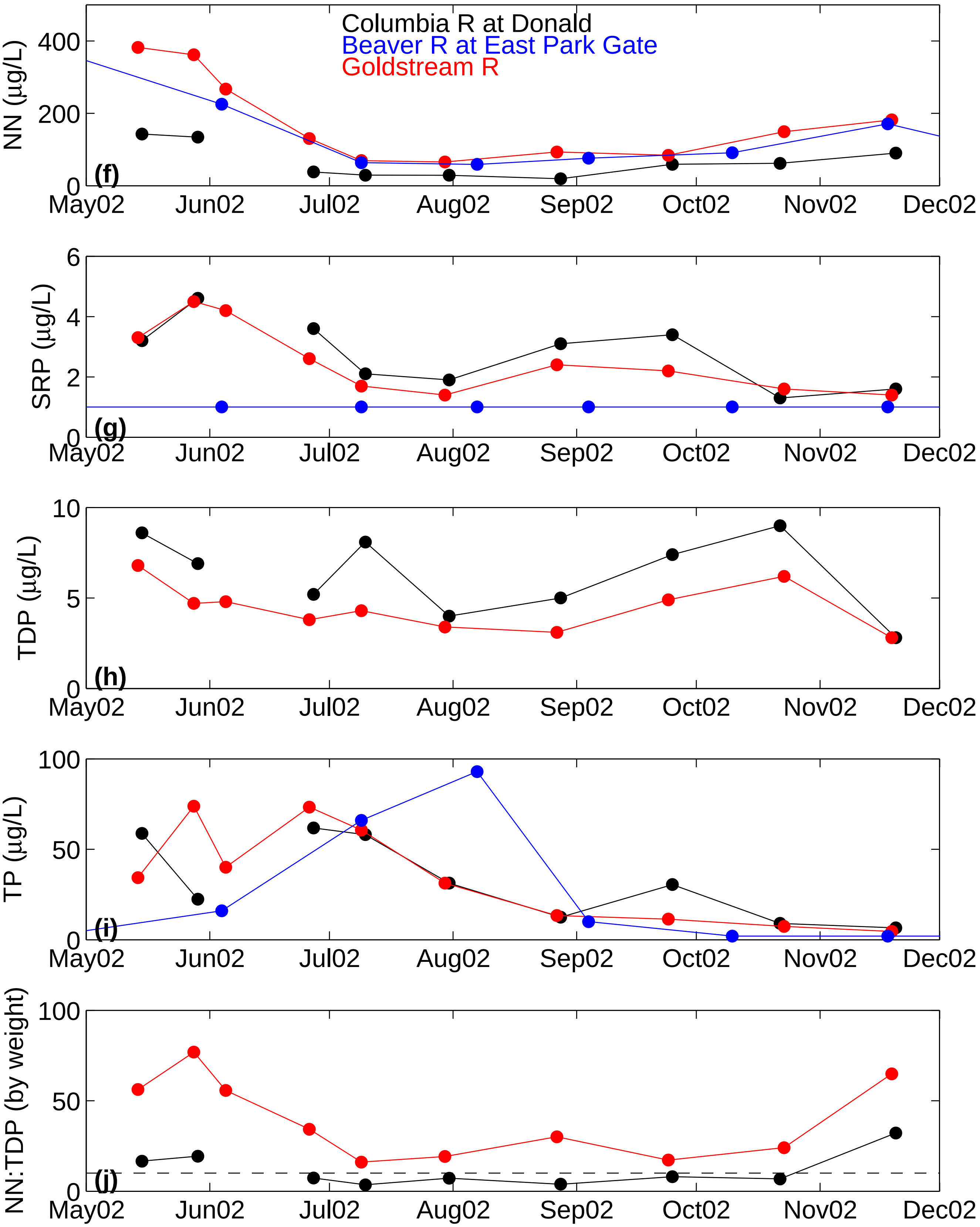

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Figure 5 Flow and water quality of Columbia River, 2009

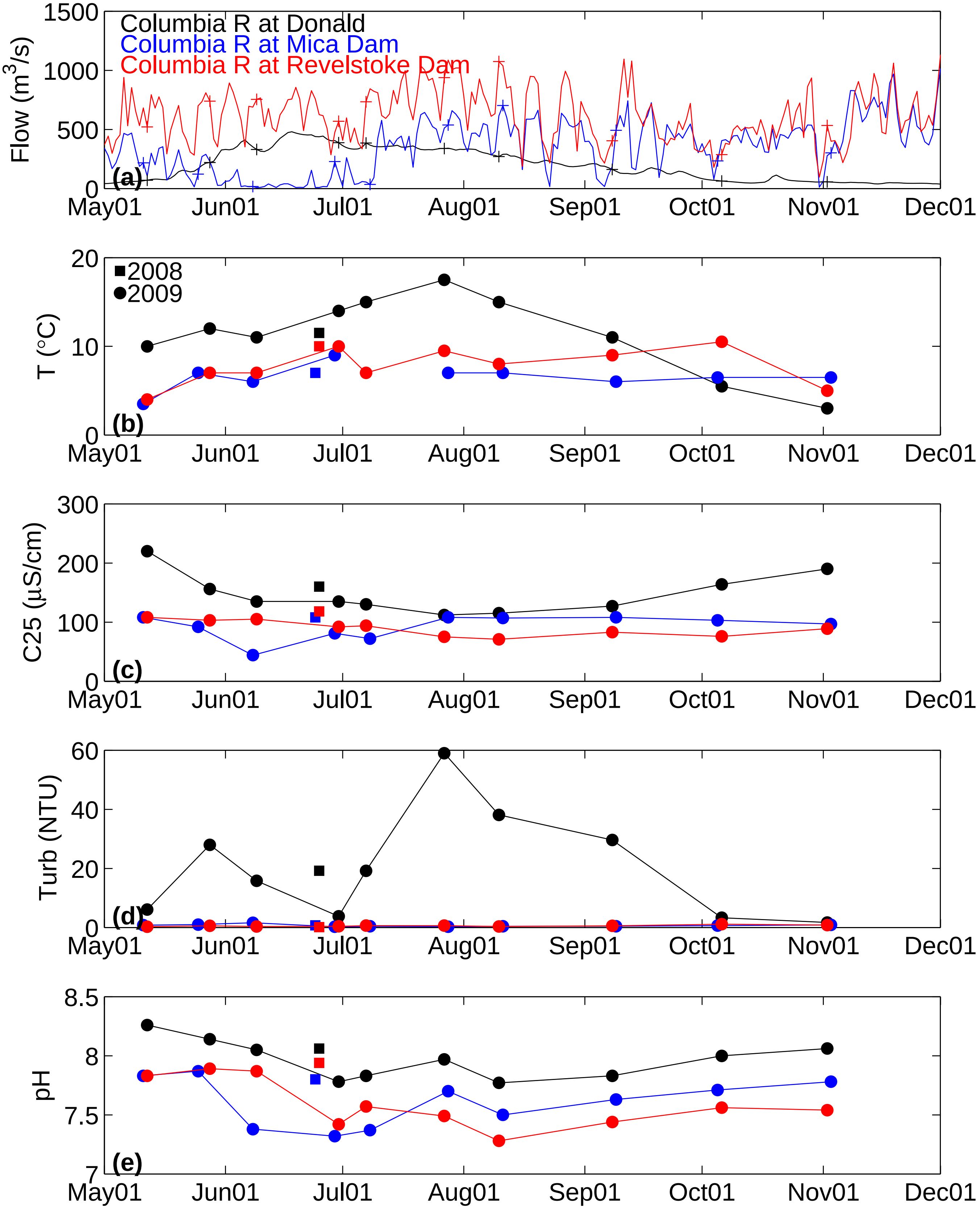

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Figure 5 con't Flow and water quality of Columbia River, 2009

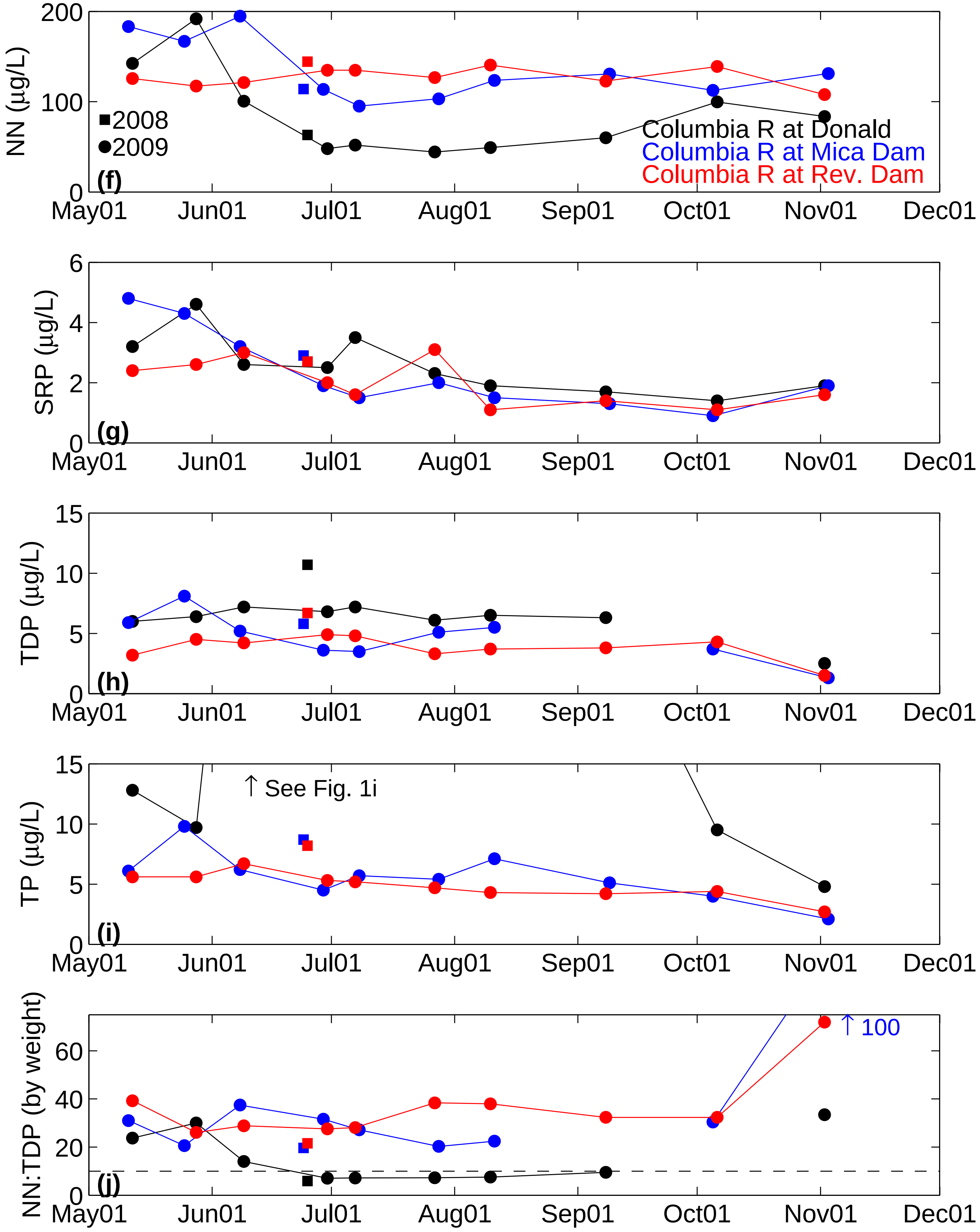

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Figure 6 Flow and water quality of Columbia River, 2010

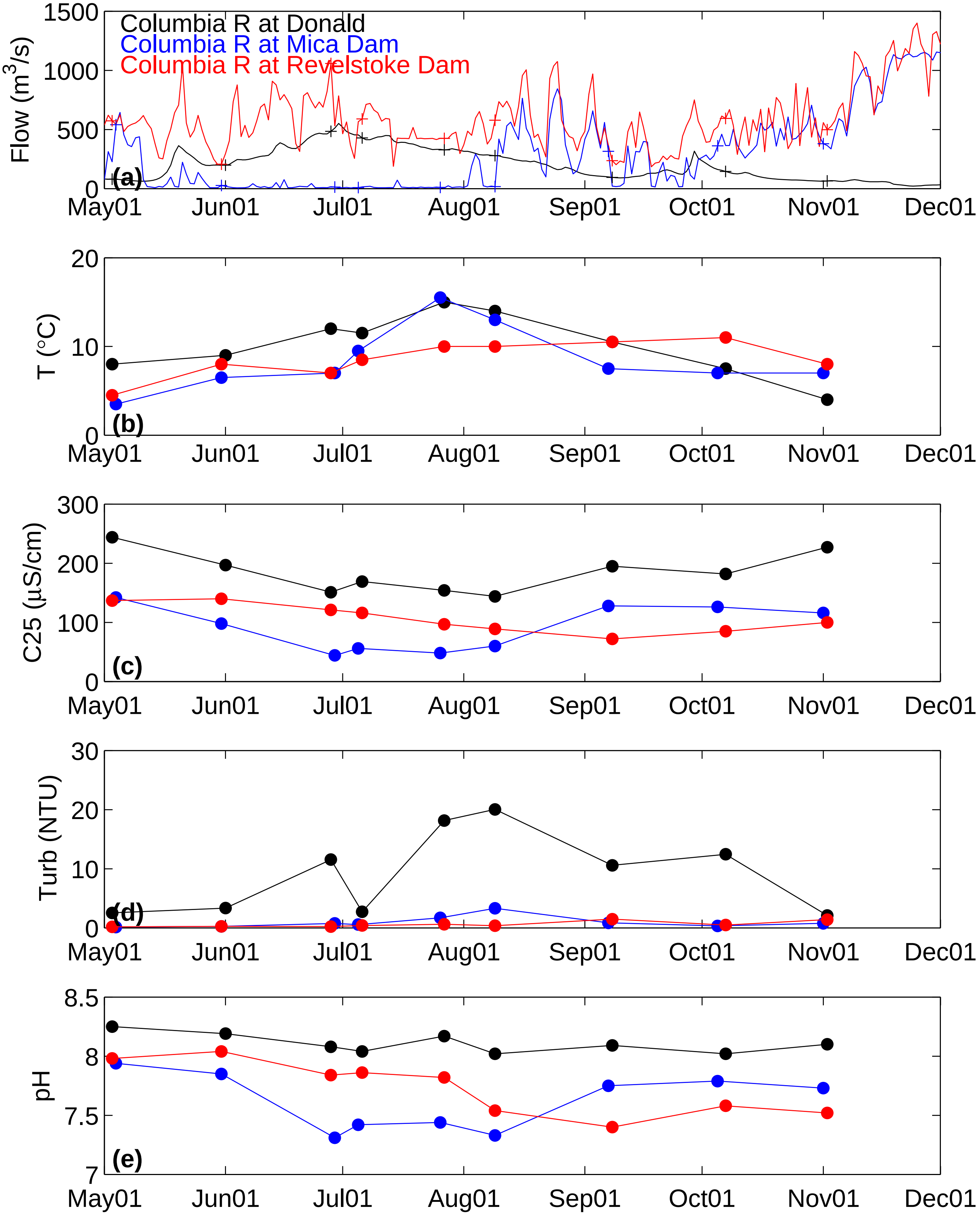

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Figure 6 con't Flow and water quality of Columbia River, 2010

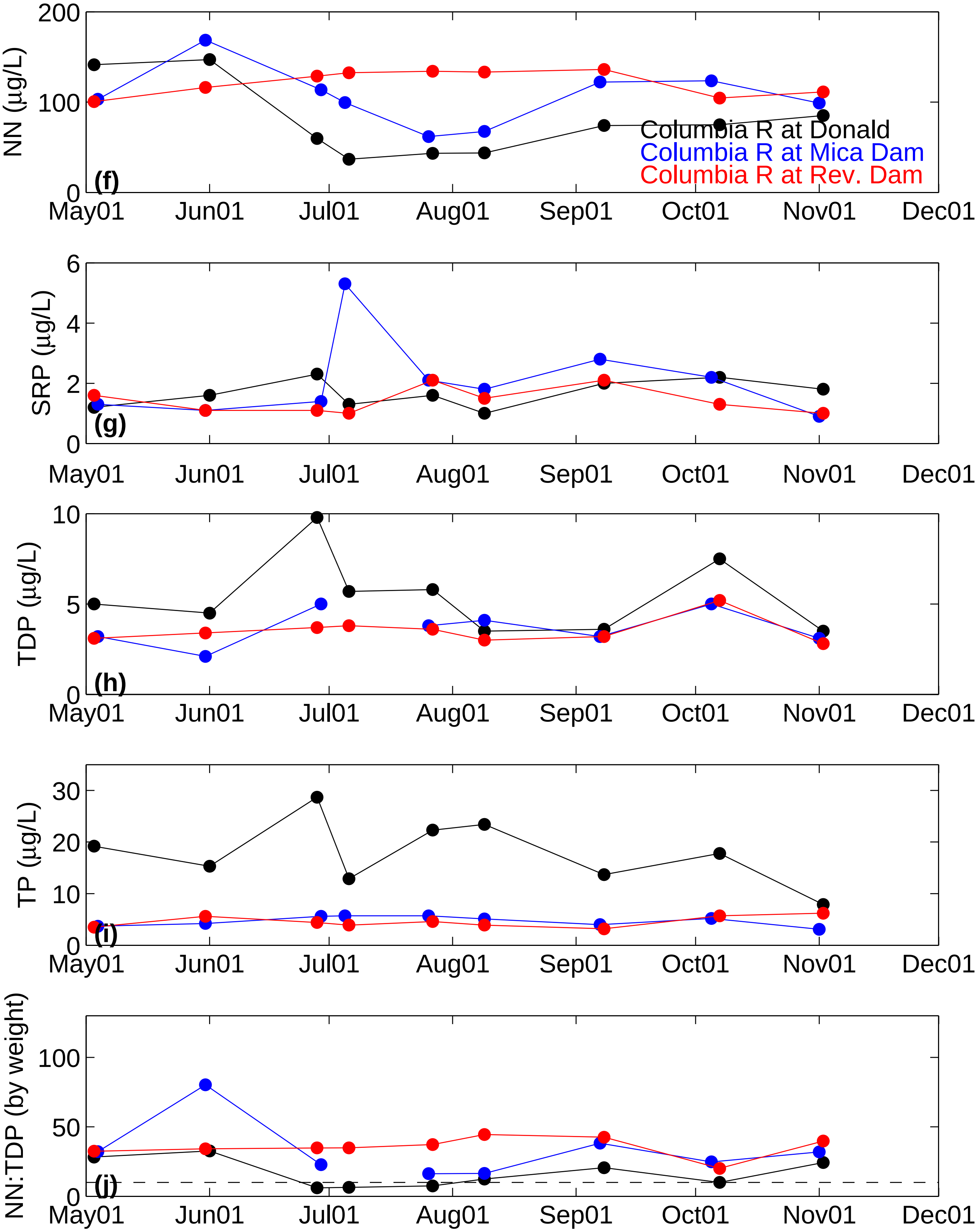

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Figure 7 Flow and water quality of Columbia River, 2011

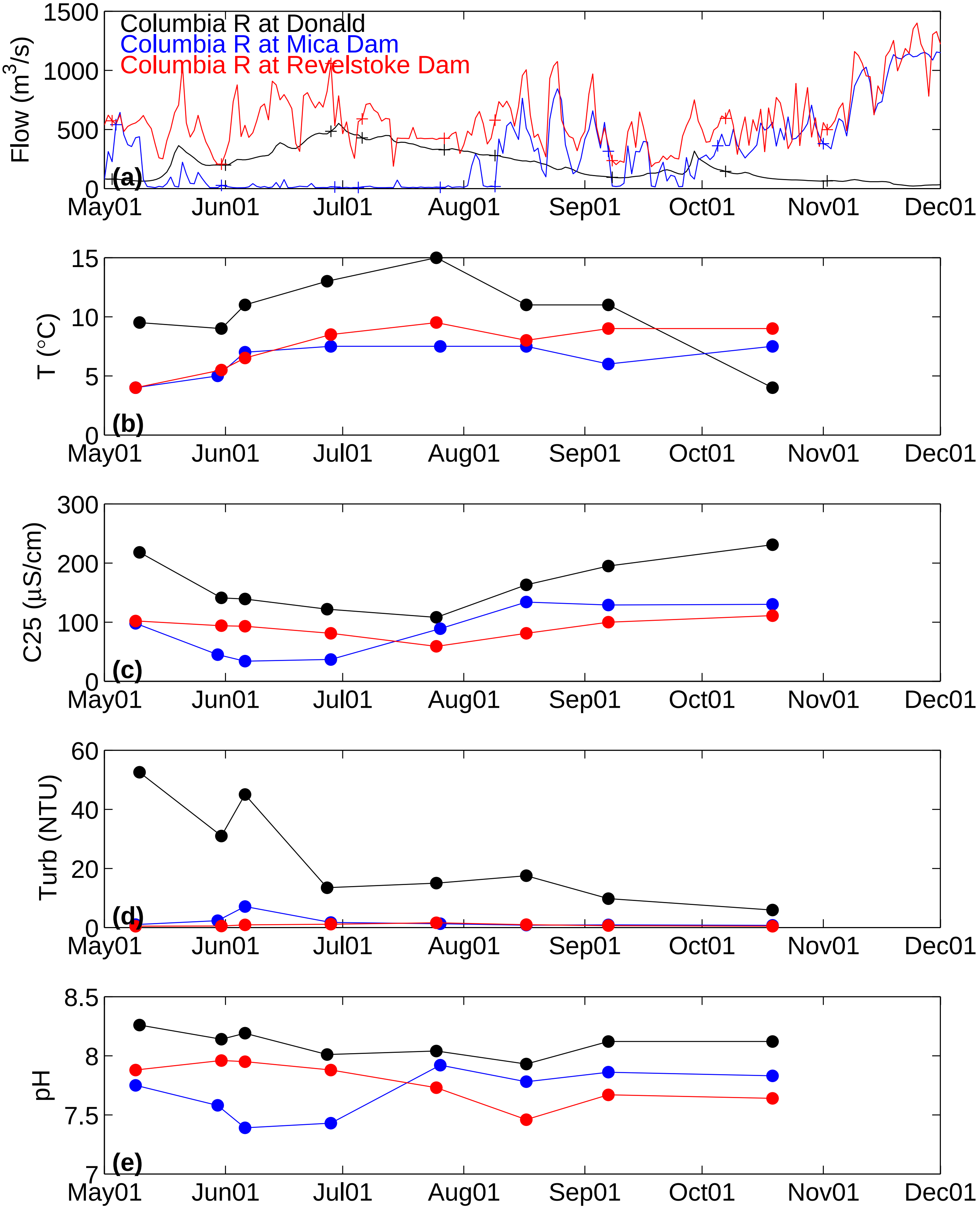

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Figure 7 con't Flow and water quality of Columbia River, 2011

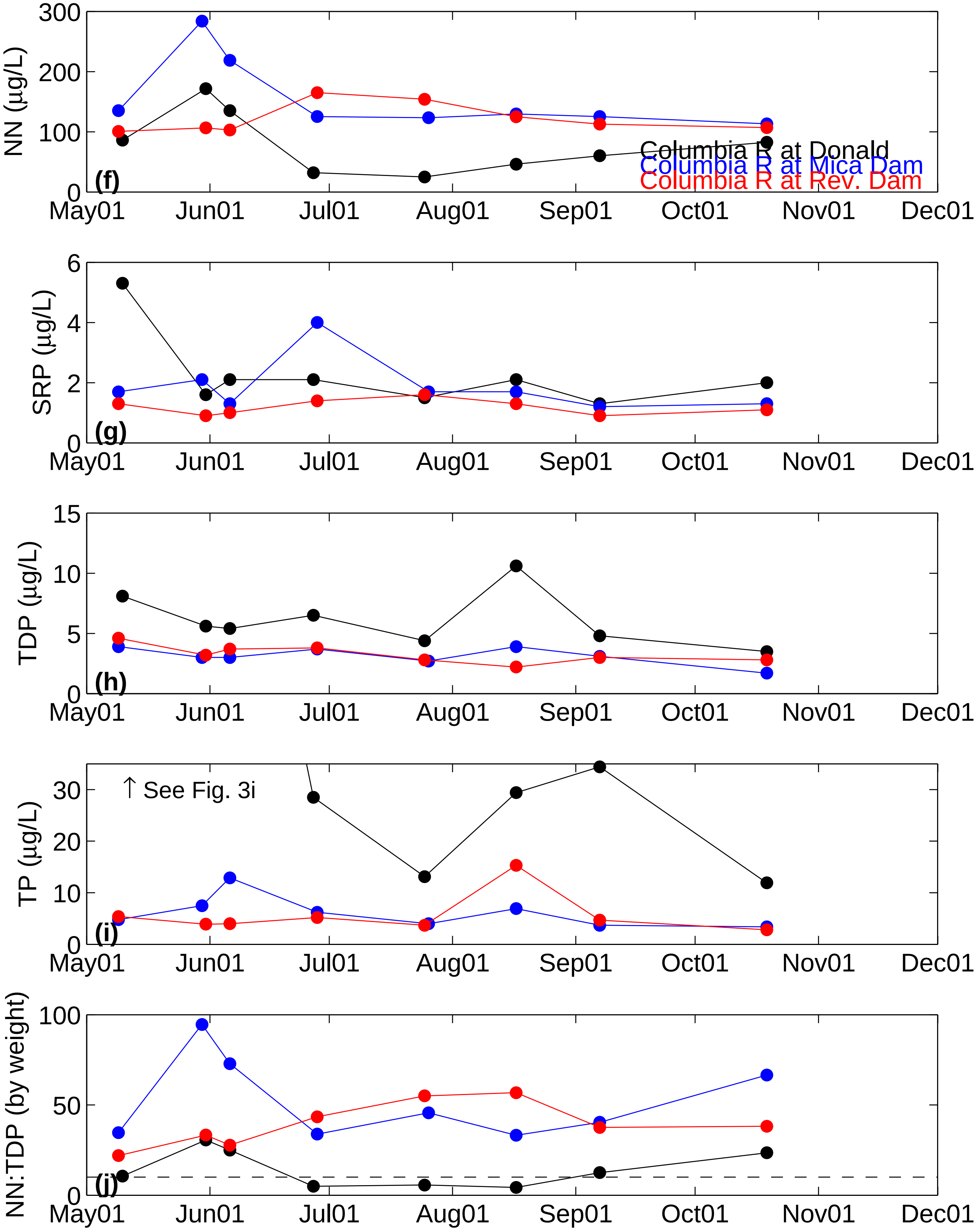

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Figure 8 Flow and water quality of Columbia River, 2012

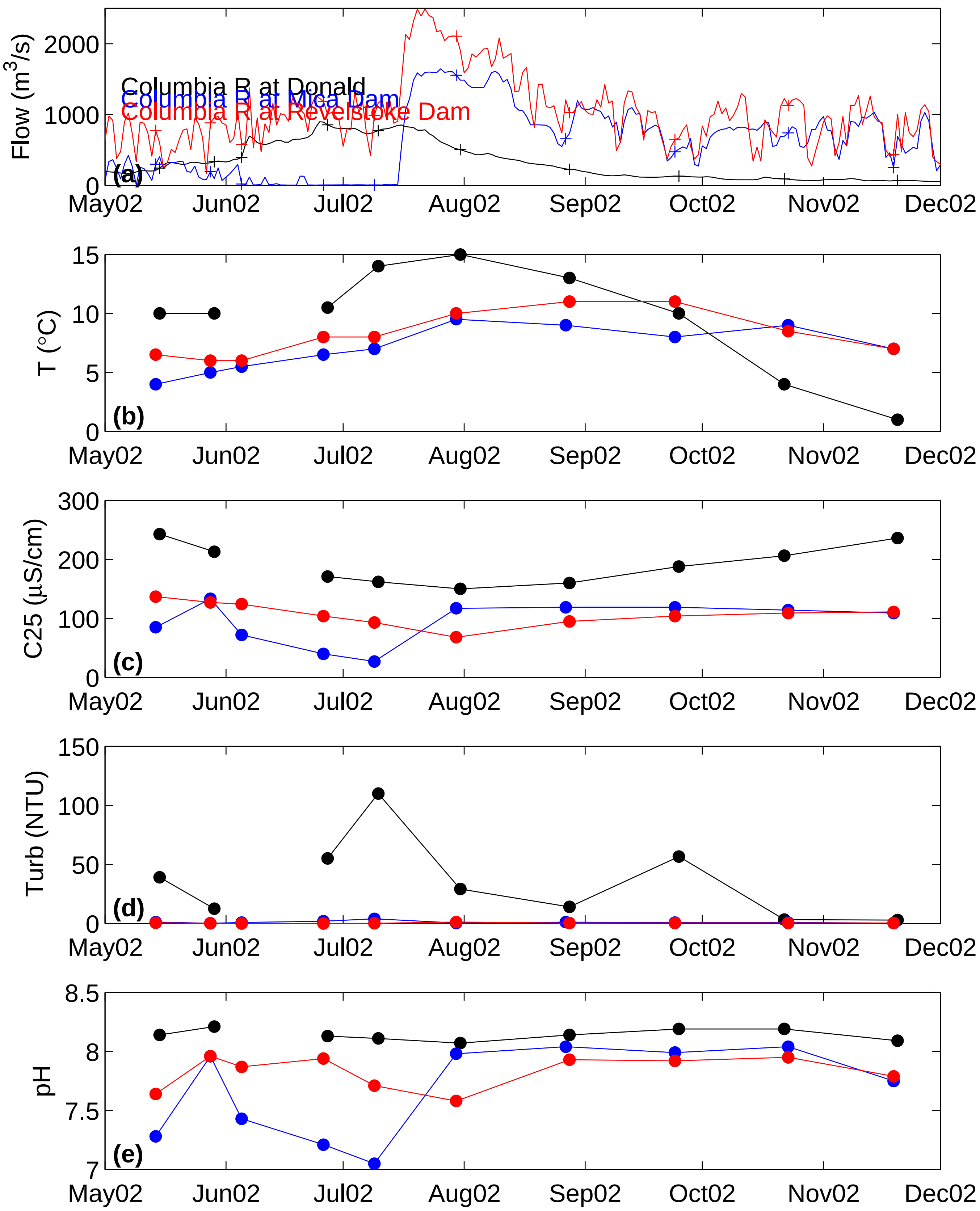

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Figure 8 con't Flow and water quality of Columbia River, 2012

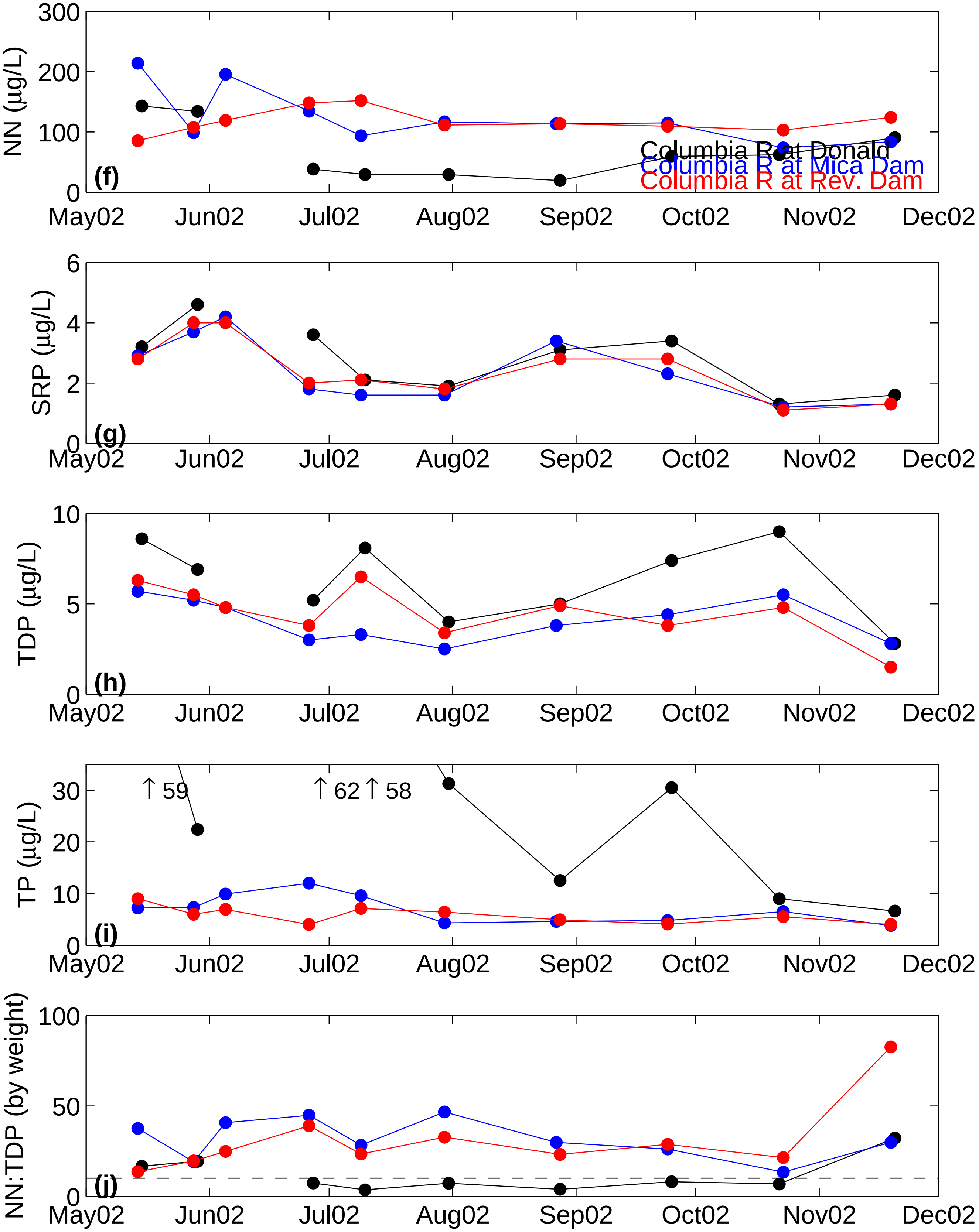

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Figure 9 Comparison of Columbia R. at Donald, 2009, 2010,2011 & 2012

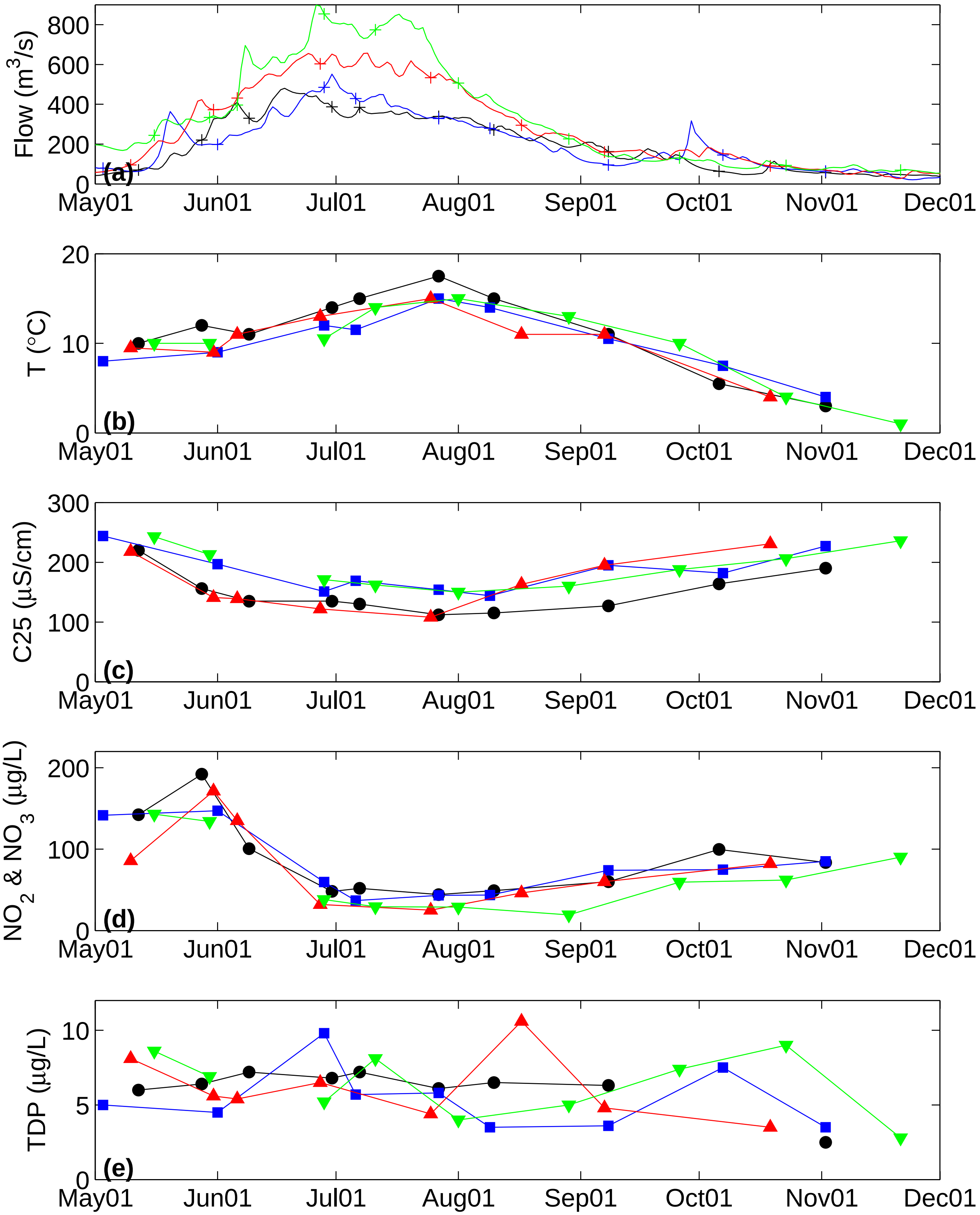

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Figure 10 Comparison of Goldstream River, 2009, 2010,2011 & 2012

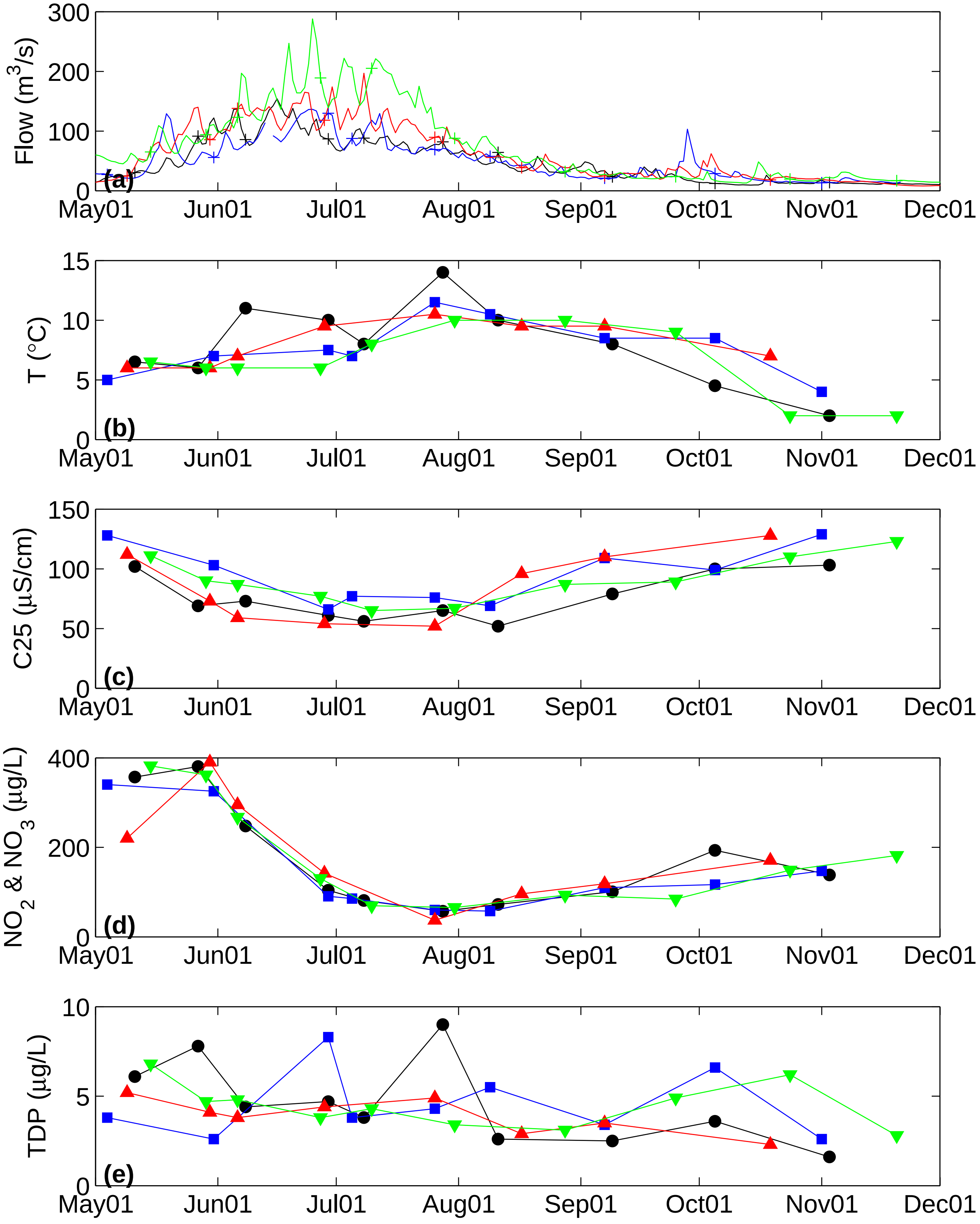

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Figure 11 Comparison of Beaver River, 2009, 2010,2011 & 2012

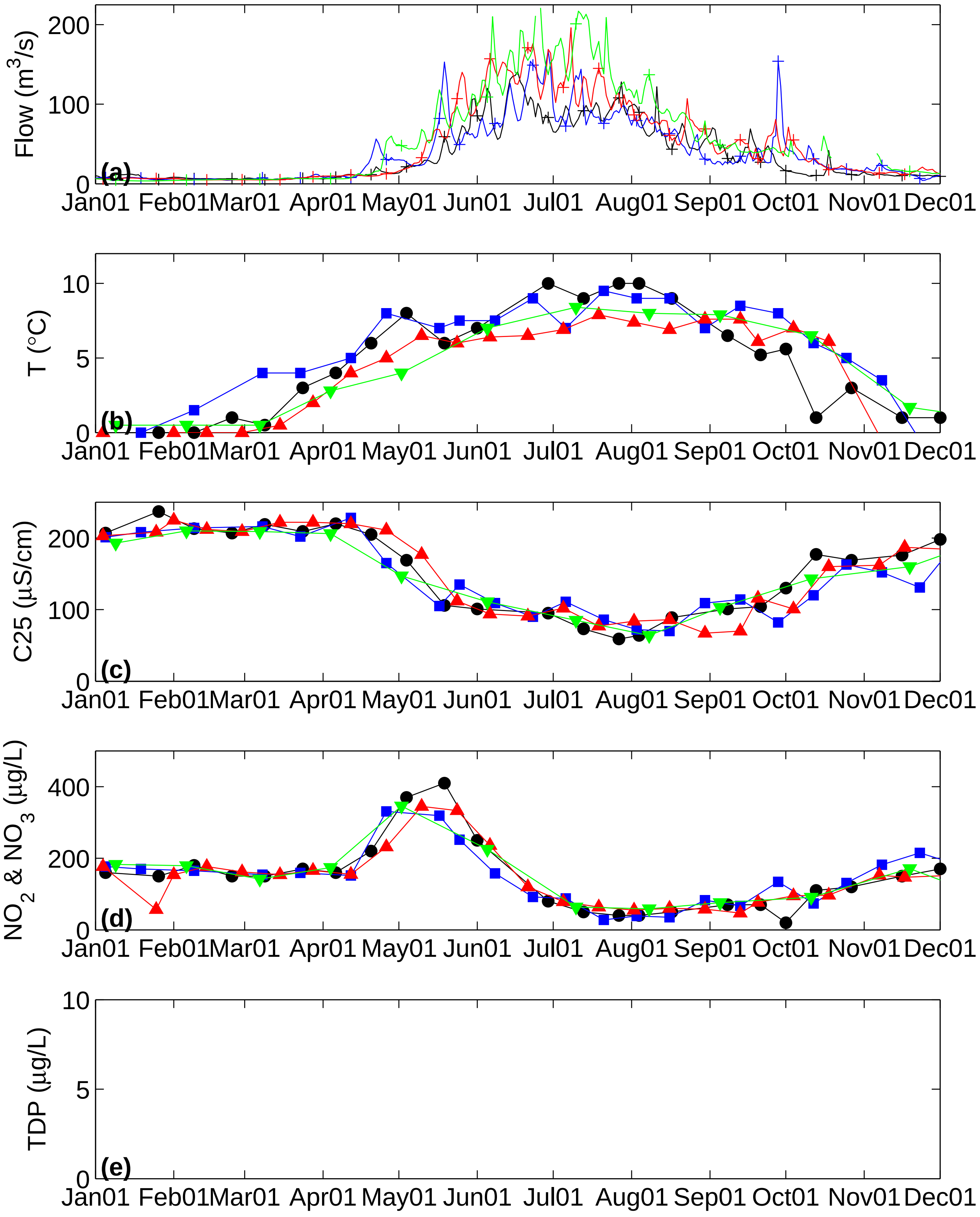

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Figure 12 Comparison of Kinbasket Outflow, 2009, 2010,2011 & 2012

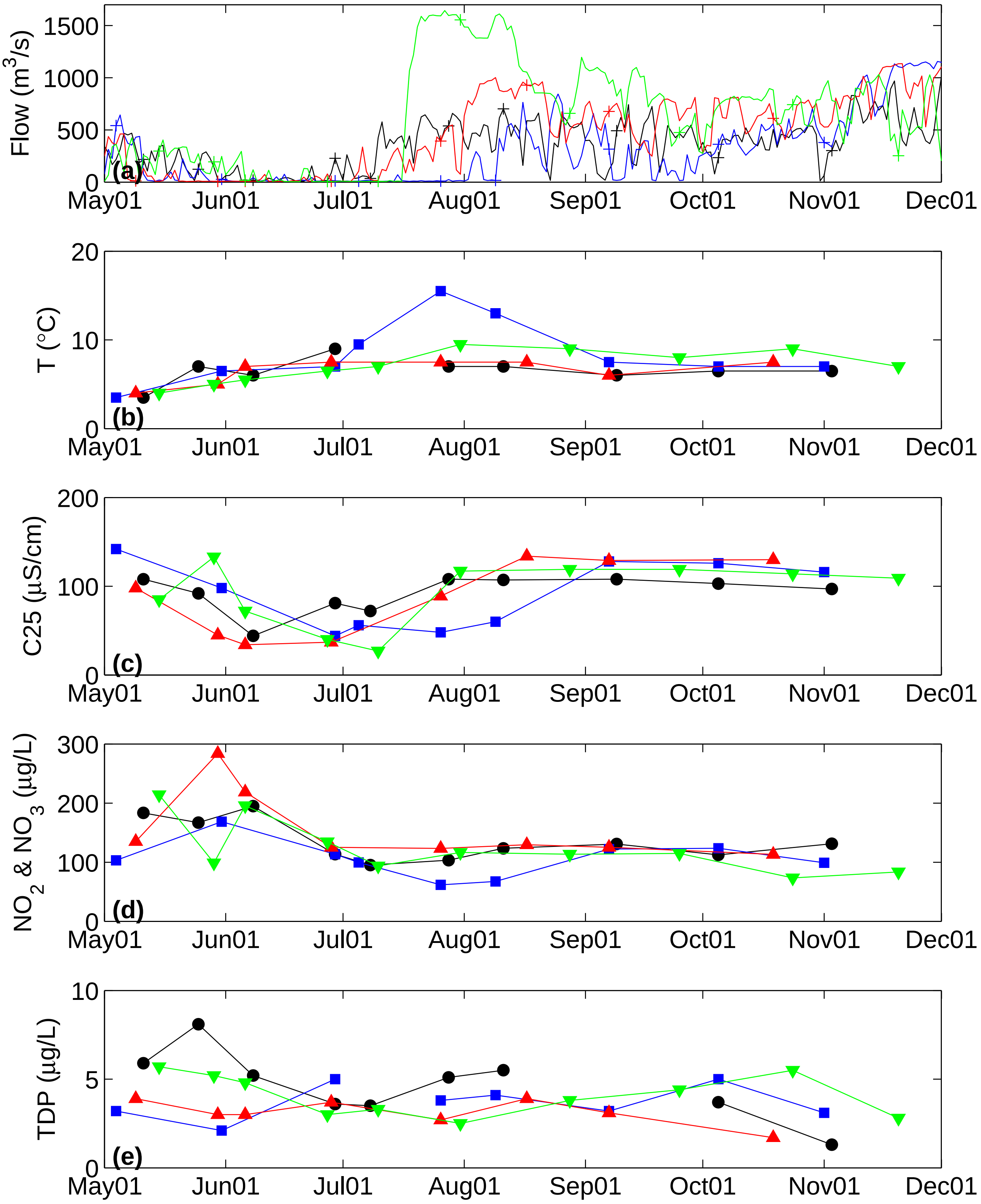

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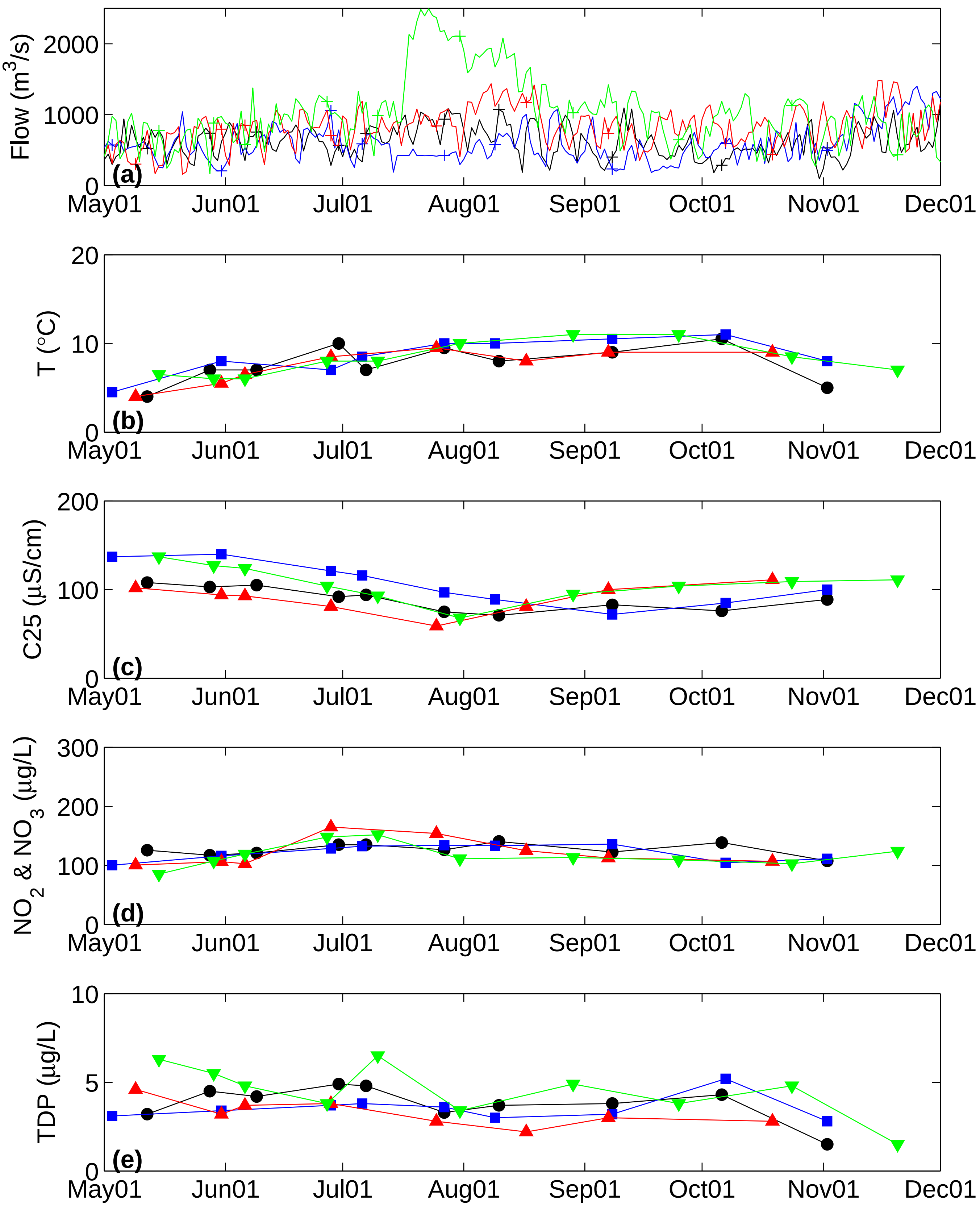
Figure 13 Comparison of Revelstoke Outflow, 2009, 2010,2011 & 2012



/ocean/rpieters/kr/chem/trib/plot/plotreftrib08to12.m fig= 5 2014−Jan−28

Figure 14 Water quality of Illecillewaet River, 1997−2001

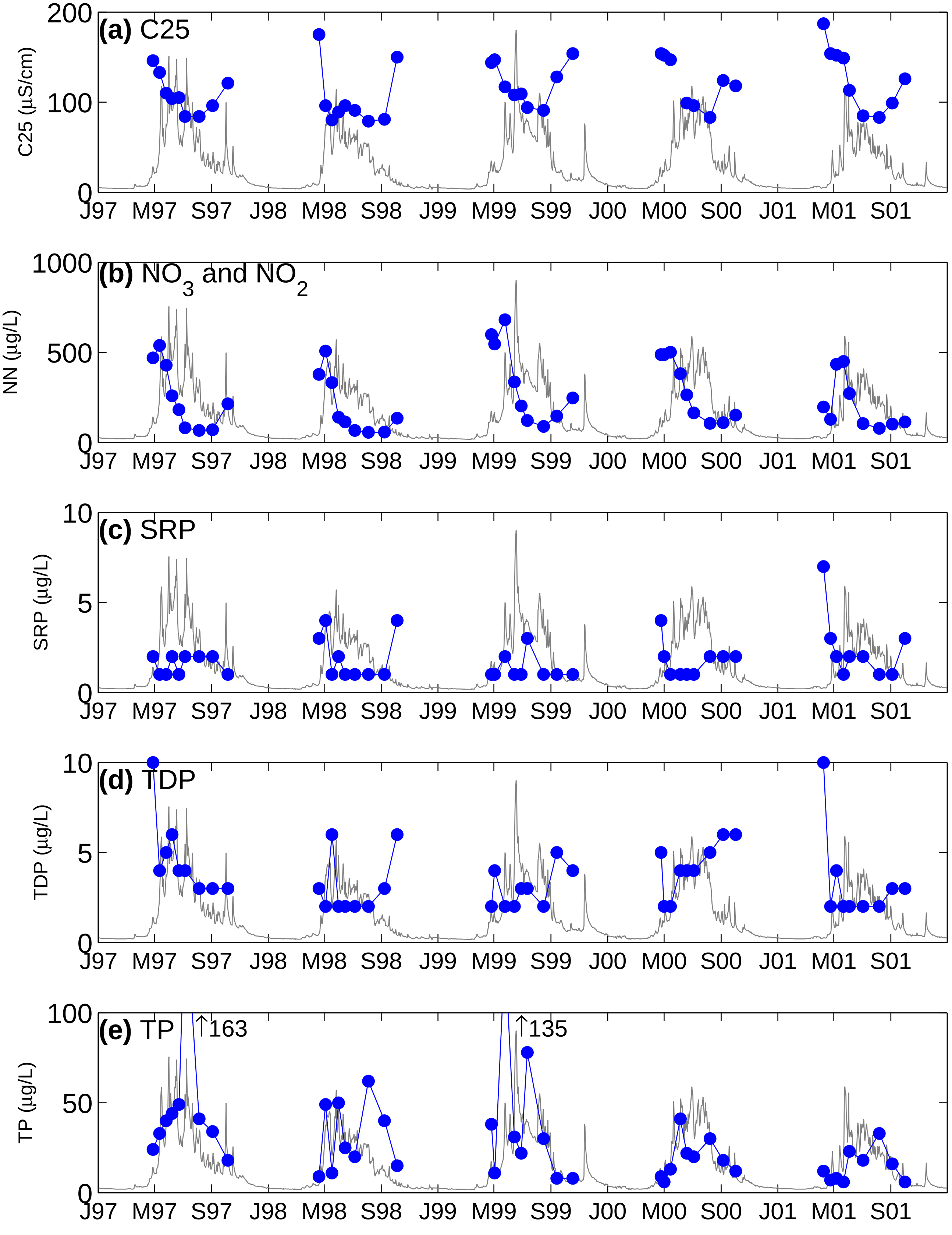


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Figure 14 con't Water quality of Illecillewaet River, 1997−2001

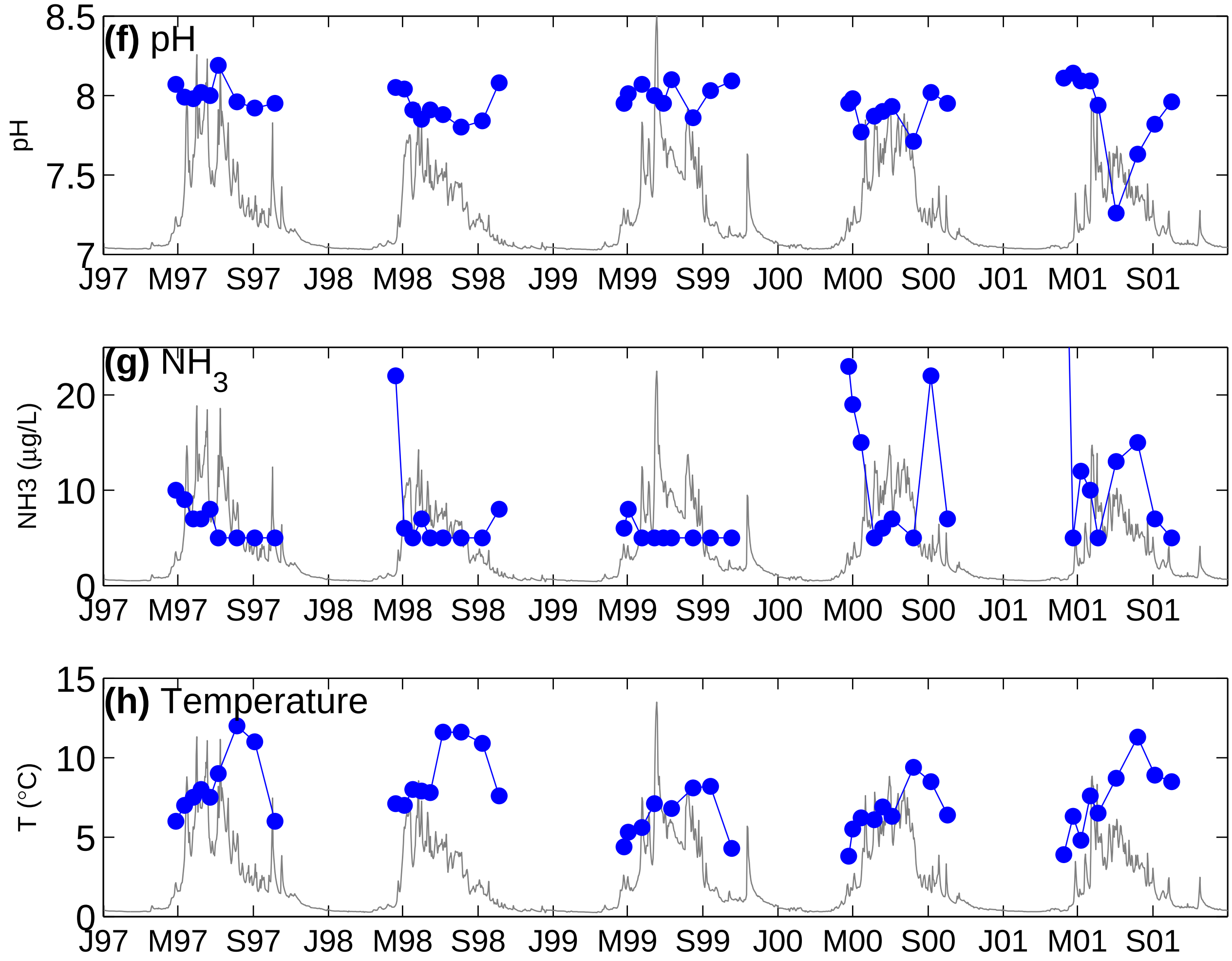

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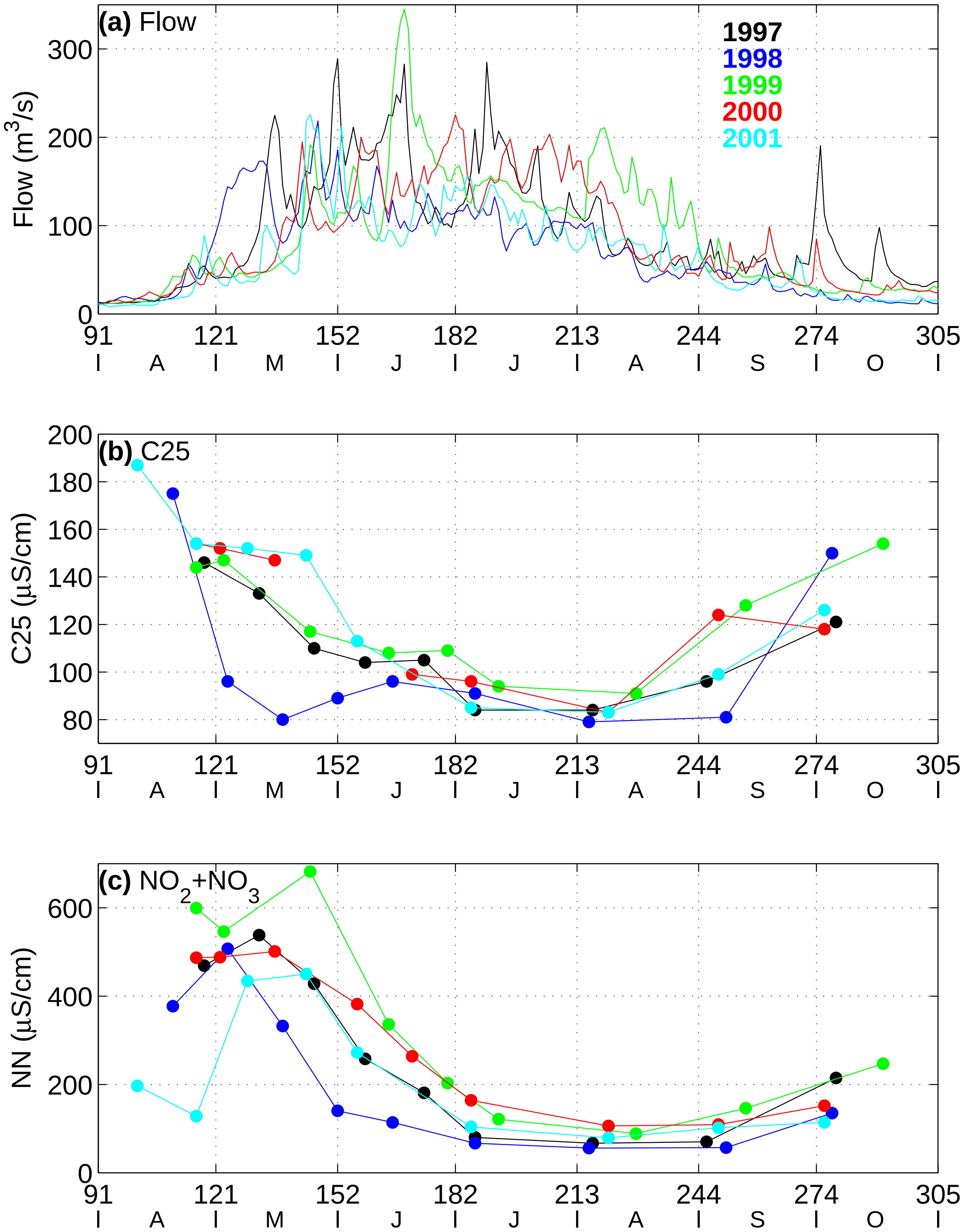
Figure 15 Flow, C25 and NN in the Illecillewaet River, 1997−2001



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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 for total phosphorus in Appendix 3 as 'TP turb'. Subtract these corrections from TP to obtain TP corrected ('TPc') 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^{o} 29.0 117^{o} 10.5	9710
Beaver River	51^{o} 23 117^{o} 27	~600[2]
Gold River	51^{o} 41.5 117^{o} 42.5	542
Bush Arm		
Bush River	51^{o} 47.5 117^{o} 22.4	1032
Prattle Creek	51^{o} 47.3 117^{o} 25.4	199
Chatter Creek	51^{o} 47.1 117^{o} 26.3	102
Columbia Reach		
Windy Creek	51^{o} 52.5 118^{o} 01.2	243
Sullivan River	51^{o} 57.2 117^{o} 51.4	593
Kinbasket Creek	51^{o} 58.5 117^{o} 57.5	*160*
Cummins	52^{o} 03.1 118^{o} 09.5	268
Wood Arm		
Wood Creek	52^{o} 12.2 118^{o} 10.3	451
Canoe Reach		
Canoe River	52^{o} 46.4 119^{o} 09.6	611
Dave Henry Creek	52^{o} 44.4 119^{o} 05.6	96
Yellowjacket Creek	52^{o} 42.1 119^{o} 03.1	104
Bulldog Creek	52^{o} 38.4 118^{o} 58.5	107
Ptarmigan Creek	52^{o} 35.0 118^{o} 39.5	295
Hugh Allan Creek	52^{o} 26.4 118^{o} 39.5	626
Foster Creek	52^{o} 15.2 118^{o} 38.1	187
Dawson Creek	52^{o} 15.6 118^{o}29.5	108
Molson Creek	52^{o} 10.4 118^{o} 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^{o} 30.58 N and 117^{o} 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 (Kinbasket Reservoir/Mica Dam 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**	**TPc**[1]	**Turb**	**Alk**	**T**	**Color(2)**
				(µS/cm)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	(mgCaCO3/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 Donald	1	05/15/2012	8.14	243	143.0	3.2	8.6	58.7	16.4	42.3	39.0	244.7	10.0	M
Columbia at Donald	1	05/29/2012	8.21	213	134.0	4.6	6.9	22.4	2.3	20.0	12.5	221.7	10.0	TB
Columbia at Donald	1	06/05/2012	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	n/a
Columbia at Donald	1	06/27/2012	8.13	171	38.0	3.6	5.2	61.8	21.5	40.3	55.0	221.3	10.5	TB
Columbia at Donald	1	07/10/2012	8.11	162	29.3	2.1	8.1	58.1	23.8	34.3	110.0	226.0	14.0	TB
Columbia at Donald	1	07/31/2012	8.07	150	28.9	1.9	4.0	31.3	17.6	13.7	29.1	172.7	15.0	TB
Columbia at Donald	1	08/28/2012	8.14	160	19.3	3.1	5.0	12.5	6.3	6.1	14.0	179.2	13.0	LTB
Columbia at Donald	1	09/25/2012	8.19	188	59.4	3.4	7.4	30.5	23.0	7.4	56.6	213.9	10.0	TB
Columbia at Donald	1	10/22/2012	8.19	206	62.1	1.3	9.0	9.0	1.6	7.4	3.18	215.6	4.0	C
Columbia at Donald	1	11/20/2012	8.09	236	90.2	1.6	2.8	6.6	1.7	4.9	2.78	245.6	1.0	C
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

		Date	pH	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TPc**[1]	**Turb**	**Alk**	**T**	**Color(2)**
				(µS/cm)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	(mgCaCO3/L)	C	
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
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	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	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	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
Columbia at Mica Outflow	2	05/14/2012	7.28	85	213.9	2.9	5.7	7.2	1.1	6.1	1.20	72.9	4.0	C
Columbia at Mica Outflow	2	05/28/2012	7.96	133	98.9	3.7	5.2	7.3	1.0	6.3	0.10	106.2	5.0	C
Columbia at Mica Outflow	2	06/05/2012	7.43	72	195.5	4.2	4.8	9.9	1.9	8.0	0.75	64.8	5.5	TB
Columbia at Mica Outflow	2	06/26/2012	7.21	40	134.6	1.8	3.0	12.0	5.2	6.8	1.90	33.3	6.5	TB
Columbia at Mica Outflow	2	07/09/2012	7.05	27	93.5	1.6	3.3	9.6	2.3	7.3	3.90	20.6	7.0	TB
Columbia at Mica Outflow	2	07/30/2012	7.98	117	116.5	1.6	2.5	4.3	<0.1	4.2	0.37	127.0	9.5	C
Columbia at Mica Outflow	2	08/27/2012	8.04	119	113.5	3.4	3.8	4.6	1.9	2.7	0.98	133.4	9.0	C
Columbia at Mica Outflow	2	09/24/2012	7.99	119	114.9	2.3	4.4	4.8	<0.1	4.7	0.81	126.5	8.0	C
Columbia at Mica Outflow	2	10/23/2012	8.04	114	73.5	1.2	6.5	5.5	<0.1	5.4	0.69	120.7	9.0	C
Columbia at Mica Outflow	2	11/19/2012	7.75	109	83.5	1.3	2.8	3.8	<0.1	3.7	0.24	118.6	7.0	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

		Date	pH	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TPc**^{1}	**Turb**	**Alk**	**T**	**Color(2)**
				(µS/cm)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	(mgCaCO 3/L)	C	
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
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
Goldstream River	3	05/14/2012	7.57	111	382.1	3.3	6.8	34.4	2.2	32.3	2.80	108.8	6.5	M
Goldstream River	3	05/28/2012	7.80	90	361.5	4.5	4.7	73.9	4.9	69.1	6.25	91.7	6.0	TB
Goldstream River	3	06/05/2012	7.65	87	267.3	4.2	4.8	40.1	4.3	35.8	5.80	91.0	6.0	TB
Goldstream River	3	06/26/2012	7.85	77	130.4	2.6	3.8	73.3	14.1	59.2	45.00	82.2	6.0	TB
Goldstream River	3	07/09/2012	7.50	65	69.4	1.7	4.3	60.6	7.9	52.6	27.50	72.1	8.0	TB
Goldstream River	3	07/30/2012	7.65	67	65.4	1.4	3.4	31.3	5.9	25.4	4.04	72.6	10.0	LTB
Goldstream River	3	08/27/2012	7.94	87	93.3	2.4	3.1	13.4	5.5	7.9	1.45	98.1	10.0	C
Goldstream River	3	09/24/2012	7.88	89	84.4	2.2	4.9	11.4	4.7	6.7	8.33	94.1	9.0	M
Goldstream River	3	10/23/2012	7.98	110	149.3	1.6	6.2	7.4	<0.1	7.3	0.63	128.1	2.0	C
Goldstream River	3	11/19/2012	7.82	123	181.7	1.4	2.8	4.6	<0.1	4.5	0.47	137.4	2.0	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

		Date	pH	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TPc**[1]	**Turb**	**Alk**	**T**	**Color(2)**
				(µS/cm)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(NTU)	(mgCaCO3/L)	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
Columbia above Jordan	4	05/14/2012	7.64	137	85.5	2.8	6.3	9.0	1.0	8.0	0.45	127.1	6.5	C
Columbia above Jordan	4	05/28/2012	7.96	127	107.6	4.0	5.5	6.0	1.3	4.7	0.13	123.0	6.0	C
Columbia above Jordan	4	06/05/2012	7.87	124	119.3	4.0	4.8	6.9	0.7	6.2	0.00	125.3	6.0	C
Columbia above Jordan	4	06/26/2012	7.94	104	148.1	2.0	4.0	3.8	0.7	3.1	0.00	103.3	8.0	C
Columbia above Jordan	4	07/09/2012	7.71	93	151.8	2.1	6.5	7.1	0.8	6.3	0.05	94.5	8.0	C
Columbia above Jordan	4	07/30/2012	7.58	68	111.4	1.8	3.4	6.4	2.0	4.4	1.18	69.8	10.0	C
Columbia above Jordan	4	08/28/2012	7.93	95	113.6	2.8	4.9	4.9	1.3	3.6	0.15	103.4	11.0	C
Columbia above Jordan	4	09/24/2012	7.92	104	109.4	2.8	3.8	4.1	<0.1	4.0	0.30	111.1	11.0	C
Columbia above Jordan	4	10/23/2012	7.95	109	102.8	1.1	4.8	5.5	<0.1	5.4	0.32	120.3	8.5	C
Columbia above Jordan	4	11/19/2012	7.79	111	124.0	1.3	1.5	4.0	<0.1	3.9	0.28	119.0	7.0	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

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: 2012/01/01

End Date: 2013/01/01

Date Time	ALK-T	Ca	Cl	K	Mg	Na	NH3	NO2	NO3	pH	OP	TP	SO4	Cond	T	Turb	TN	TND
Units	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	PH UNITS	MG/L	MG/L	MG/L	US/CM	DEG C	NTU	MG/L	MG/L
1 2 3 4 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
01-09-2012 10:44	86.7	24.2	1.1	0.4	8.6	1.8	NaN	0.005	0.178	7.82	0.001	0.002	17.5	193	0.5	0.45	0.17	0.16
02-06-2012 08:17	91.2	28.8	1	0.4	9.3	2	NaN	0.005	0.174	7.91	0.001	0.002	18.6	210	0.5	0.9	0.17	0.18
03-06-2012 10:20	91.9	28.4	1.3	0.4	8.9	2	NaN	0.005	0.137	8.02	0.001	0.002	16.9	209	0.5	0.51	0.14	0.14
04-03-2012 08:35	93.4	28.3	2.3	0.4	9.1	2.5	NaN	0.005	0.169	7.83	0.001	0.002	18	206	2.8	0.62	0.15	0.15
05-01-2012 09:00	60.7	19.8	2.6	0.4	6	2.6	NaN	0.005	0.341	7.91	0.001	0.005	10.7	147	4	2.54	0.38	0.36
06-04-2012 10:40	48.6	16.6	0.7	0.3	5	1.1	NaN	0.005	0.22	7.96	0.001	0.016	7.8	111	7	8.73	0.29	0.28
07-09-2012 10:00	34.7	11.8	0.3	0.2	3.7	0.5	NaN	0.005	0.059	7.91	0.001	0.066	6.5	85	8.4	30.9	0.09	0.07
08-07-2012 09:37	31.2	9.8	0.2	0.3	2.2	0.4	NaN	0.005	0.054	7.77	0.001	0.093	4.4	64	8	53.6	0.07	0.07
09-04-2012 10:00	44	15.8	0.3	0.3	4.5	0.5	NaN	0.005	0.071	7.81	0.001	0.01	8.8	103	7.9	4.87	0.07	0.07
10-10-2012 13:32	60.7	19.9	0.4	0.3	6	1	NaN	0.005	0.086	7.94	0.001	0.002	12.6	143	6.5	1.41	0.12	0.11
11-18-2012 11:20	71.5	22.3	0.9	0.4	6.9	1.6	NaN	0.005	0.166	7.99	0.001	0.002	15.2	160	1.7	0.46	0.18	0.18
12-04-2012 11:15	78.3	24.4	0.8	0.4	7.7	1.8	NaN	0.005	0.124	8.04	0.001	0.002	15.6	180	1.3	0.67	0.16	0.16

Appendix 3

CTD Surveys Kinbasket and Revelstoke Reservoirs, 2012

Roger Pieters and Greg Lawrence
University of British Columbia

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2012

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

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Revelstoke Reservoir, 29 Aug 2013

Prepared for

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1. Introduction

We report on CTD (conductivity-temperature-depth) profiles collected from Kinbasket and Revelstoke Reservoirs in 2012. This is the fifth year of data collected for the B.C. Hydro project "CLBMON-3 Kinbasket and Revelstoke Ecological Productivity Monitoring".[*]

2. Methods

Sampling stations

Sampling Kinbasket and Revelstoke Reservoirs is challenging 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 location of the sampling stations is shown in Figure A1. Stations are 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). Station locations are given in Appendix 1.

In 2012, sampling was conducted in both reservoirs monthly from June to October. A list of the profiles collected in 2012 is given in Appendix 2, and a summary is given in Tables 2.1 and 2.2. Unlike previous years, no intensive CTD surveys were collected in 2012. The profiler was tested in the Revelstoke forebay at the end of May. Regular sampling was begun a month later than in 2011 due to administrative delays, with the first complete set of profiles in June. During the October survey, no profile was collected at K2mi due to a storm with high waves (10-15ft). Sampling of the reservoirs in early November was planned; however, in Kinbasket it was only possible to collect a profile from the Canoe site (Kca1) due to bad weather, and sampling of Revelstoke was not attempted due to snow.

Additional casts were collected during measurement of primary production in Kinbasket Reservoir, and these data are shown in Appendix 4.

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[*] 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).

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 2.6 provides an estimate of the 1% light level (Figure A4).

Pump problems In 2009 to 2011 the pump on the profiler did not turn on due to a problem with the setting of the ‘minimum conductivity frequency’; for more detail see Appendix 4. The pump affects the temperature, conductivity and dissolved oxygen readings; even with the pump off, most of the temperature and conductivity data collected was satisfactory as descent forced water through the plumbing (Pieters and Lawrence, 2013).

In 2012, the minimum conductivity frequency was correctly set to zero. To evaluate the effect of having the pump off, three casts were collected in the forebay of Revelstoke Reservoir in May 2012 (Figure D1). During the first and last casts (RED) the pump was on, while during the second cast (BLACK) the pump was turned off. The data for light transmission and fluorescence (Chl a) are independent of the pump and show good agreement (Figures D1d,g).

The temperature and conductivity data were very similar between all three casts (Figure D1b,c). This confirms that temperature and conductivity data collected in 2009 to 2011 were accurate, excluding casts where bubbles evidently blocked the flow (see Pieters and Lawrence 2013 for detail). However, having the pump off did affect the dissolved oxygen readings: without the pump the readings were noisier and lower by about 1 mg/L. As a result the oxygen data for 2009-2011, other than confirming generally oxygenated conditions, were not accurate.

Table 2.1 Kinbasket surveys, 2012

Date	FB K1	K1.5	MI K2	CO K3	CA Kca1	WO Kwo1
11-12 June	✓		✓	✓	✓	✓
20 June		✓*				
16-17 July	✓		✓	✓	✓	✓
26 July		✓*				
19-20 August	✓		✓	✓	✓	✓
23 August		-**				
17-18 September	✓	✓*	✓	✓	✓	✓
1-2 October	✓		-	✓	✓	✓
5 November					✓	

* Collected during measurement of primary production (see Appendix 3)
** No CTD collected during primary production

Table 2.2 Revelstoke surveys, 2012

Date	FB	MI	UP
31 May	✓+2		
18-19 June	✓	✓	✓
21 June		✓*	
18 July	boom		
24-25 July	✓*	✓*	✓
21-22 August	✓*	✓*	✓
10-11 September	✓	✓	✓
19-20 September	✓*	✓*	
9-10 October	✓	✓	✓

* Primary production (see Appendix 3)

3. Results

We first look at the water levels and flows during 2012, shown in Figure A2. In Kinbasket Reservoir the surveys began in June, well after the minimum water level, and end in October, after the maximum water level (Figure A2a). Note the water level rose very high in 2012, reaching normal full pool (754.4 m ASL) on 23 July, and peaking at 754.7 on 28 August (Figure A2a inset). The center of the outlet from Kinbasket Reservoir is located 64.6 m below normal full pool; in 2012, the mid-depth of the outlet varied from 32.2 m on 22 April to 64.9 m on 29 August. In Revelstoke Reservoir there is normally little variation in water level (< 1.3 m), but in 2012 the water level varied by 2.2 m with four brief drawdowns just below normal minimum (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, the Columbia River at Donald, was sampled 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 19 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. 2014b). This seasonal change in the conductivity of the inflow will assist in identifying water masses as discussed below.

3.1 Kinbasket Reservoir

June 2012 Line plots for the six monthly surveys of Kinbasket Reservoir are shown in Figures B1-6. In June 2012, the surface temperature varied from 10 to 12 ºC (Figure B1b). There was no clearly defined surface mixed layer; instead there was a broad thermocline, which extended from the surface to around 25 m. During this time, the outlet from Kinbasket reservoir was 44 m below the surface, as marked in Figure B1. Note that the temperature in the Columbia Reach, K3co, is distinctly different (black, Figure B1b).

The conductivity varied from ~150 μS/cm near the surface to ~200 μS/cm at depth through most of the reservoir (Figure B1c). The exception again is the Columbia reach, K3co, which had a higher conductivity of 200-250 μS/cm (black, 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 B1-6c) and relatively unchanged (Figure B9c) throughout the summer. In Canoe Reach, slightly reduced conductivity around 20 m suggests low-conductivity inflow (green, Figure B1c).

For stations K1fb and K2mi, near the center of the reservoir, the water remained quite clear in June (high light transmission, Figure B1d). However, the stations in the three reaches - K3co, Kca1, and Kwo1 - had layers of significantly reduced light transmission in the top 50 m, likely the result of turbid inflows. Kca1 also showed some lenses of high turbidity below 50 m, which is unusual, but was confirmed by data from the up cast (Figure B1d). This deep turbidity could have several origins such as winter inflow, a spring inflow with sufficient turbidity to go to the bottom, or an underwater slump.

Dissolved oxygen was high (>9 mg/L) throughout the reservoir (Figure B1e). The nominal concentration of chlorophyll was generally low (< 1.3 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 5 to 20 m, just below the chlorophyll layer.

July 2012 In July, surface temperature varied from 13 to 20 ºC (Figure B2b). As in June, there was a broad thermocline, now extending from the surface to at least 40 m depth. The stratification is reduced in the top 5 to 10 m in a couple of the casts, suggesting some surface mixing. In conductivity, the most notable feature is the decline in the conductivity in the top 60 m at K3co (black, Figure B2c).

In July, turbidity in the top 60 m increased from that in June, including layers of very high turbidity (low light transmission) in Wood Arm (blue), Canoe Reach (green) and the Columbia Reach (black, Figure B2d). Oxygen remained high (Figure B2e,f) and chlorophyll values were a little higher than in June with peaks between 1 and 2 µg/L (Figure B2g).

August 2012 The temperature at the surface warmed to ~20 ºC at all stations, and the broad thermocline extended to about 60 m (Figure B3b). The overall conductivity of the surface layer continued to decline (Figure B3c). All locations showed layers of turbidity between 20 and 50 m, with the high turbidity in Wood Arm between 30 and 50 m particularly notable (Figure B3d).

The chlorophyll layer around 10 m had decreased slightly from that in July (compare Figures B2g and B3g). Two anomalous readings should be ignored. The first is a peak in fluorescence in Wood Arm at 30 to 50 m (cyan, Figure B3g), which results from the corresponding layer of high turbidity and does not represent biological activity. Second, in Canoe reach, high readings of fluorescence (5.5 µg/L) were observed in the top 3 m (green, Figure B3g). A sudden increase in fluorescence appeared while the instrument was soaking and then declined suddenly when the instrument reached 3 m; this, and the absence of a similar peak in the up cast, suggests the high readings above 3 m are erroneous.

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 ~80% at depth, indicating that the water was well oxygenated as would be expected for an oligotrophic system.

September 2012 The surface had cooled to about 15 °C with a surface mixed layer around 20 m deep. The conductivity structure remained much the same as it was in August. Layers of turbidity (low light transmission) continued to be observed in Wood Arm between 20 and 60 m depth.

October 2012 By early October, the surface layer had not cooled much from mid-September, dropping only to ~14 °C (Figure B5b), and the conductivity, clarity and oxygen were also similar to that in September (Figure B5c,d,e). A distinct peak in Chl a was absent (Figure B5g).

November 2012 The one cast collected in Canoe Reach in November 2012 shows the surface layer having cooled and mixed to about 50 m (Figure B6).

Seasonal changes Seasonal changes at the Forebay (K1fb), Middle (K2mi), Columbia (K3co), Canoe (Kca1) and Wood (Kwo1) stations, are shown in Figures B7 to B11, 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 declined 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). 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 surface layer depth and temperature was relatively uniform along the reservoir during each survey (Figure C1-5a). As the summer progresses, a distinct layer of low conductivity appears in the top 60 m (Figures C1-5b). The conductivity is lowest in Canoe Reach (e.g. Figure C1b). Light transmission was generally high (turbidity low) in the deep water (Figures C1-5c), with the exception of the Canoe Reach in June (Figure C1c). Lenses of turbidity can be observed in the thermocline at different times and locations along the reservoir (Figure C1-5c). Oxygen is generally high (Figures C1-5d). Chlorophyll is generally low, with peaks <2 μg/L in the top 20 m, just above the 1% light level (marked by black bars).

3.2 Revelstoke Reservoir

June 2012 The surface temperature varied from 9 to 13 ºC, below which a broad thermocline extended to about 60 m (Figure D2b). The conductivity of the top 40 m was slightly less than that of the water below (Figure D2c), while the turbidity was slightly higher in the top 40 m at some stations (Figure D2d), both likely the result of freshet inflow. Dissolved oxygen was high with > 90% saturation throughout (Figure D2f). Chlorophyll fluorescence shows small peaks just over 1 µg/L above the depth of the one percent light level (Figure D2g).

July to October 2012

From early May through to the middle of July, the inflow from Mica Dam to Revelstoke Reservoir was very low, while at the same time local inflow increased due to snow melt (Figure A2d). During this time, the conductivity of the top 50 m of Revelstoke Reservoir declined, as a result of the local freshet inflow with low conductivity (Figures D1-3c).

From mid-July to October, changes in the reservoir are then dominated by the inflow from Mica, which increased from < 20 m^3/s on 15 July 2012 to 1,590 m^3/s on 20 July 2012, an inflow which is both cooler and higher in conductivity. In the 24-25 July profiles, the effect of the Kinbasket inflow can be seen at the upper station, R3up, which is uniformly 9 °C and 135 µS/cm (black, Figures D3b,c). This cool water plunges and forms an interflow at around the level of the outlet, 30 m, the beginnings of which can be seen in July at the mid station (blue, R2mi, Figure D3c). An interflow layer from 15 to 50 m of relatively uniform temperature and conductivity can be seen in at both R2mi and R1fb in August (Figures D4b,c), September (Figures D5b,c and D6b,c) and October (Figure D7b,c). By early October, surface cooling has mixed the surface layer to 15 m, into the top of this interflow layer (Figure D7b,c). The interflow can also be seen in the contour plots (Figure E2-6).

Comparison of casts in the forebay (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 <2 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 (<1 nominal mg/L) and Revelstoke Reservoirs (<2 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 declines in oxygen in Kinbasket and Revelstoke Reservoirs are 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 (32 to 65 m in Kinbasket and 28 m in Revelstoke), high inflow, and short residence time (< 1 yr) may also be 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. (2014a), 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 2014b). 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.

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Figure A1 Map showning approximate location of profile stations

/ocean/rpieters/kr/bathy/map/map1REP09.m fig= 1 2011−Jan−26

Figure A2 Water level and flow, Kinbasket and Revelstoke Reservoirs, 2012

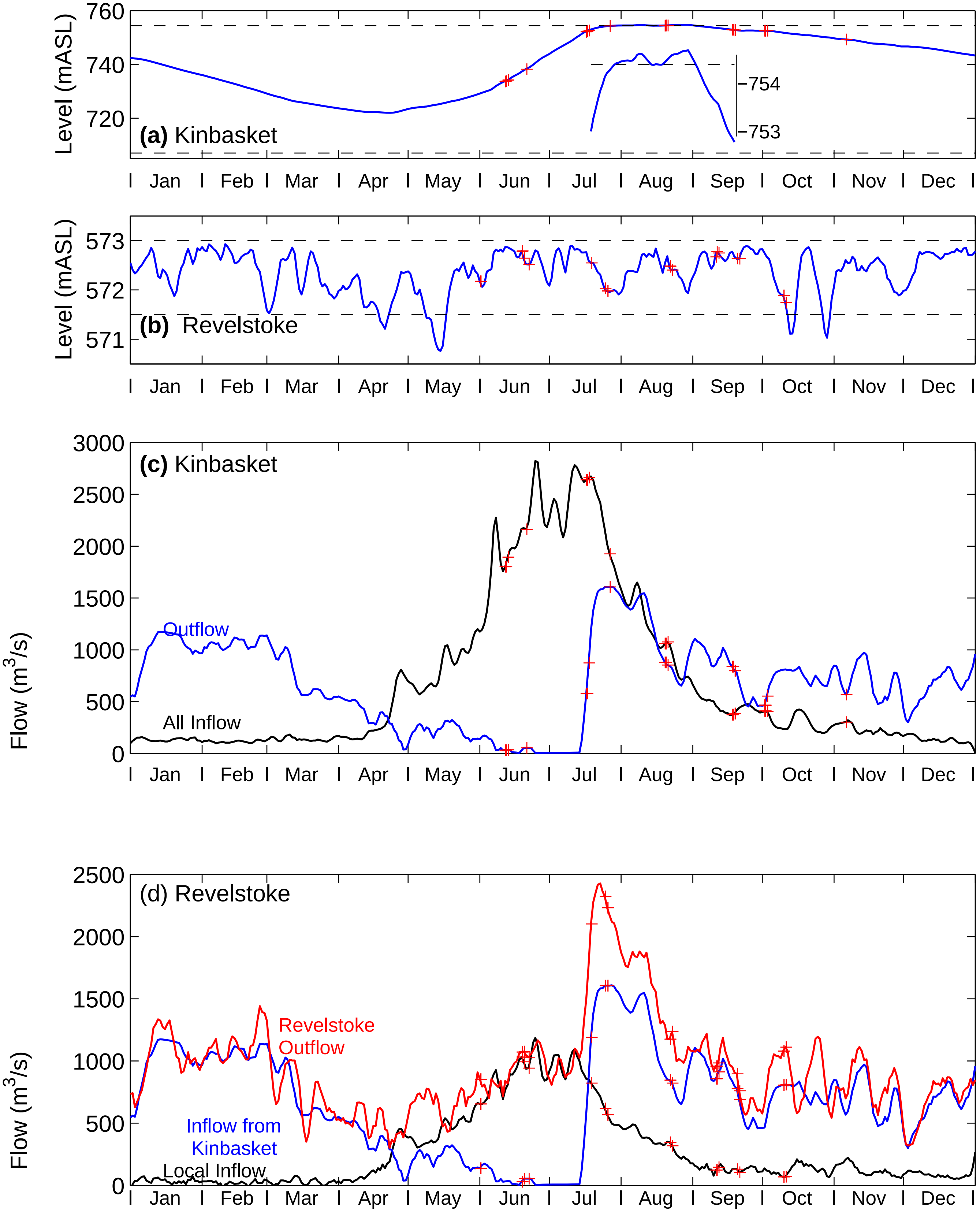

Figure A3 Columbia River at Donald, T and C25, 1984−1995

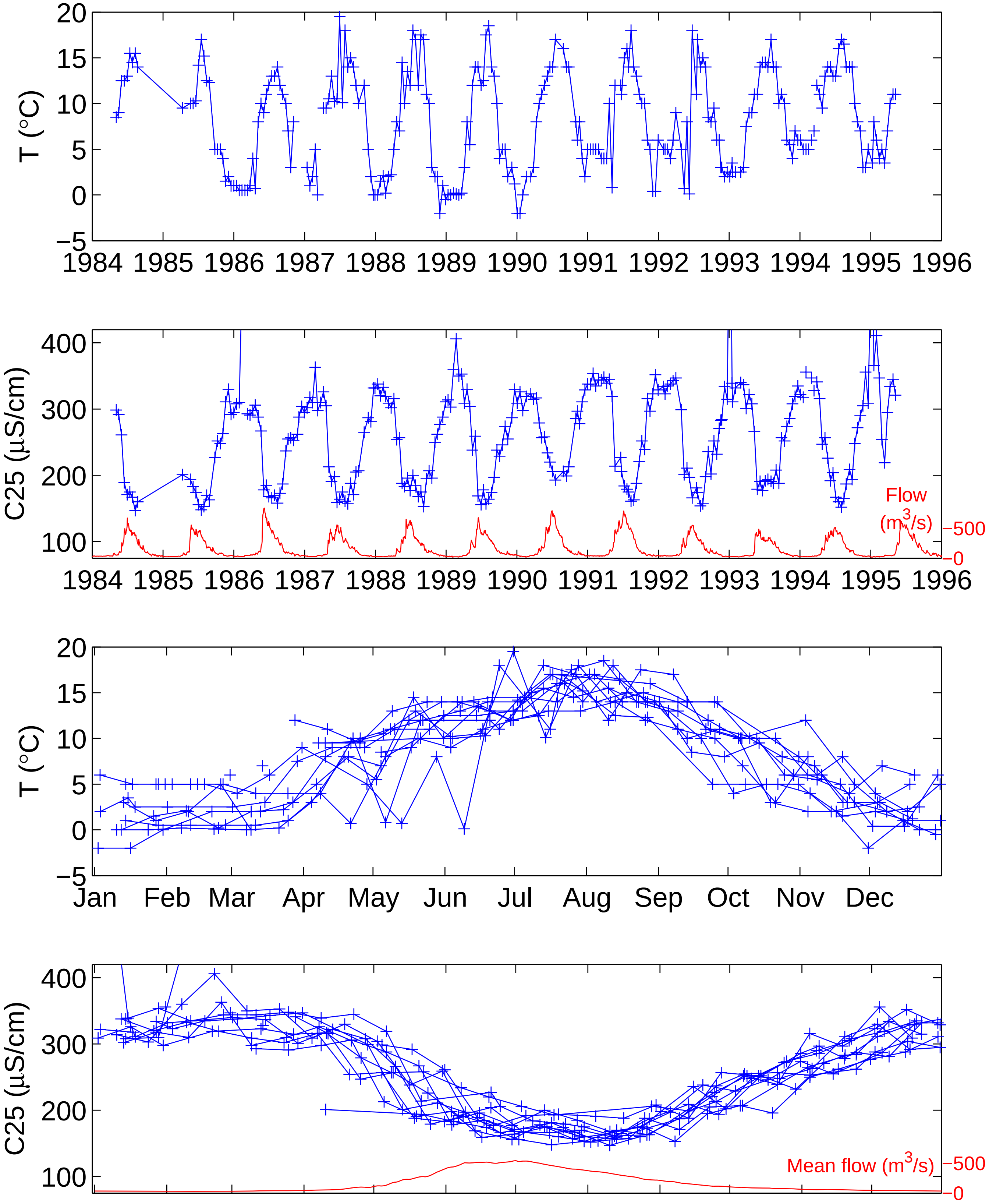

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Figure A4 1% Light Level = 2.6 X Secchi Depth,

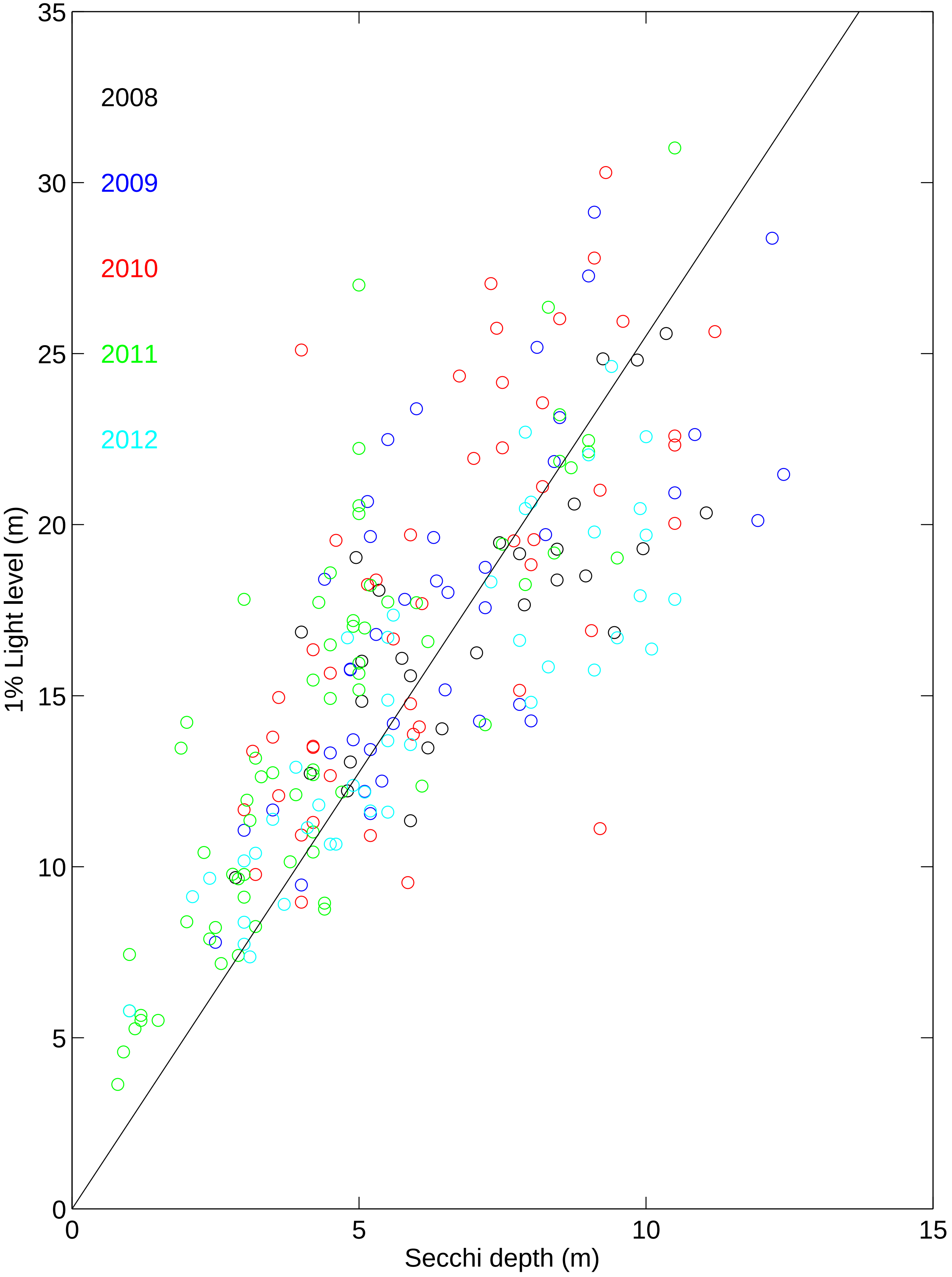


Figure B1 Kinbasket Reservoir, 11−12 Jun 2012

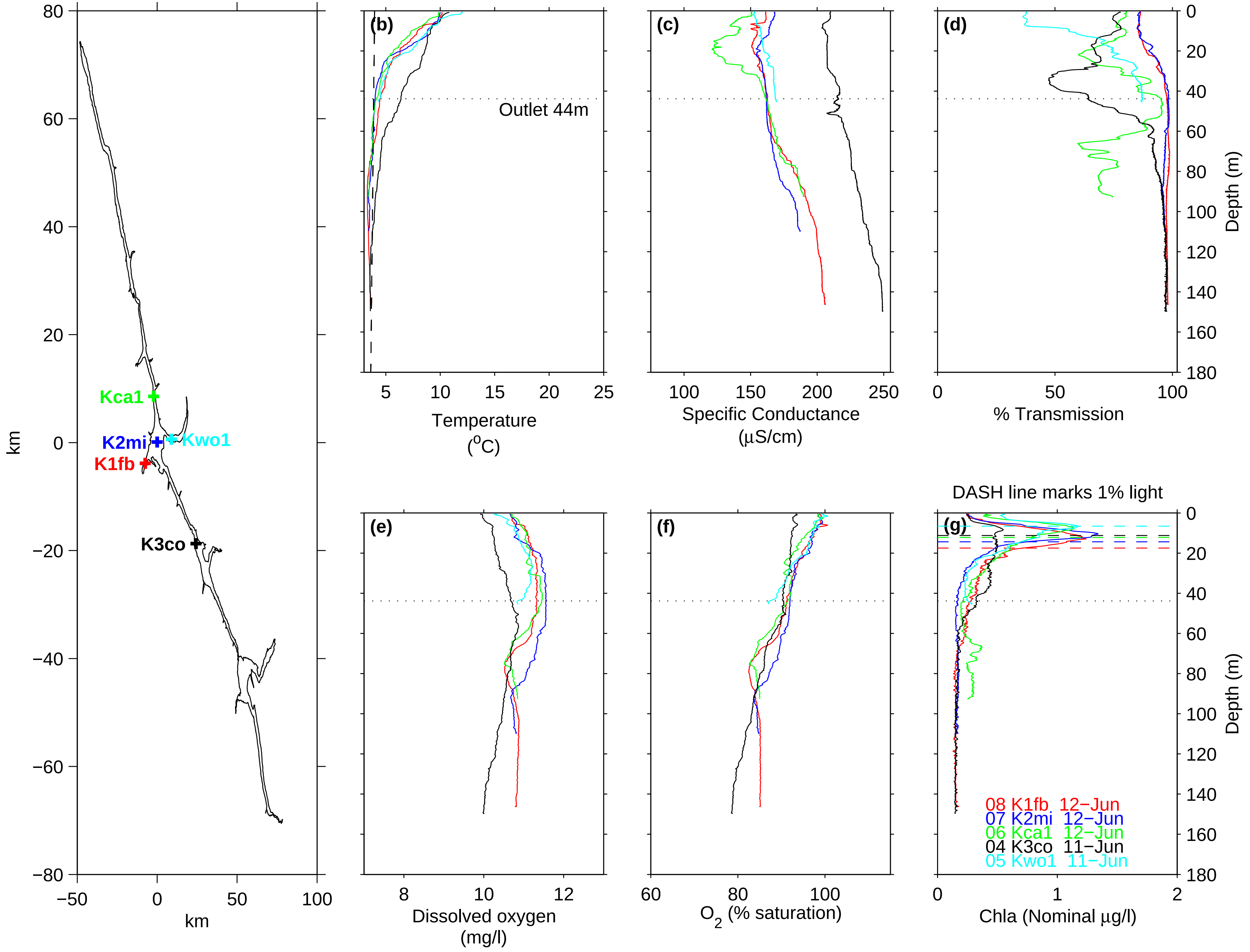


Figure B2 Kinbasket Reservoir, 16−17 Jul 2012

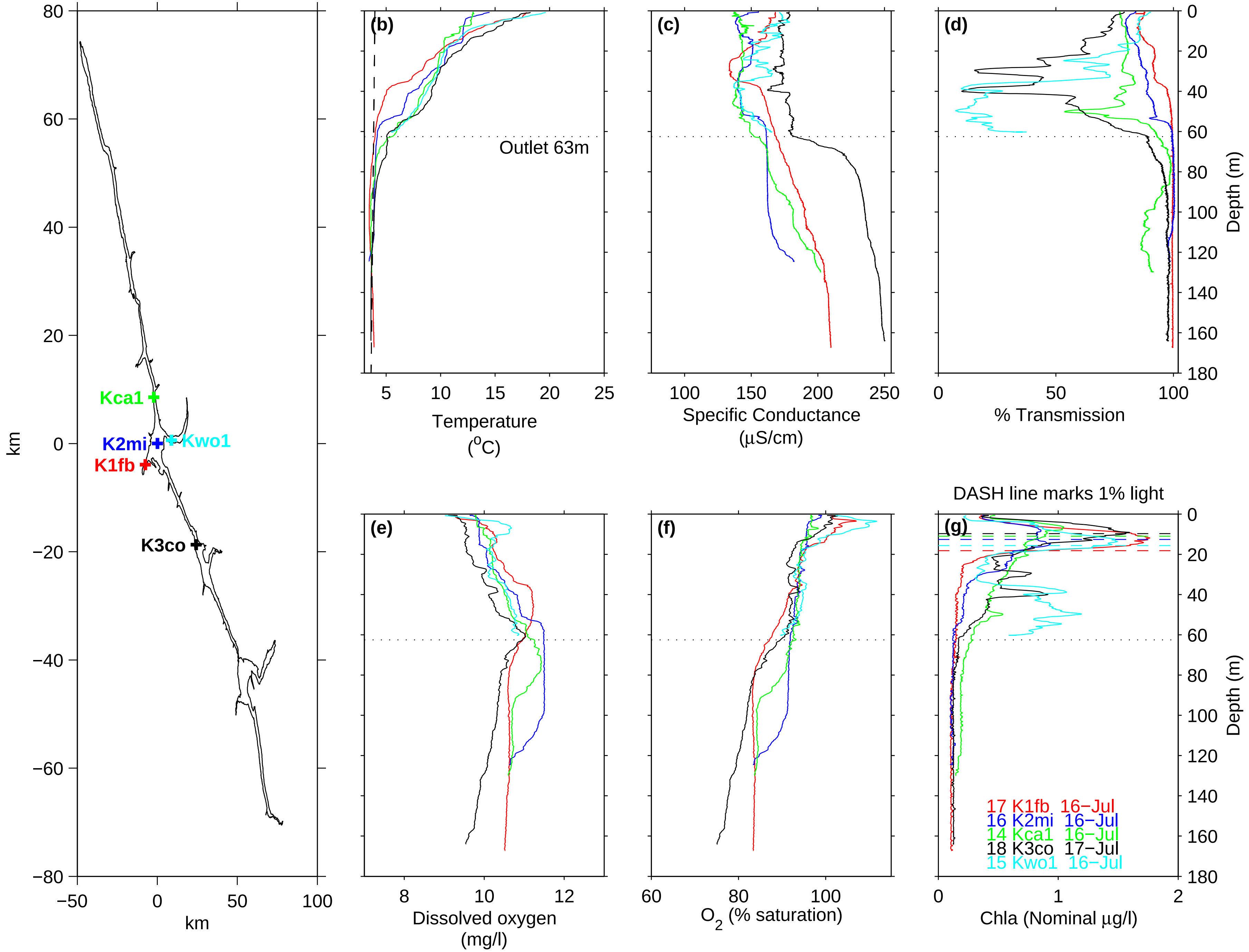


Figure B3 Kinbasket Reservoir, 19−20 Aug 2012

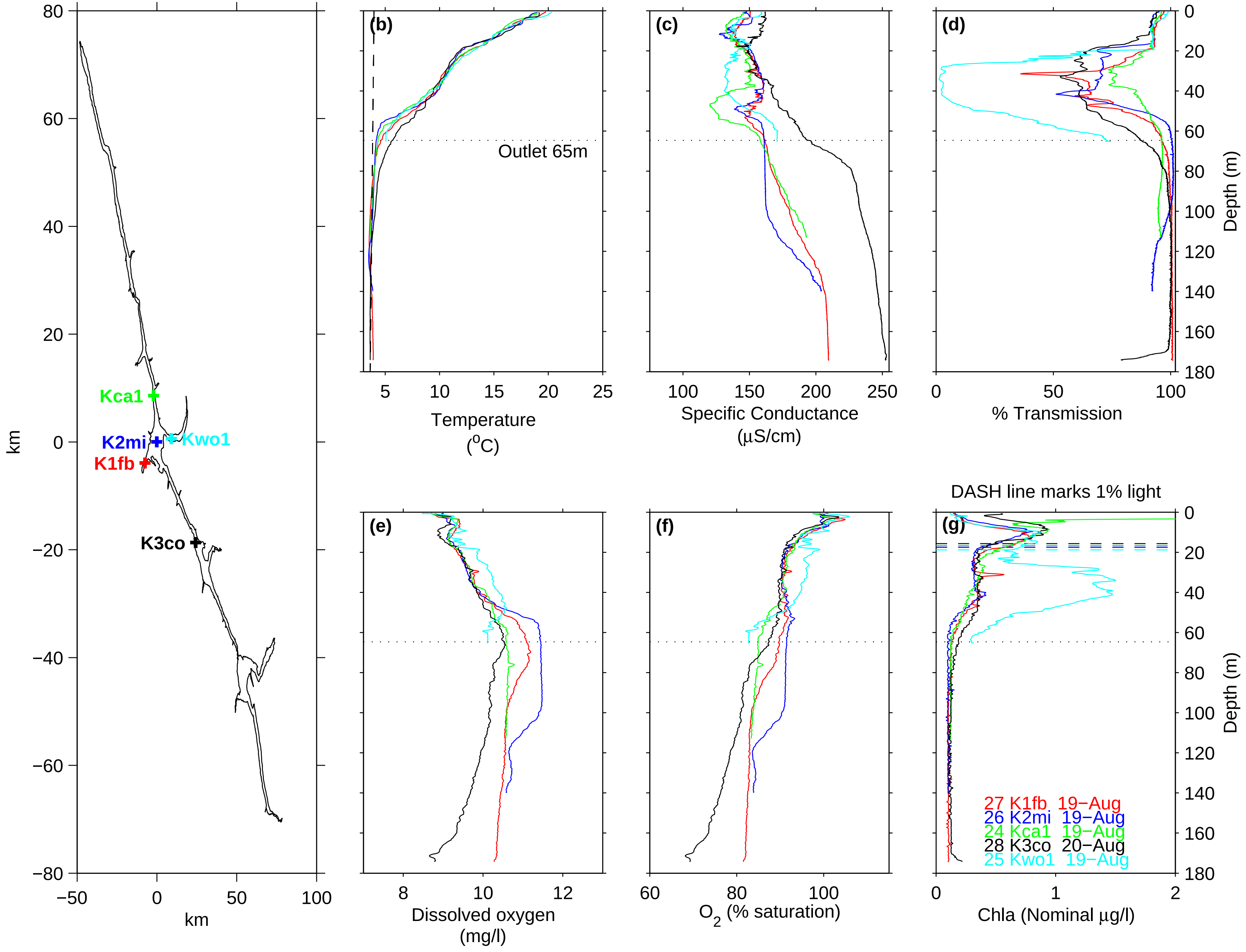


Figure B4 Kinbasket Reservoir, 17−18 Sep 2012

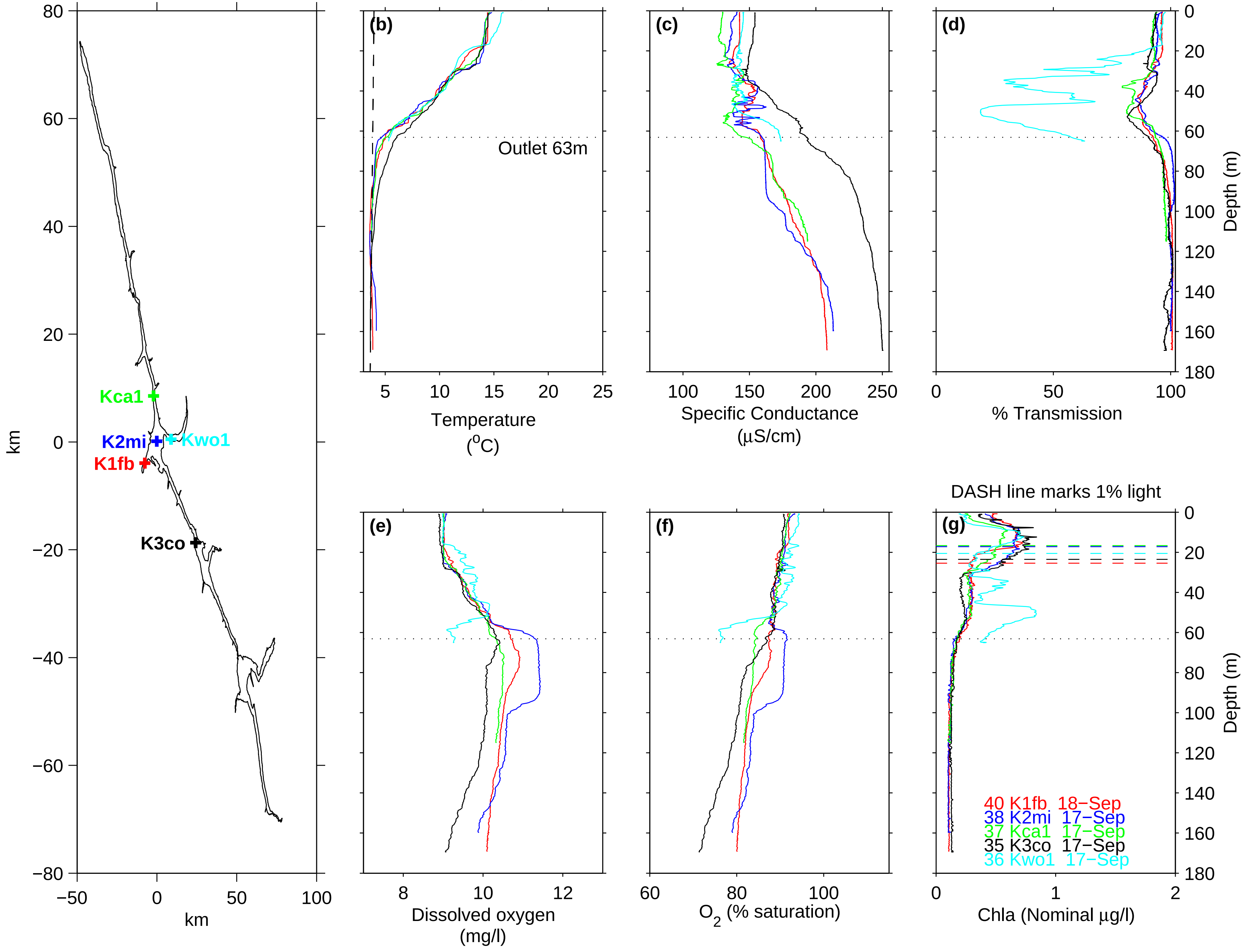


Figure B5 Kinbasket Reservoir, 1−2 Oct 2012

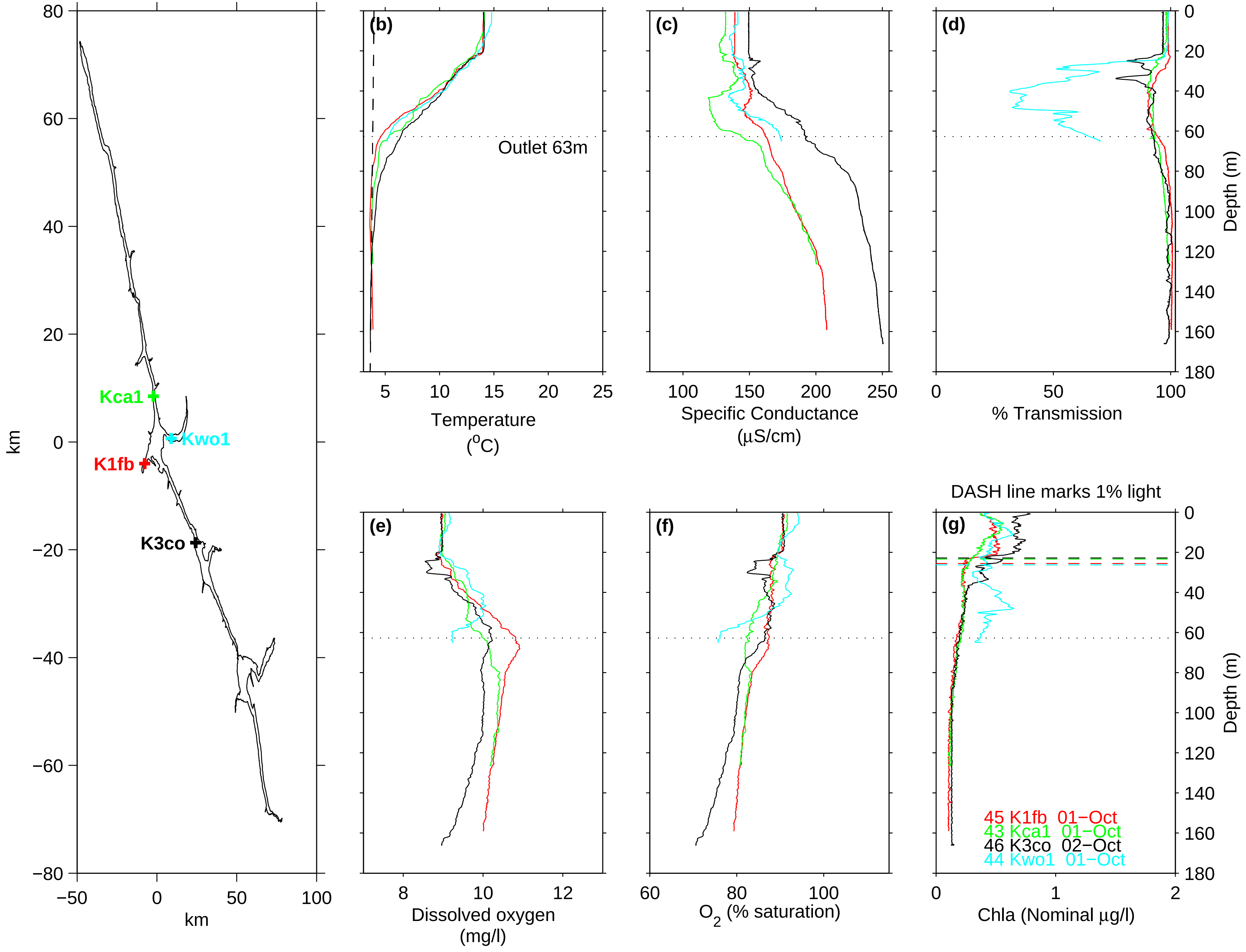


Figure B6 Kinbasket Reservoir, 5 Nov 2012

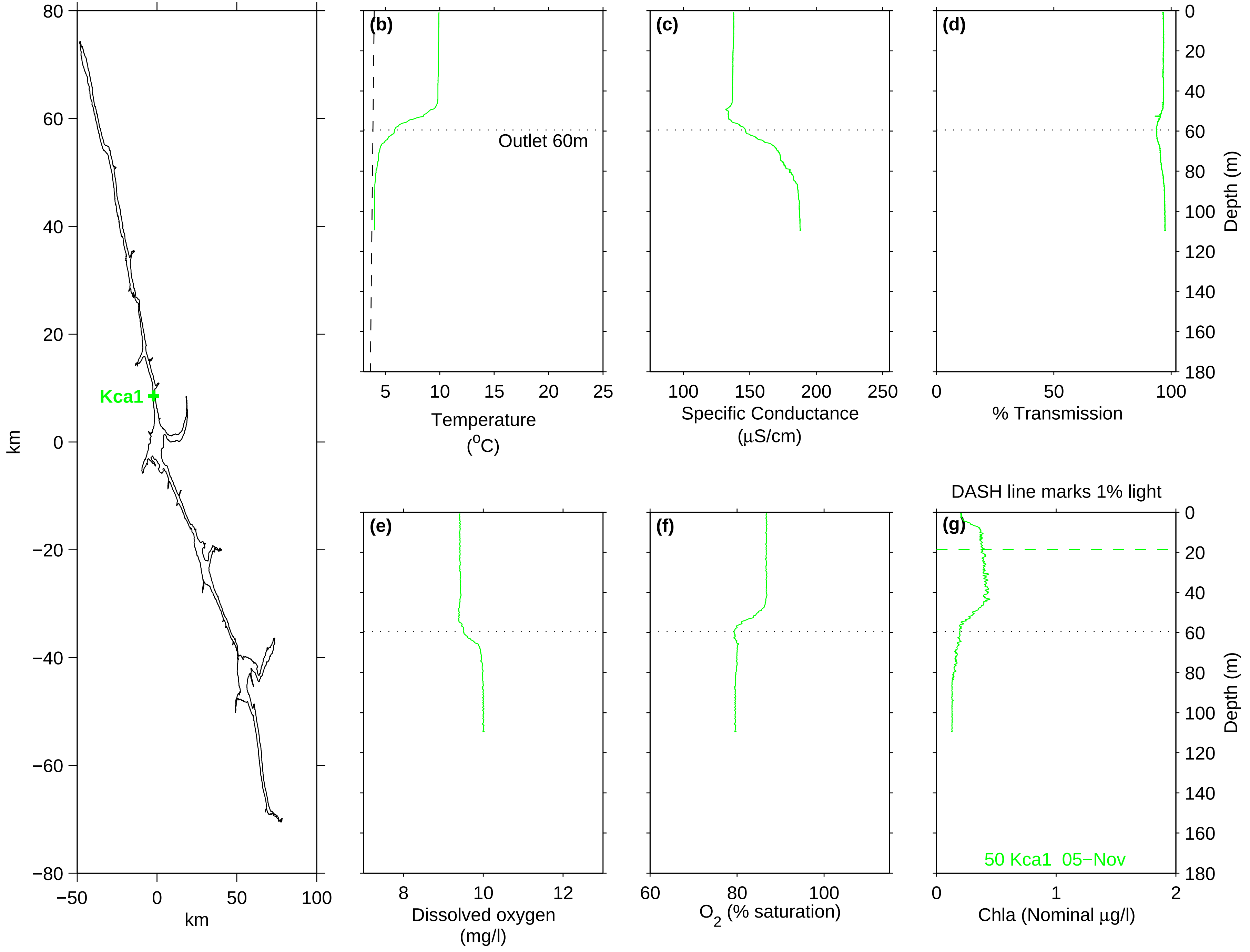


Figure B7 Kinbasket Reservoir, Forebay, K1fb, 2012

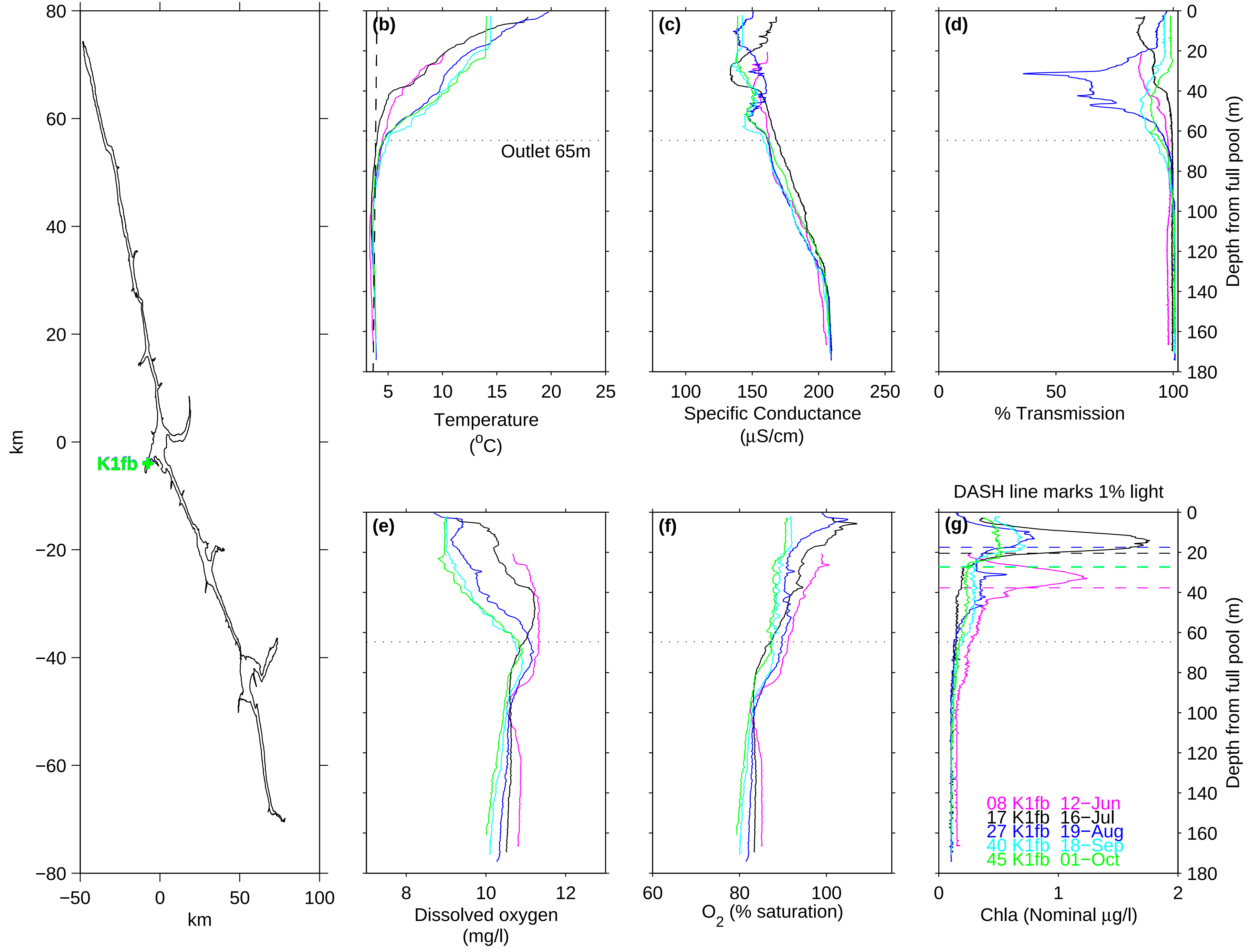


Figure B8 Kinbasket Reservoir, Middle, K2mi, 2012

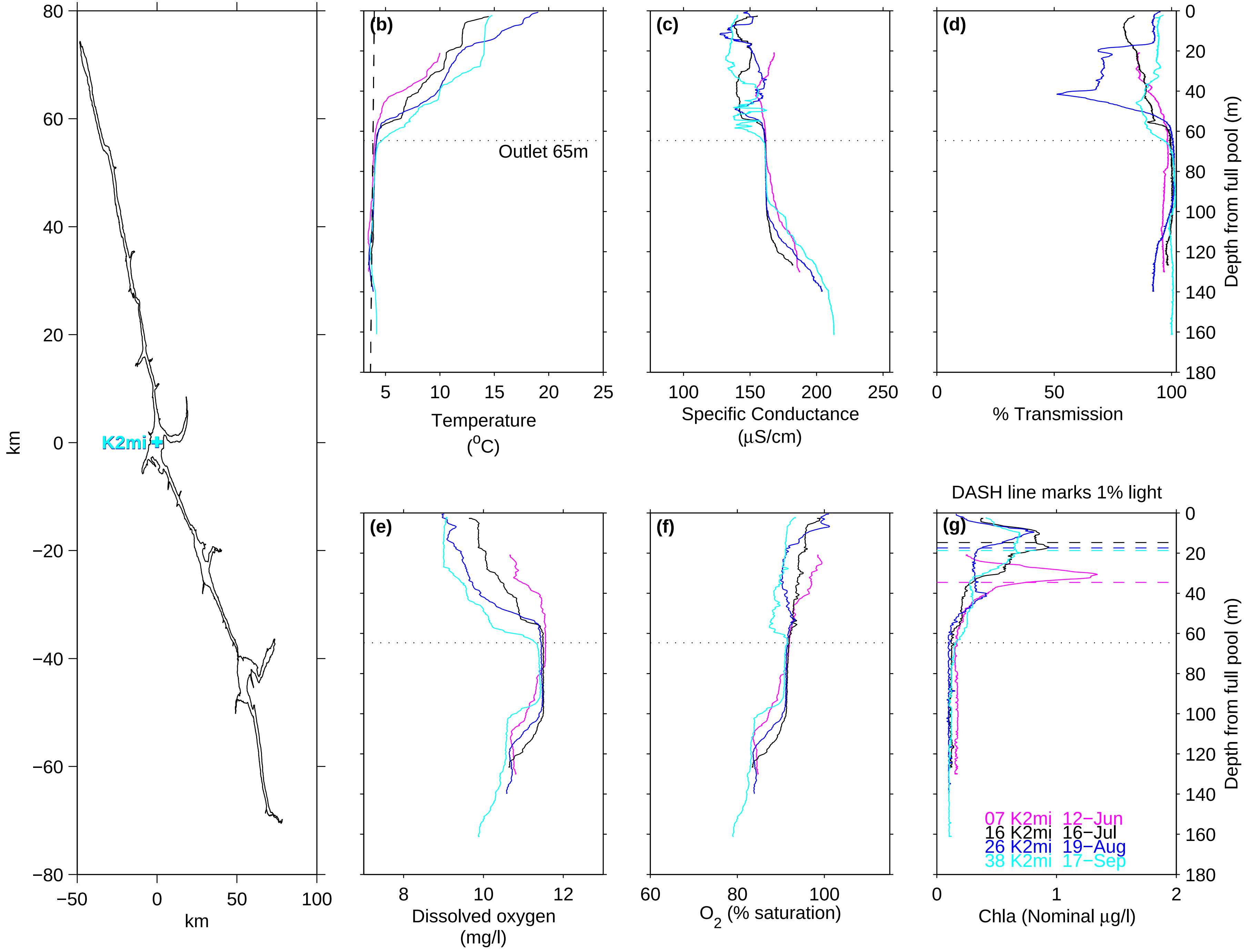


Figure B9 Kinbasket Reservoir, Columbia, K3co, 2012

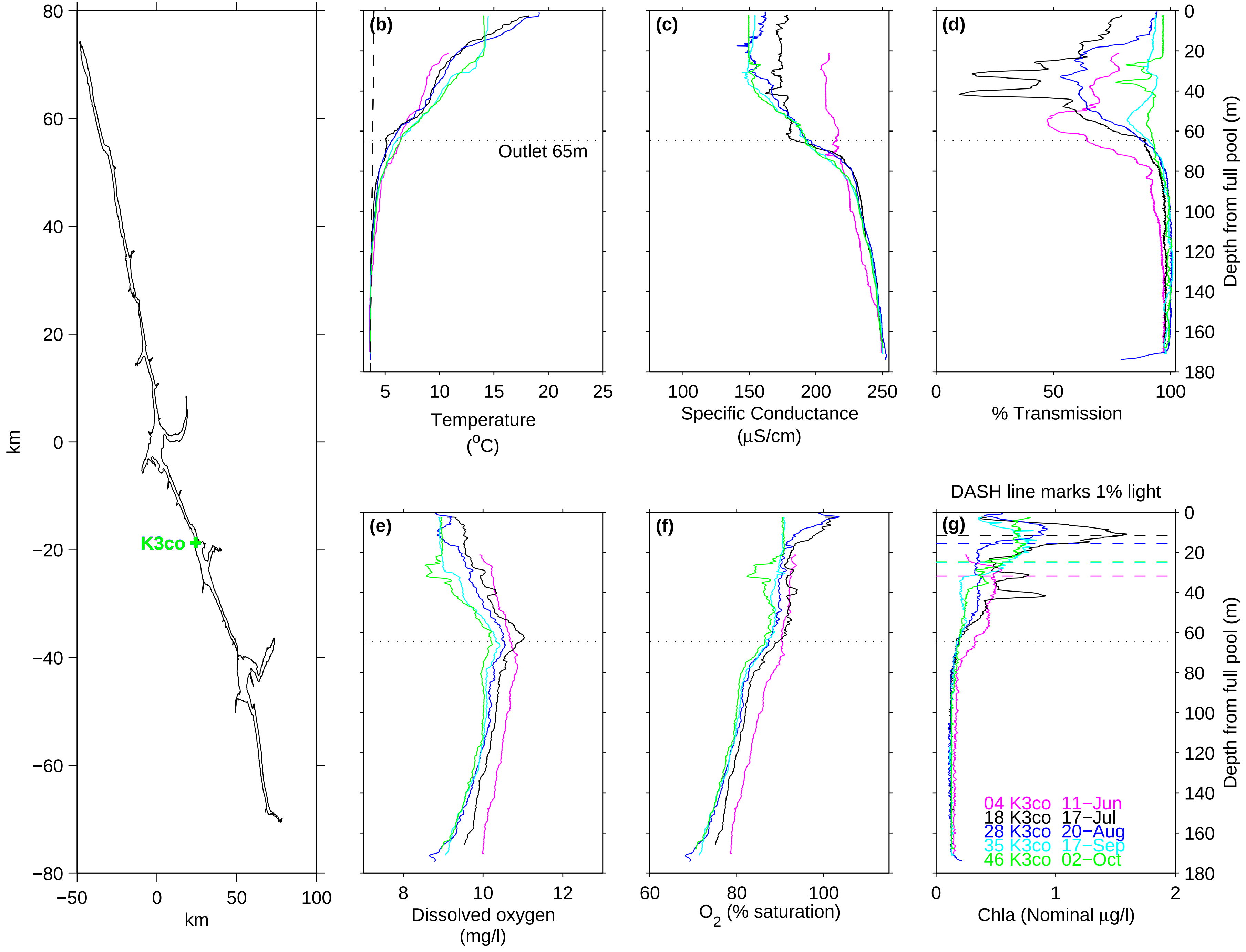


Figure B10 Kinbasket Reservoir, Canoe, Kca1, 2012

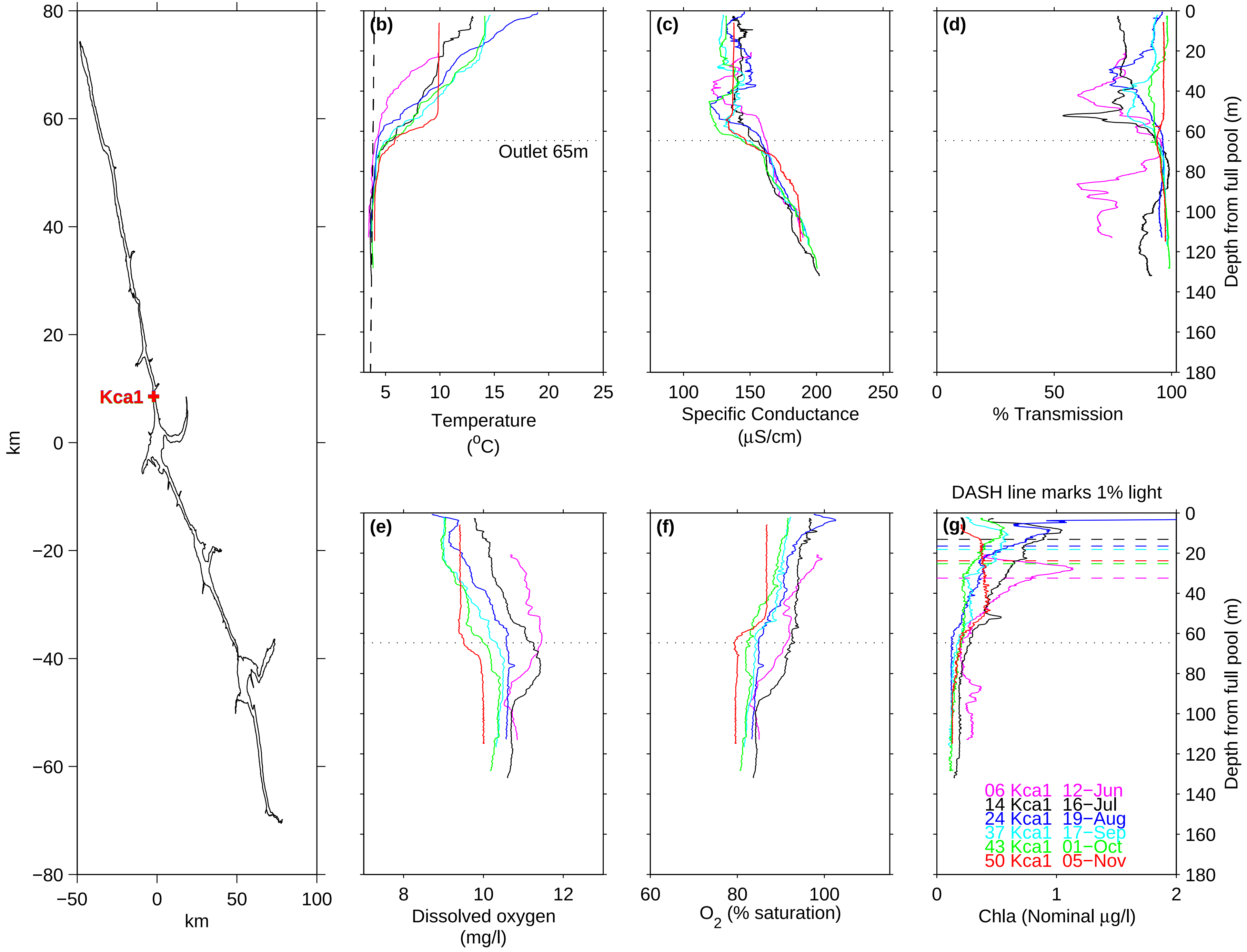


Figure B11 Kinbasket Reservoir, Wood, Kwo1, 2012

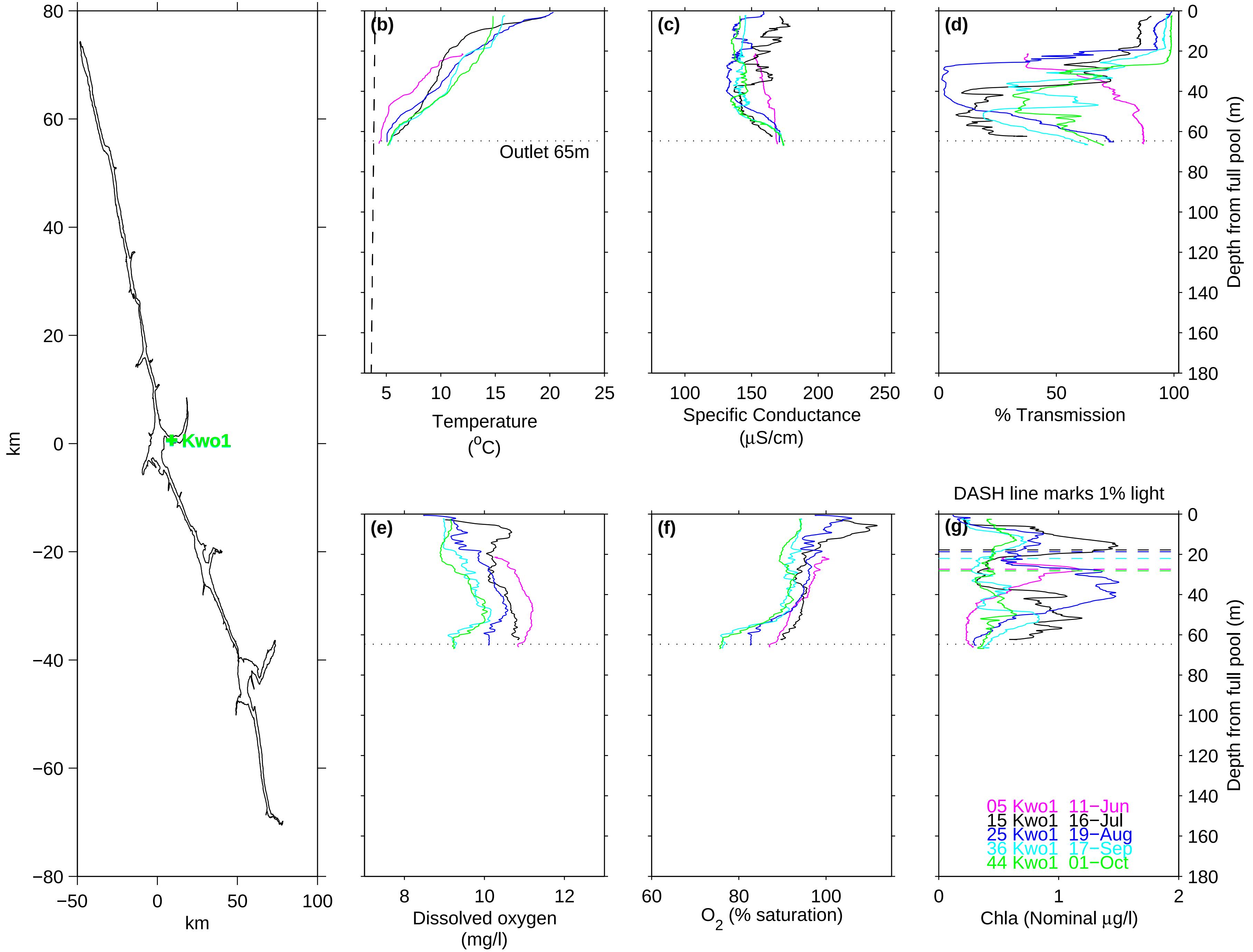


Figure C1 Kinbasket Reservoir 11−12 Jun, 2012

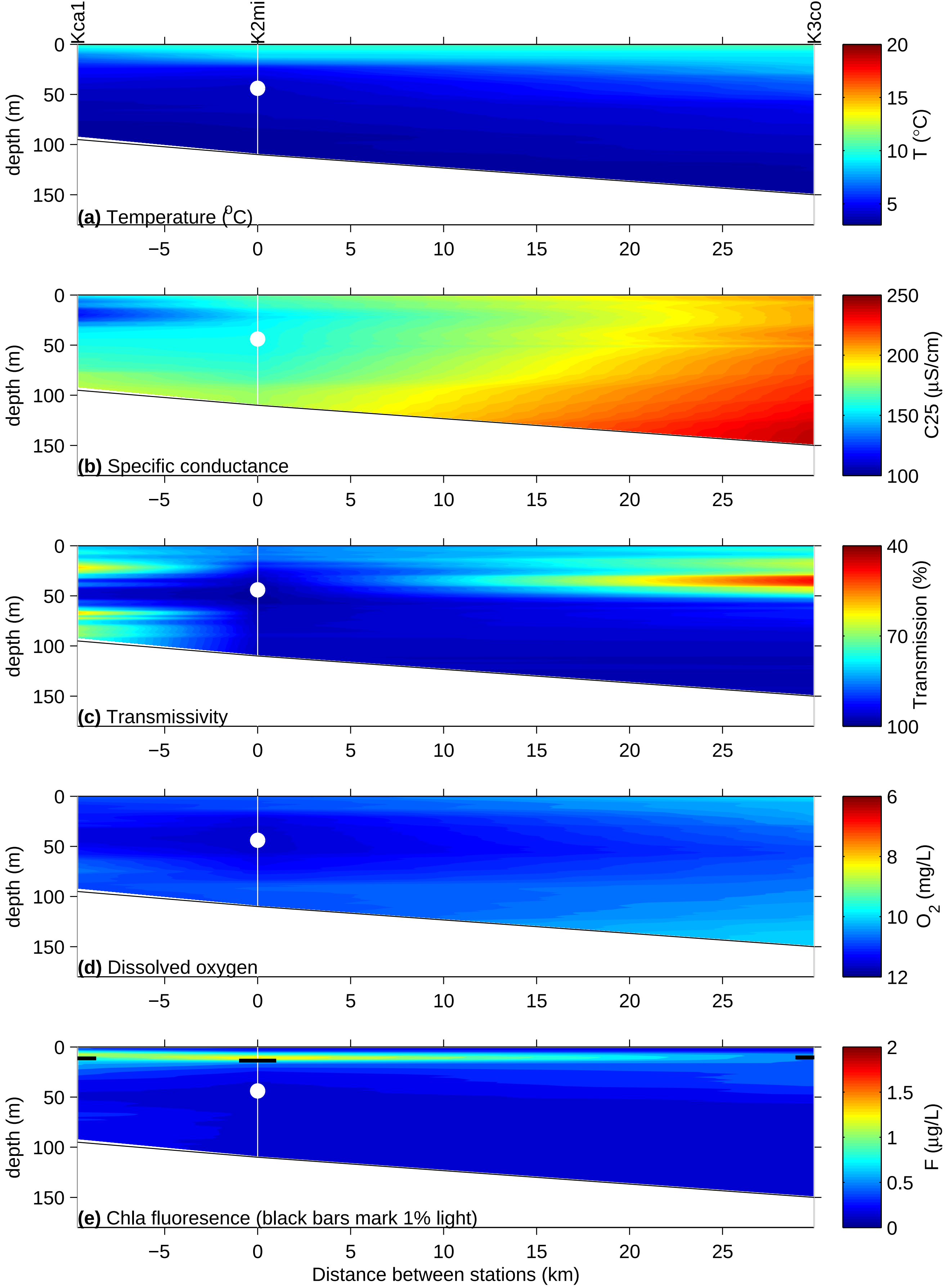


Figure C2 Kinbasket Reservoir 16−17 Jul, 2012

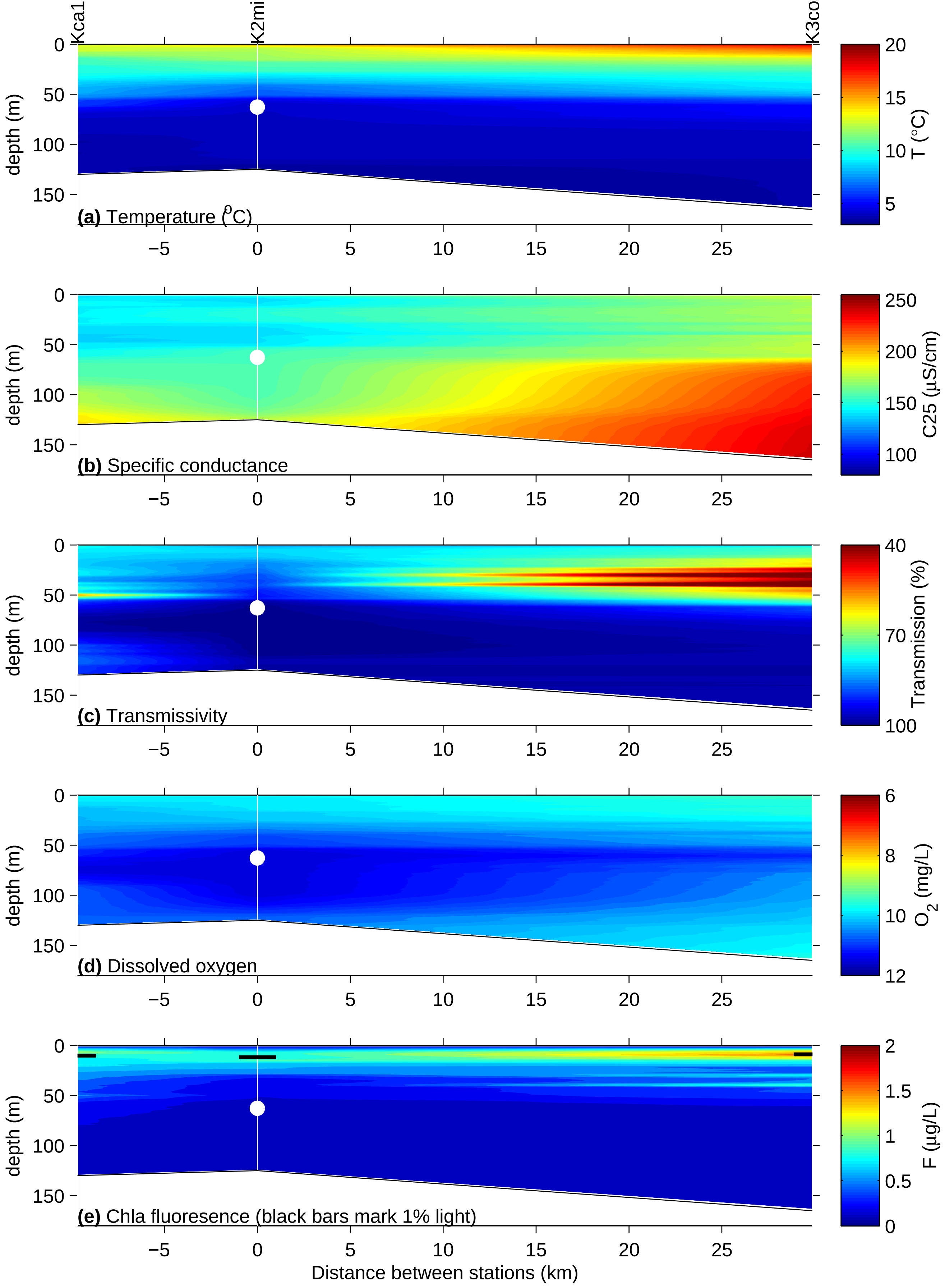


Figure C3 Kinbasket Reservoir 19−20 Aug, 2012

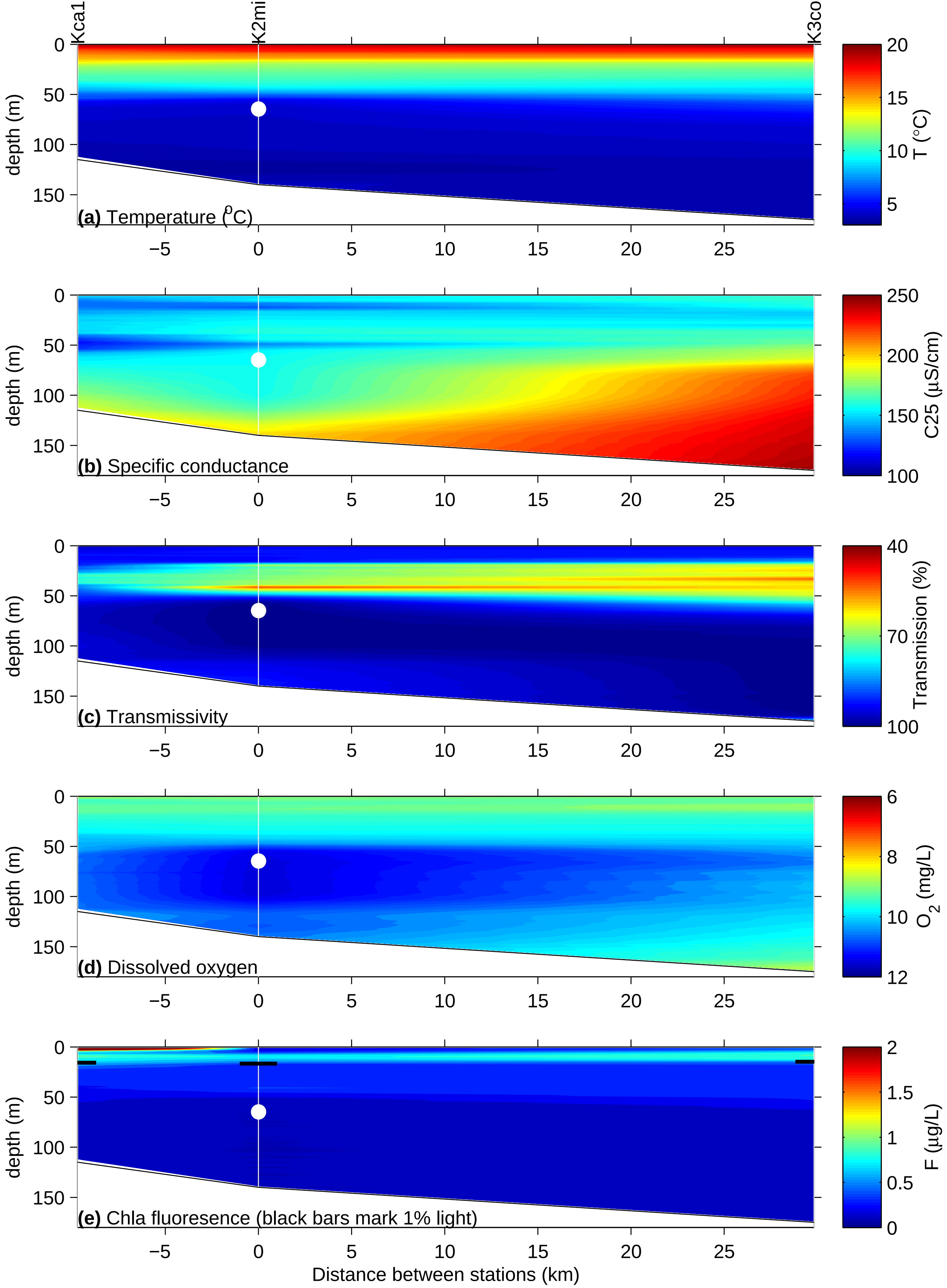


Figure C4 Kinbasket Reservoir 17−18 Sep, 2012

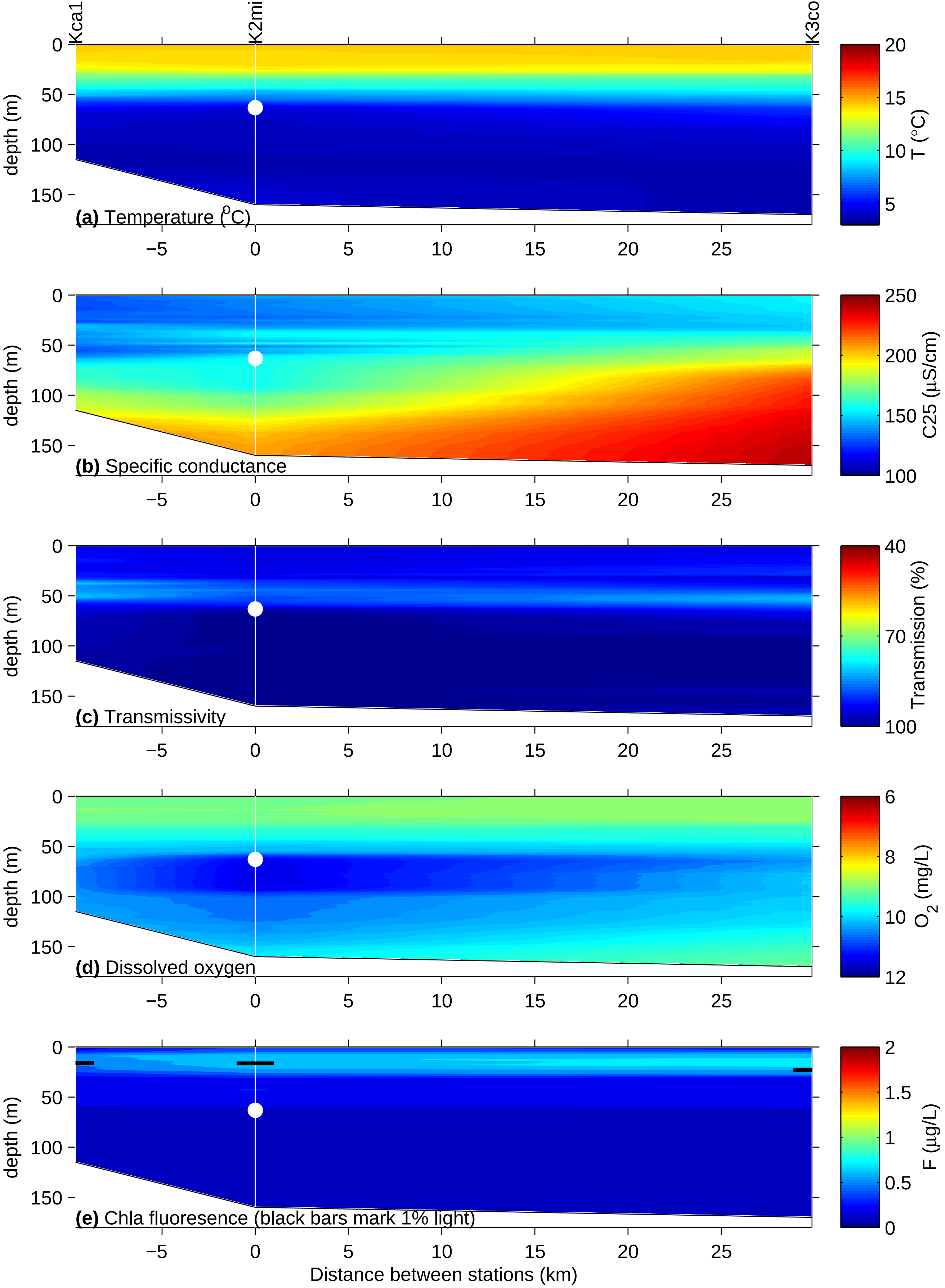


Figure C5 Kinbasket Reservoir 1−2 Oct, 2012

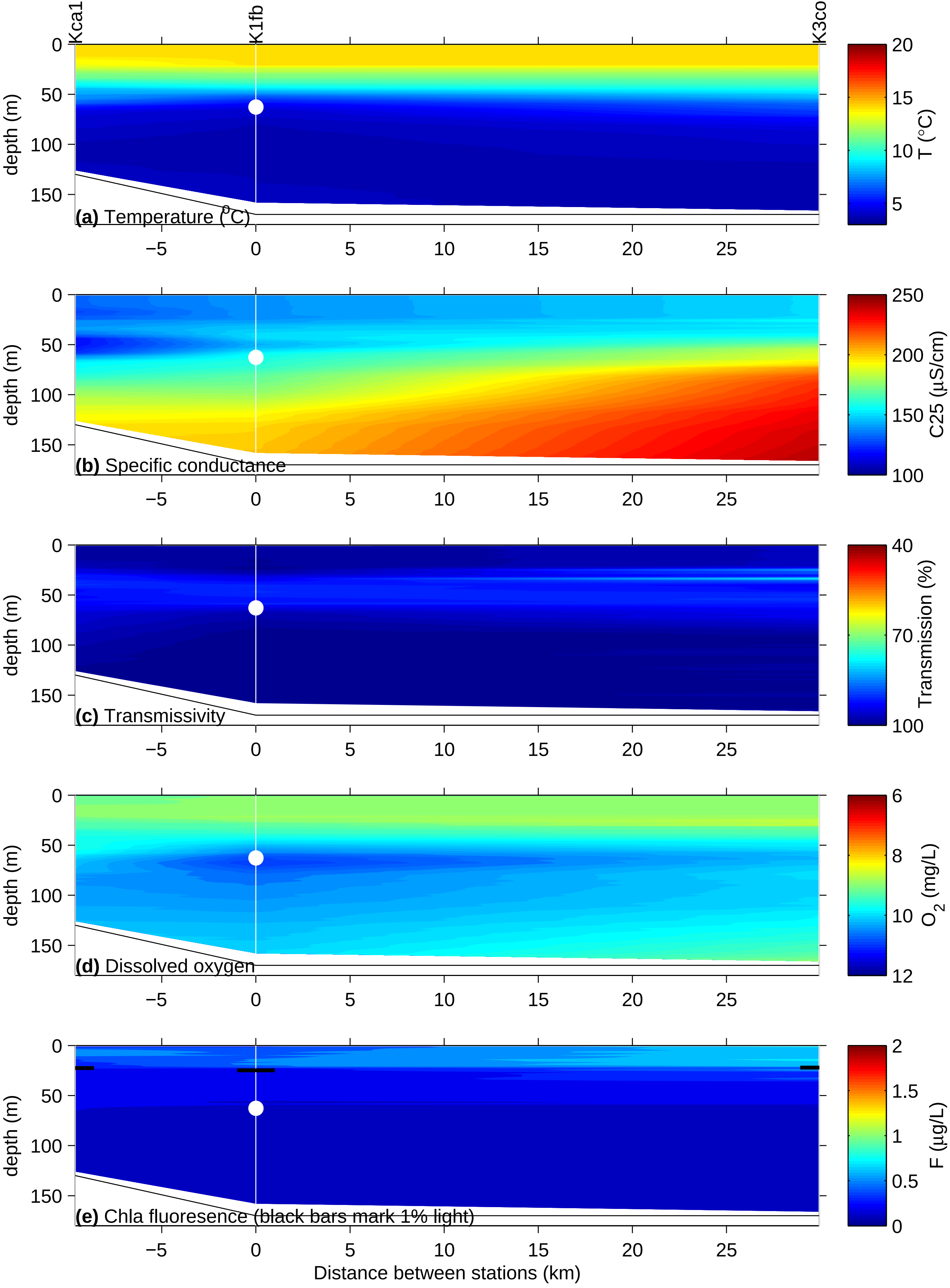


Figure D1 Revelstoke Reservoir, 31 May 2012

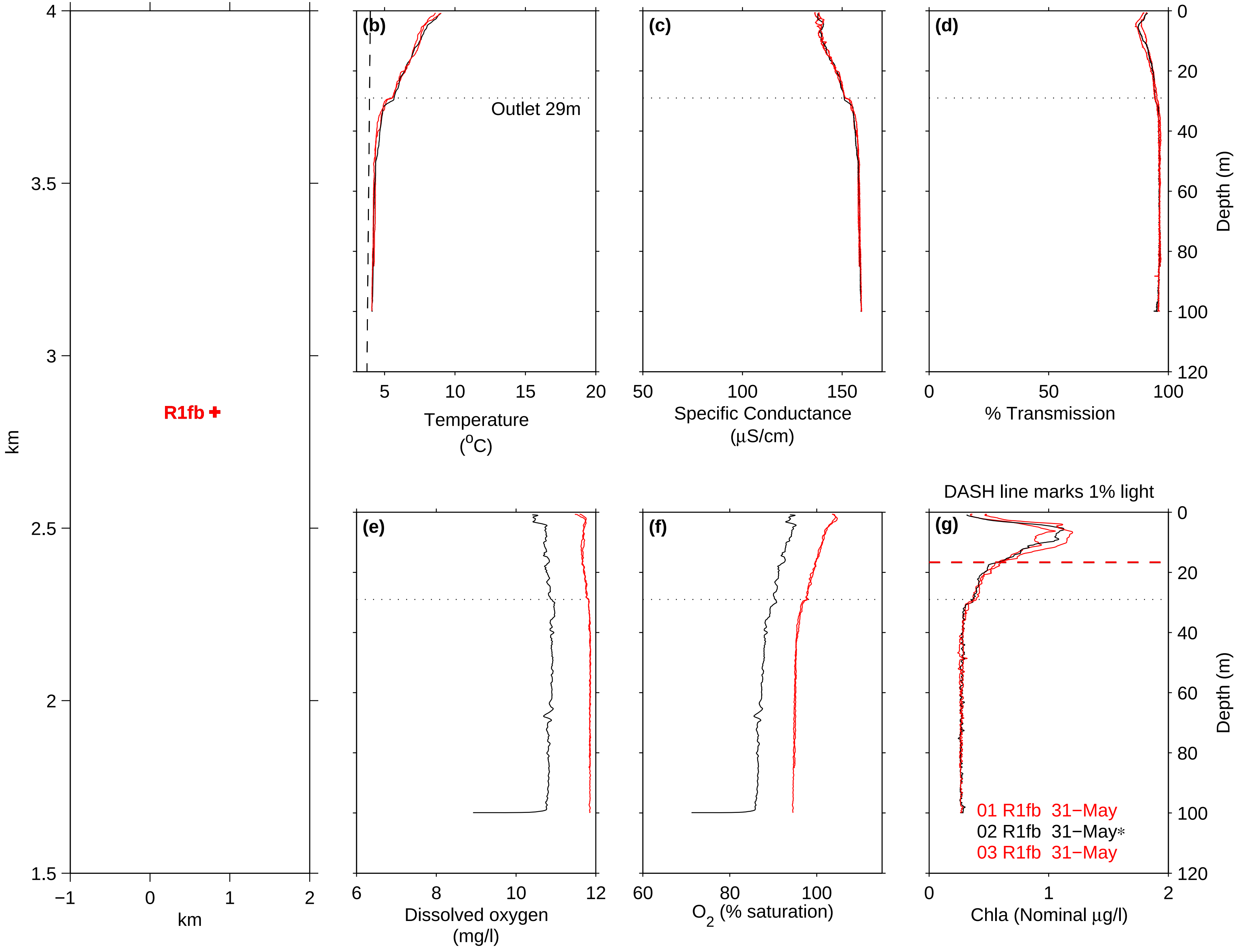


Figure D2 Revelstoke Reservoir, 18−19 Jun 2012

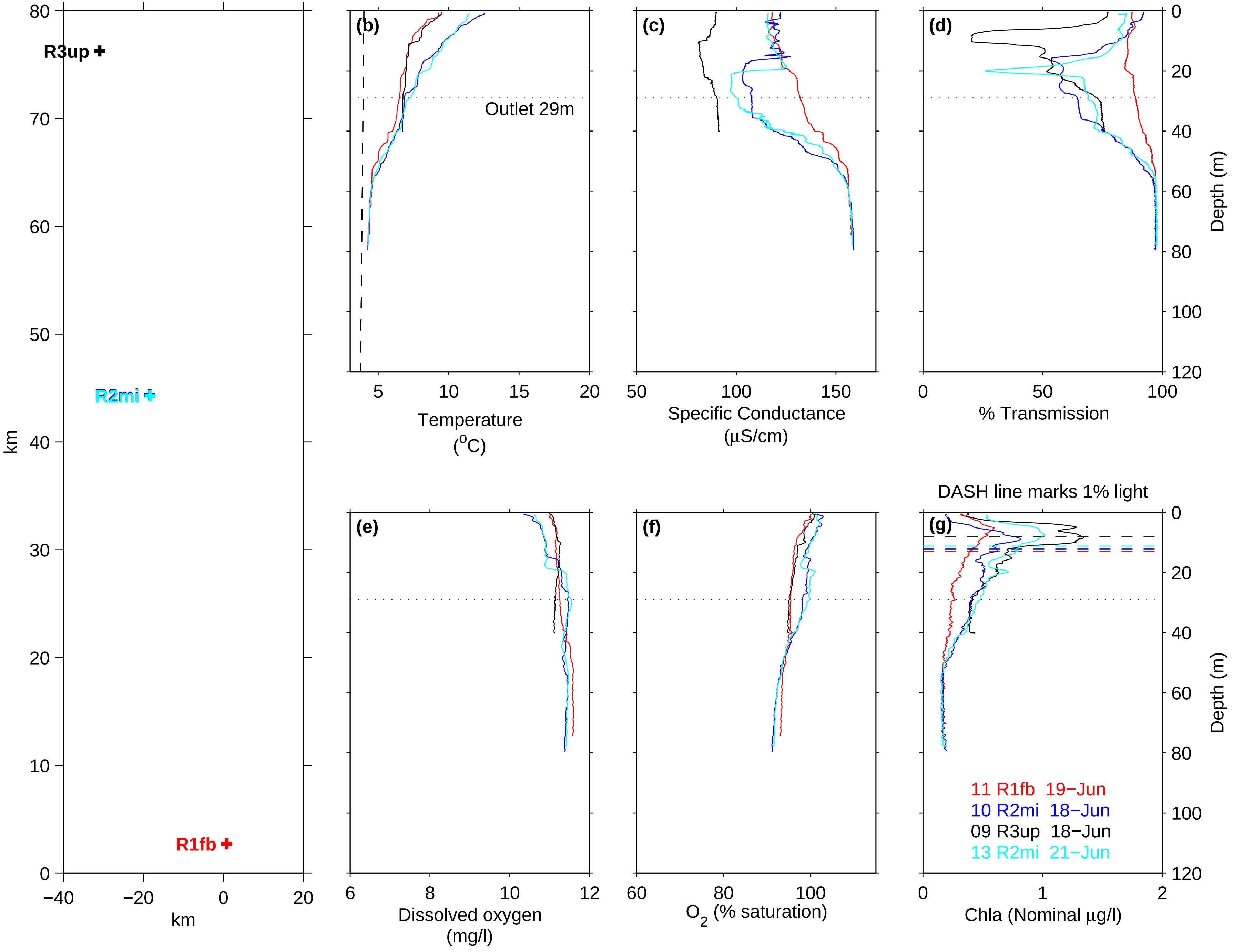


Figure D3 Revelstoke Reservoir, 24−25 Jul 2012

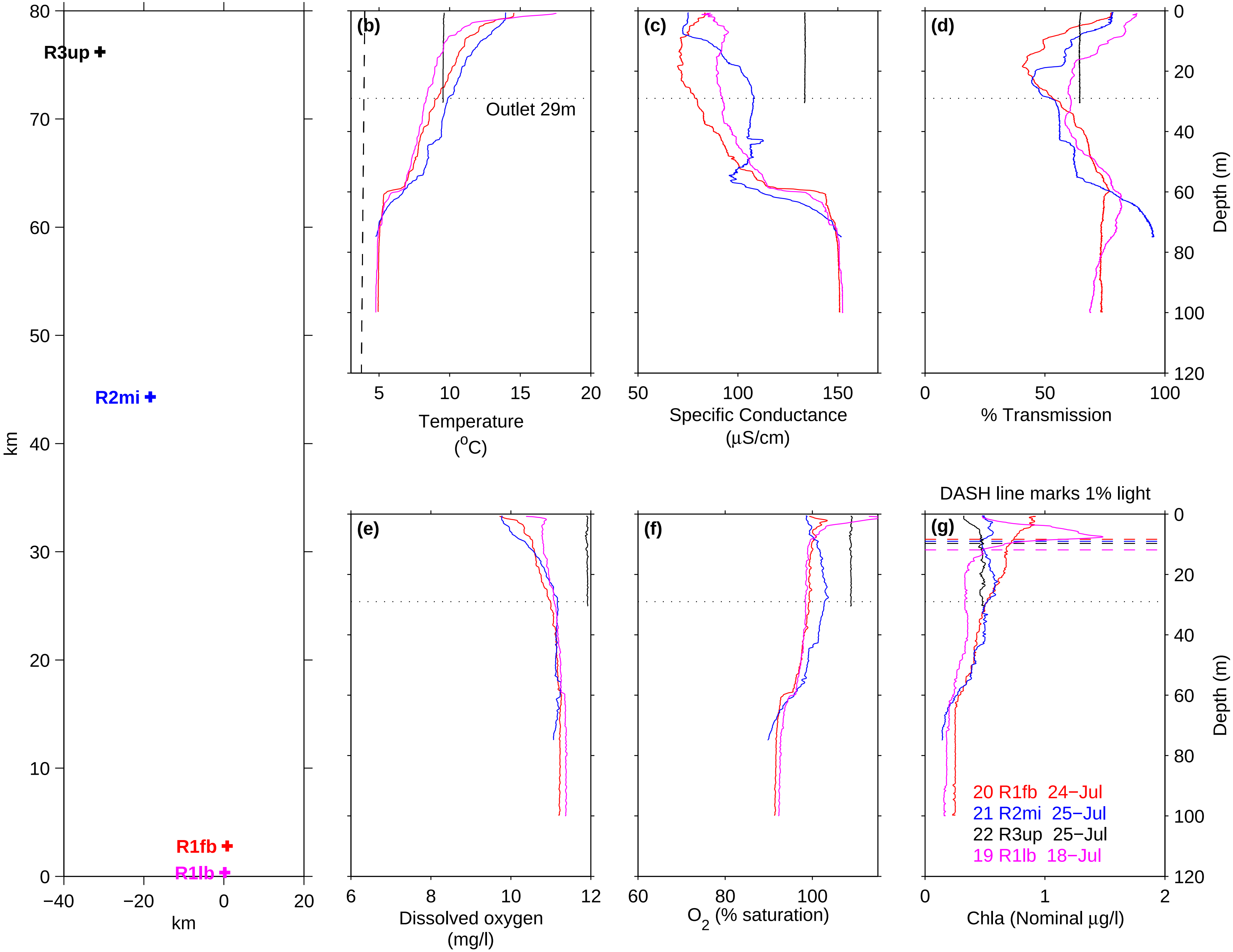


Figure D4 Revelstoke Reservoir, 21−22 Aug 2012

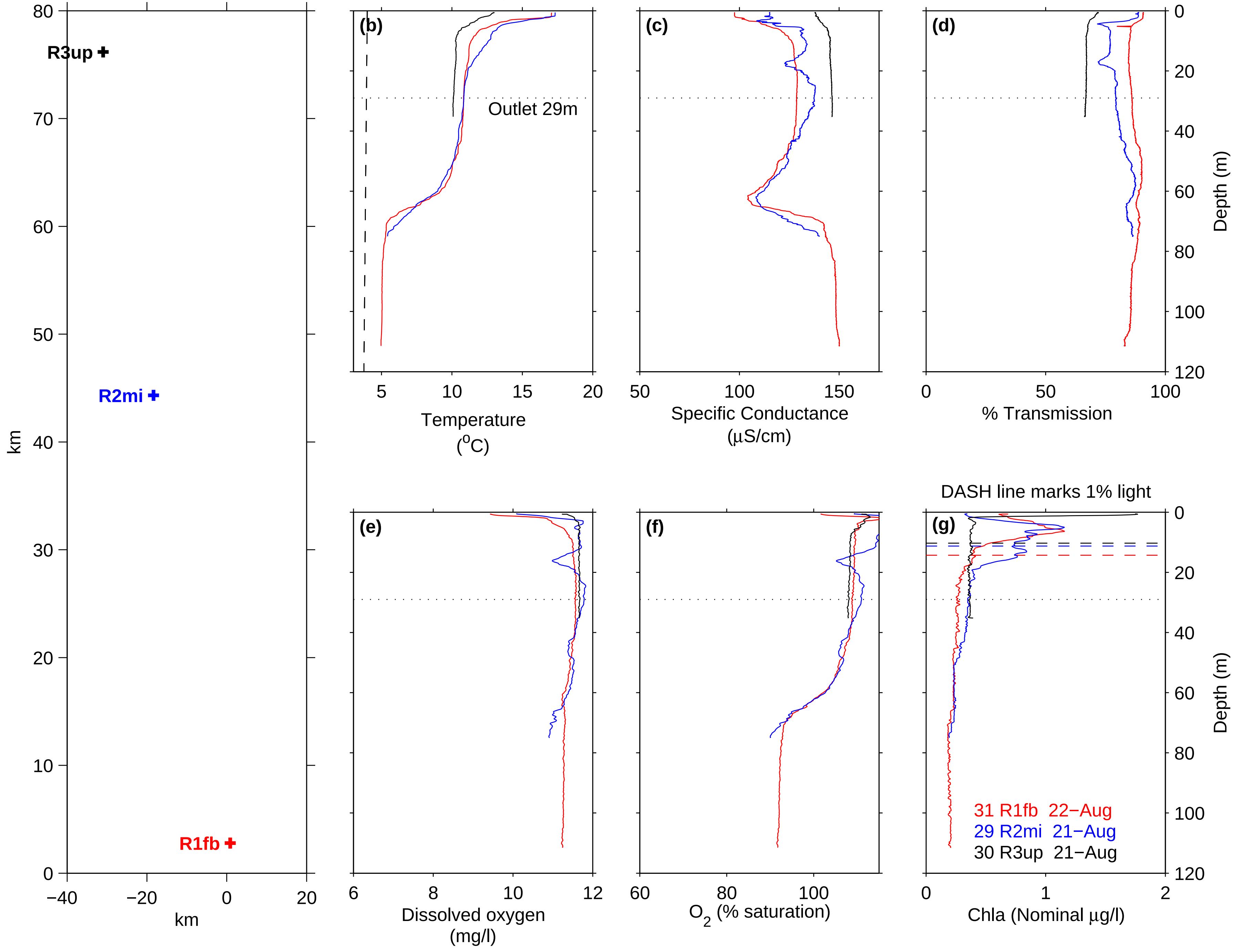


Figure D5 Revelstoke Reservoir, 10−11 Sep 2012

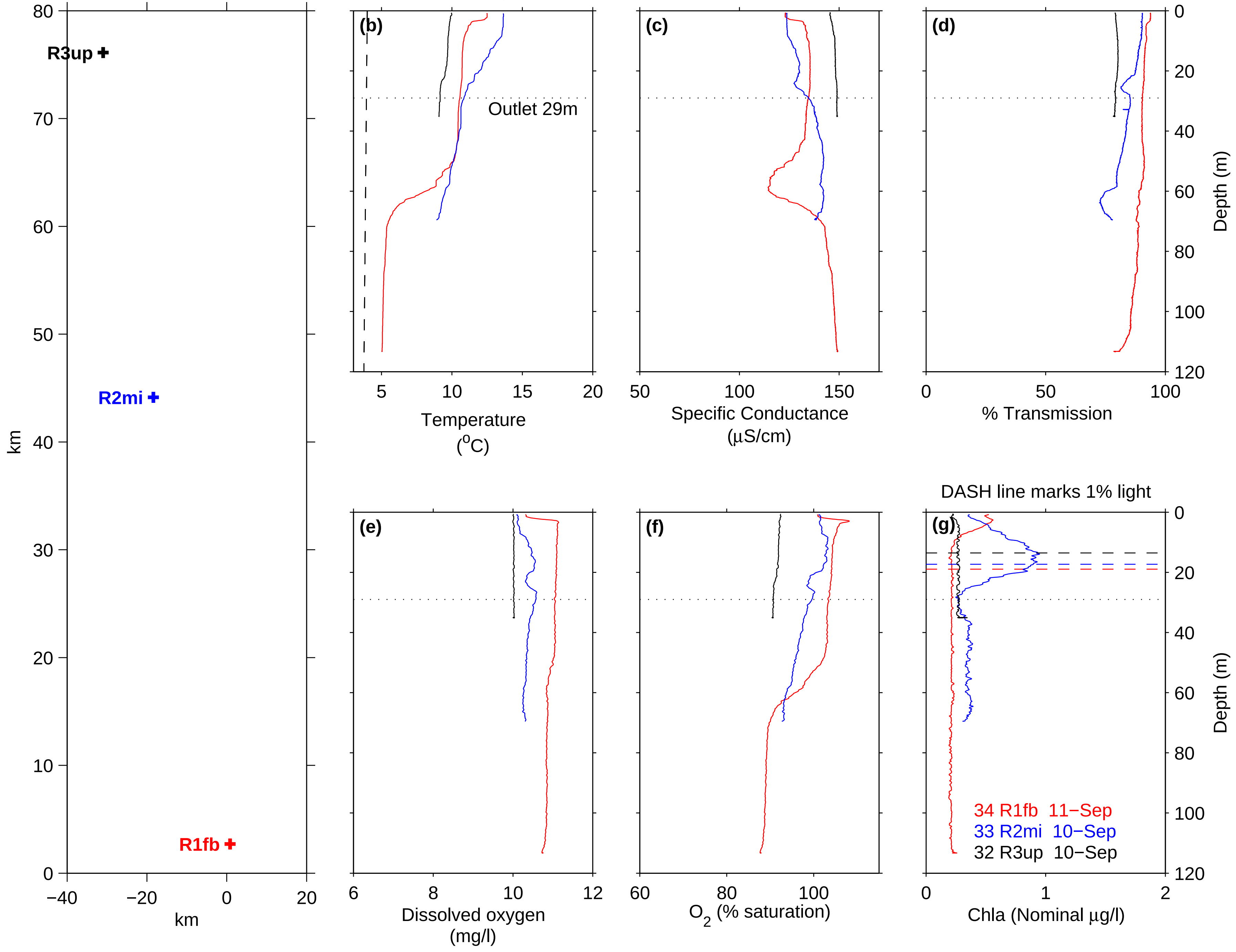


Figure D6 Revelstoke Reservoir, 19−20 Sep 2012

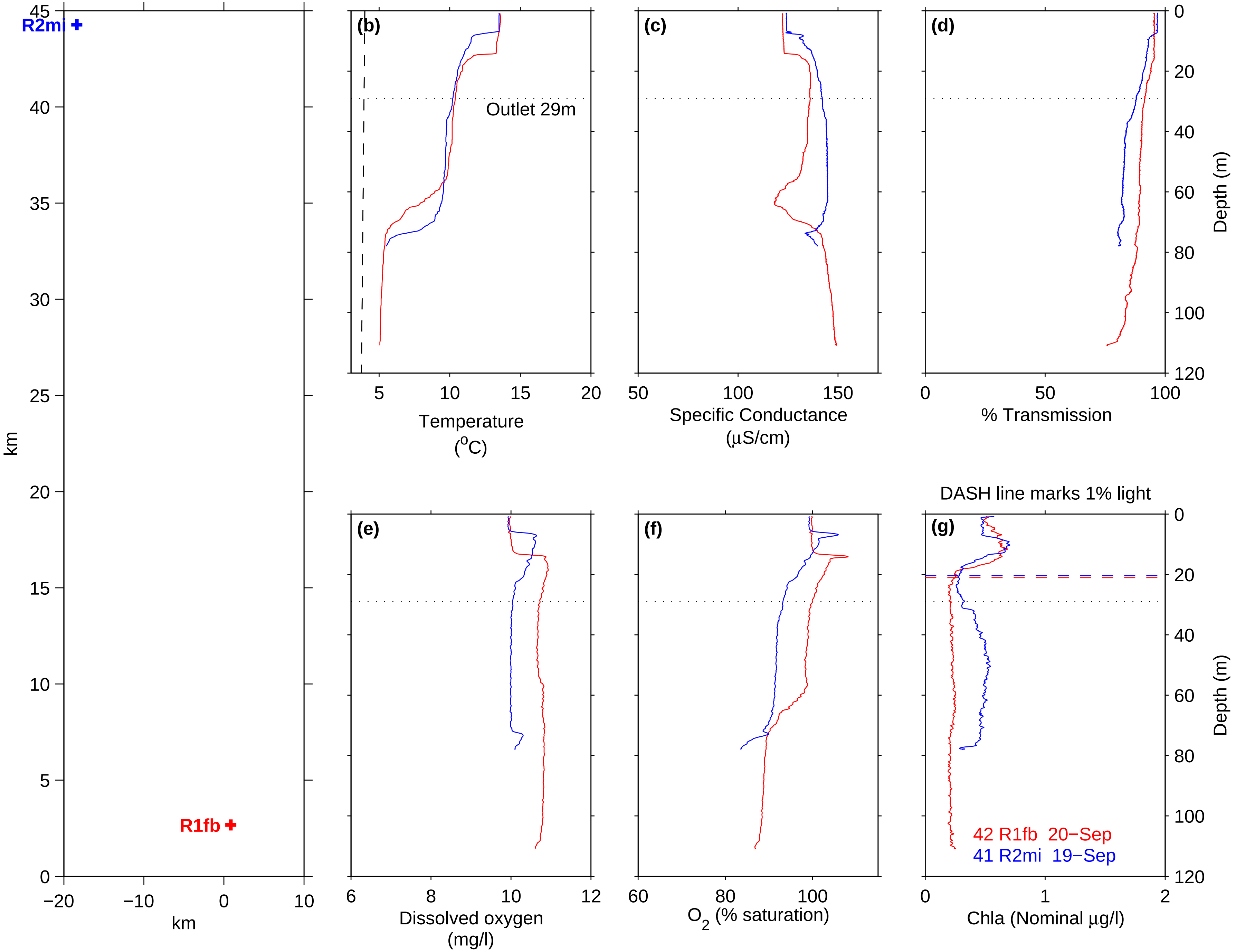


Figure D7 Revelstoke Reservoir, 9–10 Oct 2012

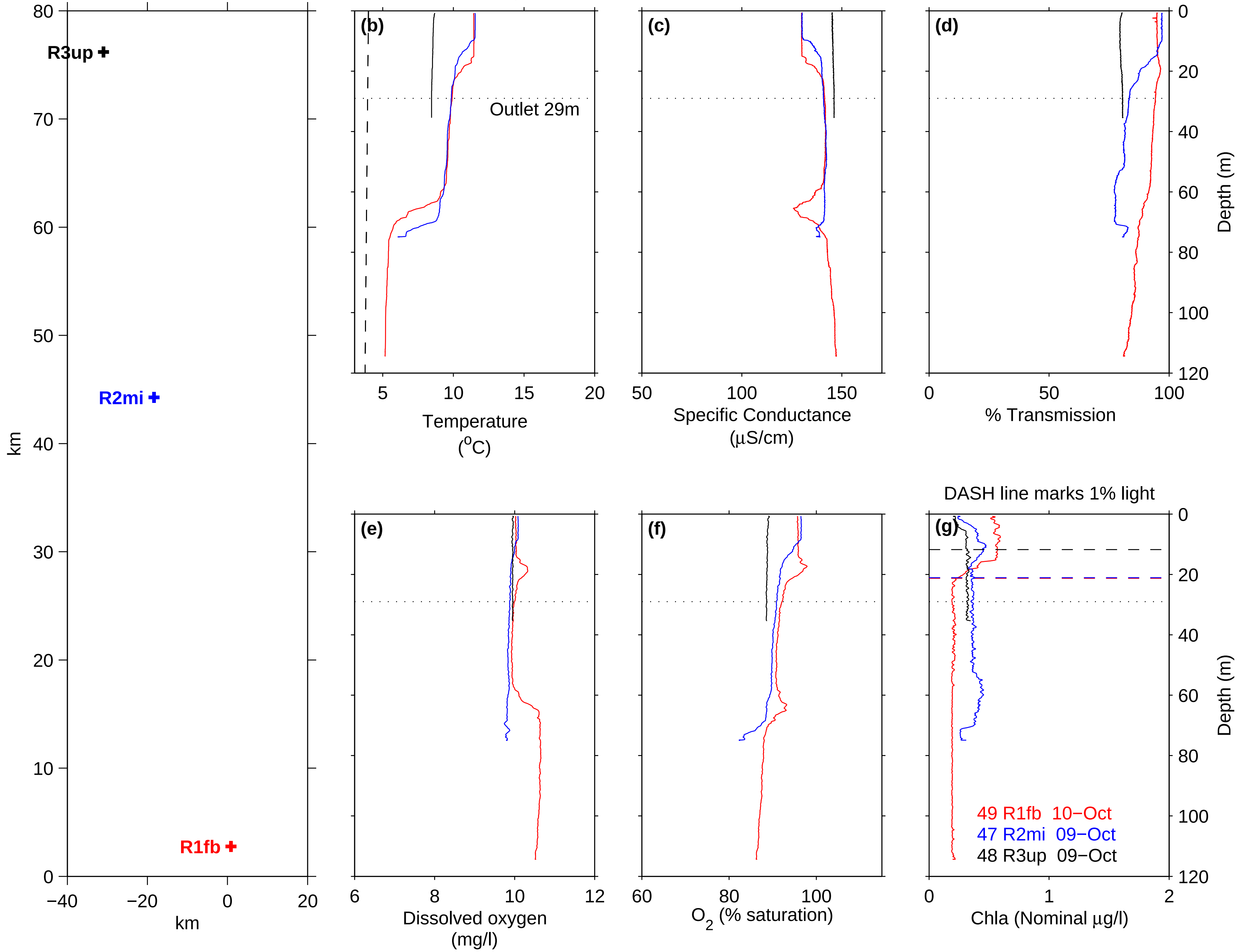


Figure D8 Revelstoke Reservoir, Forebay 2012

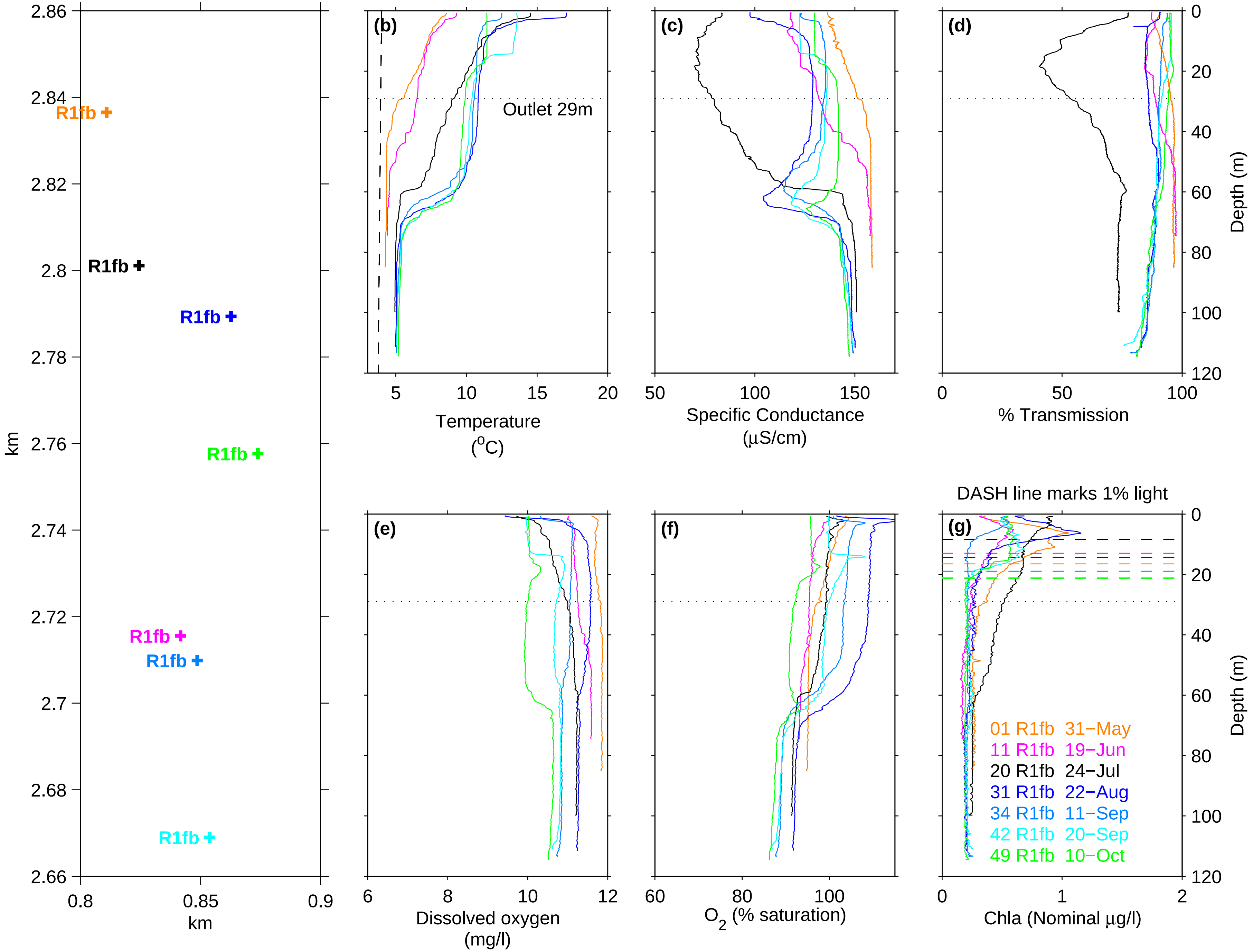


Figure D9 Revelstoke Reservoir, Middle 2012

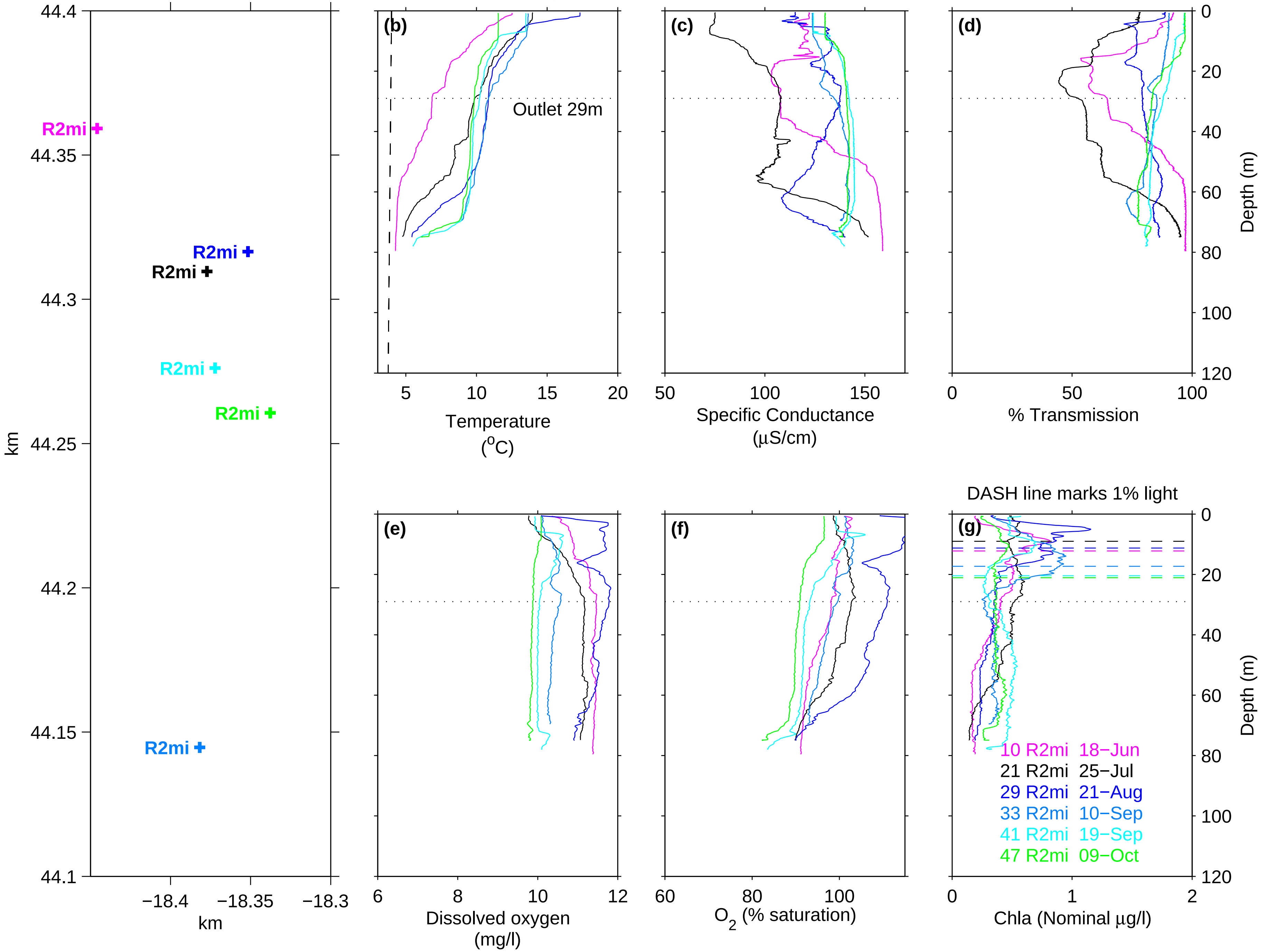


Figure D10 Revelstoke Reservoir, Upper 2012

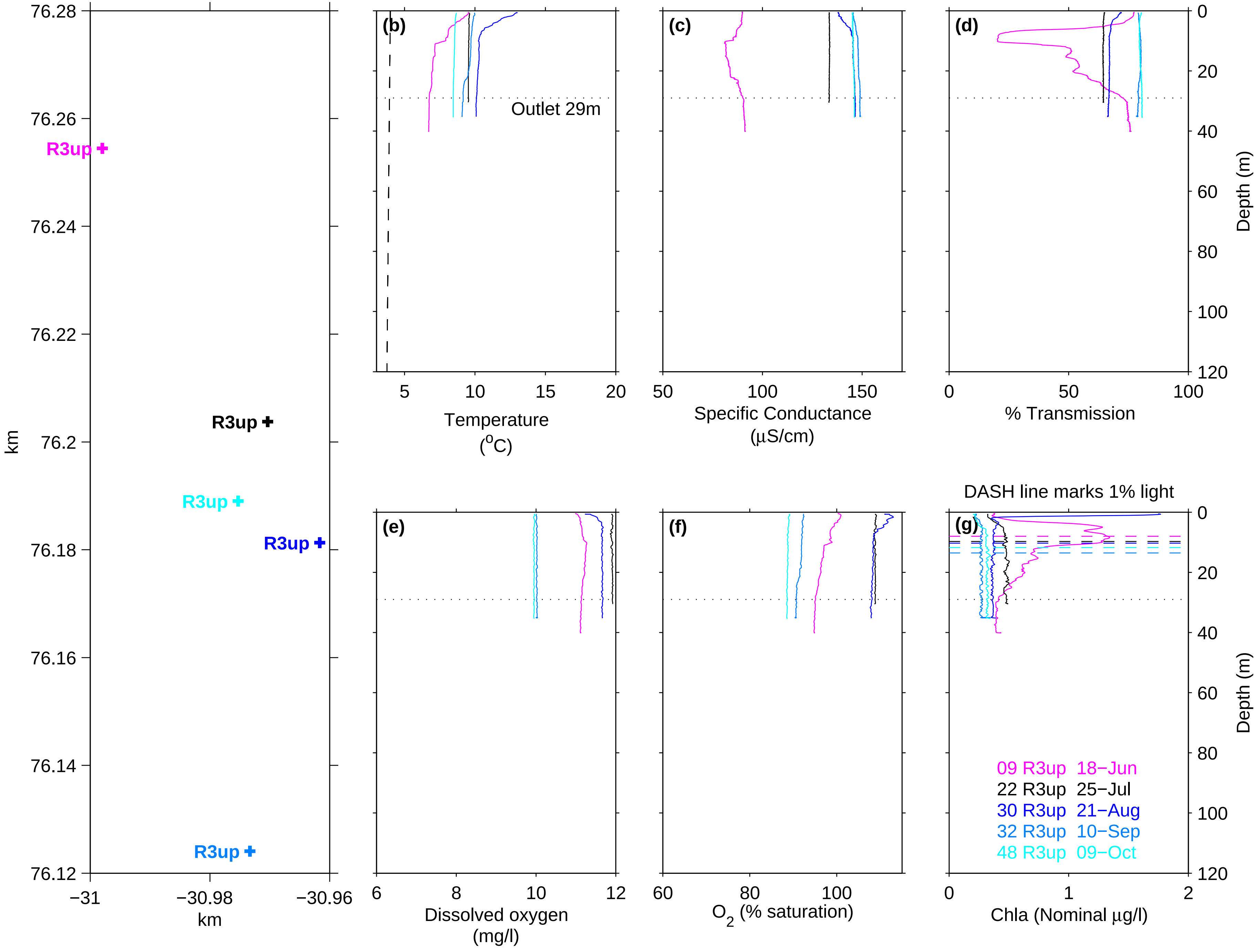


Figure E1 Revelstoke Reservoir 18−19 Jun, 2012

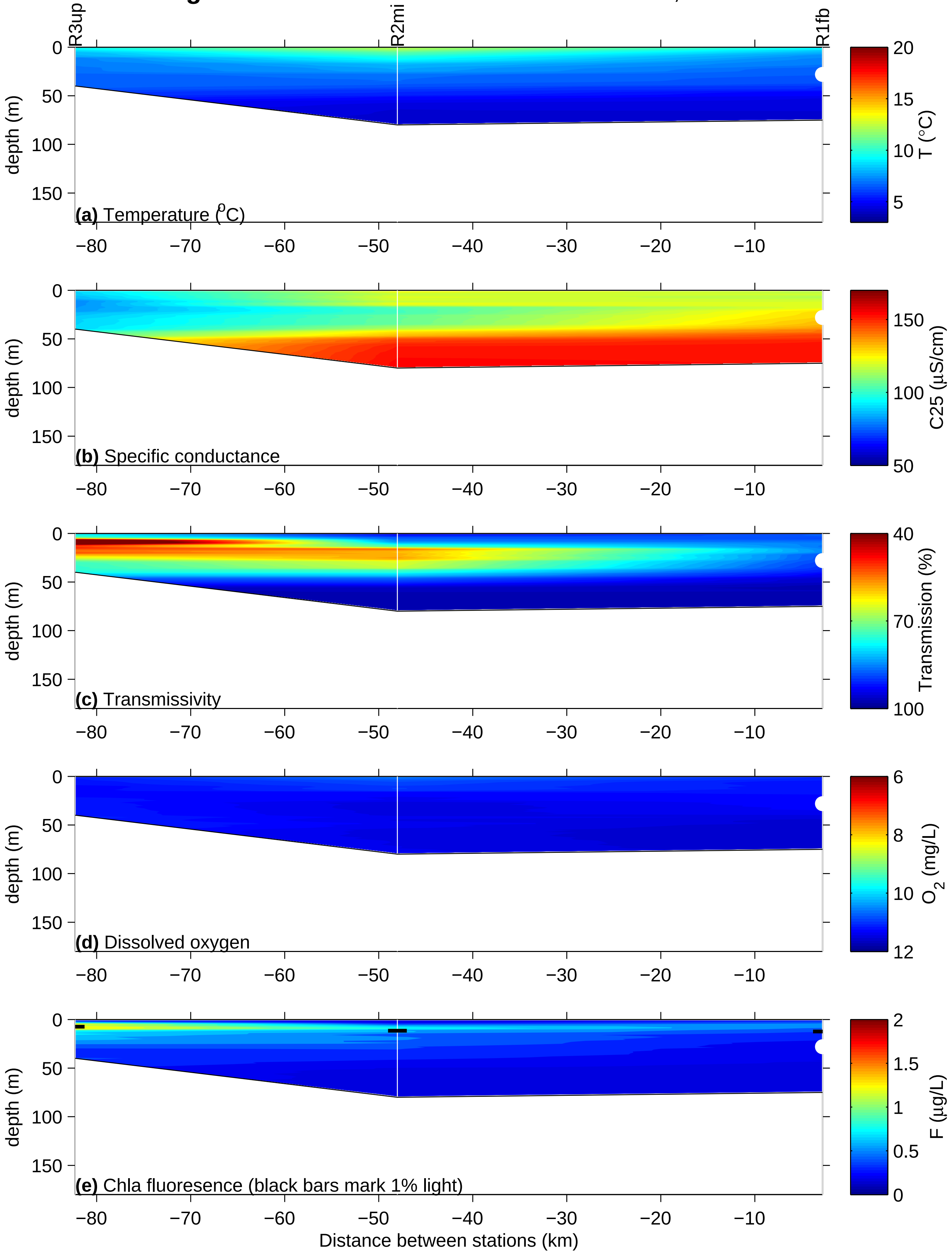


Figure E2 Revelstoke Reservoir 24−25 Jul, 2012

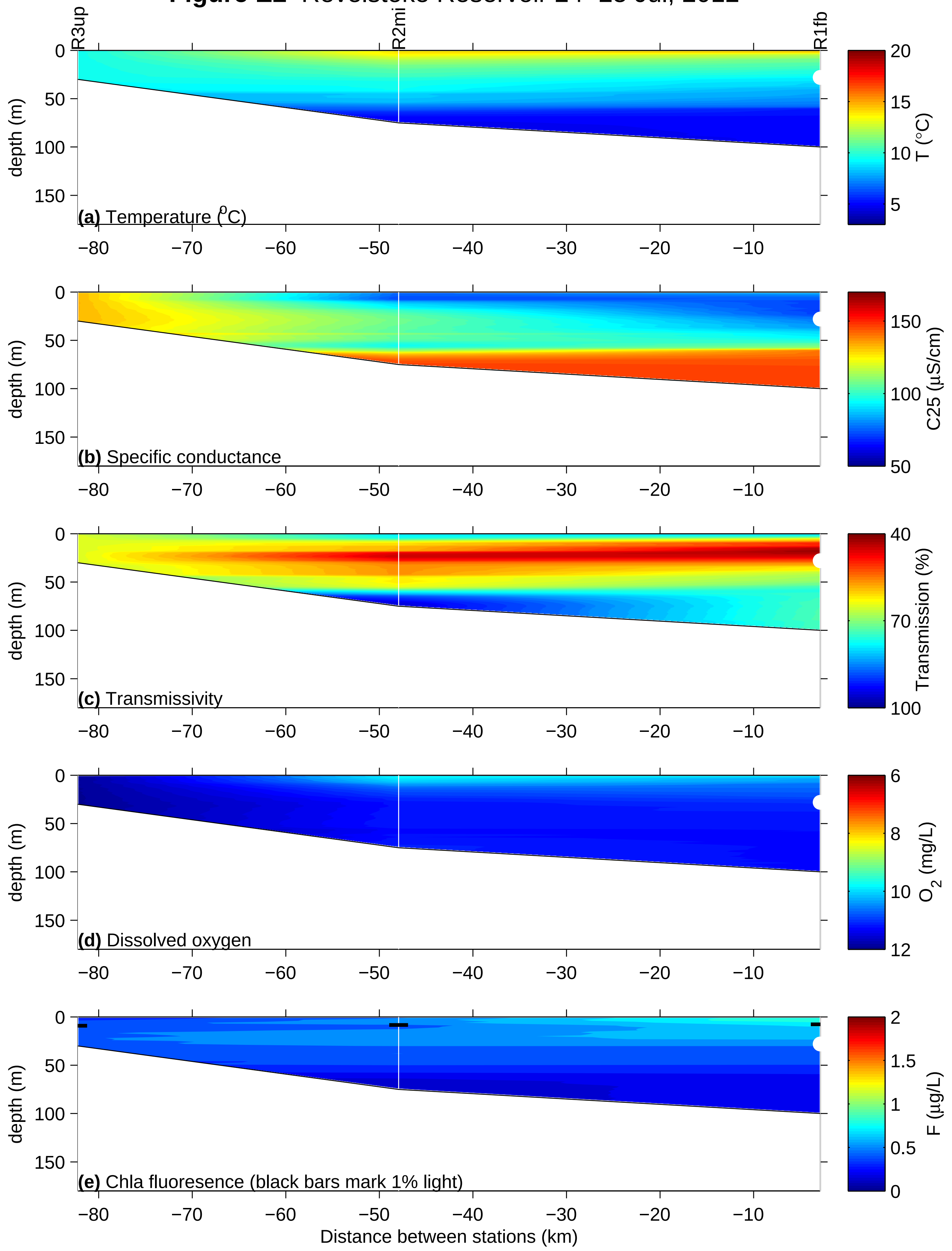


Figure E3 Revelstoke Reservoir 21−22 Aug, 2012

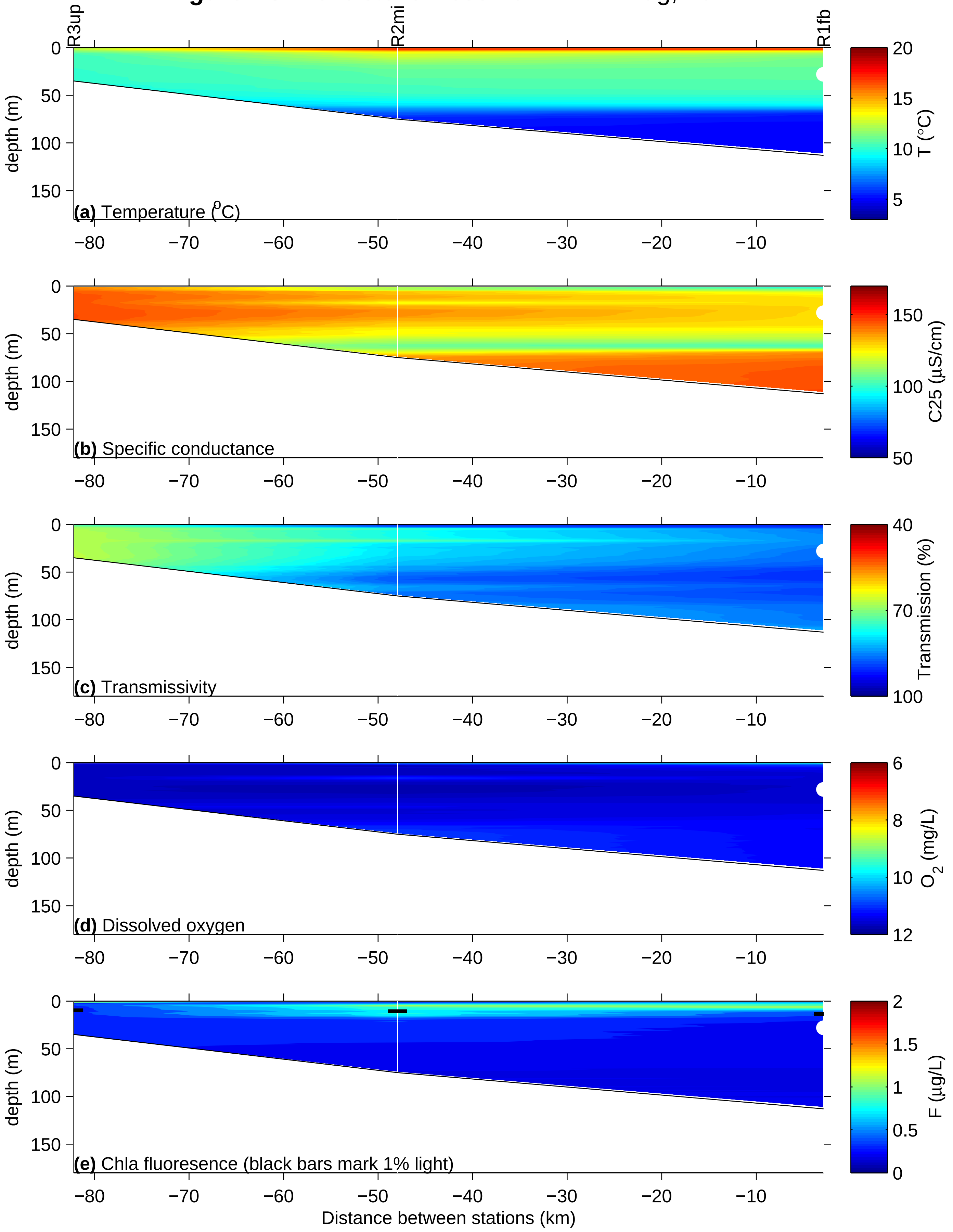


Figure E4 Revelstoke Reservoir 10−11 Sep, 2012

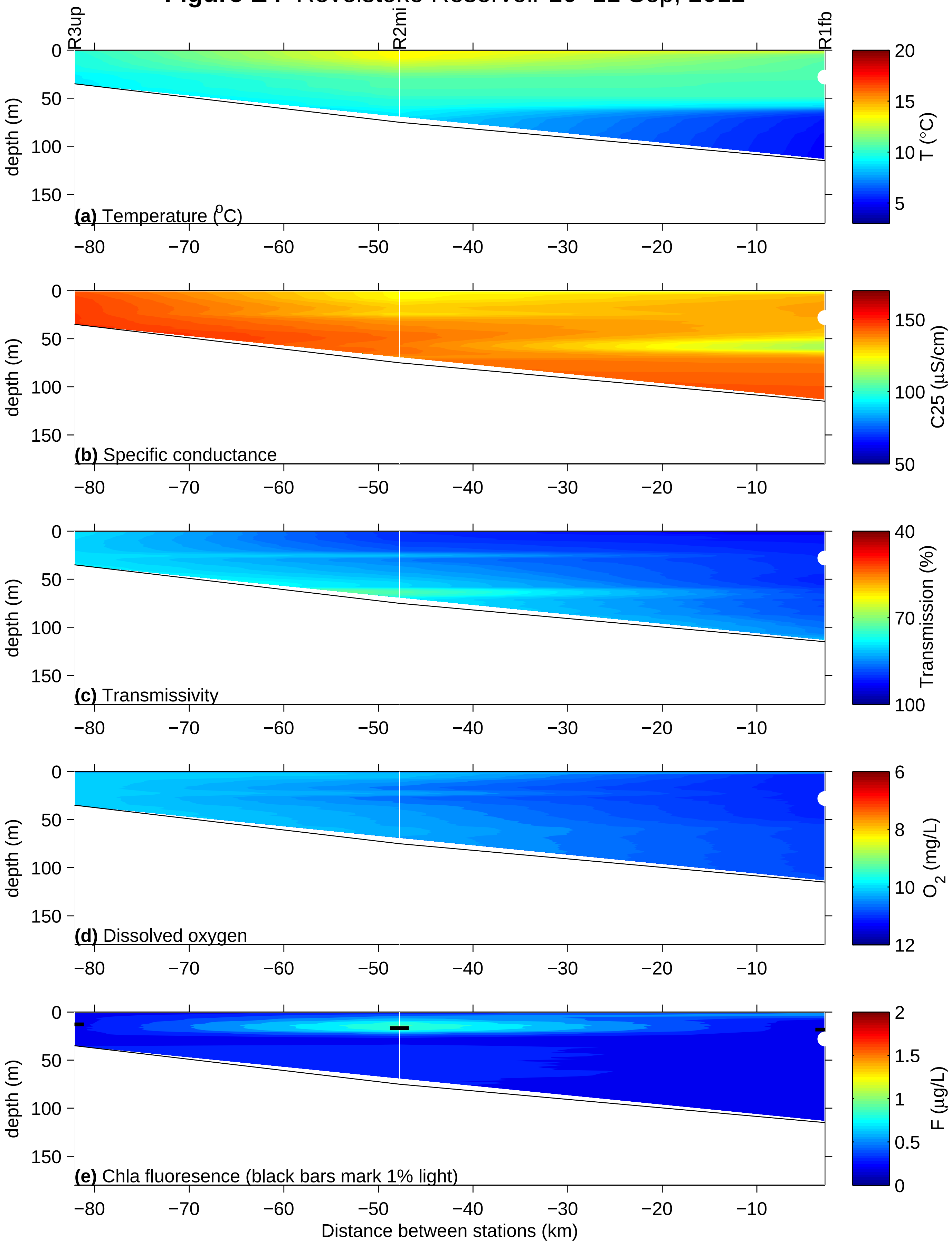


Figure E5 Revelstoke Reservoir 19−20 Sep, 2012

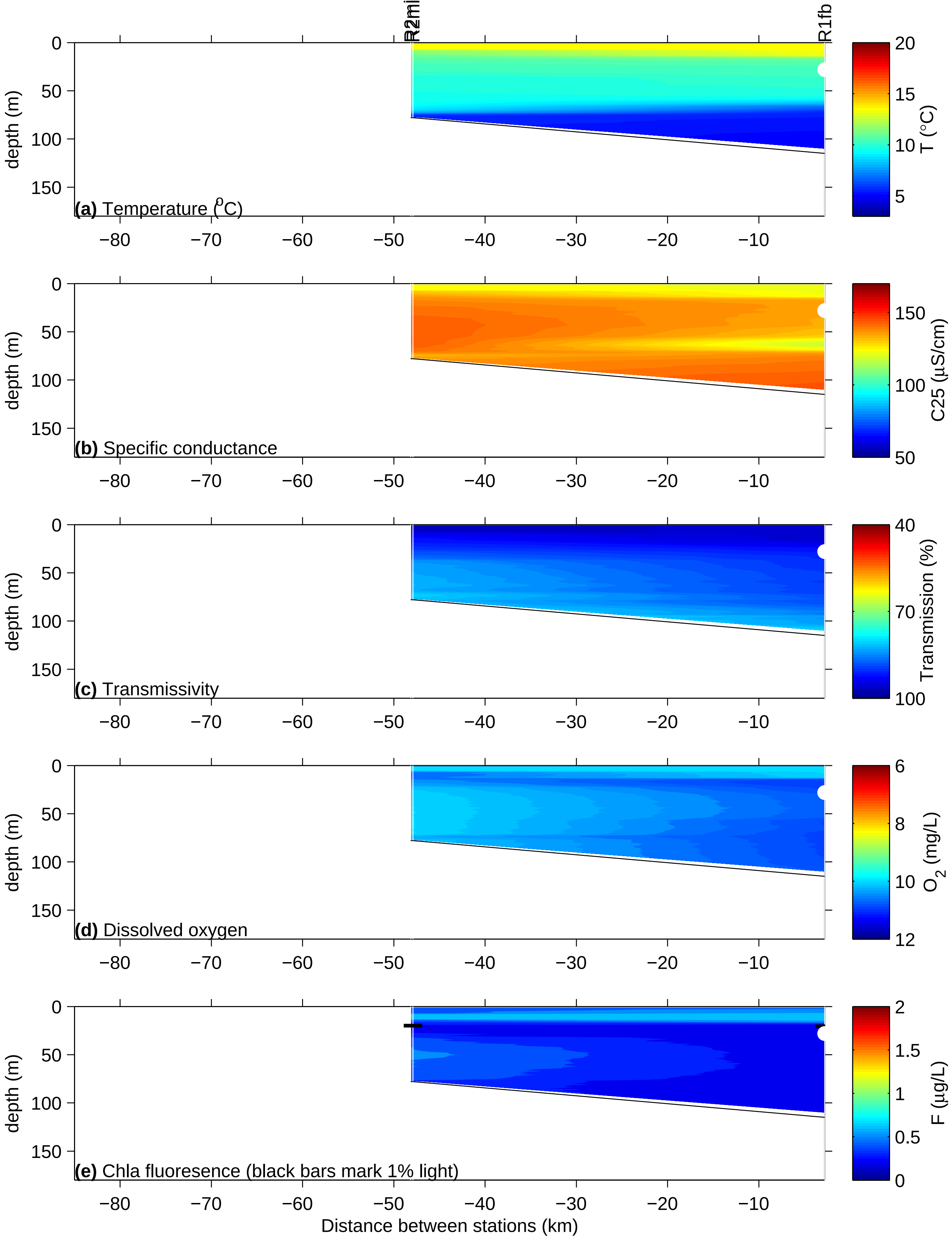


Figure E6 Revelstoke Reservoir 9−10 Oct, 2012

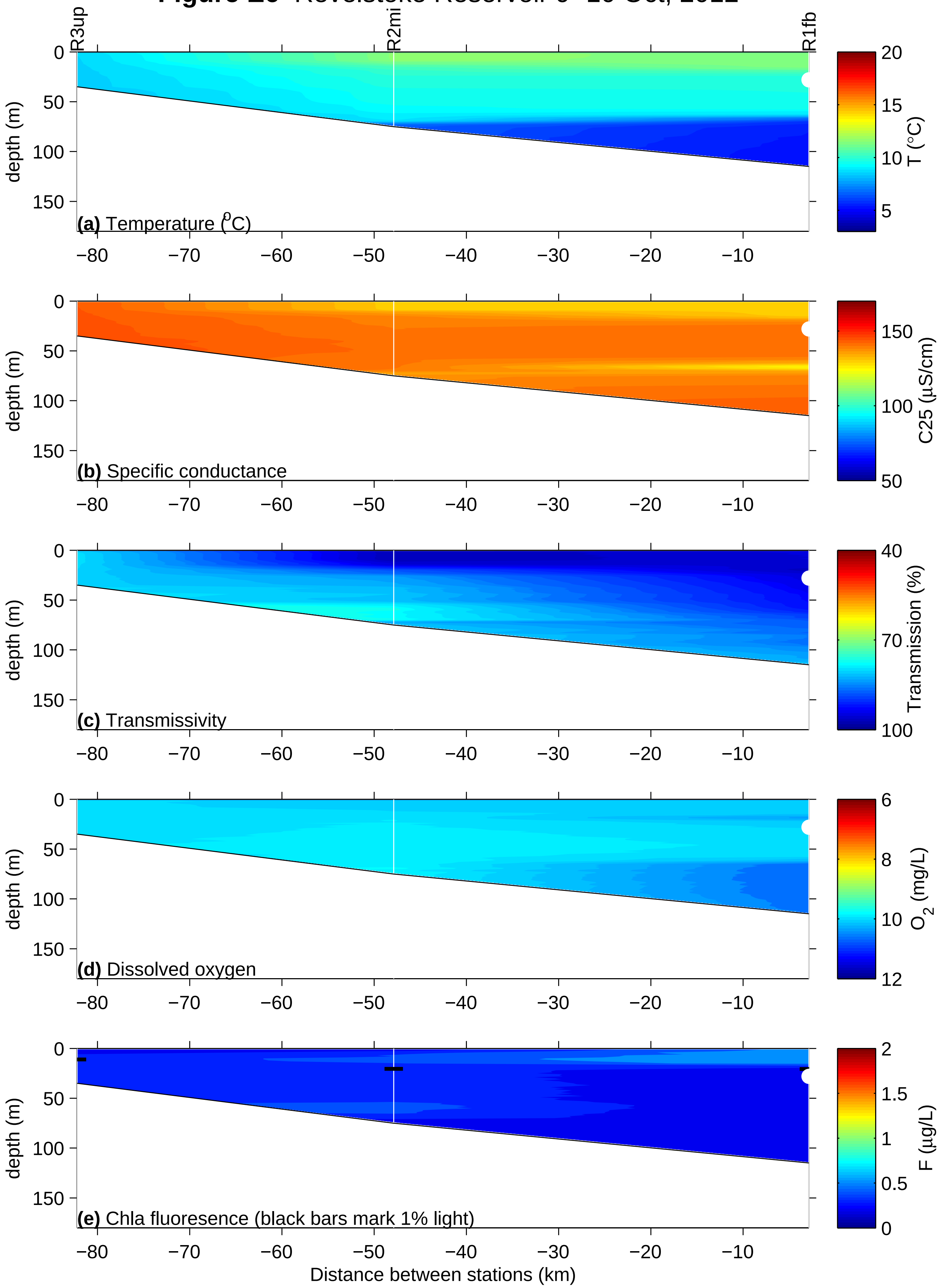
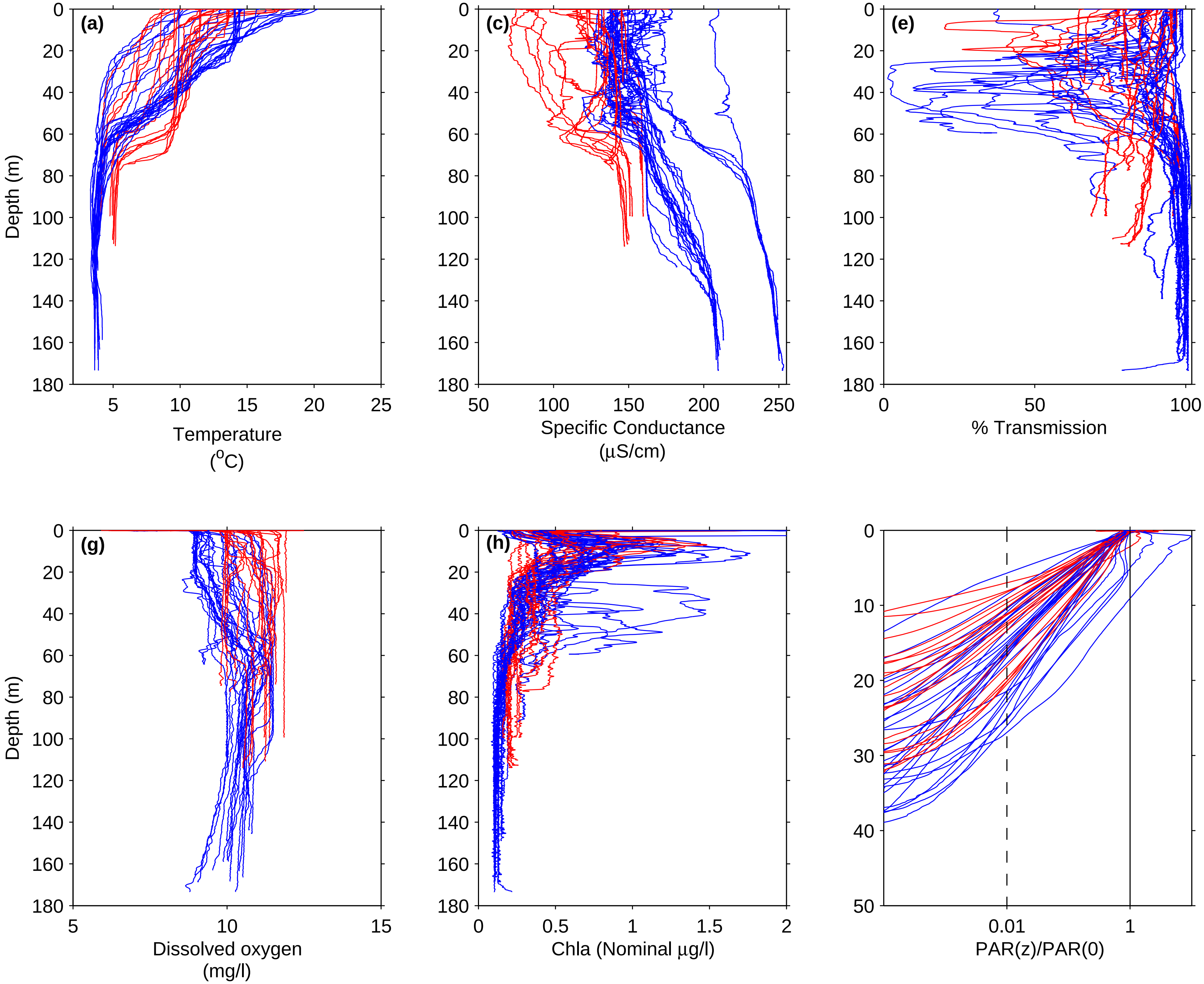


Figure F1 All Kinbasket (BLU) and Revesltoke (RED) Data, 2012



Appendix 1
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

Cast Number	Date	Site Name	Time On	Time Off	GPS	Depth (m)	Stn
1	31/May/2012	Rev - Forebay (boat test run, fresh)	11:00	11:10	51°04.519 118°10.976	85	R1fb
2	31/May/2012	Rev - Forebay (boat test run, salt)	11:19	11:30	51°04.519 118°10.976	100	R1fb
3	31/May/2012	Rev - Forebay (boat test run, fresh)	11:38	11:47	51°04.519 118°10.976	100	R1fb
4	11/Jun/2012	Kin - Columbia	11:13	11:28	51°57.980 118°04.884	150	K3co
5	11/Jun/2012	Kin - Wood	1:44	1:51	52°08.273 118°18.639	45	Kwo1
6	12/Jun/2012	Kin - Canoe	7:26	7:36	52°12.439 118°28.470	95	Kca1
7	12/Jun/2012	Kin - Middle	8:32	8:44	52°07.899 118°26.443	110	K2mi
8	12/Jun/2012	Kin - Forebay	9:47	10:03	52°05.694 118°32.899	150	K1fb
9	18/Jun/2012	Rev - Upper	9:24	9:30	51°43.784 118°39.633	40	R3up
10	18/Jun/2012	Rev - Middle	11:19	11:28	51°26.728 118°28.175	80	R2mi
11	19/Jun/2012	Rev - Forebay	8:53	9:02	51°04.454 118°10.948	75	R1fb
12	20/Jun/2012	Kin - PP	7:57	8:12	52°06.856 118°30.125	145	K1.5
13	21/Jun/2012	Rev - Middle PP	8:02	8:11	51°26.681 118°28.098	78	R2mi
14	16/Jul/2012	Kin - Canoe	9:57	10:11	52°12.445 118°28.474	130	Kca1
15	16/Jul/2012	Kin - Wood	11:50	11:57	52°08.270 118°18.703	60	Kwo1
16	16/Jul/2012	Kin - Middle	12:39	12:52	52°07.857 118°26.354	125	K2mi
17	16/Jul/2012	Kin - Forebay	1:43	2:00	52°05.661 118°32.917	170	K1fb
18	17/Jul/2012	Kin - Columbia Reach	7:47	8:03	51°57.999 118°04.912	165	K3co
19	18/Jul/2012	Rev - Forebay in front of log boom	9:37	9:48	51°03.172 118°11.429	100	R1lb
20	24/Jul/2012	Rev - Forebay & PP	8:03	8:14	51°04.500 118°10.964	100	R1fb
21	25/Jul/2012	Rev - Middle PP	8:16	8:25	51°26.702 118°28.115	75	R2mi
22	25/Jul/2012	Rev - Upper	9:55	10:00	51°43.757 118°39.608	30	R3up
23	26/Jul/2012	Kin - PP	7:36	7:53	52°06.856 118°30.155	165	K1.5
24	19/Aug/2012	Kin - Canoe	10:14	10:26	52°12.457 118°28.451	115	Kca1
25	19/Aug/2012	Kin - Wood	12:14	12:22	52°08.267 118°18.564	65	Kwo1
26	19/Aug/2012	Kin - Middle	1:44	1:59	52°07.850 118°26.461	140	K2mi
27	19/Aug/2012	Kin - Forebay	2:12	2:30	52°05.659 118°32.919	175	K1fb
28	20/Aug/2012	Kin - Columbia Reach	7:58	8:15	51°58.016 118.04.938	175	K3co
29	21/Aug/2012	Rev - Middle and PP	8:01	8:10	51°26.706 118°28.093	75	R2mi
30	21/Aug/2012	Rev - Upper	9:39	9:45	51°43.745 118°39.600	35	R3up
31	22/Aug/2012	Rev - Forebay and PP	7:41	7:53	51°04.494 118°10.931	113	R1fb
32	10/Sep/2012	Rev - Upper	12:44	12:50	51°43.714 118°39.609	35	R3up
33	10/Sep/2012	Rev - Middle	2:42	2:50	51°26.613 118°28.116	75	R2mi
34	11/Sep/2012	Rev - Forebay	8:06	8:18	51°04.451 118°10.942	115	R1fb
35	17/Sep/2012	Kin - Columbia Reach	9:32	9:51	51°57.997 118°04.916	170	K3co
36	17/Sep/2012	Kin - Wood	12:06	12:14	52°08.212 118°18.676	65	Kwo1
37	17/Sep/2012	Kin - Canoe	1:40	1:52	52°12.425 118°28.434	115	Kca1
38	17/Sep/2012	Kin - Middle	2:40	2:56	52°07.913 118°26.482	160	K2mi
39	18/Sep/2012	Kin - PP	7:48	8:04	52°06.839 118°30.216	165	K1.5
40	18/Sep/2012	Kin - Forebay	9:19	9:36	52°05.647 118°33.023	175	K1fb
41	19/Sep/2012	Rev - Middle PP	7:48	7:58	51°26.684 118°28.110	78	R2mi
42	20/Sep/2012	Rev - Forebay PP	7:45	7:57	51°04.429 118°10.937	115	R1fb
43	01/Oct/2012	Kin - Canoe	10:12	10:26	52°12.392 118°28.459	130	Kca1
44	01/Oct/2012	Kin - Wood	12:01	12:09	52°08.283 118°18.587	65	Kwo1
45	01/Oct/2012	Kin - Forebay	1:51	2:08	52°05.599 118°33.026	170	K1fb
46	02/Oct/2012	Kin - Columbia	7:52	8:09	51°57.990 118°04.872	170	K3co
47	09/Oct/2012	Rev - Middle	9:09	9:17	51°26.676 118°28.080	75	R2mi
48	09/Oct/2012	Rev - Upper	11:06	11:11	51°43.749 118°39.612	35	R3up
49	10/Oct/2012	Rev - Forebay	8:31	8:43	51°04.477 118°10.921	115	R1fb
50	05/Nov/2012	Kin - Canoe	10:55	11:08	52°12.420 118°28.446	157	Kca1

Appendix 3
Seabird pump operation

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 the bleed valve (pinhole). 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.

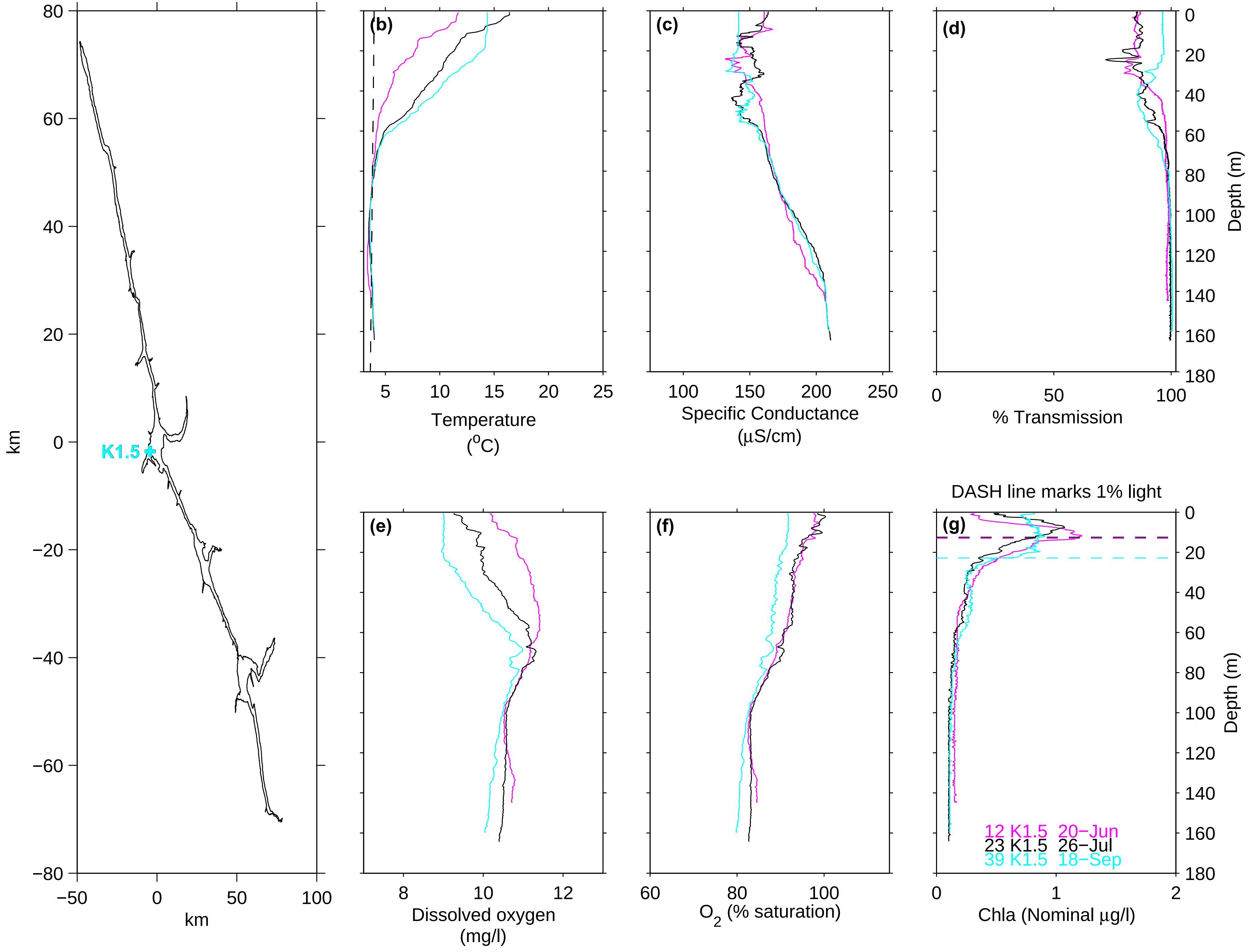
In 2008 the minimum conductivity frequency was set to zero. However, in 2009, 2010 and 2011, after calibration of the instrument by Sea-Bird, the minimum conductivity frequency was set for ocean use, and the pump did not run. Nevertheless, most of the temperature and conductivity data collected was satisfactory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

To avoid this, 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.

Appendix 4
Additional Profiles

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

Figure A4 Kinbasket Reservoir, K1.5, 2012



Appendix 4

Reservoir Water Chemistry Kinbasket and Revelstoke Reservoirs, 2012

Karen Bray
BC Hydro

Reservoir Water Chemistry
Kinbasket and Revelstoke Reservoirs, 2012

Debris piled on the Kinbasket boat launch, September 2012

Prepared By:
Karen Bray
Revelstoke, B.C.

February 2014

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1. Introduction

This report summarises Year 5 (2012) 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 2012 the May session was not conducted due to delays external to the project. Turbidity and conductivity for all Kinbasket stations in June are not recorded due to a lab error.

Five litre Niskin bottles were lowered by cable in series to collect discrete depth samples at 2, 5, 10, 15, 20, 40, 60 and 80m. Following recommendations from 2011, the 35m and 45m were changed to a single 40m sample and an additional sample at 80m was added to provide more information from the hypolimnion. A sample at 5m above bottom was collected at all stations except for REV Upper and for some months Kinbasket Wood as they are <65m depth. 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 (2014a). 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 in Kinbasket and Revelstoke reservoirs (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 to a depth where it could no longer be seen by the naked eye (i.e., no sunglasses) and then raised to where it became visible; the two depths were averaged to arrive at the final reading.

Table 1. Summary of reservoir station coordinates, maximum sampled depths, and dates of 2012 sampling.

Station	Coordinates	Maximum Depth Sampled (m)	Dates Sampled in 2012
KIN Forebay	52°05.611 118°32.932	175	June 12, July 16, Aug 19,Sep 18, Oct 1
KIN Canoe Reach	52°12.400 118°28.417	130	June 12, July 16, Aug 19, Sep 17, Oct 1
KIN Wood Arm	52°08.314 118°18.637	65	June 11, July 16, Aug 19, Sep 17, Oct 1
KIN Columbia Reach	51°58.448 118°05.061	175	June 11, July 17, Aug 20,Sep 17, Oct 2
REV Forebay	51°04.504 118°10.981	115	June 19, July 24, Aug 22, Sep 11, Oct 10
REV Middle	51°26.495 118°28.116	80	June 18, July 25, Aug 21, Sep 10, Oct 9
REV Upper	51°43.797 118°39.579	40	June 18, July 25, Aug 21, Sep 10, Oct 9

3. Results

Stations were sampled at reservoir forebay elevations between 733.3m and 754.5m; full pool is 754.4m and minimum level is 707.1m (cf. Figure 2). The reservoir reached its minimum level (722m) for the year on April 22, 2012, and its maximum level (754.7m) on August 29, 2012. Kinbasket reservoir was surcharged by 0.3m in August, 2012, due to an unusually high inflow early in the year and operational constraints at Mica Dam. The total range of elevation in 2012 was 32.7m whereas the maximum range is normally 47m without surcharge. The average reservoir elevation range between 1977 and 2012 has been 25.4m.

In 2012, Revelstoke reservoir daily average elevations ranged by 1.3m between 570.7m and 572.9m. Full pool is 573m and the normal operating range is within 1.5m (to 571.5m or Nmin), although the water licence allowable minimum level is much lower. Daily average elevation dipped below the Nmin for 19 days in spring and fall for operational flexibility. 2012 represents the second full year of a continuous 142 m^3/s minimum discharge at Revelstoke Generating Station.

Nitrite and Nitrate (*NO_2+NO_3 *or NN) – Average NN was similar across stations in Kinbasket reservoir (95.5 – 106 µg/L), with the greatest total seasonal variation at the KIN Columbia as a result of highest values in June and lowest values in August to October (Table 2, Figures 2,4,6). Average NN was also similar across stations in Revelstoke reservoir (115-125 µg/L), with REV Middle having the greatest seasonal variation (Table 2, Figures 3,5). Overall NN tends to peak in June and decline steadily into the fall, a trend that is consistent across reservoirs and years (Figures 2,3). In 2012, epilimnetic NN in June, particularly in Revelstoke reservoir and at KIN Columbia is notably higher than other months (Figure 6). Kin Columbia station was the only station where epilimnetic NN values were consistently below 50 µg/L in August to October. The NN profile tends to remain distinct through the water column until about 40m where values begin to converge (Figure 6).

Phosphorus (TP/TDP/SRP) – Average Total Phosphorus (TP) in Kinbasket ranged from 4.3 - 5.4 µg/L with highest seasonal averages in KIN Wood and KIN Columbia stations (Table 2) and reservoir values peaking in June (Figures 2, 4). Revelstoke stations average TP ranged from 4.1 – 4.5 µg/L with the highest seasonal average at REV Middle station (Table 2). TP peaked in July in Revelstoke reservoir (Figures 3,5) although across years the trend is a decline from spring to fall (Figure 5). 2012 TP was not notably different from previous years (Figures 2,3).

Average Total Dissolved Phosphorus (TDP) in Kinbasket ranged from 3.1 – 3.6 µg/L and from 2.5 – 3.0 µg/L in Revelstoke reservoir in 2012 (Table 2) with a total range between 0.6 µg/L at KIN Forebay and 12 µg/L at KIN Wood and Columbia stations (Table 3, Figures 2-5). As with TP, TDP generally declines throughout the season from spring to fall. 2012 TDP was not notably different from previous years (Figures 2,3).

Soluble Reactive Phosphorus (SRP) across Kinbasket reservoir stations was on average 1.8 or 1.9 µg/L and 1.6 µg/L at all Revelstoke stations although the total range was between 0.6 and 3.4 µg/L (Table 2). SRP differs little among stations in each reservoir (Figures 2-5) and usually reaches a low in the summer period (August). Unlike TP and TDP, 2012 SRP was generally higher than previous years (Figures 2,3). SRP in the epilimnion (0-20m) was usually high in June in both reservoirs. October values in Kinbasket were also usually on the higher side whereas October SRP in Revelstoke reservoir was at its lowest, both seasonally and between reservoirs (Figure 7).

Alkalinity and Conductivity – Alkalinity was higher in Kinbasket reservoir, average seasonal values ranging from 123-163 mg$CaCO_3$/L in Kinbasket and from 97-110 mg$CaCO_3$/L in Revelstoke reservoir (Table 2). Average seasonal conductivity is also higher in Kinbasket (114-142 µohms) than in Revelstoke (91-131 µohms) (Table 2). Highest conductivity water in Kinbasket comes from the Columbia Reach while the Canoe Reach station is lowest in both seasonal average alkalinity and conductivity. In Revelstoke reservoir, both parameters decline along the downstream, north-south axis of the reservoir from Rev Upper to REV Forebay stations.

pH and Turbidity - pH varies little and is always slightly alkaline. Average turbidity was similar across most stations (0.3 – 0.7 NTUs) (Table 2) although KIN Columbia Wood and REV Upper, the two most shallow sites, had the highest seasonal average turbidity levels (2.0 and 1.1 NTUs, respectively). KIN Columbia, while having on average low turbidity, also had the highest point sample (3.2 NTU) in 2012. This compares with Secchi depth data below.

Silica (Si) – Silica concentrations were similar across stations in each reservoir and trended down through the sampling season as in previous years (Figure 8). The reservoir average was 1.35 mg/L and ranged from 1.1 to 1.7 mg/L (Table 2).

Secchi – Secchi depths averaged from 5.7 – 7.4 m across the four Kinbasket reservoir stations in 2012 and from 3.1 – 6.1 m in Revelstoke with lowest values at the two shallowest stations, Wood Arm and REV Upper (Table 2). In Kinbasket reservoir there was a marked increase in Secchi depth (clarity) from July to August likely reflecting the increased effect of plunging inflows. Revelstoke stations also increase in clarity throughout the summer and fall although not as much as in Kinbasket. REV Upper, in particular, showed the least change across the year (Figure 9).

Table 2**.** Average water chemistry values for all depths combined at Kinbasket and Revelstoke reservoir stations, sampled monthly June to October, 2012. Range of values shown in parentheses.

Parameter	**Units**	**STATIONS**						
		KIN Forebay	***Canoe Reach***	***Wood Arm***	***Columbia Reach***	***REV Forebay***	***REV Middle***	***REV Upper***
NO_2+NO_3 (NN)	µg/L	95.5 (55.7 – 133)	106 (65 – 175)	104 (54.7 – 166)	98.7 (21.5 - 192)	116 (73 – 171)	115 (80 - 177)	125 (101 - 191)
TP	µg/L	4.3 (2.0 – 12)	4.7 (2.7 – 9.3)	5.4 (2.2 – 11)	5.1 (3.0 – 8.5)	4.2 (1.9 – 9.9)	4.5 (2.4 – 9.1)	4.1 (1.0 – 6.7)
TDP	µg/L	3.1 (1.1 – 7.1)	3.3 (1.4 – 9.2)	3.6 (1.8 – 6.4)	3.5 (1.8 – 7.2)	2.6 (1.7 – 6.8)	3.0 (1.4 – 7.8)	2.5 (1.6 – 5.6)
SRP	µg/L	1.8 (0.9 – 2.9)	1.9 (1.3 – 2.9)	1.8 (1.1 – 2.6)	1.9 (1.1 – 3.4)	1.6 (0.6 – 2.5)	1.6 (0.8 – 2.3)	1.6 (0.8 – 2.4)
NN:TDP*		37 (17 – 122)	38 (21 – 82)	32 (12 – 65)	30 (8.4 – 76)	51 (25 – 99)	44 (22 – 94)	60 (32 – 105)
Alkalinity	mgCaCO$_3$/L	136 (118 – 177)	123 (93.5 - 166)	134 (117 - 153)	163 (129 - 211)	97 (57 - 130)	105 (62 – 130)	110 (65 – 129)
pH		8.0 (7.8 – 8.3)	8.0 (7.7 – 8.3)	8.1 (7.7 – 8.4)	8.1 (7.9 – 8.4)	7.8 (7.5 – 8.0)	7.9 (7.4 – 8.1)	7.9 (7.6 – 8.0)
Conductivity[‡]	µohms	125 (106 – 169)	114 (96 - 161)	121 (104 - 143)	142 (115 - 200)	91 (56 - 129)	99 (60 - 131)	131 (68 – 119)
Turbidity[‡]	NTU	0.3 (0.0 – 1.2)	0.4 (0.0 – 1.0)	2.0 (0.0 – 2.4)	0.6 (0.0 – 3.2)	0.4 (0.0 – 2.2)	0.7 (0.0- 2.5)	1.1 (0.3 – 3.1)
Silica**	mg/L	1.34 (1.2 – 1.5)	1.41 (1.3 – 1.6)	1.33 (1.2 – 1.5)	1.31 (1.1 – 1.7)	1.47 (1.4 – 1.5)	1.43 (1.3 – 1.7)	1.40 (1.3 – 1.6)
Secchi	m	7.3 (4.8 – 9.5)	7.4 (3.0 – 10.5)	6.6 (1.0 -10)	5.7 (3.2 – 8.0)	6.1 (3.0 – 8.0)	6.0 (3.0 – 9.9)	3.1 (2.1 – 4.1)

*NN:TP(corrected) used where TDP values were removed.
**Silica values are from a single 0-20 integrated sample per month.
[‡] Kinbasket values for June missing due to lab error.

4. Discussion

The 2012 results represent the fifth year of sampling sessions on Kinbasket and Revelstoke reservoirs, adding to the dataset begun in 2008. Results from 2008 are not included in summary charts as the sampling season began in July that year. With this increasing dataset, seasonal and spatial comparisons and trends will start to become possible in future.

Nitrite-nitrate remains relatively consistent among years with values peaking in June in both Kinbasket and Revelstoke reservoirs and declining through the season. Total phosphorus in all samples across both reservoirs ranged from 0.4 to 12 µg/L and SRP from 0.6 to 3.4 µg/L, confirming the oligotrophic status of both reservoirs according to Wetzel's (2001) classification of productivity. On average Revelstoke Reservoir has higher NN and lower phosphorus (all fractions) than Kinbasket that would lead to even greater phosphorus limitation (N:P) in that reservoir.

The glacial nature of the watershed is noticeable in higher TP, turbidity, conductivity and lower Secchi depths in spring as freshet inflows increase and especially while mixing in the epilimnion is occurring in Kinbasket. Neither reservoir demonstrates a lack of silica despite declines throughout the productive period. Diatoms require a minimum of 0.5 mg/L silica (Wetzel 2001) for growth

As conditions permit, the sampling season should also be extended earlier into April to help determine the boundaries of the productive season in the reservoirs. Sampling in November has been attempted; however, as reservoir conditions are often unpredictable and unsafe at that time of year, particularly on Kinbasket, sampling later than October is not recommended.

5. References

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Figure 1. Location of sampling stations on Kinbasket and Revelstoke reservoirs, 2012.

Figure 2. Average Kinbasket reservoir monthly NN, TP, TDP, and SRP (µg/L), 2009-2012.

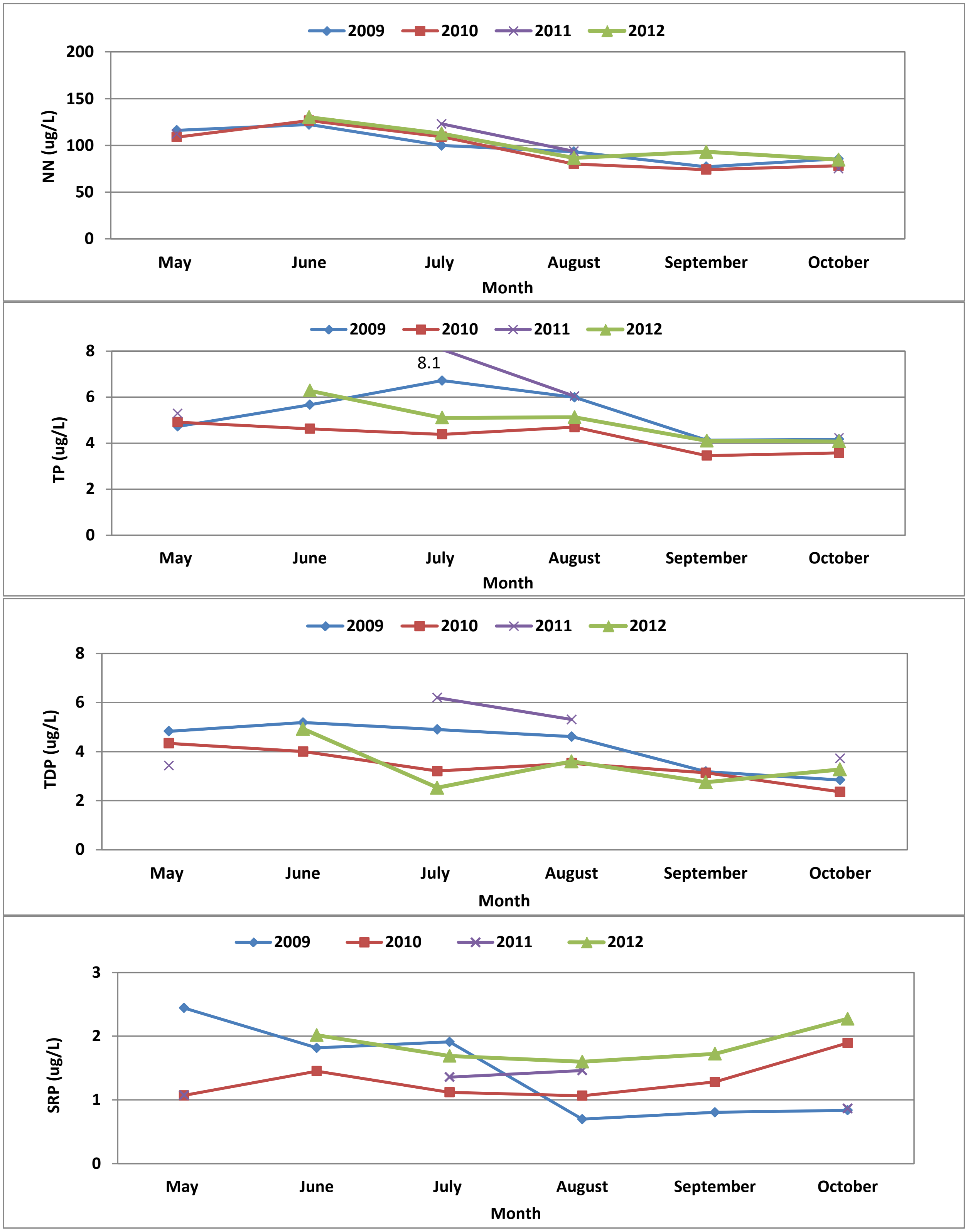


Figure 3. Average Revelstoke reservoir monthly NN, TP, TDP, and SRP (µg/L), 2009-2012.

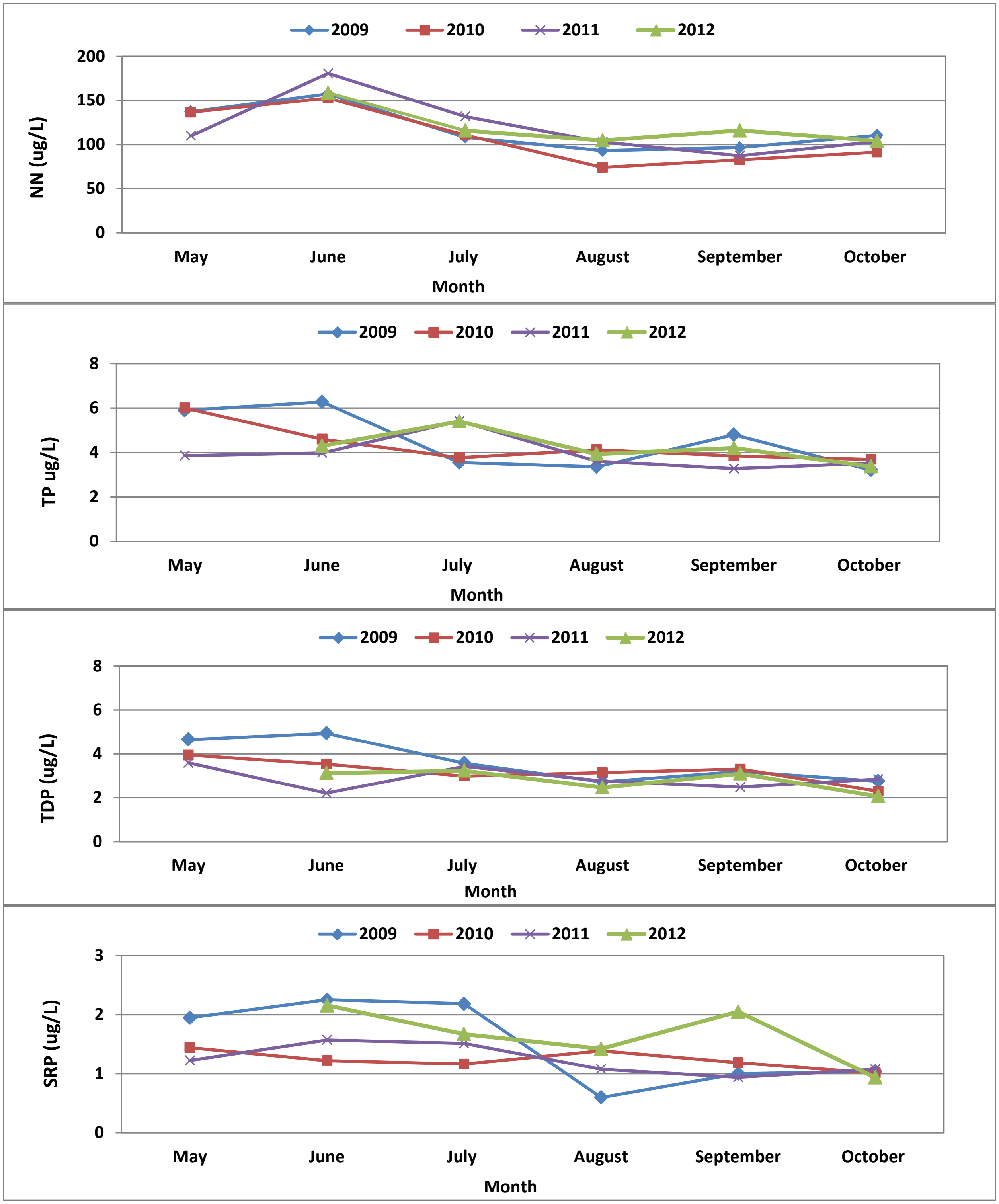


Figure 4. Average monthly NN, TP, TDP, and SRP (µg/L) at Kinbasket reservoir stations, 2009-2012.

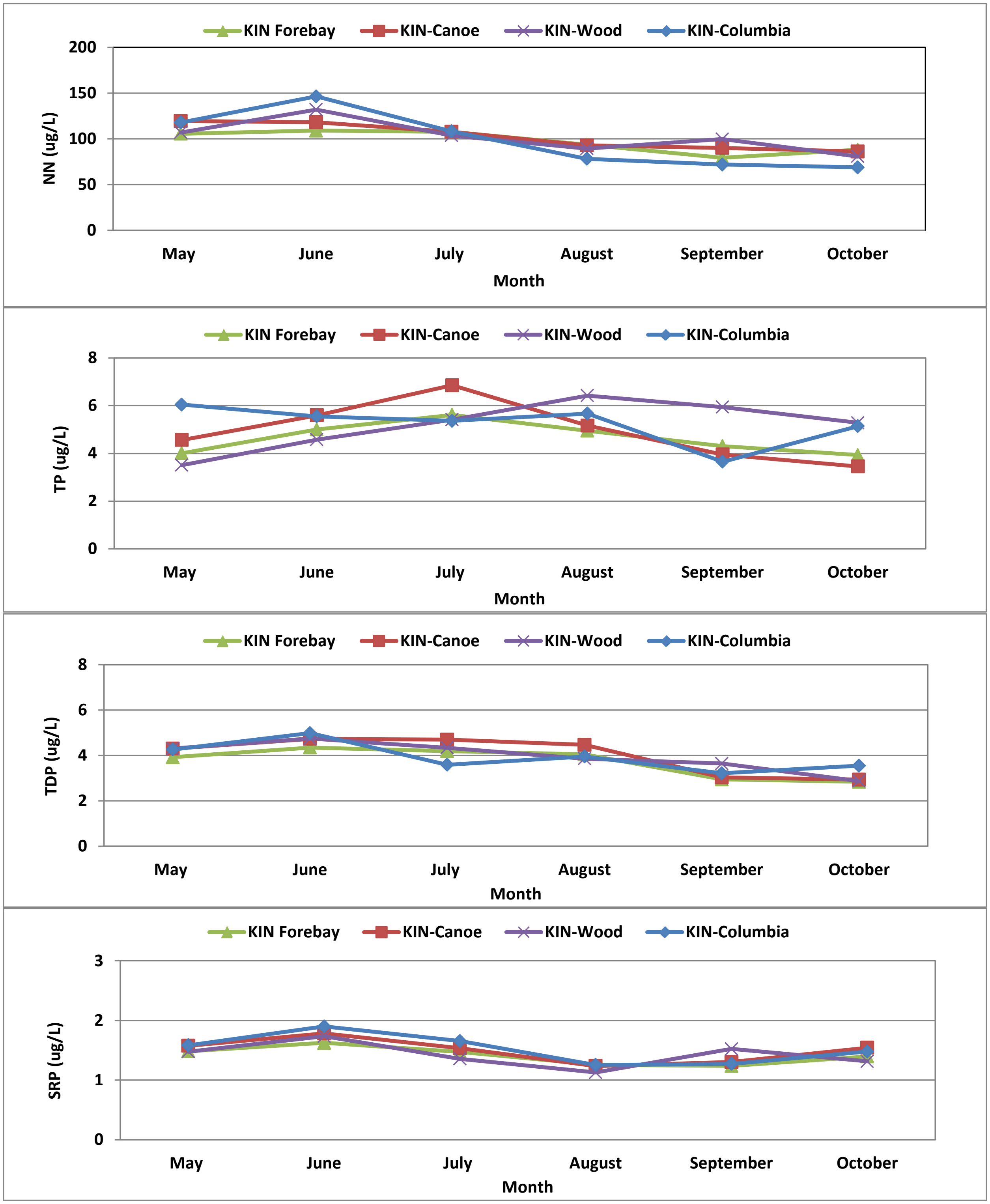


Figure 5. Average monthly NN, TP, TDP, and SRP (µg/L) at Revelstoke reservoir stations, 2009-2012.

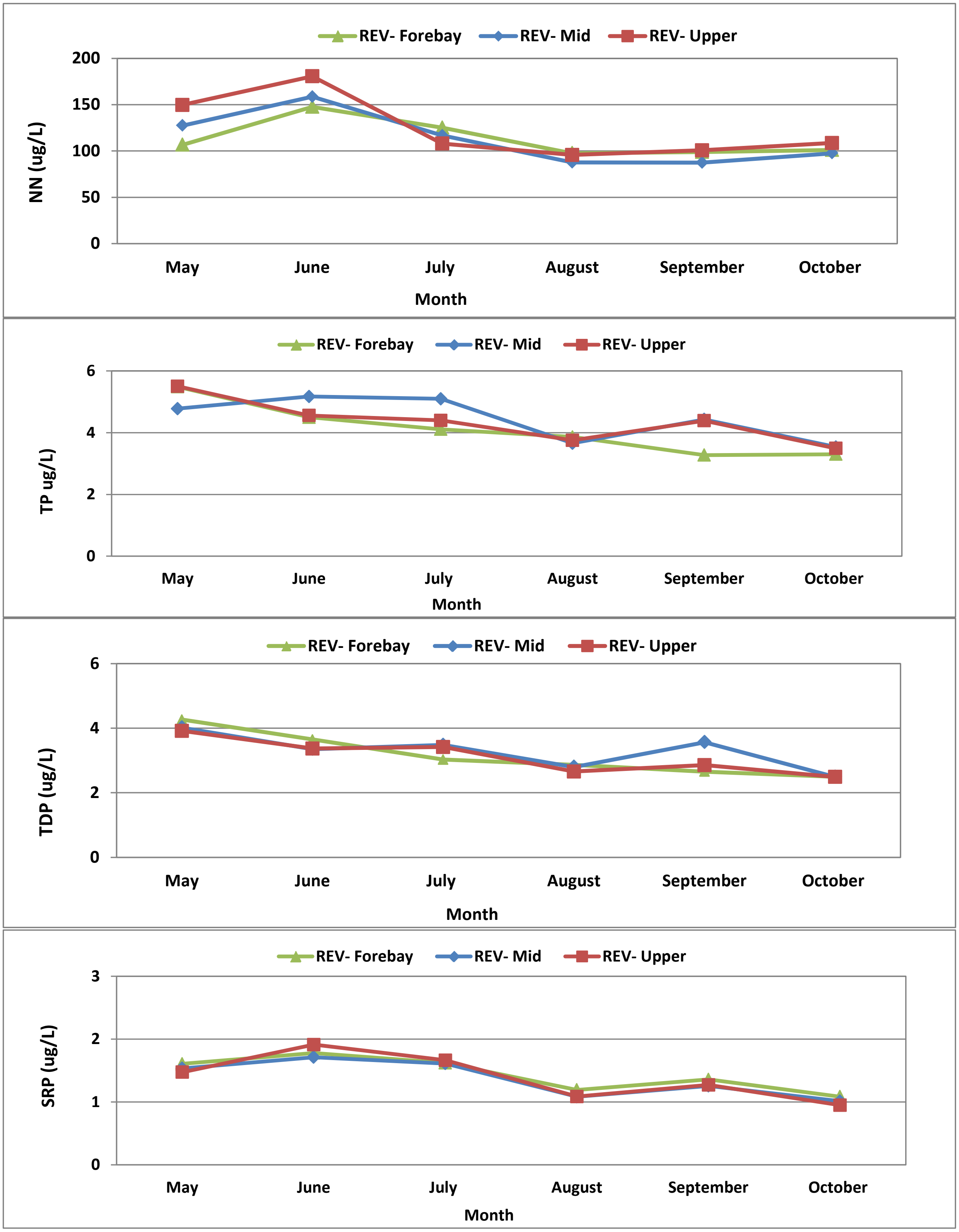
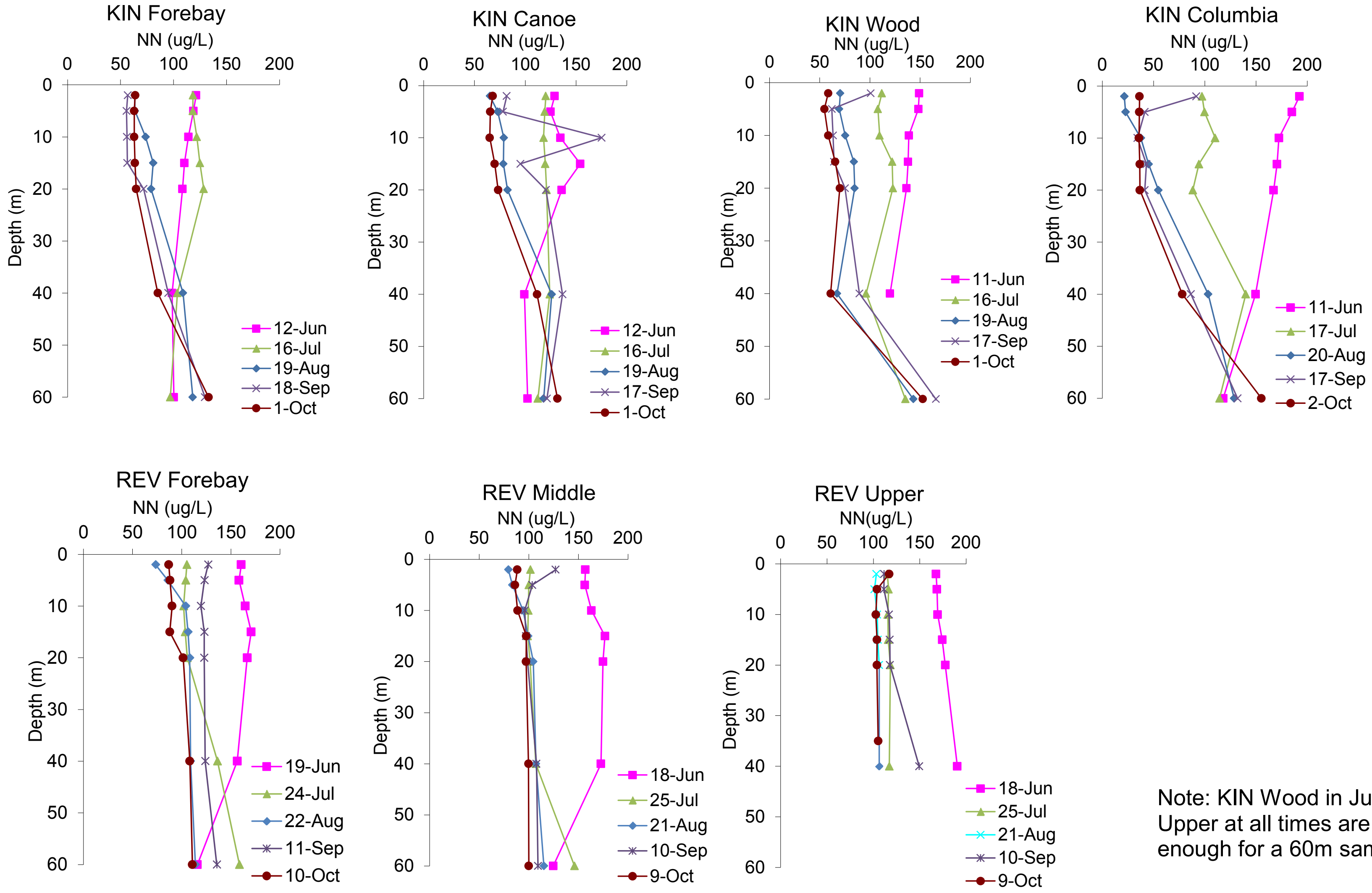


Figure 6. NN (µg/L) depth profiles (0-60m) for stations in Kinbasket and Revelstoke reservoirs, 2012.



Note: KIN Wood in June and REV Upper at all times are not deep enough for a 60m sample.

Figure 7. Epilimnetic SRP (µg/L) (0-20m) for stations in Kinbasket and Revelstoke reservoirs, 2012.

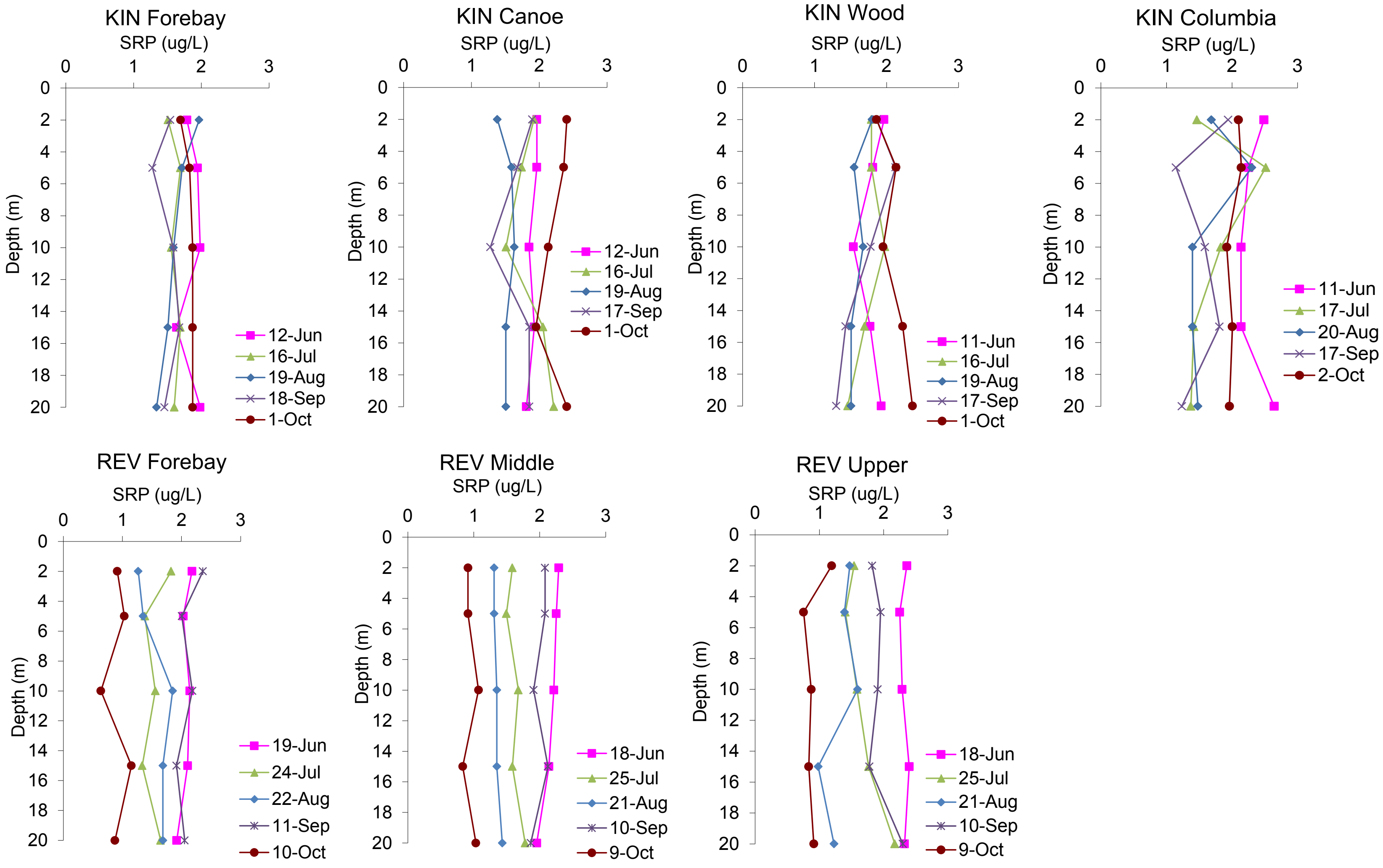
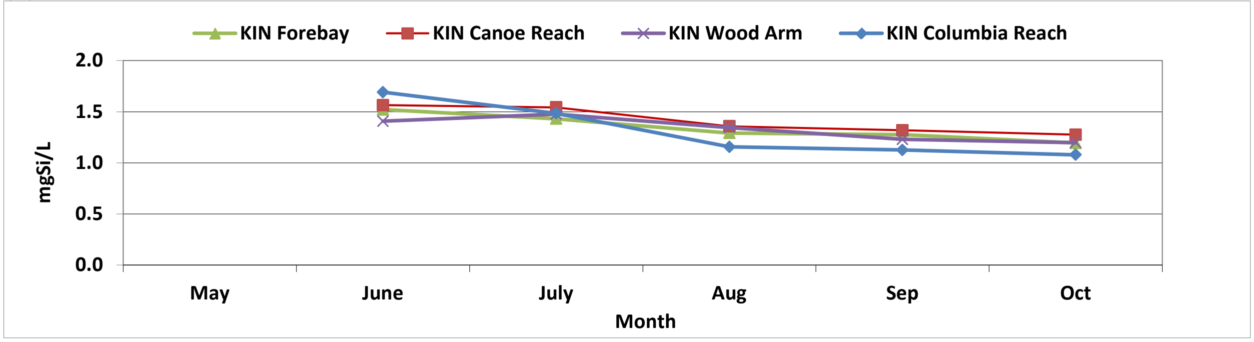


Figure 8. Seasonal silica (mg/L) from a 0-20m integrated tube sample at (a) Kinbasket and (b) Revelstoke stations, 2012.

(a)



(b)

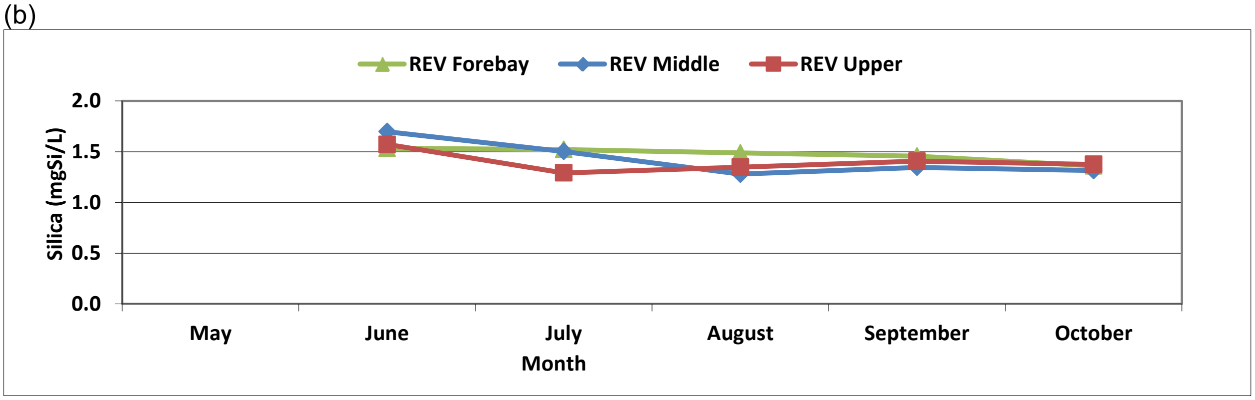
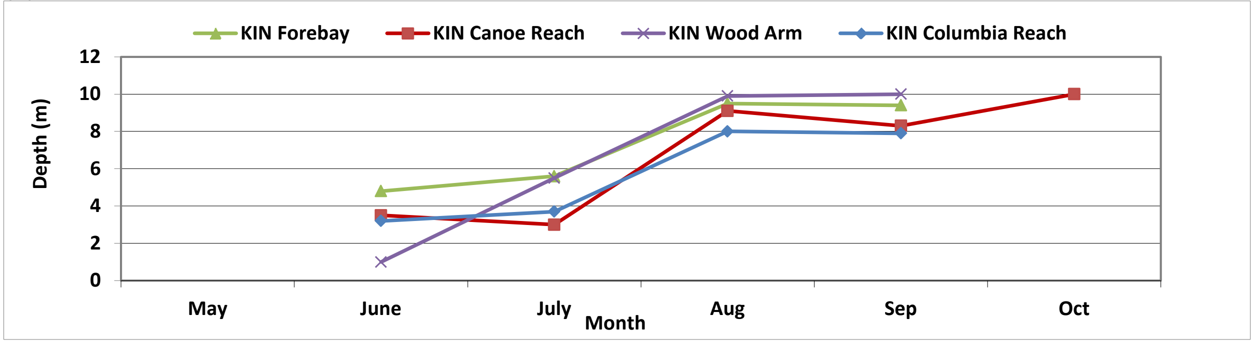
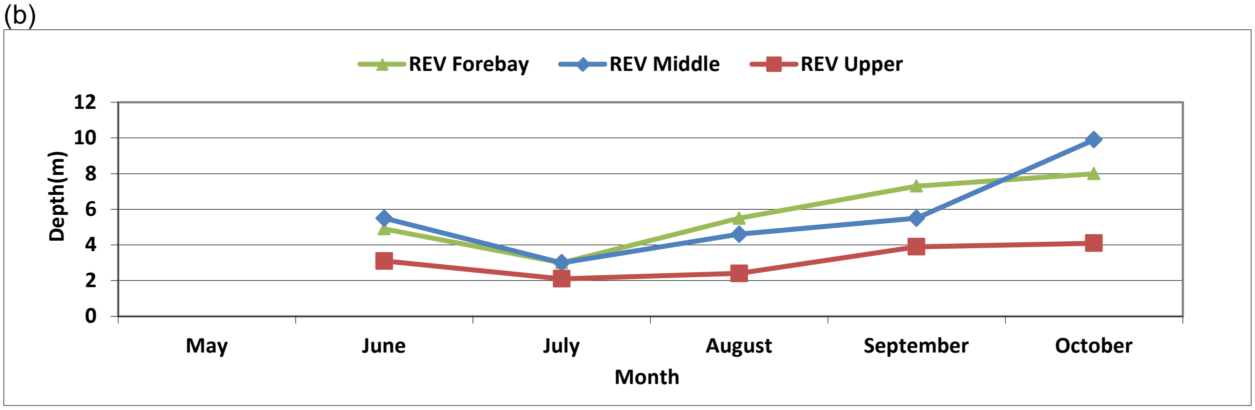


Figure 9. Seasonal Secchi depth (m) at (a) Kinbasket and (b) Revelstoke stations, 2012. Note no readings for October other than Canoe Reach as disk was lost.

(a)



(b)



Appendix 1 – Data

Site	Depth	Date	Nitrate/ Nitrite	SRP	TP	TP Turbidity	TDP	SRS	Alkalinity	pH	Turbidity	Cond.
	m		ug/L	ug/L	ug/L	ug/L	ug/L	mgSi/L	mgCaCO3/L		(NTU)	uohms
Kinbasket - Columbia	0 - 20	11-Jun-12	.	.	.	.	.	1.69	.	.	.	.
Kinbasket - Columbia	2	11-Jun-12	192.3	2.5	6.1	<0.1	4.6	.	184.9	8.04	.	.
Kinbasket - Columbia	5	11-Jun-12	185.0	2.3	6.2	<0.1	4.9	.	185.6	8.17	.	.
Kinbasket - Columbia	10	11-Jun-12	172.3	2.1	7.0	<0.1	4.6	.	179.5	8.15	.	.
Kinbasket - Columbia	15	11-Jun-12	170.5	2.1	7.7	2.0	7.2	.	182.6	8.13	.	.
Kinbasket - Columbia	20	11-Jun-12	167.1	2.6	6.9	1.6	6.0	.	181.9	8.08	.	.
Kinbasket - Columbia	40	11-Jun-12	149.5	2.1	8.5	1.7	6.4	.	187.0	8.09	.	.
Kinbasket - Columbia	60	11-Jun-12	117.9	2.2	6.2	<0.1	4.9	.	186.5	8.05	.	.
Kinbasket - Columbia	80	11-Jun-12	110.3	2.3	5.6	<0.1	4.3	.	193.3	8.03	.	.
Kinbasket - Columbia	150	11-Jun-12	106.5	2.4	7.1	<0.1	7.2	.	208.3	7.95	.	.
Kinbasket - Forebay	0 - 20	12-Jun-12	.	.	.	.	.	1.52	.	.	.	.
Kinbasket - Forebay	2	12-Jun-12	121.2	1.8	3.8	<0.1	3.8	.	139.4	8.00	.	.
Kinbasket - Forebay	5	12-Jun-12	118.7	1.9	4.6	<0.1	4.5	.	139.4	8.04	.	.
Kinbasket - Forebay	10	12-Jun-12	114.0	2.0	4.8	<0.1	4.6	.	137.5	8.04	.	.
Kinbasket - Forebay	15	12-Jun-12	110.2	1.6	11.9	<0.1	3.7	.	130.3	7.95	.	.
Kinbasket - Forebay	20	12-Jun-12	108.4	2.0	3.6	<0.1	3.6	.	129.2	7.91	.	.
Kinbasket - Forebay	40	12-Jun-12	98.5	1.9	5.6	<0.1	7.1	.	137.0	7.93	.	.
Kinbasket - Forebay	60	12-Jun-12	100.2	1.9	4.2	<0.1	4.6	.	141.8	7.88	.	.
Kinbasket - Forebay	80	12-Jun-12	104.9	2.0	4.0	<0.1	4.8	.	153.0	7.81	.	.
Kinbasket - Forebay	150	12-Jun-12	104.0	2.2	4.4	<0.1	4.1	.	177.3	7.94	.	.
Kinbasket - Canoe	0 - 20	12-Jun-12	.	.	.	.	.	1.56	.	.	.	.
Kinbasket - Canoe	2	12-Jun-12	129.0	2.0	6.8	<0.1	5.0	.	137.7	8.06	.	.
Kinbasket - Canoe	5	12-Jun-12	124.8	2.0	5.5	<0.1	4.4	.	131.4	8.02	.	.
Kinbasket - Canoe	10	12-Jun-12	134.6	1.8	4.8	1.3	3.9	.	112.4	7.91	.	.
Kinbasket - Canoe	15	12-Jun-12	154.2	1.9	6.5	1.8	4.2	.	93.5	7.74	.	.
Kinbasket - Canoe	20	12-Jun-12	135.9	1.8	8.5	2.4	3.6	.	100.5	7.78	.	.
Kinbasket - Canoe	40	12-Jun-12	99.2	2.9	4.2	<0.1	3.6	.	134.0	7.91	.	.
Kinbasket - Canoe	60	12-Jun-12	102.3	1.9	4.4	<0.1	4.0	.	140.0	7.89	.	.
Kinbasket - Canoe	80	12-Jun-12	104.0	1.9	6.2	1.9	9.2	.	157.1	7.91	.	.
Kinbasket - Canoe	95	12-Jun-12	102.1	2.2	5.8	<0.1	4.7	.	161.3	7.91	.	.
Kinbasket - Wood	0 - 20	11-Jun-12	.	.	.	.	.	1.41	.	.	.	.
Kinbasket - Wood	2	11-Jun-12	149.0	2.0	10.3	2.2	4.7	.	139.2	8.19	.	.
Kinbasket - Wood	5	11-Jun-12	148.3	1.8	7.2	2.2	5.1	.	138.3	8.13	.	.
Kinbasket - Wood	10	11-Jun-12	138.7	1.5	6.9	<0.1	6.4	.	139.0	8.02	.	.
Kinbasket - Wood	15	11-Jun-12	138.0	1.8	6.7	<0.1	4.1	.	137.9	8.08	.	.
Kinbasket - Wood	20	11-Jun-12	136.4	1.9	7.4	<0.1	5.3	.	136.5	8.13	.	.
Kinbasket - Wood	40	11-Jun-12	120.0	2.0	4.9	<0.1	4.2	.	140.6	8.09	.	.
Kinbasket - Columbia	0 - 20	17-Jul-12	.	.	.	.	.	1.48	.	.	.	.
Kinbasket - Columbia	2	17-Jul-12	97.4	1.5	6.3	1.1	5.1	.	160.8	8.16	1.16	147
Kinbasket - Columbia	5	17-Jul-12	99.7	2.5	7.0	0.9	2.4	.	157.5	8.26	1.11	144
Kinbasket - Columbia	10	17-Jul-12	110.1	1.8	5.9	0.9	2.0	.	152.0	8.17	1.34	141
Kinbasket - Columbia	15	17-Jul-12	94.3	1.4	8.4	1.2	2.2	.	156.3	8.08	2.11	143
Kinbasket - Columbia	20	17-Jul-12	88.3	1.4	5.8	0.9	3.5	.	155.6	8.09	1.76	143
Kinbasket - Columbia	40	17-Jul-12	140.0	1.5	5.6	1.4	1.8	.	160.2	7.99	3.17	148
Kinbasket - Columbia	60	17-Jul-12	114.4	1.7	.	.	2.3	.	151.8	8.03	1.15	146
Kinbasket - Columbia	80	17-Jul-12	112.7	1.8	4.0	0.9	3.4	.	191.9	7.98	0.47	147
Kinbasket - Columbia	150	17-Jul-12	109.4	1.7	3.9	1.1	2.7	.	207.9	7.92	0.33	200
Kinbasket - Forebay	0 - 20	16-Jul-12	.	.	.	.	.	1.43	.	.	.	.
Kinbasket - Forebay	2	16-Jul-12	118.3	1.5	3.3	0.9	1.5	.	146.9	8.29	0.45	138
Kinbasket - Forebay	5	16-Jul-12	118.2	1.7	4.9	0.7	2.8	.	144.4	8.27	0.68	137
Kinbasket - Forebay	10	16-Jul-12	121.9	1.6	7.1	1.2	2.9	.	141.0	8.22	0.74	135
Kinbasket - Forebay	15	16-Jul-12	124.8	1.7	3.5	0.8	3.7	.	156.0	8.26	0.73	133
Kinbasket - Forebay	20	16-Jul-12	128.4	1.6	2.3	0.8	1.1	.	129.1	8.04	0.64	123
Kinbasket - Forebay	40	16-Jul-12	103.6	1.6	2.8	0.8	1.4	.	127.5	7.76	0.38	127
Kinbasket - Forebay	60	16-Jul-12	96.9	1.9	2.8	0.8	1.4	.	136.3	7.88	0.36	134
Kinbasket - Forebay	80	16-Jul-12	101.0	1.4	2.8	0.7	2.7	.	146.4	7.85	0.21	143
Kinbasket - Forebay	170	16-Jul-12	108.7	2.1	4.2	0.8	3.0	.	173.8	7.90	0.33	169
Kinbasket - Canoe	0 - 20	16-Jul-12	.	.	.	.	.	1.54	.	.	.	.
Kinbasket - Canoe	2	16-Jul-12	120.2	1.9	5.3	1.2	2.3	.	100.4	8.07	0.92	103
Kinbasket - Canoe	5	16-Jul-12	119.1	1.7	6.8	1.0	1.4	.	109.3	7.83	0.91	108
Kinbasket - Canoe	10	16-Jul-12	118.1	1.5	7.0	1.3	1.6	.	112.8	7.95	0.76	110
Kinbasket - Canoe	15	16-Jul-12	119.7	2.1	4.7	0.9	1.6	.	117.0	7.92	0.77	113
Kinbasket - Canoe	20	16-Jul-12	121.0	2.2	3.7	0.5	1.8	.	119.4	7.87	0.78	116
Kinbasket - Canoe	40	16-Jul-12	124.2	1.8	3.4	1.3	2.3	.	118.3	7.89	0.97	115
Kinbasket - Canoe	60	16-Jul-12	112.4	1.8	3.1	1.0	2.0	.	123.0	7.87	0.41	121
Kinbasket - Canoe	80	16-Jul-12	95.7	1.6	3.6	<0.1	1.8	.	136.2	7.86	0.32	133
Kinbasket - Canoe	130	16-Jul-12	100.6	1.6	5.0	<0.1	2.8	.	165.9	7.91	0.32	161

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 - Wood	0 - 20	16-Jul-12	.	.	.	.	.	1.48	.	.	.	.
Kinbasket - Wood	2	16-Jul-12	111.9	1.8	4.2	0.9	3.6	.	150.7	8.34	0.47	140
Kinbasket - Wood	5	16-Jul-12	107.9	1.8	5.1	0.8	2.5	.	152.9	8.14	0.55	143
Kinbasket - Wood	10	16-Jul-12	109.7	2.0	5.8	0.9	1.8	.	141.9	8.32	0.55	134
Kinbasket - Wood	15	16-Jul-12	122.2	1.7	5.0	0.9	2.1	.	145.3	8.18	0.39	135
Kinbasket - Wood	20	16-Jul-12	122.9	1.5	4.0	1.0	3.6	.	136.7	8.11	0.67	126
Kinbasket - Wood	40	16-Jul-12	96.2	1.1	9.1	3.6	2.2	.	130.0	8.19	8.72	114
Kinbasket - Wood	60	16-Jul-12	135.3	1.3	8.9	2.1	4.8	.	142.8	8.15	3.89	131
Kinbasket - Columbia	0 - 20	20-Aug-12	.	.	.	.	.	1.16	.	.	.	.
Kinbasket - Columbia	2	20-Aug-12	21.5	1.7	3.9	0.4	2.4	.	143.8	8.35	0.00	132
Kinbasket - Columbia	5	20-Aug-12	22.6	2.3	3.6	0.5	2.4	.	143.5	8.34	0.05	130
Kinbasket - Columbia	10	20-Aug-12	37.6	1.4	5.3	0.3	2.8	.	139.9	8.24	0.00	129
Kinbasket - Columbia	15	20-Aug-12	45.2	1.4	4.4	0.5	2.8	.	135.6	8.11	0.05	125
Kinbasket - Columbia	20	20-Aug-12	54.7	1.5	6.4	1.5	3.2	.	134.6	8.08	1.70	123
Kinbasket - Columbia	40	20-Aug-12	103.3	1.5	8.0	1.3	5.2	.	148.2	8.09	1.30	135
Kinbasket - Columbia	60	20-Aug-12	128.7	1.6	3.7	0.6	2.6	.	158.8	8.08	0.63	149
Kinbasket - Columbia	80	20-Aug-12	122.5	1.9	3.6	0.5	3.2	.	188.9	8.04	0.38	171
Kinbasket - Columbia	175	20-Aug-12	131.5	2.2	6.0	0.7	2.7	.	208.3	7.97	0.05	190
Kinbasket - Forebay	0 - 20	19-Aug-12	.	.	.	.	.	1.29	.	.	.	.
Kinbasket - Forebay	2	19-Aug-12	63.3	2.0	6.4	0.6	2.8	.	129.7	8.31	0.00	121
Kinbasket - Forebay	5	19-Aug-12	63.5	1.7	4.1	0.3	6.4	.	126.4	8.32	0.00	121
Kinbasket - Forebay	10	19-Aug-12	73.6	1.6	3.2	0.3	2.3	.	118.6	8.20	0.00	113
Kinbasket - Forebay	15	19-Aug-12	80.8	1.5	4.0	0.2	2.3	.	118.0	8.11	0.00	113
Kinbasket - Forebay	20	19-Aug-12	78.8	1.3	3.6	0.5	2.8	.	126.4	8.07	0.03	118
Kinbasket - Forebay	40	19-Aug-12	108.9	1.5	3.3	1.3	2.6	.	144.1	8.12	1.15	130
Kinbasket - Forebay	60	19-Aug-12	118.0	0.9	2.0	0.2	3.1	.	125.9	7.98	0.00	123
Kinbasket - Forebay	80	19-Aug-12	102.1	1.5	6.9	0.2	4.4	.	131.5	7.94	0.00	133
Kinbasket - Forebay	175	19-Aug-12	112.1	2.0	3.8	0.4	5.9	.	174.8	7.84	0.00	166
Kinbasket - Canoe	0 - 20	19-Aug-12	.	.	.	.	.	1.36	.	.	.	.
Kinbasket - Canoe	2	19-Aug-12	65.3	1.4	3.5	0.7	3.3	.	124.7	8.25	0.00	112
Kinbasket - Canoe	5	19-Aug-12	72.9	1.6	9.3	<0.1	3.0	.	118.2	8.26	0.00	106
Kinbasket - Canoe	10	19-Aug-12	78.8	1.6	4.3	<0.1	3.0	.	111.1	8.17	0.00	102
Kinbasket - Canoe	15	19-Aug-12	78.4	1.5	5.8	<0.1	3.2	.	117.4	7.96	0.00	106
Kinbasket - Canoe	20	19-Aug-12	82.5	1.5	5.0	<0.1	3.2	.	125.5	8.07	0.15	111
Kinbasket - Canoe	40	19-Aug-12	126.0	1.6	5.5	<0.1	4.7	.	128.5	8.02	0.08	113
Kinbasket - Canoe	60	19-Aug-12	118.2	1.4	3.7	<0.1	3.7	.	114.3	7.78	0.00	108
Kinbasket - Canoe	80	19-Aug-12	112.4	1.5	3.2	<0.1	6.7	.	135.4	7.87	0.00	126
Kinbasket - Canoe	115	19-Aug-12	109.3	1.9	7.2	<0.1	3.8	.	158.1	7.90	0.00	145
Kinbasket - Wood	0 - 20	19-Aug-12	.	.	.	.	.	1.35	.	.	.	.
Kinbasket - Wood	2	19-Aug-12	70.4	1.8	4.0	<0.1	3.1	.	137.5	8.38	0.00	127
Kinbasket - Wood	5	19-Aug-12	69.4	1.5	4.2	<0.1	3.1	.	127.4	8.36	0.05	120
Kinbasket - Wood	10	19-Aug-12	75.4	1.7	6.1	<0.1	3.8	.	116.5	8.25	0.13	112
Kinbasket - Wood	15	19-Aug-12	84.0	1.5	5.6	<0.1	5.2	.	119.0	7.86	0.00	112
Kinbasket - Wood	20	19-Aug-12	84.8	1.5	6.0	<0.1	3.4	.	129.6	8.16	0.10	119
Kinbasket - Wood	40	19-Aug-12	67.2	1.3	10.7	.	5.4	.	127.1	8.27	23.50	108
Kinbasket - Wood	60	19-Aug-12	143.3	1.5	6.4	4.2	3.9	.	143.8	8.11	2.30	135
Kinbasket - Wood	5 m of bottom	19-Aug-12	139.0	1.6	6.0	2.3	4.3	.	144.9	8.08	0.45	135
Kinbasket - Columbia	0 - 20	17-Sep-12	.	.	.	.	.	1.13	.	.	.	.
Kinbasket - Columbia	2	17-Sep-12	91.7	1.9	3.7	<0.1	2.8	.	137.8	8.21	0.37	124
Kinbasket - Columbia	5	17-Sep-12	41.4	1.1	3.0	<0.1	2.6	.	137.2	8.22	0.34	124
Kinbasket - Columbia	10	17-Sep-12	34.2	1.6	3.6	<0.1	2.4	.	136.6	8.20	0.51	123
Kinbasket - Columbia	15	17-Sep-12	43.0	1.8	3.2	0.8	2.8	.	136.0	8.18	0.54	122
Kinbasket - Columbia	20	17-Sep-12	41.4	1.2	3.4	0.4	3.0	.	133.6	8.13	0.64	121
Kinbasket - Columbia	40	17-Sep-12	86.5	1.2	4.2	0.9	2.5	.	143.6	8.10	0.70	126
Kinbasket - Columbia	60	17-Sep-12	132.0	1.7	7.6	1.5	2.6	.	164.6	8.07	0.79	150
Kinbasket - Columbia	80	17-Sep-12	134.4	1.9	3.3	0.5	2.9	.	187.6	7.95	0.23	175
Kinbasket - Columbia	170	17-Sep-12	136.6	2.6	4.2	0.5	3.7	.	210.9	7.94	0.38	198
Kinbasket - Forebay	0 - 20	18-Sep-12	.	.	.	.	.	1.28	.	.	.	.
Kinbasket - Forebay	2	18-Sep-12	56.8	1.5	4.8	0.9	1.9	.	125.6	8.16	0.22	114
Kinbasket - Forebay	5	18-Sep-12	55.7	1.3	5.5	0.5	1.7	.	124.6	8.15	0.24	114
Kinbasket - Forebay	10	18-Sep-12	56.1	1.6	5.3	1.7	2.4	.	124.7	8.17	0.28	114
Kinbasket - Forebay	15	18-Sep-12	56.4	1.7	3.2	0.4	2.2	.	124.2	8.16	0.20	113
Kinbasket - Forebay	20	18-Sep-12	71.8	1.5	5.4	0.7	1.7	.	122.2	8.06	0.37	112
Kinbasket - Forebay	40	18-Sep-12	95.0	1.5	4.9	0.6	2.5	.	134.7	8.07	0.72	120
Kinbasket - Forebay	60	18-Sep-12	129.6	1.6	3.6	0.5	2.9	.	120.4	7.89	0.75	115
Kinbasket - Forebay	80	18-Sep-12	111.8	1.9	3.4	0.5	3.9	.	135.1	7.88	0.31	129

Site	Depth	Date	Nitrate/ Nitrite	SRP	TP	TP Turbidity	TDP	SRS	Alkalinity	pH	Turbidity	Cond.
	m		ug/L	ug/L	ug/L	ug/L	ug/L	mgSi/L	mgCaCO3/L		(NTU)	uohms
Kinbasket - Forebay	175	18-Sep-12	88.0	1.9	3.3	0.5	2.8	.	173.8	7.88	0.13	164
Kinbasket - Canoe	0 - 20	17-Sep-12	.	.	.	.	.	1.32	.	.	.	.
Kinbasket - Canoe	2	17-Sep-12	81.8	1.9	3.4	0.5	2.3	.	108.5	8.01	0.38	103
Kinbasket - Canoe	5	17-Sep-12	78.1	1.7	6.0	0.5	3.5	.	108.2	8.04	0.43	104
Kinbasket - Canoe	10	17-Sep-12	175.2	1.3	3.5	<0.1	4.5	.	106.7	8.04	0.55	103
Kinbasket - Canoe	15	17-Sep-12	95.2	1.9	3.1	<0.1	2.1	.	106.7	7.99	0.57	102
Kinbasket - Canoe	20	17-Sep-12	120.4	1.9	3.2	0.4	1.9	.	114.4	8.09	0.52	108
Kinbasket - Canoe	40	17-Sep-12	136.7	2.1	4.5	0.6	3.6	.	117.9	7.97	0.86	111
Kinbasket - Canoe	60	17-Sep-12	121.4	2.2	4.9	0.7	2.5	.	108.1	7.78	1.02	109
Kinbasket - Canoe	80	17-Sep-12	112.9	2.0	3.8	0.5	2.6	.	134.9	7.88	0.34	132
Kinbasket - Canoe	115	17-Sep-12	83.7	1.8	3.4	0.5	2.4	.	159.5	7.91	0.16	153
Kinbasket - Wood	0 - 20	17-Sep-12	.	.	.	.	.	1.23	.	.	.	.
Kinbasket - Wood	2	17-Sep-12	100.9	1.9	2.2	0.5	2.8	.	127.7	8.22	0.21	117
Kinbasket - Wood	5	17-Sep-12	62.0	2.1	5.0	0.7	2.3	.	127.7	8.24	0.28	116
Kinbasket - Wood	10	17-Sep-12	63.2	1.8	3.0	0.4	3.4	.	126.4	8.23	0.33	116
Kinbasket - Wood	15	17-Sep-12	64.2	1.4	3.3	<0.1	3.9	.	123.4	8.05	0.24	115
Kinbasket - Wood	20	17-Sep-12	75.2	1.3	2.4	0.5	2.4	.	126.1	8.09	1.20	114
Kinbasket - Wood	40	17-Sep-12	89.5	1.3	6.3	3.1	2.9	.	126.3	8.16	4.07	113
Kinbasket - Wood	60	17-Sep-12	165.7	2.1	5.0	3.1	3.6	.	145.5	8.04	4.99	134
Kinbasket - Wood	65	17-Sep-12	166.3	2.1	4.6	2.2	2.6	.	147.8	7.76	2.85	138
Kinbasket - Columbia	0 - 20	2-Oct-12	.	.	.	.	.	1.08	.	.	.	.
Kinbasket - Columbia	2	2-Oct-12	36.2	2.1	3.0	0.4	3.2	.	130.9	8.22	0.20	115
Kinbasket - Columbia	5	2-Oct-12	36.1	2.1	5.0	0.4	3.0	.	130.3	8.23	0.14	116
Kinbasket - Columbia	10	2-Oct-12	35.7	1.9	3.6	0.4	4.2	.	128.5	8.20	0.16	116
Kinbasket - Columbia	15	2-Oct-12	36.5	2.0	3.2	0.4	3.1	.	130.9	8.22	0.39	115
Kinbasket - Columbia	20	2-Oct-12	36.6	2.0	4.8	0.4	4.6	.	130.8	8.22	0.13	115
Kinbasket - Columbia	40	2-Oct-12	78.0	1.9	3.0	0.4	2.8	.	136.2	8.13	0.35	118
Kinbasket - Columbia	60	2-Oct-12	155.2	2.4	5.6	0.7	3.6	.	160.4	8.10	0.26	143
Kinbasket - Columbia	80	2-Oct-12	139.5	3.1	3.2	0.7	3.0	.	180.6	8.05	0.41	164
Kinbasket - Columbia	170	2-Oct-12	140.3	3.4	5.0	0.4	3.6	.	210.6	7.99	0.09	188
Kinbasket - Forebay	0 - 20	1-Oct-12	.	.	.	.	.	1.19	.	.	.	.
Kinbasket - Forebay	2	1-Oct-12	63.8	1.7	3.5	0.3	2.5	.	118.1	8.09	0.29	107
Kinbasket - Forebay	5	1-Oct-12	62.9	1.8	3.9	0.4	3.5	.	119.3	8.11	0.23	106
Kinbasket - Forebay	10	1-Oct-12	62.9	1.9	4.0	0.3	2.7	.	118.1	8.09	0.14	106
Kinbasket - Forebay	15	1-Oct-12	63.6	1.9	3.3	0.2	2.1	.	118.5	8.09	0.12	107
Kinbasket - Forebay	20	1-Oct-12	64.7	1.9	3.4	0.4	2.6	.	118.3	8.06	0.07	106
Kinbasket - Forebay	40	1-Oct-12	85.1	2.7	3.6	0.7	2.9	.	129.3	8.06	0.37	112
Kinbasket - Forebay	60	1-Oct-12	133.0	2.6	8.0	0.4	3.0	.	120.9	7.88	0.65	111
Kinbasket - Forebay	80	1-Oct-12	111.2	2.9	3.2	0.4	2.2	.	136.1	7.86	0.28	128
Kinbasket - Forebay	170	1-Oct-12	123.7	2.8	4.3	0.2	3.2	.	172.7	7.89	0.11	157
Kinbasket - Canoe	0 - 20	1-Oct-12	.	.	.	.	.	1.28	.	.	.	.
Kinbasket - Canoe	2	1-Oct-12	67.9	2.4	3.4	0.4	1.8	.	111.5	8.11	0.35	101
Kinbasket - Canoe	5	1-Oct-12	65.5	2.4	3.3	0.3	2.3	.	110.6	8.10	0.11	100
Kinbasket - Canoe	10	1-Oct-12	65.0	2.1	3.3	0.2	3.9	.	110.4	8.11	0.15	101
Kinbasket - Canoe	15	1-Oct-12	69.9	2.0	2.8	0.4	2.7	.	110.2	8.05	0.09	101
Kinbasket - Canoe	20	1-Oct-12	73.3	2.4	2.7	0.3	3.0	.	111.8	8.04	0.14	102
Kinbasket - Canoe	40	1-Oct-12	111.6	2.0	4.1	0.6	4.0	.	118.5	8.00	0.41	105
Kinbasket - Canoe	60	1-Oct-12	131.7	2.4	5.6	1.1	3.3	.	98.6	7.65	0.26	96
Kinbasket - Canoe	80	1-Oct-12	119.0	2.7	3.5	0.4	2.6	.	130.9	7.84	0.24	123
Kinbasket - Canoe	115	1-Oct-12	119.3	2.8	5.5	0.4	6.6	.	163.1	7.93	0.09	151
Kinbasket - Wood	0 - 20	1-Oct-12	.	.	.	.	.	1.20	.	.	.	.
Kinbasket - Wood	2	1-Oct-12	58.5	1.9	3.0	0.3	4.0	.	120.1	8.22	0.10	107
Kinbasket - Wood	5	1-Oct-12	54.7	2.1	4.8	0.2	5.0	.	120.5	8.21	0.10	107
Kinbasket - Wood	10	1-Oct-12	58.5	2.0	3.3	0.4	2.0	.	118.4	8.16	0.23	107
Kinbasket - Wood	15	1-Oct-12	65.5	2.2	2.7	0.3	3.0	.	117.5	8.08	0.11	104
Kinbasket - Wood	20	1-Oct-12	70.0	2.4	3.8	0.3	2.5	.	117.8	8.04	0.37	106
Kinbasket - Wood	40	1-Oct-12	60.9	1.8	5.9	4.1	2.6	.	128.1	7.72	1.96	113
Kinbasket - Wood	60	1-Oct-12	152.6	2.5	4.5	1.8	4.6	.	144.5	8.11	1.06	129
Kinbasket - Wood	65	1-Oct-12	155.6	2.6	6.4	1.4	4.0	.	146.4	8.10	1.04	133
Revelstoke - Upper	0 - 20	18-Jun-12	.	.	.	.	.	1.57	.	.	.	.
Revelstoke - Upper	2	18-Jun-12	167.6	2.4	3.0	1.2	1.8	.	71.1	7.72	0.85	75
Revelstoke - Upper	5	18-Jun-12	168.6	2.3	4.1	1.4	1.8	.	70.4	7.70	1.20	74
Revelstoke - Upper	10	18-Jun-12	169.4	2.3	4.7	2.7	3.7	.	65.8	7.71	3.10	72
Revelstoke - Upper	15	18-Jun-12	174.3	2.4	6.4	2.6	2.9	.	64.6	7.65	2.20	68
Revelstoke - Upper	20	18-Jun-12	177.6	2.3	4.8	2.1	5.0	.	66.2	7.65	2.45	70
Revelstoke - Upper	40	18-Jun-12	190.5	2.2	4.1	1.3	2.5	.	74.9	7.61	0.78	78

Site	Depth	Date	Nitrate/ Nitrite	SRP	TP	TP Turbidity	TDP	SRS	Alkalinity	pH	Turbidity	Cond.
	m		ug/L	ug/L	ug/L	ug/L	ug/L	mgSi/L	mgCaCO3/L		(NTU)	uohms
Revelstoke - Middle	0 - 20	18-Jun-12	.	.	.	.	.	1.70	.	.	.	.
Revelstoke - Middle	2	18-Jun-12	157.0	2.3	3.0	0.8	2.6	.	101.9	7.94	0.11	103
Revelstoke - Middle	5	18-Jun-12	156.5	2.3	5.1	1.1	3.6	.	99.3	7.84	0.28	100
Revelstoke - Middle	10	18-Jun-12	163.2	2.2	4.7	0.6	1.7	.	95.4	7.88	0.53	101
Revelstoke - Middle	15	18-Jun-12	176.8	2.1	4.9	4.5	2.9	.	104.2	7.94	1.55	103
Revelstoke - Middle	20	18-Jun-12	174.8	2.0	5.9	1.6	3.9	.	94.4	7.85	2.45	93
Revelstoke - Middle	40	18-Jun-12	172.7	2.0	4.5	1.6	3.2	.	95.3	7.78	1.05	95
Revelstoke - Middle	60	18-Jun-12	124.7	2.1	4.2	0.8	4.6	.	127.1	7.85	0.00	128
Revelstoke - Middle	80	18-Jun-12	116.2	2.0	5.1	0.8	3.6	.	129.5	7.80	0.00	131
Revelstoke - Forebay	0 - 20	19-Jun-12	.	.	.	.	.	1.53	.	.	.	.
Revelstoke - Forebay	2	19-Jun-12	160.5	2.2	4.5	0.8	3.0	.	98.4	7.86	0.15	98
Revelstoke - Forebay	5	19-Jun-12	158.3	2.0	2.9	1.0	2.3	.	97.6	7.81	0.13	96
Revelstoke - Forebay	10	19-Jun-12	164.6	2.1	3.6	1.1	2.7	.	97.6	7.79	0.38	97
Revelstoke - Forebay	15	19-Jun-12	170.6	2.1	2.8	1.1	2.6	.	100.2	7.81	0.45	99
Revelstoke - Forebay	20	19-Jun-12	166.6	1.9	4.1	1.0	3.5	.	105.7	7.83	0.35	105
Revelstoke - Forebay	40	19-Jun-12	156.5	2.1	3.5	0.9	3.1	.	112.0	7.83	0.20	113
Revelstoke - Forebay	60	19-Jun-12	115.8	2.0	5.5	0.8	5.0	.	127.5	7.91	0.00	128
Revelstoke - Forebay	80	19-Jun-12	112.3	2.0	3.5	0.8	3.3	.	128.8	7.91	0.00	128
Revelstoke - Forebay	115	19-Jun-12	111.0	2.0	3.0	0.8	3.3	.	129.9	7.90	0.00	129
Revelstoke - Upper	0 - 20	25-Jul-12	.	.	.	.	.	1.29	.	.	.	.
Revelstoke - Upper	2	25-Jul-12	115.1	1.5	3.2	0.9	2.1	.	109.9	7.98	0.96	105
Revelstoke - Upper	5	25-Jul-12	116.4	1.4	6.5	1.1	2.1	.	109.9	8.01	0.76	105
Revelstoke - Upper	10	25-Jul-12	115.5	1.6	4.4	1.2	2.0	.	110.0	7.99	1.53	106
Revelstoke - Upper	15	25-Jul-12	116.1	1.8	4.6	0.9	5.6	.	109.8	8.03	0.96	107
Revelstoke - Upper	20	25-Jul-12	118.4	2.2	4.4	1.0	2.0	.	110.0	7.99	0.74	106
Revelstoke - Upper	40	25-Jul-12	117.2	1.8	4.0	1.0	2.4	.	110.0	8.01	0.72	106
Revelstoke - Middle	0 - 20	25-Jul-12	.	.	.	.	.	1.50	.	.	.	.
Revelstoke - Middle	2	25-Jul-12	101.7	1.6	8.2	1.1	4.6	.	62.3	7.64	1.65	60
Revelstoke - Middle	5	25-Jul-12	100.1	1.5	8.0	1.2	3.3	.	62.1	7.54	1.31	60
Revelstoke - Middle	10	25-Jul-12	99.5	1.7	4.9	1.1	2.7	.	72.7	7.52	1.98	67
Revelstoke - Middle	15	25-Jul-12	99.0	1.6	7.0	1.1	3.2	.	82.2	7.72	2.37	80
Revelstoke - Middle	20	25-Jul-12	101.4	1.8	5.1	1.2	3.9	.	84.8	7.79	1.75	84
Revelstoke - Middle	40	25-Jul-12	107.1	1.8	4.9	1.1	2.7	.	91.6	7.79	1.83	89
Revelstoke - Middle	60	25-Jul-12	146.1	1.8	9.1	1.2	4.1	.	87.8	7.68	1.11	83
Revelstoke - Middle	80	25-Jul-12	129.6	1.8	3.9	1.0	7.8	.	127.2	7.76	0.26	120
Revelstoke - Forebay	0 - 20	24-Jul-12	.	.	.	.	.	1.52	.	.	.	.
Revelstoke - Forebay	2	24-Jul-12	105.2	1.8	3.6	1.3	2.8	.	70.1	7.66	1.06	65
Revelstoke - Forebay	5	24-Jul-12	104.0	1.4	5.6	2.0	2.5	.	67.6	7.72	0.87	62
Revelstoke - Forebay	10	24-Jul-12	101.9	1.6	5.2	2.3	2.7	.	60.0	7.59	1.23	57
Revelstoke - Forebay	15	24-Jul-12	103.6	1.3	9.9	3.1	2.2	.	59.2	7.59	2.17	56
Revelstoke - Forebay	20	24-Jul-12	105.6	1.6	6.0	2.8	2.0	.	57.4	7.47	1.80	56
Revelstoke - Forebay	40	24-Jul-12	136.4	1.6	4.4	1.3	2.0	.	72.9	7.57	1.55	68
Revelstoke - Forebay	60	24-Jul-12	158.7	1.5	4.6	1.1	2.0	.	95.7	7.81	1.38	91
Revelstoke - Forebay	80	24-Jul-12	133.3	1.9	4.6	0.9	6.8	.	125.1	7.90	1.03	118
Revelstoke - Forebay	100	24-Jul-12	134.1	1.7	4.1	0.8	4.1	.	125.2	7.95	0.82	119
Revelstoke - Upper	0 - 20	21-Aug-12	.	.	.	.	.	1.35	.	.	.	.
Revelstoke - Upper	2	21-Aug-12	103.2	1.5	4.3	1.3	2.9	.	120.0	8.02	0.78	106
Revelstoke - Upper	5	21-Aug-12	101.2	1.4	5.1	3.4	3.3	.	120.1	8.03	0.28	107
Revelstoke - Upper	10	21-Aug-12	104.2	1.6	4.0	1.6	1.8	.	121.9	8.01	1.18	110
Revelstoke - Upper	15	21-Aug-12	104.8	1.0	4.3	1.2	2.5	.	124.3	8.03	0.73	113
Revelstoke - Upper	20	21-Aug-12	106.3	1.2	5.5	1.7	2.1	.	103.3	7.80	1.35	113
Revelstoke - Upper	40	21-Aug-12	106.3	1.3	1.0	<0.1	2.7	.	124.3	8.02	1.30	113
Revelstoke - Middle	0 - 20	21-Aug-12	.	.	.	.	.	1.28	.	.	.	.
Revelstoke - Middle	2	21-Aug-12	79.5	1.3	3.6	0.6	3.0	.	97.3	8.05	0.00	87
Revelstoke - Middle	5	21-Aug-12	83.5	1.3	4.3	0.6	2.6	.	98.2	8.06	0.70	89
Revelstoke - Middle	10	21-Aug-12	94.4	1.4	3.6	0.9	3.2	.	110.2	8.02	0.65	99
Revelstoke - Middle	15	21-Aug-12	99.4	1.4	4.1	0.7	2.3	.	112.1	7.97	1.00	101
Revelstoke - Middle	20	21-Aug-12	104.6	1.4	3.3	0.9	1.8	.	118.9	8.00	0.73	107
Revelstoke - Middle	40	21-Aug-12	107.2	1.1	4.9	0.8	3.2	.	114.8	7.93	0.63	104
Revelstoke - Middle	60	21-Aug-12	115.3	1.4	2.9	0.6	1.4	.	98.0	7.83	0.25	90
Revelstoke - Middle	80	21-Aug-12	140.1	1.3	3.8	0.5	1.7	.	114.7	7.40	0.35	108
Revelstoke - Forebay	0 - 20	22-Aug-12	.	.	.	.	.	1.49	.	.	.	.
Revelstoke - Forebay	2	22-Aug-12	73.4	1.3	4.2	0.4	1.7	.	81.1	7.96	0.10	75
Revelstoke - Forebay	5	22-Aug-12	85.7	1.4	5.7	0.4	2.1	.	89.6	7.79	0.33	83
Revelstoke - Forebay	10	22-Aug-12	104.0	1.8	3.3	0.5	2.2	.	104.3	7.93	0.05	95
Revelstoke - Forebay	15	22-Aug-12	106.4	1.7	1.9	<0.1	3.4	.	106.8	7.94	0.25	98

Site	Depth	Date	Nitrate/ Nitrite	SRP	TP	TP Turbidity	TDP	SRS	Alkalinity	pH	Turbidity	Cond.
	m		ug/L	ug/L	ug/L	ug/L	ug/L	mgSi/L	mgCaCO3/L		(NTU)	uohms
Revelstoke - Forebay	20	22-Aug-12	108.1	1.7	3.8	0.7	3.8	.	107.5	7.94	0.10	98
Revelstoke - Forebay	40	22-Aug-12	109.0	1.6	2.9	0.7	2.4	.	106.3	7.91	0.00	97
Revelstoke - Forebay	60	22-Aug-12	113.9	1.6	3.5	0.6	2.4	.	92.9	7.81	0.05	86
Revelstoke - Forebay	80	22-Aug-12	131.5	1.8	5.4	0.5	2.4	.	120.9	7.87	0.05	110
Revelstoke - Forebay	110	22-Aug-12	130.2	1.7	5.2	0.5	2.2	.	123.6	7.86	0.08	113
Revelstoke - Upper	0 - 20	10-Sep-12	.	.	.	.	.	1.41	.	.	.	.
Revelstoke - Upper	2	10-Sep-12	111.6	1.8	3.8	0.8	3.7	.	125.9	7.99	0.80	118
Revelstoke - Upper	5	10-Sep-12	111.4	2.0	4.7	1.1	2.1	.	125.9	8.01	0.83	118
Revelstoke - Upper	10	10-Sep-12	116.9	1.9	3.5	0.3	1.9	.	126.4	8.00	1.05	118
Revelstoke - Upper	15	10-Sep-12	117.7	1.8	3.4	0.9	2.4	.	128.3	7.99	1.15	118
Revelstoke - Upper	20	10-Sep-12	117.9	2.3	3.5	0.9	3.2	.	128.8	7.94	0.65	119
Revelstoke - Upper	40	10-Sep-12	149.5	2.1	6.7	0.9	2.8	.	128.7	7.89	1.10	119
Revelstoke - Middle	0 - 20	10-Sep-12	.	.	.	.	.	1.34	.	.	.	.
Revelstoke - Middle	2	10-Sep-12	127.1	2.1	5.5	0.7	3.2	.	106.5	7.96	0.00	99
Revelstoke - Middle	5	10-Sep-12	103.7	2.1	3.8	0.5	3.4	.	106.5	7.98	0.00	99
Revelstoke - Middle	10	10-Sep-12	96.0	1.9	3.9	0.5	4.4	.	107.0	7.99	0.00	100
Revelstoke - Middle	15	10-Sep-12	97.2	2.1	3.8	0.6	3.6	.	110.5	7.98	0.00	103
Revelstoke - Middle	20	10-Sep-12	98.8	1.9	4.3	<0.1	3.0	.	112.5	7.95	0.00	104
Revelstoke - Middle	40	10-Sep-12	107.7	1.8	4.1	0.8	3.1	.	120.4	7.92	0.23	111
Revelstoke - Middle	60	10-Sep-12	109.3	1.8	5.5	1.1	3.2	.	123.7	7.92	0.58	115
Revelstoke - Middle	80	10-Sep-12	122.5	1.7	4.4	0.6	3.4	.	119.2	7.84	0.60	110
Revelstoke - Forebay	0 - 20	11-Sep-12	.	.	.	.	.	1.46	.	.	.	.
Revelstoke - Forebay	2	11-Sep-12	126.9	2.4	3.2	0.9	2.6	.	104.1	8.00	0.00	97
Revelstoke - Forebay	5	11-Sep-12	123.1	2.0	4.0	0.7	3.7	.	109.6	7.91	0.00	103
Revelstoke - Forebay	10	11-Sep-12	119.5	2.2	4.7	0.7	2.5	.	114.2	7.89	0.15	107
Revelstoke - Forebay	15	11-Sep-12	122.9	1.9	3.7	0.8	2.5	.	115.0	7.89	0.00	108
Revelstoke - Forebay	20	11-Sep-12	122.8	2.1	3.2	0.7	2.9	.	115.6	7.89	0.15	108
Revelstoke - Forebay	40	11-Sep-12	123.9	2.3	3.9	0.6	5.1	.	112.5	7.82	0.23	107
Revelstoke - Forebay	60	11-Sep-12	135.7	2.4	4.8	0.6	3.2	.	97.4	7.72	0.13	92
Revelstoke - Forebay	80	11-Sep-12	100.5	2.5	3.7	0.9	3.8	.	120.9	7.78	0.25	114
Revelstoke - Forebay	115	11-Sep-12	98.2	2.5	4.3	1.2	2.7	.	124.3	7.80	0.93	117
Revelstoke - Upper	0 - 20	9-Oct-12	.	.	.	.	.	1.38	.	.	.	.
Revelstoke - Upper	2	9-Oct-12	117.0	1.2	3.4	1.3	1.8	.	122.7	7.94	0.98	107
Revelstoke - Upper	5	9-Oct-12	103.9	0.8	3.9	0.9	1.8	.	122.8	7.97	0.76	111
Revelstoke - Upper	10	9-Oct-12	102.7	0.9	3.2	1.0	1.8	.	123.2	7.95	0.99	111
Revelstoke - Upper	15	9-Oct-12	103.9	0.8	2.9	0.9	1.6	.	123.0	7.94	0.95	112
Revelstoke - Upper	20	9-Oct-12	103.8	0.9	2.5	0.8	1.7	.	123.0	7.93	0.79	112
Revelstoke - Upper	35	9-Oct-12	105.2	0.9	2.8	0.7	2.2	.	122.7	7.93	1.23	112
Revelstoke - Middle	0 - 20	9-Oct-12	.	.	.	.	.	1.31	.	.	.	.
Revelstoke - Middle	2	9-Oct-12	88.5	0.9	2.4	0.5	1.8	.	111.5	7.95	0.25	100
Revelstoke - Middle	5	9-Oct-12	86.1	0.9	3.2	0.7	1.9	.	110.7	7.99	0.28	99
Revelstoke - Middle	10	9-Oct-12	88.8	1.1	4.5	0.5	2.5	.	111.4	8.03	0.34	101
Revelstoke - Middle	15	9-Oct-12	97.5	0.8	3.5	0.6	1.9	.	117.7	7.95	0.46	106
Revelstoke - Middle	20	9-Oct-12	97.3	1.0	2.5	0.6	1.6	.	118.9	7.97	0.72	107
Revelstoke - Middle	40	9-Oct-12	99.7	1.0	3.7	0.8	2.7	.	119.5	7.94	0.74	109
Revelstoke - Middle	60	9-Oct-12	100.0	0.9	3.3	0.9	2.3	.	120.5	7.92	0.56	108
Revelstoke - Middle	75	9-Oct-12	142.7	0.8	3.8	0.7	2.5	.	117.3	7.71	0.97	105
Revelstoke - Forebay	0 - 20	10-Oct-12	.	.	.	.	.	1.36	.	.	.	.
Revelstoke - Forebay	2	10-Oct-12	86.8	0.9	2.9	0.4	2.0	.	110.4	8.00	0.26	100
Revelstoke - Forebay	5	10-Oct-12	88.1	1.0	3.4	0.5	3.2	.	110.6	8.01	0.32	100
Revelstoke - Forebay	10	10-Oct-12	90.2	0.6	5.2	0.4	1.9	.	110.8	7.99	0.24	99
Revelstoke - Forebay	15	10-Oct-12	87.8	1.2	4.0	1.4	2.9	.	110.9	7.96	0.23	100
Revelstoke - Forebay	20	10-Oct-12	101.4	0.9	3.2	0.4	1.7	.	115.7	7.86	0.33	104
Revelstoke - Forebay	40	10-Oct-12	108.2	0.9	3.3	0.5	1.9	.	110.3	7.77	0.65	109
Revelstoke - Forebay	60	10-Oct-12	110.8	1.0	3.0	0.5	3.2	.	118.5	7.78	0.50	107
Revelstoke - Forebay	80	10-Oct-12	141.9	1.1	3.8	0.7	2.0	.	117.5	7.69	0.55	108
Revelstoke - Forebay	115	10-Oct-12	140.5	1.0	3.8	0.9	2.4	.	121.7	7.69	0.56	112

Appendix 5

Primary Productivity
Kinbasket and Revelstoke Reservoirs, 2012

Shannon Harris
Ministry of Environment

PRIMARY PRODUCTIVITY IN KINBASKET AND REVELSTOKE RESERVOIRS, 2012

by

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1 Introduction

It is well established that the creation of a hydroelectric reservoir has significant short term and long terms effects on fish and fish habitats such as but not limited to trophic upsurge and depression, loss of habitat connectivity, loss of fish passage, and modification of natural flow regimes (Baxter, 1985). It is also becoming increasing apparent that reservoir operations can have significant negative effects on productive capacity and thus hydroelectric companies must minimize such effects from operation of their facilities (Canadian Electricity Association, 2001). To this end, a number of complementary monitoring programs were proposed by the consultative committee to examine the effects of reservoir operations on the productive capacity of Kinbasket and Revelstoke Reservoirs. This project is not only a sub-component of the Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring project (CLBMON-3), but it also supports and complements the Kinbasket and Revelstoke Reservoirs Fish Productivity Monitoring project. Given the complexity of the tasks and overall objectives these projects aim to achieve, a collaborative approach integrating expertise from a range of disciplines including hydrology to fish biology must be utilized.

The primary productivity studies discussed in this report examine the size structure of the phytoplankton community in terms of chlorophyll and primary productivity, particularly the relative contribution of three commonly studied fractions: picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm). Our overarching goal is to further understand reservoir dynamics, including identification of key factors that regulate trophic web dynamics within Kinbasket and Revelstoke reservoirs.

2 Methods

2.1 Field Sampling

Primary productivity was measured from June-September on Kinbasket Reservoir at the Forebay station and on Revelstoke Reservoir at the Forebay station and Middle station. Water samples for alkalinity, chlorophyll and primary productivity were collected between 08:00 and 09:00 using Niskin water samplers. Chlorophyll and primary productivity samples were collected from the surface to the 1% light depth as determined with a Licor LI-185A quantum sensor and meter; the profile was recorded for determination of the light attenuation coefficient. Water transparency was measured near 12:00 with a standard 20 cm Secchi disk. Alkalinity samples were collected from the surface and the deepest sample depth. All sample bottles were rinsed three times with lake water before filling with the sample. Alkalinity and chlorophyll samples were stored in a cooler until arrival at the lab that same day.

For primary productivity, two light and one dark 300 ml acid-cleaned BOD bottles were used and 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 suspended *in situ* for 3-4 hours, generally between 09:00 and 14:00. At the end of the incubation period, BOD bottles were stored in a dark box until the incubations were terminated by filtration in the lab. 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).

Table 1 provides field and incubation information for the 2012 study.

Table 1. Field observations and incubation (Inc.) information for the 2012 primary productivity study. KB=Kinbasket-Forebay, RM=Revelstoke-Middle (also called Downie), RF=Revelstoke-Forebay, AC=attenuation coefficient calculated from vertical profiles of photosynthetically active radiation.

Date	**Stn**	**Weather**	**AC** (cm^{-1})	**Inc Start** (hh:mm)	**Inc End** (hh:mm)	**Total Inc Time** (hh.mm)	**Inc Depths** (m)
20 June 2012	KB	partly sunny	0.32	09:06	13:06	4.0	0,1,2,5,10,13
26 July 2012	KB	sunny	0.39	09:42	12:05	2.38	0,1,2,5,10,12
23 Aug 2012	KB	sunny	0.34	09:26	12:26	4	0,1,2,5,10,15
18 Sept 2012	KB	sunny	0.28	09:04	12:38	3.57	0,1,2,5,10,15,20
21 June 2012	RM	sunny	0.40	08:59	13:24	4.42	0,1,2,5,10
25 July 2012	RM	sunny	0.60	09:12	13:12	4.0	0,1,2,5,10
21 Aug 2012	RM	overcast	0.39	08:57	12:57	4.0	0,1,2,5,10,12
19 Sept 2012	RM	sunny	0.28	08:50	12:22	3.53	0,1,2,5,10,15,20
19 June 2012	RF	overcast	0.40	10:10	14:10	4.0	0,1,2,5,10,13
24 July 2012	RF	overcast	0.60	09:04	13:04	4.0	0,1,2,5,10
22 Aug 2012	RF	fog with sun	0.34	08:39	12:40	4.0	0,1,2,5,10,15
20 Sept 2012	RF	sunny	0.25	08:54	12:29	3.58	0,1,2,5,10,15,20

2.2 Laboratory Analyses

Total alkalinity was determined with a Beckman 44 pH meter and electrode 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. Water samples (0.2-1 L) were filtered 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. Chl *a* was extracted from the sample in 5 mL of 90% acetone and refrigerated 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 and vertical integration of all depths according to procedures of Ichimura *et al*. (1980) are provided in Appendix A. The average phytoplankton biomass of the euphotic zone was determined by calculating the mean of all sampling depths.

For primary productivity, one hundred ml from each BOD bottle was filtered through each of a 0.2, 2.0 and 20.0 μm 47-mm diameter polycarbonate filter using <100 mm Hg vacuum differential (Joint and Pomroy, 1983). Each filter was placed in a 7 mLl scintillation vial and stored in the dark until processing at the UBC lab. 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 the current study with the data collected in 2008 due to lack of a clear separation between nanoplankton and microplankton. Results from the 2012 study are comparable to those collected in 2009-2011 and 2002 (Stockner and Korman 2002).

At the UBC lab, 100 μL of 0.5 N HCl were added to each scintillation vial in the fumehood to eliminate unincorporated inorganic $NaH^{14}CO_3$. The scintillation vials were left uncapped in the fumehood until the filters were dry (approximately 48 h), after which 5 ml of Scintisafe® scintillation fluor was added to each vial. The vials were stored in the dark for >24 hours before the samples were counted using a Beckman® Model LS 6000IC 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.

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. 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 period to the solar radiation of the incubation day. Raw data are provided in Appendix A.

3 Results

Photosynthetically active radiation (PAR), defined as the radiation in the 400-700 nm waveband, was consistently high throughout the season at Kinbasket Forebay. During June and July, PAR was >1300 μmol/m^2/s and during August and September PAR was >800 μmol/m^2/s (Figure 1). Similarly, PAR was reasonably high at Revelstoke with values of >1000 μmol/m^2/s in all months with the exception of moderate values of ~500 μmol/m^2/s in August. PAR was variable at Revelstoke Forebay with a low of <100 μmol/m^2/s in July up to a high of ~1100 in August (Figure 1). Overall, the mean euphotic zone depth was 15.0 m in Kinbasket Forebay, 12.8 m at Revelstoke Forebay and 11.5 m at the Revelstoke Middle station (Figure 1).

Trends in the attenuation coefficient, a measure of the transparency, have been consistent since 2009; on average, the seasonal mean attenuation coefficient was 0.33 cm^{-1} (about 67% transmission m^{-1}) at Kinbasket Forebay, followed by 0.40 cm^{-1} (about 60% transmission m^{-1}) at Revelstoke Forebay and highest at Revelstoke Middle at 0.42 cm^{-1} (Table 1). In 2012, light transmission was generally highest in June and September and was the lowest in July at all three stations. It is important to note that in previous studies, seasonal variability has been low in Kinbasket and Revelstoke where transmission generally varied by less than 10% over the June-September period. This was also true for Kinbasket in 2012 where transmission varied by 5% over the four month period; in Revelstoke, however, transmission varied by 16% at the Middle station and 18% at the Forebay station, which has not previously been observed.

Secchi disk depths were generally higher in Kinbasket than in Revelstoke. In 2012, the mean Secchi depth in Kinbasket was 6.2 m followed by Revelstoke Forebay at 5.3 m and Revelstoke Middle at 4.1 m. In general, Secchi depths increased as the season progressed reaching maximum depth in September, as observed in Kinbasket (Figure 2). In Revelstoke, Secchi depths decreased slightly in July and remained relatively shallow well into September at the Middle station, while the Forebay station experienced the expected increase from August to September (Figure 2).

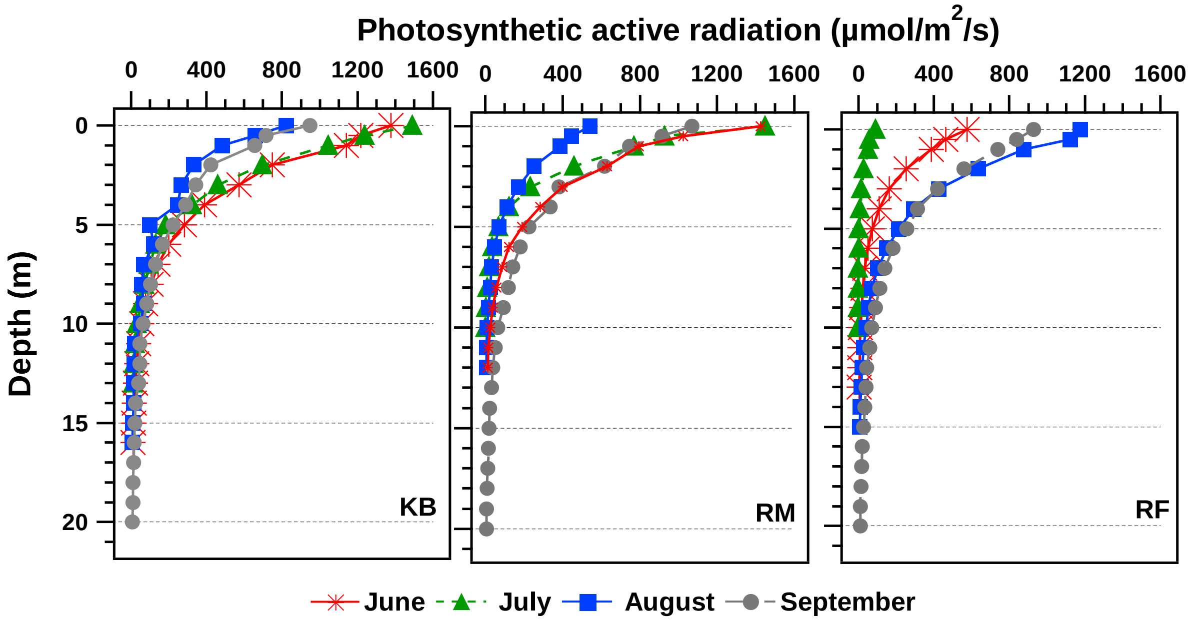

Figure 1. Photosynthetic active radiation (µmol/m^2/s) at Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2012. PAR measurements recorded to the depth of 1% of surface light.

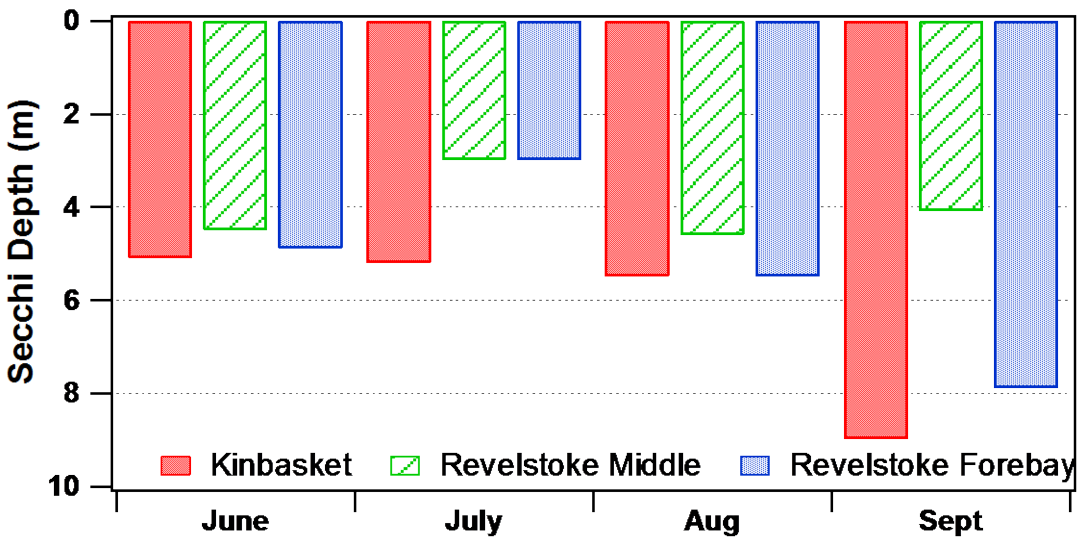

Figure 2. Secchi disk depths (m) in Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2012.

Vertical profiles of Chl *a* concentration were low and on average were less than 2 mg/m^3 at all stations and depths throughout the sampling season (Figure 3). At Kinbasket Reservoir, Chl a concentrations generally were between 1-2 mg/m^3 while at Revelstoke Middle and Forebay the concentrations were generally <1 mg/m^3 with the exception of higher concentrations found in August at both stations. This is similar to the concentration of ~1 mg/m^3 commonly observed among pristine arctic and alpine oligotrophic lakes (Wetzel 2001). Subsurface chlorophyll maximums were typically observed between 5-10 m at all stations in most months (Figure 3). While seasonal variation was relatively static, small changes were observed. Phytoplankton biomass was generally low in June, peaking mid-season to ~2 mg/m^3 in August at Revelstoke Middle and Revelstoke Forebay. In Kinbasket, phytoplankton dynamics showed a mid-season low in August (concentrations generally <1 mg/m^3) and a seasonal peak later in the growing season during September. Seasonal mean Chl *a* was 1.37 mg/m^3 in Kinbasket, 1.14 mg/m^3 at Revelstoke Forebay and 0.94 mg/m^3 at Revelstoke Middle which are characteristic of ultra-oligotrophic systems (Wetzel 2001).

As measured in earlier years (Harris 2009, 2010, 2011), depth integrated phytoplankton biomass was higher in Kinbasket than in Revelstoke for all months, and biomass was slightly higher at Revelstoke Forebay than Revelstoke Middle for all months (Figure 4). Despite the spatial heterogeneity, seasonal mean values at all stations were low and less than 25 mg/m^2. Depth integrated biomass values are not available for Kinbasket in June due to a processing error; still, it appears biomass peaked in September at 31.5 mg/m^2 as opposed to in August like at Revelstoke Middle and Forebay where biomass was 21.9 and 25.4 mg/m^2 respectively. The seasonal average biomass was 22.0 mg/m^2 in Kinbasket followed by 16.5 mg/m^2 at Revelstoke Forebay and 13.0 mg/m^2 at Revelstoke Middle (Table 2). The concentrations measured in Kinbasket and Revelstoke were all low compared to those found in fertilized Kootenay Lake where summer concentrations can reach 143.8 mg/m^2 and mean summer concentrations were 90.5 mg/m^2 (Wright 2002, Schindler 2010) but were 2-3 fold higher than concentrations of 7.5 mg/m^2 found in Williston Reservoir (Stockner and Langston 2001).

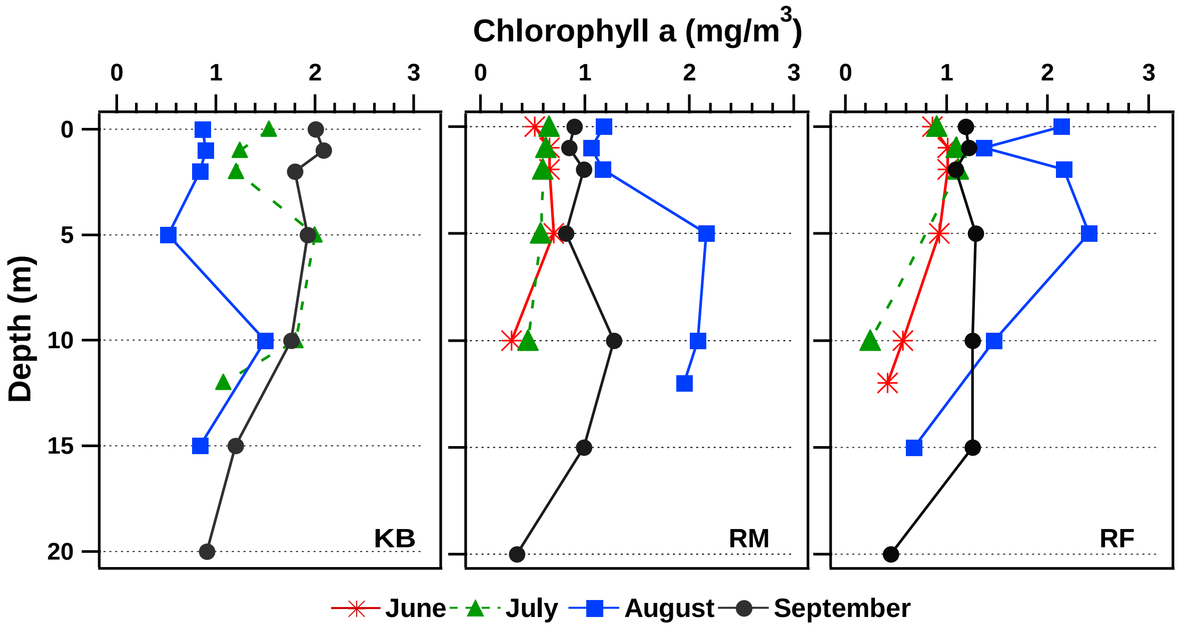

Figure 3. Vertical profiles of chlorophyll *a* (mg/m^3) for Kinbasket Forebay and Revelstoke Middle and Revelstoke Forebay in 2012. Note: no data for June at Kinbasket Reservoir due to a processing error.

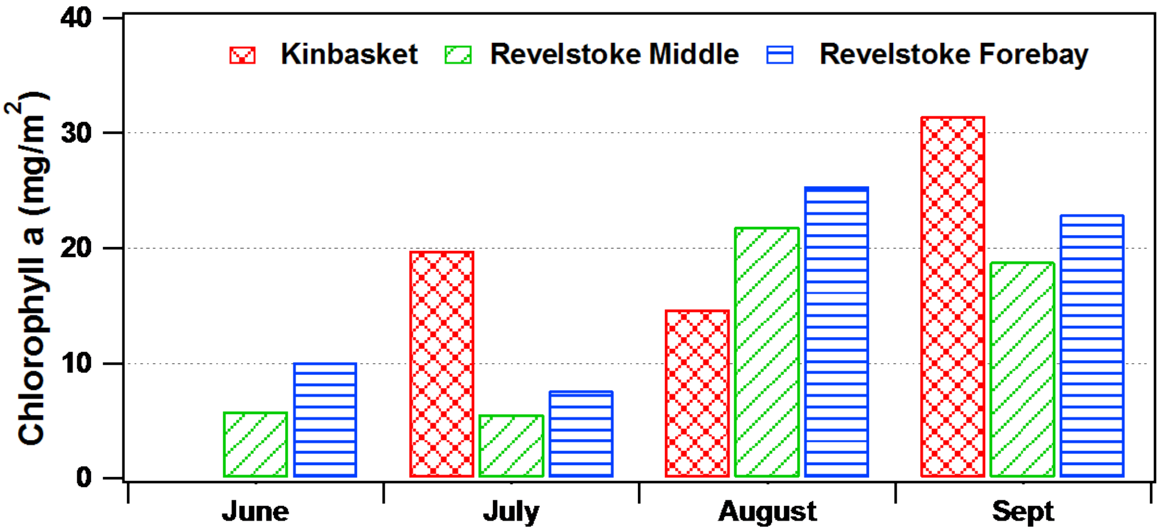

Figure 4. Integrated chlorophyll *a* (mg Chl *a*/m^2) in Kinbasket and Revelstoke in 2012. Note: no data for June at Kinbasket Reservoir due to a processing error.

Table 2. Integrated chlorophyll a for Kinbasket and Revelstoke reservoirs in 2012.

	Chlorophyll *a* (mg Chl *a*/m^2)		
Month	**KB**	**RM**	**RF**
Jun	-	5.8	10.1
Jul	19.8	5.6	7.6
Aug	14.7	21.9	25.4
Sep	31.5	18.8	22.9
Mean	22.0	13.0	16.5

Diversity in size structure of the phytoplankton community is obscured by measurement of total chlorophyll, therefore chlorophyll measurements were size fractionated to gain further insights into the ecosystem dynamics of the two reservoirs. On average, picoplankton sized cells (0.2-2.0 µm) accounted for 44% of the total phytoplankton biomass, followed closely by nanoplankton (2.0-20.0 µm) at 41%; microplankton (>20.0 µm) accounted for 15% of the total phytoplankton biomass (Figure 5). In 2012, picoplankton and nanoplankton sized cells accounted for nearly 86% of the biomass in Kinbasket and Revelstoke which is similar to 2010 and 2011 where 82% and 85% of the biomass was composed of picoplankton and nanoplankton sized phytoplankton, respectively (Bray *et al*. 2013).

The size structure of the phytoplankton community in Kinbasket was relatively dynamic as large variations in the relative proportion of the size classes were observed. For instance picoplankton accounted for 5-25% of the community, nanoplankton contributions ranged from 37-64% and microplankton (which typically account for less than 20% in these reservoirs) ranged from 15% to nearly 30%. Conversely, the size structure was relatively static at Revelstoke Middle and Revelstoke Forebay; phytoplankton <20 µm accounted for 80-90% of the biomass (Figure 5). Nanoplankton, the size class preferred by *Daphnia* sp. (Thompson, 1999), were a large component of the community accounting for 35-46% of the biomass in Revelstoke Middle and 28-45% at Revelstoke Forebay. Microplankton generally accounted for less than 20% of the community, suggesting nutrient limitation or specifically nitrate limitation (Dugdale and Wilkerson, 1998).

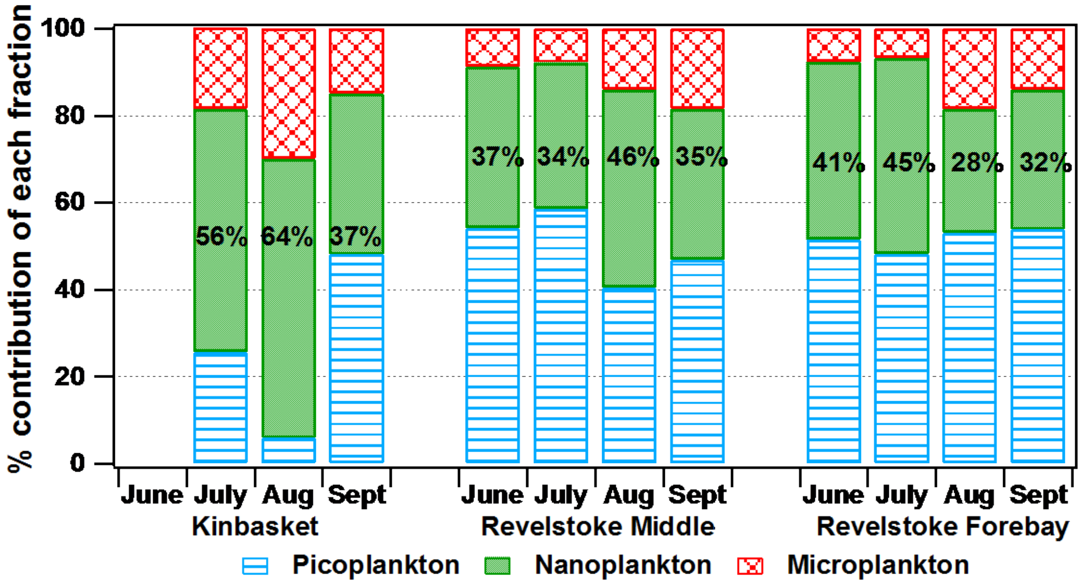

Figure 5. Relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to chlorophyll in Kinbasket and Revelstoke in 2012. Note: no June data at Kinbasket due to processing error.

Total primary production, measured as the radioactive carbon retained on the 0.2 µm filter, was extremely low and never exceeded 50 mg C/m^2/d on any occasion (Figure 6). These rates are clearly indicative of ultraoligotrophic conditions following Wetzel's (2001) trophic classification matrix. Phytoplankton production dynamics were similar at Kinbasket Forebay and Revelstoke Forebay in terms of production rates and observed seasonal patterns. Primary production rates of were on average 30.2 and 29.0 mg C/m^2/d at Kinbasket and Revelstoke Forebay respectively this was approximately double the rates measured at Revelstoke Middle where primary productivity was 15.3 mg C/m^2/d (Table 3). This may suggest biophysical factors controlling phytoplankton growth are more similar between Kinbasket Forebay and Revelstoke Forebay than those at Revelstoke Middle.

In general, the lowest primary production rates were measured in June, followed by intermediary rates in the summer and peak rates in September, which is similar to seasonal Chl *a* patterns (Figure 6). The lowest rate measured in 2012 was 5.6 mg C/m^2/d at Revelstoke Middle in June; this is one of the lowest rates measured to date (Table 3). The highest primary productivity rate was 48.9 mg C/m^2/d measured at Revelstoke Forebay in September (Figure 6), which is similar to previous years (Table 3). Seasonal phytoplankton production dynamics at Kinbasket and Revelstoke Forebay follow a similar trend: increasing from June to July, dropping in August, and increasing again in September. Revelstoke Middle observed a steady increase in production from

June to August and a drop in September. For Kinbasket and Revelstoke Forebay, the seasonal peak in September coincides with a deep euphotic zone (Table 1), deep secchi disk readings, and high light availability suggesting favorable fall growth conditions. At Revelstoke Forebay, it appeared that the drop in primary productivity in September was not due to light availability, as PAR values were extremely favorable for growth (Figure 1). Rather, low transparency as indicated by secchi disk measurements (Figure 2) suggest primary productivity was perhaps limited by localized turbidity at this station.

The pattern of highest production at Kinbasket and lowest production at Revelstoke Middle was also observed in earlier study years (Harris, 2011). Throughout the study period, Kinbasket has consistently had the highest water transparency reflected in low attenuation factors; whereas Revelstoke Reservoir has had the least transparent water suggesting physical factors play an important role in regulating primary productivity in these reservoirs.

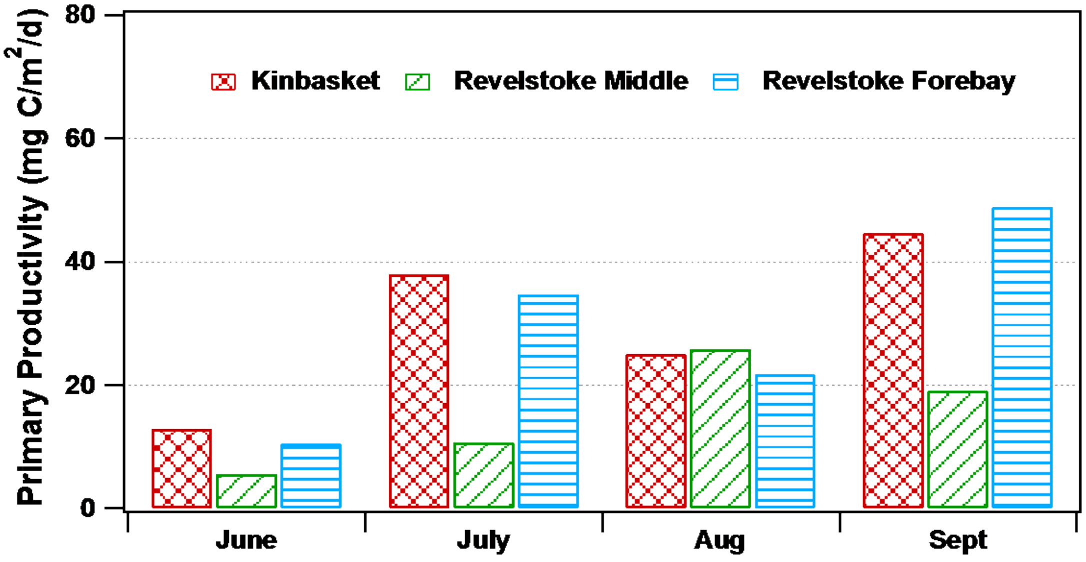

Figure 6. Primary productivity (mg C/m^2/d) in Kinbasket and Revelstoke in 2012.

Table 3. Total daily primary productivity (mg C/m^2/d) in Kinbasket and Revelstoke in 2002 and 2008-2012.

		Primary Productivity (mg C m^{-2} d^{-1})		
Year	**Month**	**Kinbasket Forebay**	**Revelstoke Middle**	**Revelstoke Forebay**
2002	Aug	77.6	-	-
2008	Jul	84.4	33.6	51.8
2008	Aug	42.2	9.6	13.4
2008	Sep	25.3	11.0	18.8
2009	Jun	29.5	11.6	6.9
2009	Jul	11.0	12.1	29.8
2009	Aug	16.5	12.6	11.9
2009	Sep	13.1	10.4	0.5*
2010	Jun	14.8	27.1	32.5
2010	Jul	35.7	24.4	9.9
2010	Aug	43.9	33.8	17.4
2010	Sep	72.9	29.5	33.8
2011	Jun	22.8	24.1	21.6
2011	Jul	41.4	36.3	25.9
2011	Aug	-	25.8	20.5
2011	Sep	-	44.2	44.2
2012	Jun	12.9	5.6	10.6
2012	Jul	38.1	10.7	34.7
2012	Aug	25.0	25.8	21.8
2012	Sep	44.6	19.0	48.9
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
2012	Mean	30.2	15.3	29.0

As observed in earlier years, production in Kinbasket and Revelstoke in 2012 was dominated by phytoplankton less than 20.0 µm in size (i.e. pico- and nanoplankton). Picoplankton and nanoplankton accounted for 69% of the total production in Kinbasket in 2012, down from 83% in 2011 (Figure 7; Harris 2011). At Revelstoke Middle and Revelstoke Forebay, the picoplankton and nanoplankton fractions accounted for 80% of total production which is similar to the relative contribution of these size classes 2011 (Figure 7; Harris 2011). Microplankton were the least productive fraction, accounting for on average 25% of total production across all stations and all dates, which is a 6% increase compared to 2011 (Harris 2011).

In Kinbasket, picoplankton on average was the most productive fraction followed by nanoplankton then microplankton (Figure 7) but the relative contribution of each size class was dynamic throughout the growing season. Early in the season in June and late in the season in September, picoplankton production was relatively high at 55% and 62% respectively, while during mid-summer in July and August, nanoplankton were the dominate producer accounting for 45% and 49% of total production (Figure 7). Microplankton production was also dynamic in Kinbasket accounting for 24% of total production in June, increasing in July to 33% and again in August to 38% of total production. In Revelstoke Middle, the relative contribution of each fraction was relatively static in June, July and August. In September a large increase in production was observed in the nanoplankton fraction which accounted for the majority of primary production (Figure 7). At Revelstoke Forebay, the community structure in June through to August was similar and relatively stable but a large shift to picoplankton production was observed in September.

Earlier reports noted that from 2009-2011 the relative importance of picoplankton production was increasing while the relative contribution of nanoplankton and microplankton was decreasing (Harris, 2011). In 2012, this trend was not observed. The relative contribution of each fraction in 2012 more closely resembled the community structure observed during 2010 (Figure 8); nanoplankton was the most productive fraction on average, followed by picoplankton and microplankton.

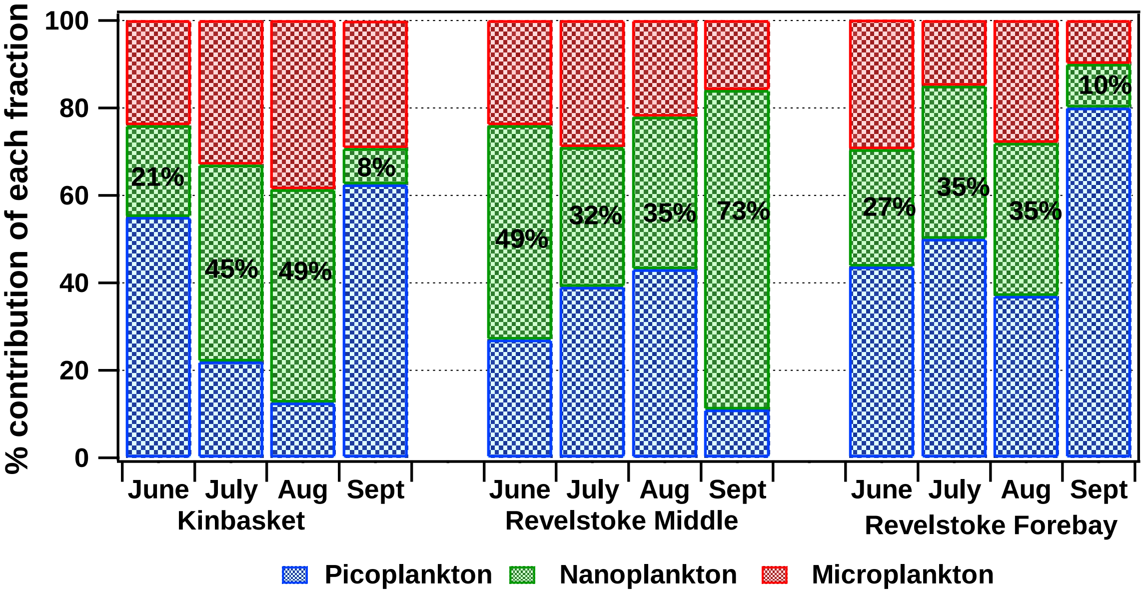

Figure 7. Relative contribution of picoplankton (0.2-2 μm), nanoplankton (2-20 μm), and microplankton (>20 μm) to primary productivity in Kinbasket and Revelstoke in 2012.

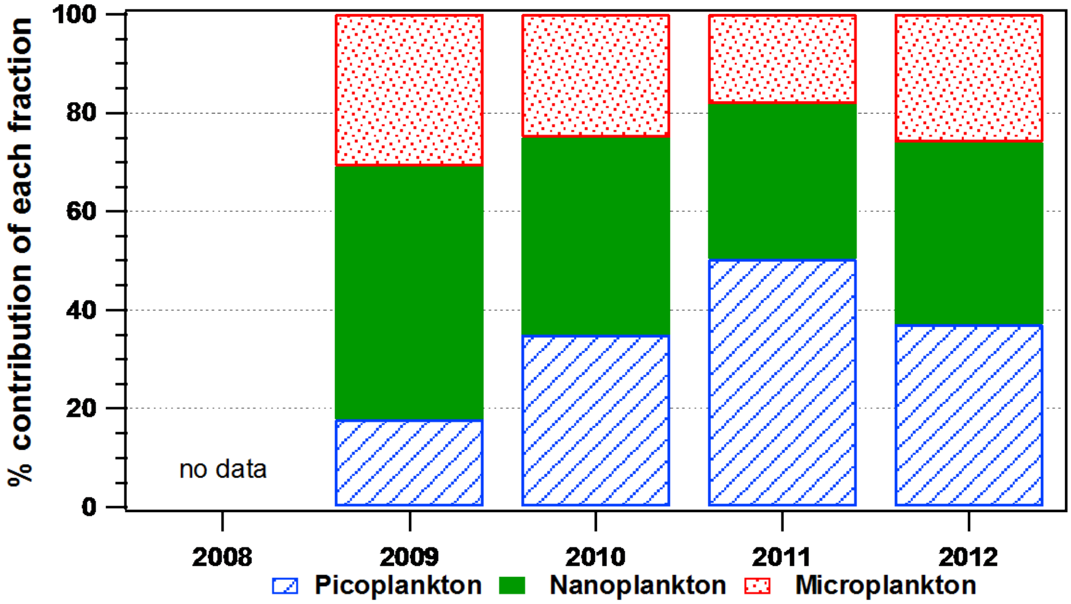

Figure 8. Mean annual contribution of each fraction to primary productivity in Columbia Basin in 2009-2012. Note: Monthly means for Kinbasket and Revelstoke were averaged.

4 Discussion

A key objective of the primary productivity monitoring program is to characterize phytoplankton biomass and *in situ* rates of primary productivity in Kinbasket and Revelstoke Reservoirs. Additionally, this study provides an in-depth examination of the phytoplankton community size structure which will provide insight into likely food web interactions in the two reservoirs, as well as the potential productive capacity.. This was the fourth year of the primary productivity monitoring program and represents the longest time series of primary productivity available for these two Columbia Basin reservoirs.

Kinbasket and Revelstoke Reservoirs share many similar characteristics in terms of the production and phytoplankton community structure. In both reservoirs, mean phytoplankton biomass levels are extremely low (<30 mg/m^2) and primary productivity rates are also low (<50 mg C/m^2/d). Primary productivity rates have been consistently low since first measured in 2002, suggesting the productive capacity of both reservoirs may be limited. The size structure of the phytoplankton community was consistent in both reservoirs, where 86% of the biomass was accounted for by picoplankton and nanoplankton fractions. This finding suggests most of the total primary production is supported by nitrogen regenerated in reduced forms as a result of zooplankton grazing

(Dugdale and Wilkerson 1998). Microplankton, while still a contributor to the plankton community, represents less than 20% of total biomass on average.

Wetzel (2001) uses ranges of primary productivity and related characteristics such as chlorophyll concentrations to classify different trophic categories ranging from ultra-oligotrophic to hyper-eutrophic types. Using this approach, chlorophyll and primary productivity data clearly classify Kinbasket and Revelstoke Reservoirs as ultra-oligotrophic. All measurements to date indicate that productivity in Kinbasket and Revelstoke Reservoirs is low with values similar to many other large ultra-oligotrophic lakes and reservoirs in British Columbia (Table 4).

This study unequivocally defines the ultra-oligotrophic nature of Kinbasket and Revelstoke Reservoirs. 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.

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 Reservoir, Forebay	22.0	30.2	Current study
Revelstoke Reservoir, Middle	13.0	15.3	Current study
Revelstoke Reservoir, Forebay	16.5	29.0	Current study
Elsie Reservoir	8.1	13.9	Perrin and Harris 2005
Williston Reservoir, embayment	10.3	32.6	Harris *et al*. 2005
Williston Reservoir, pelagic	7.6	34.3	Stockner and Langston 2001
Slocan Lake	26.3	59.3	Harris 2002
Okanagan Lake	27.2	72.2	Andrusak *et al*. 2004
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	Schindler *et al*. 2010

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Appendix A. Raw chlorophyll and primary productivity data for 2012.

Station	Date	Fraction (μm)	Depth (m)	Chl (mg/m^3)	PP mg/C/m^3/hr	PP mgC/m^3/day
KB	20 June 2012	0.2	0	-	0.16	0.87
KB	20 June 2012	0.2	1	-	0.13	0.71
KB	20 June 2012	0.2	2	-	0.22	1.15
KB	20 June 2012	0.2	5	-	0.17	0.89
KB	20 June 2012	0.2	10	-	0.20	1.08
KB	20 June 2012	0.2	15	-	0.20	1.09
KB	20 June 2012	2	0	-	0.07	0.37
KB	20 June 2012	2	1	-	0.09	0.50
KB	20 June 2012	2	2	-	0.11	0.59
KB	20 June 2012	2	5	-	0.09	0.46
KB	20 June 2012	2	10	-	0.08	0.42
KB	20 June 2012	2	15	-	0.05	0.29
KB	20 June 2012	20	0	-	0.03	0.18
KB	20 June 2012	20	1	-	0.03	0.18
KB	20 June 2012	20	2	-	0.05	0.26
KB	20 June 2012	20	5	-	0.05	0.29
KB	20 June 2012	20	10	0.03	0.05	0.24
KB	20 June 2012	20	15	0.05	0.02	0.11
KB	26 July 2012	0.2	0	1.54	0.11	2.66
KB	26 July 2012	0.2	1	1.25	0.11	3.72
KB	26 July 2012	0.2	2	1.21	0.11	3.71
KB	26 July 2012	0.2	5	2.00	0.11	4.53
KB	26 July 2012	0.2	10	1.81	0.11	1.96
KB	26 July 2012	0.2	12	1.08	0.11	0.60
KB	26 July 2012	2	0	0.77	0.34	1.93
KB	26 July 2012	2	1	0.96	0.49	2.81
KB	26 July 2012	2	2	0.94	0.52	2.94
KB	26 July 2012	2	5	1.34	0.63	3.58
KB	26 July 2012	2	10	1.37	0.26	1.46
KB	26 July 2012	2	12	1.09	0.11	0.61
KB	26 July 2012	20	0	0.22	0.15	0.87
KB	26 July 2012	20	1	0.21	0.23	1.32
KB	26 July 2012	20	2	0.22	0.17	0.99
KB	26 July 2012	20	5	0.28	0.29	1.65
KB	26 July 2012	20	10	0.29	0.09	0.54
KB	26 July 2012	20	12	0.35	0.05	0.30
KB	23 Aug 2012	0.2	0	0.87	0.10	1.01
KB	23 Aug 2012	0.2	1	0.90	0.22	2.34
KB	23 Aug 2012	0.2	2	0.84	0.25	2.57
KB	23 Aug 2012	0.2	5	0.52	0.29	3.00
KB	23 Aug 2012	0.2	10	1.50	0.06	0.63
KB	23 Aug 2012	0.2	15	0.84	0.07	0.75
KB	23 Aug 2012	2	0	0.93	0.19	2.03

KB	23 Aug 2012	2	1	0.89	0.27	2.77
KB	23 Aug 2012	2	2	0.87	0.24	2.49
KB	23 Aug 2012	2	5	0.80	0.20	2.12
KB	23 Aug 2012	2	10	1.12	0.08	0.79
KB	23 Aug 2012	2	15	0.77	0.03	0.28
KB	23 Aug 2012	20	0	0.30	0.09	0.98
KB	23 Aug 2012	20	1	0.27	0.06	0.62
KB	23 Aug 2012	20	2	0.28	0.11	1.17
KB	23 Aug 2012	20	5	0.29	0.09	0.93
KB	23 Aug 2012	20	10	0.34	0.04	0.37
KB	23 Aug 2012	20	15	0.22	0.02	0.25
KB	18 Sept 2012	0.2	0	2.01	0.54	3.79
KB	18 Sept 2012	0.2	1	2.09	0.60	4.21
KB	18 Sept 2012	0.2	2	1.80	0.93	6.45
KB	18 Sept 2012	0.2	5	1.93	0.27	1.88
KB	18 Sept 2012	0.2	10	1.76	0.45	3.14
KB	18 Sept 2012	0.2	15	1.20	0.08	0.56
KB	18 Sept 2012	2	0	0.85	0.11	0.76
KB	18 Sept 2012	2	1	0.95	0.19	1.33
KB	18 Sept 2012	2	2	0.90	0.18	1.26
KB	18 Sept 2012	2	5	0.76	0.18	1.22
KB	18 Sept 2012	2	10	0.89	0.15	1.04
KB	18 Sept 2012	2	15	0.79	0.06	0.39
KB	18 Sept 2012	20	0	0.24	0.03	0.22
KB	18 Sept 2012	20	1	0.24	0.14	0.95
KB	18 Sept 2012	20	2	0.24	0.11	0.75
KB	18 Sept 2012	20	5	0.22	0.12	0.83
KB	18 Sept 2012	20	10	0.24	0.18	1.26
KB	18 Sept 2012	20	15	0.22	0.03	0.18
RM	21 June 2012	0.2	0	0.52	0.10	0.44
RM	23 Aug 2012	0.2	1	0.66	0.16	0.67
RM	23 Aug 2012	0.2	2	0.66	0.19	0.80
RM	23 Aug 2012	0.2	5	0.70	0.16	0.68
RM	23 Aug 2012	0.2	10	0.30	0.04	0.16
RM	23 Aug 2012	2	0	0.22	0.07	0.29
RM	23 Aug 2012	2	1	0.23	0.11	0.48
RM	23 Aug 2012	2	2	0.27	0.13	0.56
RM	23 Aug 2012	2	5	0.29	0.13	0.53
RM	23 Aug 2012	2	10	0.21	0.02	0.10
RM	23 Aug 2012	20	0	0.04	0.02	0.10
RM	23 Aug 2012	20	1	0.05	0.03	0.12
RM	23 Aug 2012	20	2	0.05	0.04	0.18
RM	23 Aug 2012	20	5	0.05	0.04	0.18
RM	23 Aug 2012	20	10	0.04	0.01	0.05
RM	25 July 2012	0.2	0	0.66	0.20	1.29
RM	25 July 2012	0.2	1	0.63	0.22	1.45
RM	25 July 2012	0.2	2	0.60	0.24	1.57

RM	25 July 2012	0.2	5	0.58	0.20	1.29
RM	25 July 2012	0.2	10	0.46	0.02	0.14
RM	25 July 2012	2	0	0.33	0.11	0.71
RM	25 July 2012	2	1	0.27	0.18	1.14
RM	25 July 2012	2	2	0.25	0.17	1.09
RM	25 July 2012	2	5	0.24	0.11	0.68
RM	25 July 2012	2	10	0.14	0.004	0.03
RM	25 July 2012	20	0	0.05	0.05	0.35
RM	25 July 2012	20	1	0.04	0.08	0.52
RM	25 July 2012	20	2	0.05	0.09	0.57
RM	25 July 2012	20	5	0.07	0.05	0.31
RM	25 July 2012	20	10	0.03	0.001	0.01
RM	21 Aug 2012	0.2	0	1.18	0.10	0.84
RM	21 Aug 2012	0.2	1	1.06	0.31	0.84
RM	21 Aug 2012	0.2	2	1.17	0.38	0.84
RM	21 Aug 2012	0.2	5	2.16	0.26	0.84
RM	21 Aug 2012	0.2	10	2.08	0.19	0.84
RM	21 Aug 2012	0.2	12	1.95	0.10	0.84
RM	21 Aug 2012	2	0	0.57	0.20	1.79
RM	21 Aug 2012	2	1	0.65	0.18	1.57
RM	21 Aug 2012	2	2	0.65	0.17	1.47
RM	21 Aug 2012	2	5	1.28	0.22	1.94
RM	21 Aug 2012	2	10	1.43	0.05	0.44
RM	21 Aug 2012	2	12	1.25	0.02	0.16
RM	21 Aug 2012	20	0	0.15	0.05	0.43
RM	21 Aug 2012	20	1	0.15	0.07	0.64
RM	21 Aug 2012	20	2	0.17	0.08	0.68
RM	21 Aug 2012	20	5	0.35	0.08	0.72
RM	21 Aug 2012	20	10	0.27	0.02	0.17
RM	21 Aug 2012	20	12	0.27	0.01	0.06
RM	19 Sept 2012	0.2	0	0.90	0.42	2.95
RM	19 Sept 2012	0.2	1	0.85	0.23	1.59
RM	19 Sept 2012	0.2	2	0.99	0.26	1.81
RM	19 Sept 2012	0.2	5	0.82	0.10	0.70
RM	19 Sept 2012	0.2	10	1.28	0.19	1.29
RM	19 Sept 2012	0.2	15	0.99	0.20	1.41
RM	19 Sept 2012	0.2	20	0.35	-	-
RM	19 Sept 2012	2	0	0.42	0.16	1.08
RM	19 Sept 2012	2	1	0.36	0.15	1.02
RM	19 Sept 2012	2	2	0.46	0.19	1.35
RM	19 Sept 2012	2	5	0.43	0.23	1.61
RM	19 Sept 2012	2	10	0.58	0.14	1.00
RM	19 Sept 2012	2	15	0.44	0.09	0.63
RM	19 Sept 2012	2	20	0.33	0.07	0.51
RM	19 Sept 2012	20	0	0.17	0.21	1.43
RM	19 Sept 2012	20	1	0.20	0.09	0.60
RM	19 Sept 2012	20	2	0.20	0.12	0.84

RM	19 Sept 2012	20	5	0.19	0.07	0.50
RM	19 Sept 2012	20	10	0.12	-	-
RM	19 Sept 2011	20	15	0.06	-	-
RM	19 Sept 2012	20	20	0.10	-	-
RF	19 June 2012	0.2	0	0.86	0.17	1.12
RF	19 June 2012	0.2	1	1.01	0.14	0.93
RF	19 June 2012	0.2	2	1.01	0.16	1.06
RF	19 June 2012	0.2	5	0.93	0.21	1.37
RF	19 June 2012	0.2	10	0.57	0.05	0.31
RF	19 June 2012	0.2	13	0.42	0.02	0.14
RF	19 June 2012	2	0	0.41	0.10	0.65
RF	19 June 2012	2	1	0.45	0.09	0.58
RF	19 June 2012	2	2	0.39	0.13	0.83
RF	19 June 2012	2	5	0.45	0.10	0.69
RF	19 June 2012	2	10	0.32	0.02	0.14
RF	19 June 2012	2	13	0.23	0.01	0.05
RF	19 June 2012	20	0	0.06	0.04	0.29
RF	19 June 2012	20	1	0.06	0.04	0.25
RF	19 June 2012	20	2	0.08	0.07	0.43
RF	19 June 2012	20	5	0.08	0.06	0.39
RF	19 June 2012	20	10	0.05	0.01	0.07
RF	19 June 2012	20	13	0.04	0.00	0.00
RF	24 July 2012	0.2	0	0.91	0.27	6.97
RF	24 July 2012	0.2	1	1.10	0.34	9.01
RF	24 July 2012	0.2	2	1.12	0.28	7.24
RF	24 July 2012	0.2	5		0.06	1.63
RF	24 July 2012	0.2	10	0.25	0.02	0.48
RF	24 July 2012	2	0	0.42	0.17	4.36
RF	24 July 2012	2	1	0.49	0.19	5.07
RF	24 July 2012	2	2	0.45	0.15	3.98
RF	24 July 2012	2	5	0.37	0.02	0.49
RF	24 July 2012	2	10	0.19	0.003	0.09
RF	24 July 2012	20	0	0.07	0.06	1.50
RF	24 July 2012	20	1	0.07	0.06	1.54
RF	24 July 2012	20	2	0.07	0.04	1.01
RF	24 July 2012	20	5	0.03	0.01	0.15
RF	24 July 2012	20	10	0.02	0.004	0.11
RF	22 Aug 2012	0.2	0	2.14	0.27	1.49
RF	22 Aug 2012	0.2	1	1.37	0.19	1.03
RF	22 Aug 2012	0.2	2	2.16	0.38	2.05
RF	22 Aug 2012	0.2	5	2.41	0.42	2.30
RF	22 Aug 2012	0.2	10	1.47	0.17	0.94
RF	22 Aug 2012	0.2	15	0.68	0.15	0.79
RF	22 Aug 2012	2	0	0.74	0.21	1.17
RF	22 Aug 2012	2	1	0.68	0.31	1.67
RF	22 Aug 2012	2	2	0.87	0.27	1.44
RF	22 Aug 2012	2	5	1.13	0.28	1.51

RF	22 Aug 2012	2	10	0.81	0.08	0.44
RF	22 Aug 2012	2	15	0.38	0.02	0.11
RF	22 Aug 2012	20	0	0.28	0.12	0.63
RF	22 Aug 2012	20	1	0.25	0.15	0.79
RF	22 Aug 2012	20	2	0.26	0.12	0.64
RF	22 Aug 2012	20	5	0.47	0.12	0.64
RF	22 Aug 2012	20	10	0.37	0.04	0.21
RF	22 Aug 2012	20	15	0.16	0.01	0.03
RF	20 Sept 2012	0.2	0	1.19	-	-
RF	20 Sept 2012	0.2	1	1.22	0.91	6.27
RF	20 Sept 2012	0.2	2	1.09	0.34	2.31
RF	20 Sept 2012	0.2	5	1.29	0.34	2.32
RF	20 Sept 2012	0.2	10	1.26	0.23	1.57
RF	20 Sept 2012	0.2	15	1.26	0.37	2.55
RF	20 Sept 2012	0.2	20	0.45	0.49	3.35
RF	20 Sept 2012	2	0	0.52	0.06	0.42
RF	20 Sept 2012	2	1	0.49	0.14	0.94
RF	20 Sept 2012	2	2	0.56	0.13	0.88
RF	20 Sept 2012	2	5	0.46	0.09	0.65
RF	20 Sept 2012	2	10	0.57	0.06	0.39
RF	20 Sept 2012	2	15	0.55	0.06	0.43
RF	20 Sept 2012	2	20	0.29	0.01	0.05
RF	20 Sept 2012	20	0	0.12	0.03	0.23
RF	20 Sept 2012	20	1	0.15	0.03	0.18
RF	20 Sept 2012	20	2	0.14	0.08	0.52
RF	20 Sept 2012	20	5	0.15	0.08	0.54
RF	20 Sept 2012	20	10	0.19	0.04	0.24
RF	20 Sept 2012	20	15	0.20	0.03	0.23
RF	20 Sept 2012	20	17	0.09	-	-

Appendix 6

Phytoplankton
Kinbasket and Revelstoke Reservoirs, 2012

Darren Brandt
Advanced Eco-Solutions

PHYTOPLANKTON POPULATIONS IN KINBASKET AND REVELSTOKE RESERVOIRS, UPPER COLUMBIA BASIN, BRITISH COLUMBIA – 2012

PREPARED FOR:

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March 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 through 2012. 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 June, July, August, and October as well as a set of samples collected in November from the Canoe stations. Samples from three stations in Revelstoke Reservoir (Revelstoke-Forebay, Revelstoke-Mid and Revelstoke-Upper) were taken monthly from June to October in 2012 as well as a set of phytoplankton samples in May from the Forebay station. 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 through 2012 is compatible with the previous year's sampling methodology; however, the taxa richness could be higher in the composited samples from 2010 through 2012 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 of 3.5 mm in length 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.

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 – 2012

A complete list of the taxa identified in Kinbasket and Revelstoke Reservoirs in 2012 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), with diatoms (bacillariophytes), greens (chlorophytes) and dinoflagellates (dinophytes) considerably less abundant (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 June (11,269 cells/mL) (Figure 3). The Forebay Station had the lowest phytoplankton density at 1,496 cells/mL during October. On a seasonal average the Wood, Columbia and Canoe stations had similar mean phytoplankton densities. The Wood and Columbia stations had the highest seasonal mean biomass of the 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 2012

Station	Group	June	July	August	Sept	Oct	Nov	Seasonal Average
Kin-Canoe	Blue-greens	3,537	4,415	1,382	1,276	699	1,504	2,136
	Coccoid Greens, Desmids, etc.	146	41	106	236	220	187	156
	Diatoms	244	57	81	98	130	16	104
	Dinoflagellates	8	0	8	33	16	0	11
	Flagellates	3,520	4,008	1,545	1,537	902	1,293	2,134
	Sum of All Groups	**7,456**	**8,521**	**3,122**	**3,179**	**1,968**	**3,000**	**4,541**
Kin-Columbia	Blue-greens	2,415	4,203	1,504	1,024	748		1,979
	Coccoid Greens, Desmids, etc.	8	350	81	65	122		125
	Diatoms	24	171	106	309	81		138
	Dinoflagellates	8	16	8	24	0		11
	Flagellates	2,894	4,594	1,545	1,065	1,081		2,236
	Sum of All Groups	**5,350**	**9,334**	**3,244**	**2,488**	**2,033**		**4,490**
Kin-Forebay	Blue-greens	3,821	1,886	2,073	707	650		1,828
	Coccoid Greens, Desmids, etc.	252	98	73	65	24		102
	Diatoms	220	114	203	65	41		128
	Dinoflagellates	16	8	0	16	8		10
	Flagellates	2,935	2,155	1,894	1,016	772		1,755
	Sum of All Groups	**7,244**	**4,260**	**4,244**	**1,870**	**1,496**		**3,823**
Kin-Wood	Blue-greens	5,203	2,130	1,415	829	610		2,037
	Coccoid Greens, Desmids, etc.	154	81	203	398	49		177
	Diatoms	211	309	130	81	73		161
	Dinoflagellates	8	187	16	0	0		42
	Flagellates	5,691	1,886	1,236	902	805		2,104
	Sum of All Groups	**11,269**	**4,594**	**3,000**	**2,211**	**1,537**		**4,522**

Table 2 Kinbasket Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2012

Station	Group	June	July	August	Sept	Oct	Nov	Seasonal Average
Kin-Canoe	Blue-greens	0.0137	0.0274	0.0115	0.0072	0.0108	0.0111	0.0136
	Coccoid Greens, Desmids, etc.	0.0098	0.0033	0.0070	0.0130	0.0397	0.0192	0.0153
	Diatoms	0.0215	0.0115	0.0209	0.0186	0.0260	0.0011	0.0166
	Dinoflagellates	0.0016	0.0000	0.0016	0.0098	0.0065	0.0000	0.0033
	Flagellates	0.0452	0.0435	0.0288	0.0393	0.0261	0.0261	0.0348
	Sum of All Groups	**0.0917**	**0.0857**	**0.0698**	**0.0878**	**0.1091**	**0.0575**	**0.0836**
Kin-Columbia	Blue-greens	0.0116	0.0248	0.0159	0.0140	0.0109		0.0154
	Coccoid Greens, Desmids, etc.	0.0004	0.0243	0.0457	0.0431	0.0076		0.0242
	Diatoms	0.0018	0.0192	0.0312	0.1041	0.0454		0.0404
	Dinoflagellates	0.0033	0.0065	0.0065	0.0098	0.0000		0.0052
	Flagellates	0.0262	0.0763	0.0257	0.0277	0.0336		0.0379
	Sum of All Groups	**0.0432**	**0.1511**	**0.1250**	**0.1987**	**0.0976**		**0.1231**
Kin-Forebay	Blue-greens	0.0205	0.0332	0.0329	0.0087	0.0065		0.0204
	Coccoid Greens, Desmids, etc.	0.0162	0.0100	0.0054	0.0033	0.0016		0.0073
	Diatoms	0.0239	0.0122	0.0576	0.0267	0.0027		0.0246
	Dinoflagellates	0.0065	0.0016	0.0000	0.0098	0.0033		0.0042
	Flagellates	0.0488	0.0441	0.0425	0.0306	0.0218		0.0376
	Sum of All Groups	**0.1160**	**0.1011**	**0.1385**	**0.0791**	**0.0359**		**0.0941**
Kin-Wood	Blue-greens	0.0343	0.0242	0.0223	0.0211	0.0083		0.0220
	Coccoid Greens, Desmids, etc.	0.0215	0.0077	0.0173	0.0203	0.0088		0.0151
	Diatoms	0.0192	0.0416	0.0248	0.0281	0.0349		0.0297
	Dinoflagellates	0.0033	0.1496	0.0065	0.0000	0.0000		0.0319
	Flagellates	0.0611	0.0244	0.0252	0.0229	0.0245		0.0316
	Sum of All Groups	**0.1394**	**0.2475**	**0.0961**	**0.0923**	**0.0765**		**0.1304**

Figure 1 **Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between May - October 2012 derived from the 2, 5, 10 meter laboratory composites**

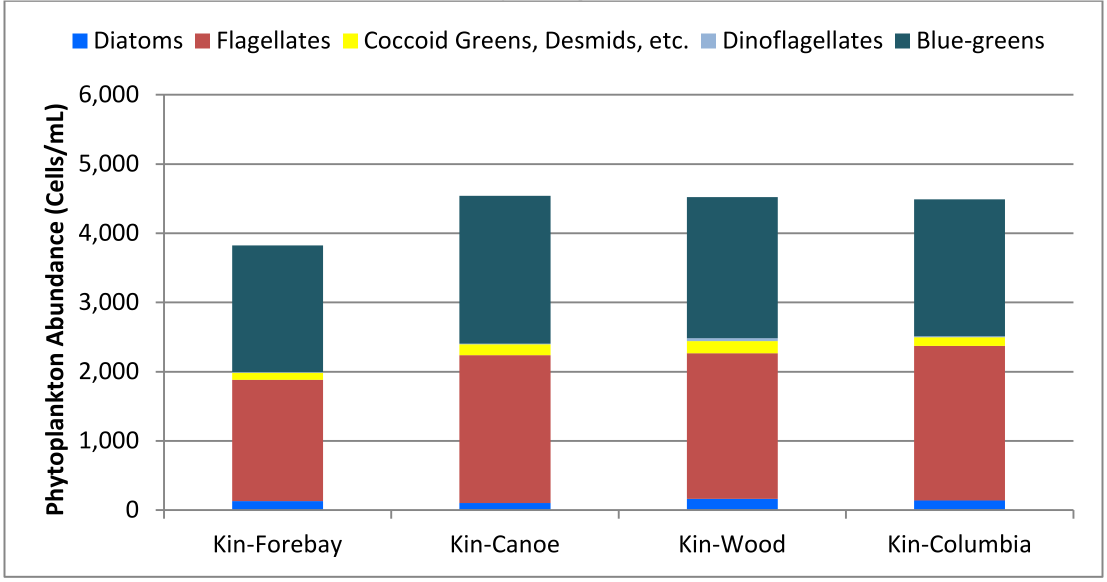


Figure 2 **Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between May - October 2012 derived from the 2, 5, and 10 meter laboratory composites**

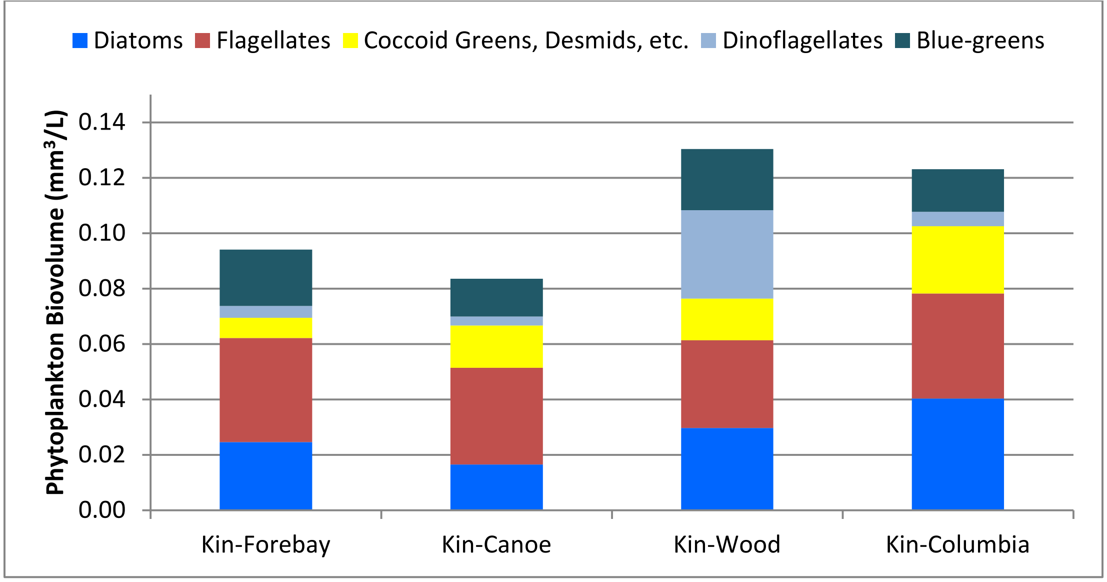


Figure 3 Kinbasket mean epilimnetic phytoplankton density by month

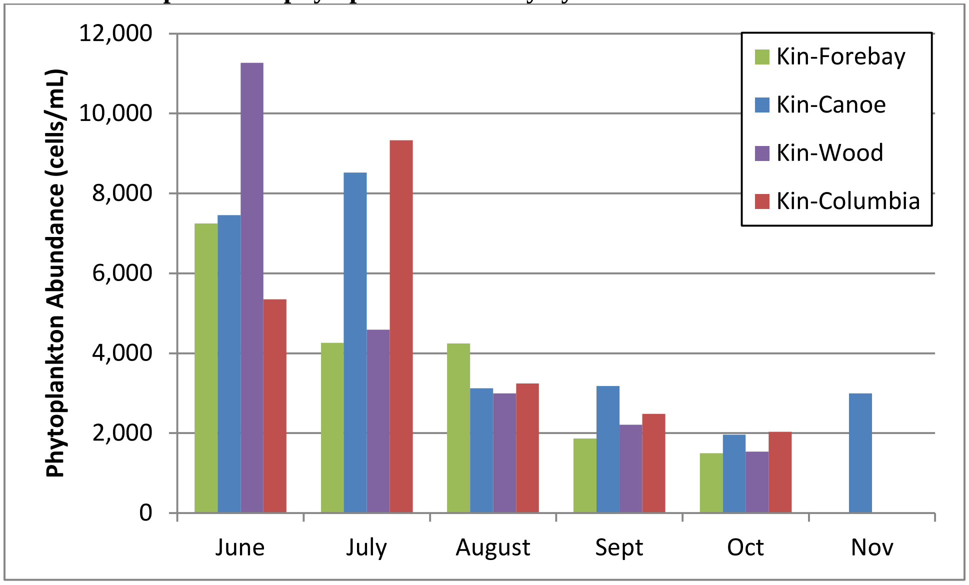
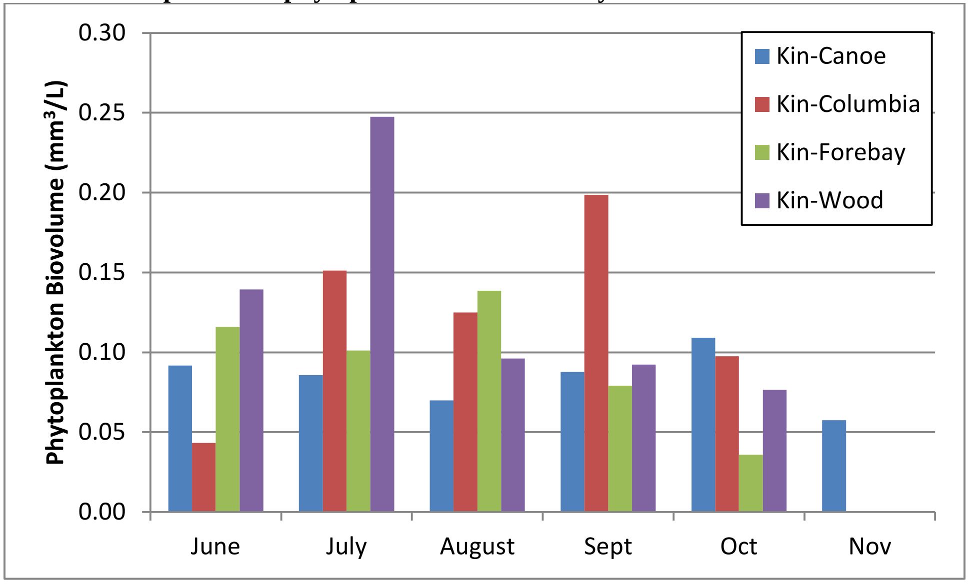


Figure 4 Kinbasket mean epilimnetic phytoplankton biovolume by month



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 (6,565 cells/mL compared to 4,344 cells/mL). Based on biovolume, the taxonomic group making up the largest percentage of the phytoplankton community 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 July (10,911 cells/mL and 0.1631 mm^3/L) (Figure 7 and Figure 8). The Mid station had the lowest phytoplankton density (1,860 cells/mL in October), but the lowest biovolume was observed in the Upper station in October (0.0449 mm^3/L).

Table 3 Revelstoke Reservoir mean phytoplankton density (Cells/mL) by group and month from the 2, 5 and 10 meter laboratory composites 2012

Station	Group	May	June	July	August	Sept	Oct	Seasonal Average
Rev-Forebay	Blue-greens	3,350	1,984	5,748	3,033	886	1,024	2,671
	Coccoid Greens, Desmids, etc.	236	390	98	732	756	130	390
	Diatoms	146	65	49	268	81	73	114
	Dinoflagellates	8	16	16	33	8	0	14
	Flagellates	2,236	2,398	5,000	2,984	1,171	1,325	2,519
	Sum of All Groups	**5,976**	**4,854**	**10,911**	**7,049**	**2,903**	**2,553**	**5,708**
Rev-Mid	Blue-greens		1,447	6,691	4,521	2,333	789	3,156
	Coccoid Greens, Desmids, etc.		309	16	211	1,309	73	384
	Diatoms		106	0	220	114	73	102
	Dinoflagellates		8	8	8	33	16	15
	Flagellates		2,317	3,976	3,870	2,764	911	2,768
	Sum of All Groups		**4,187**	**10,692**	**8,830**	**6,553**	**1,862**	**6,425**
Rev-Upper	Blue-greens		6,561	3,114	5,325	2,691	1,878	3,914
	Coccoid Greens, Desmids, etc.		163	89	24	81	33	78
	Diatoms		114	81	81	49	41	73
	Dinoflagellates		8	0	16	0	0	5
	Flagellates		5,561	3,325	3,976	2,577	2,016	3,491
	Sum of All Groups		**12,407**	**6,610**	**9,423**	**5,399**	**3,968**	**7,561**

Table 4 Revelstoke Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2012

Station	Group	May	June	July	August	Sept	Oct	Seasonal Average
Rev-Forebay	Blue-greens	0.0213	0.0118	0.0250	0.0180	0.0055	0.0199	0.0169
	Coccoid Greens, Desmids, etc.	0.0149	0.0169	0.0129	0.0502	0.0116	0.0119	0.0197
	Diatoms	0.0156	0.0050	0.0133	0.0316	0.0232	0.0122	0.0168
	Dinoflagellates	0.0033	0.0065	0.0033	0.0130	0.0033	0.0000	0.0049
	Flagellates	0.0486	0.0331	0.0626	0.0503	0.0270	0.0367	0.0431
	Sum of All Groups	**0.1036**	**0.0734**	**0.1171**	**0.1631**	**0.0705**	**0.0807**	**0.1014**
Rev-Mid	Blue-greens		0.0058	0.0331	0.0260	0.0211	0.0052	0.0182
	Coccoid Greens, Desmids, etc.		0.0221	0.0013	0.0304	0.0192	0.0035	0.0153
	Diatoms		0.0084	0.0000	0.0264	0.0111	0.0201	0.0132
	Dinoflagellates		0.0033	0.0033	0.0033	0.0114	0.0049	0.0052
	Flagellates		0.0386	0.0403	0.0672	0.0542	0.0161	0.0433
	Sum of All Groups		**0.0782**	**0.0779**	**0.1533**	**0.1169**	**0.0497**	**0.0952**
Rev-Upper	Blue-greens		0.0261	0.0144	0.0233	0.0108	0.0118	0.0173
	Coccoid Greens, Desmids, etc.		0.0124	0.0043	0.0049	0.0043	0.0027	0.0057
	Diatoms		0.0105	0.0075	0.0173	0.0055	0.0028	0.0087
	Dinoflagellates		0.0033	0.0000	0.0049	0.0000	0.0000	0.0016
	Flagellates		0.0695	0.0483	0.0327	0.0326	0.0276	0.0422
	Sum of All Groups		**0.1218**	**0.0744**	**0.0831**	**0.0533**	**0.0449**	**0.0755**

Figure 5 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between May - October 2012 derived from the 2, 5, and 10 meter laboratory composites

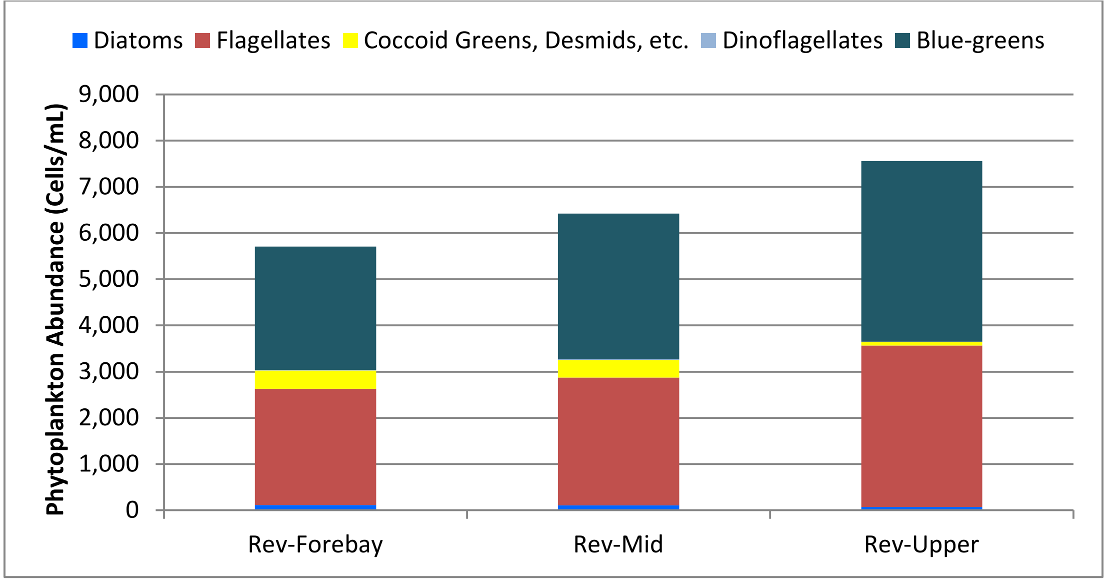


Figure 6 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2012 derived from the 2, 5, and 10 meter laboratory composites

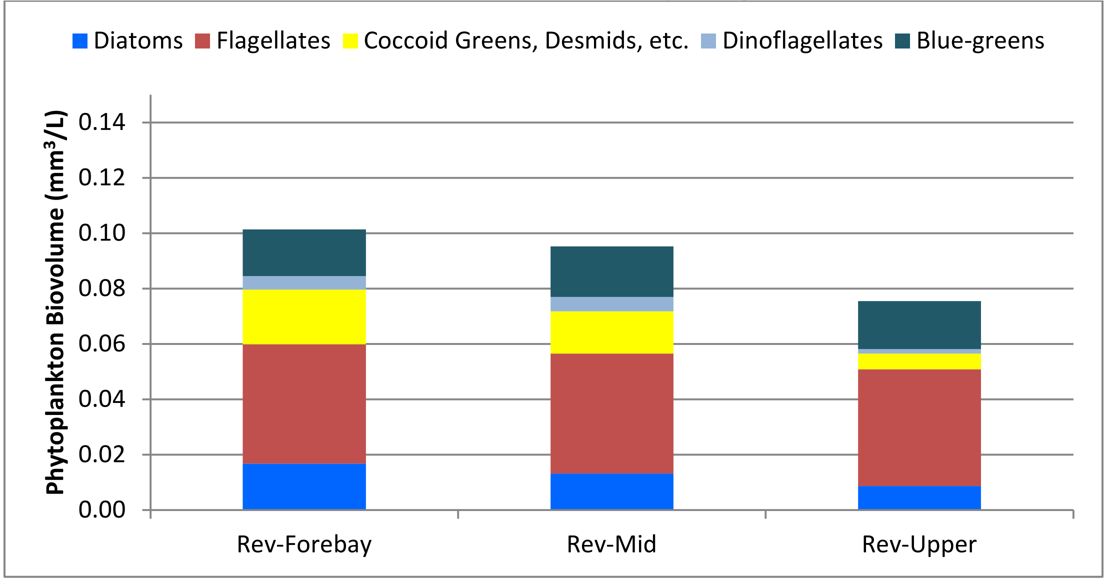


Figure 7 Revelstoke mean epilimnetic phytoplankton density by month

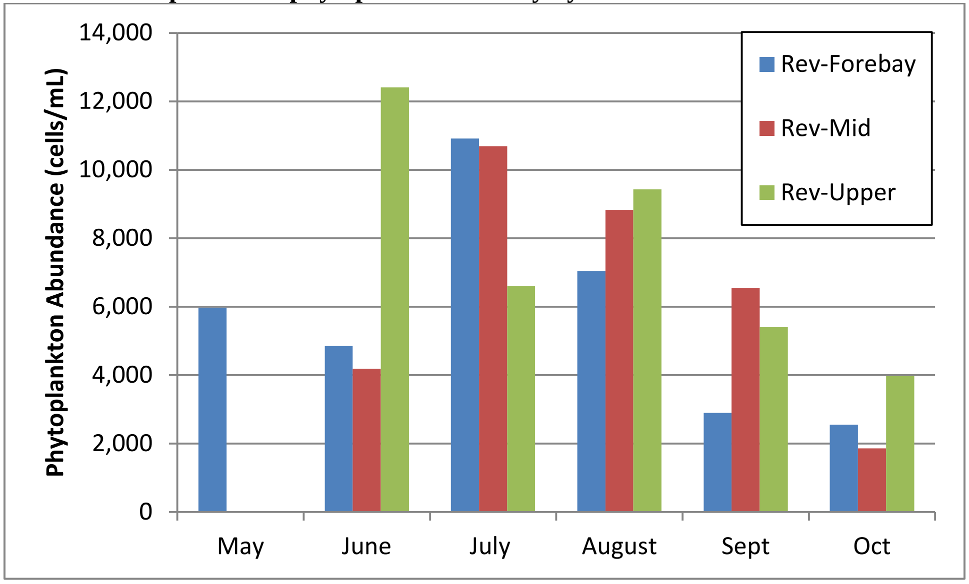
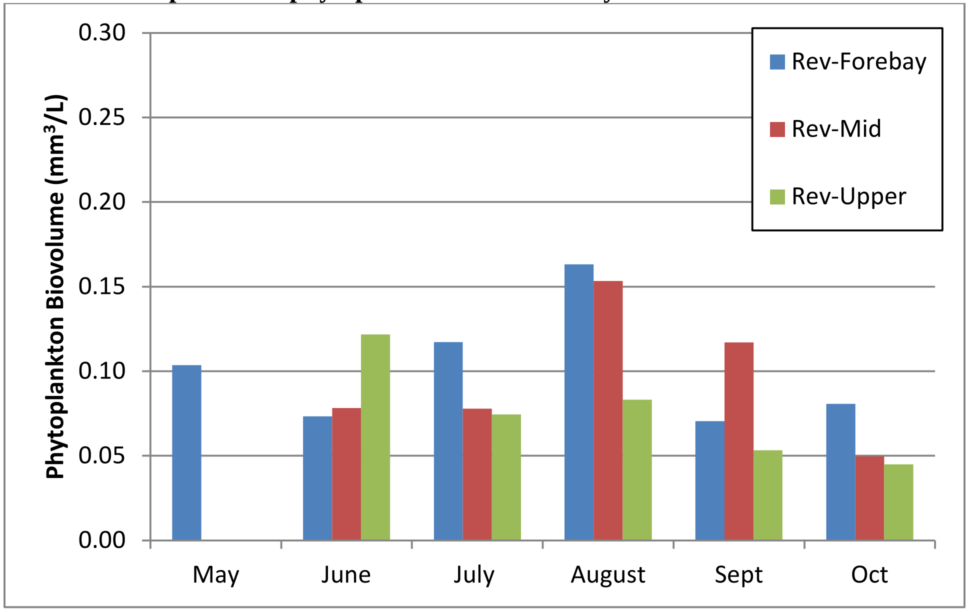


Figure 8 Revelstoke mean epilimnetic phytoplankton biovolume by month



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. Dinoflagellates, green, and blue-green contributed the least to biovolume (Table 6 and Figure 10). The Columbia Arm had the highest seasonal average phytoplankton density (4,229 cells/mL); but the highest seasonal average of biovolume occurred in the Canoe Arm(0.0934 mm^3/L). The month of June and July had the highest hypolimnetic phytoplankton cell density in all stations (Figure 11).

Table 5 Kinbasket Reservoir phytoplankton density (Cells/mL) by group and month from the 15, and 25 meter laboratory composites in 2012

Station	Group	June	July	August	Sept	Oct	Nov	Seasonal Average
Kin-Canoe	Blue-greens		2,988	2,098	2,000	720	1,378	2,455
	Coccoid Greens, Desmids, etc.	2,195	232	12	1,159	512	159	711
	Diatoms	159	98	85	85	73	73	96
	Dinoflagellates	12	0	0	24	0	0	6
	Flagellates	2,366	2,585	1,805	2,256	805	1,817	1,939
	Sum of All Groups	**10,281**	**5,903**	**4,000**	**5,525**	**2,110**	**3,427**	**5,208**
Kin-Columbia	Blue-greens	3,025	5,171	3,086	1,049	683		2,603
	Coccoid Greens, Desmids, etc.	49	37	0	24	122		46
	Diatoms	49	61	110	98	73		78
	Dinoflagellates	0	12	12	0	12		7
	Flagellates	3,781	4,329	2,415	1,207	890		2,525
	Sum of All Groups	**6,903**	**9,610**	**5,622**	**2,378**	**1,781**		**5,259**
Kin-Forebay	Blue-greens	3,537	1,671	2,464	390	622		1,737
	Coccoid Greens, Desmids, etc.	49	159	98	37	12		71
	Diatoms	98	183	98	24	49		90
	Dinoflagellates	24	12	0	12	0		10
	Flagellates	2,317	1,890	2,220	805	817		1,610
	Sum of All Groups	**6,025**	**3,915**	**4,878**	**1,268**	**1,500**		**3,517**
Kin-Wood	Blue-greens	2,305	2,049	2,317	2,329	805		1,961
	Coccoid Greens, Desmids, etc.	24	195	0	37	24		56
	Diatoms	122	122	146	24	12		85
	Dinoflagellates	0	24	0	0	0		5
	Flagellates	3,098	2,037	2,293	2,220	963		2,122
	Sum of All Groups	**5,549**	**4,427**	**4,756**	**4,610**	**1,805**		**4,229**

Table 6 Kinbasket Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2012

Station	Group	June	July	August	Sept	Oct	Nov	Seasonal Average
Kin-Canoe	Blue-greens	0.0218	0.0208	0.0113	0.0227	0.0029	0.0143	0.0156
	Coccoid Greens, Desmids, etc.	0.1172	0.0116	0.0006	0.0407	0.0129	0.0390	0.0370
	Diatoms	0.0196	0.0087	0.0244	0.0069	0.0163	0.0085	0.0141
	Dinoflagellates	0.0049	0.0000	0.0000	0.0098	0.0000	0.0000	0.0024
	Flagellates	0.0170	0.0306	0.0165	0.0410	0.0140	0.0262	0.0242
	Sum of All Groups	**0.1805**	**0.0717**	**0.0528**	**0.1210**	**0.0462**	**0.0880**	**0.0934**
Kin-Columbia	Blue-greens	0.0149	0.0233	0.0182	0.0072	0.0027		0.0133
	Coccoid Greens, Desmids, etc.	0.0044	0.0024	0.0000	0.0074	0.0069		0.0042
	Diatoms	0.0041	0.0166	0.0399	0.0062	0.0196		0.0173
	Dinoflagellates	0.0000	0.0049	0.0049	0.0000	0.0049		0.0029
	Flagellates	0.0320	0.0454	0.0331	0.0289	0.0202		0.0319
	Sum of All Groups	**0.0554**	**0.0926**	**0.0961**	**0.0497**	**0.0543**		**0.0696**
Kin-Forebay	Blue-greens	0.0140	0.0156	0.0158	0.0105	0.0025		0.0117
	Coccoid Greens, Desmids, etc.	0.0030	0.0262	0.0049	0.0022	0.0015		0.0076
	Diatoms	0.0091	0.0214	0.0326	0.0018	0.0055		0.0141
	Dinoflagellates	0.0098	0.0049	0.0000	0.0049	0.0000		0.0039
	Flagellates	0.0285	0.0324	0.0369	0.0191	0.0202		0.0274
	Sum of All Groups	**0.0644**	**0.1005**	**0.0901**	**0.0385**	**0.0298**		**0.0647**
Kin-Wood	Blue-greens	0.0135	0.0082	0.0093	0.0124	0.0091		0.0105
	Coccoid Greens, Desmids, etc.	0.0012	0.0250	0.0000	0.0068	0.0012		0.0068
	Diatoms	0.0109	0.0128	0.0432	0.0021	0.0006		0.0139
	Dinoflagellates	0.0000	0.0098	0.0000	0.0000	0.0000		0.0020
	Flagellates	0.0299	0.0271	0.0281	0.0263	0.0238		0.0270
	Sum of All Groups	**0.0554**	**0.0828**	**0.0805**	**0.0475**	**0.0347**		**0.0602**

Figure 9 Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between May - October 2012 derived from the 15, and 25 meter laboratory composites

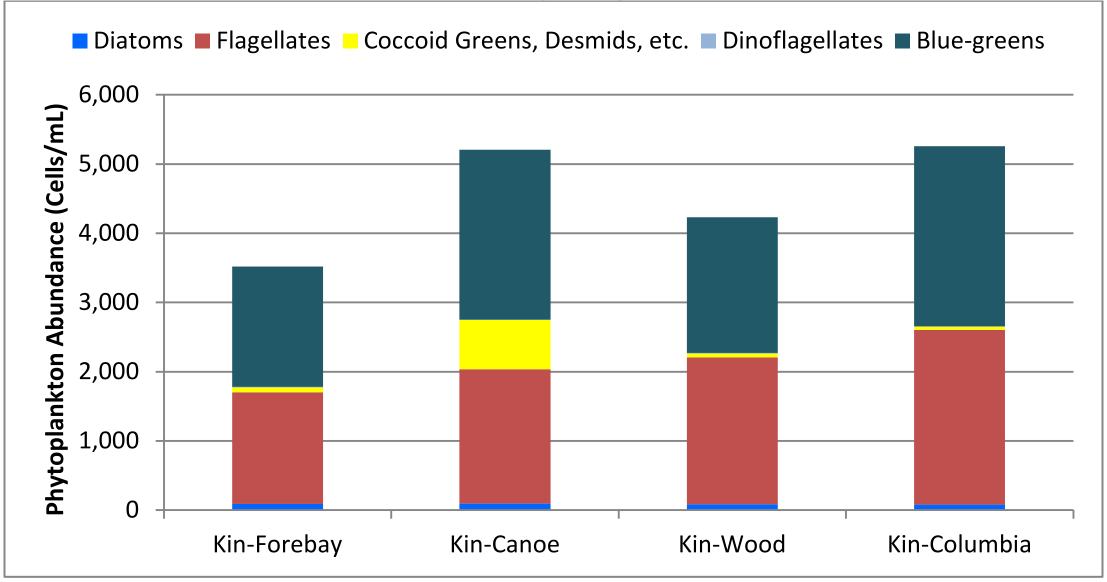


Figure 10 Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between May - October 2012 derived from the 15, and 25 meter laboratory composites

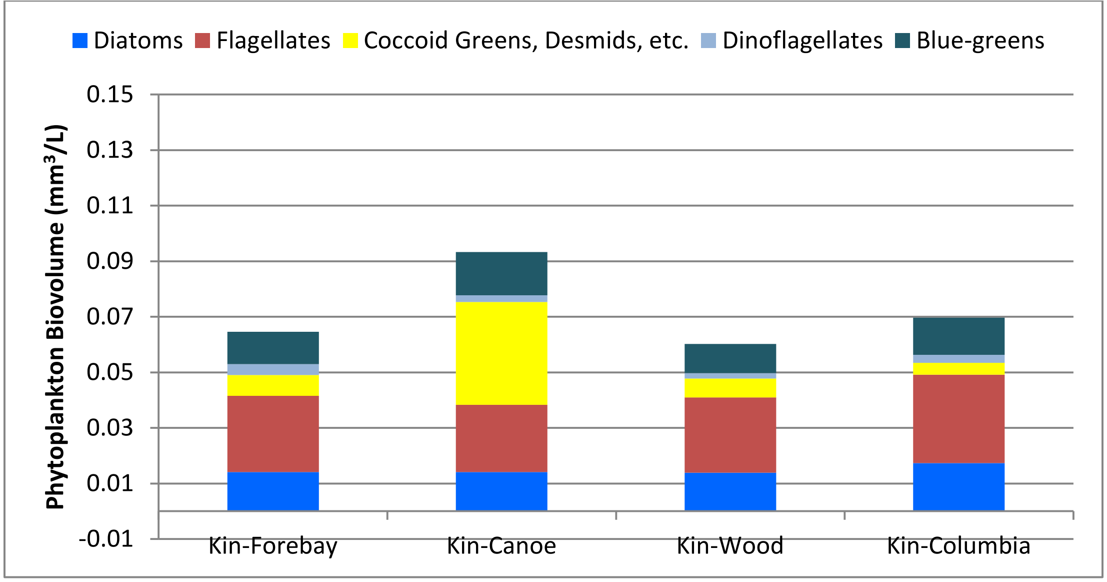


Figure 11 Kinbasket mean hypolimnetic phytoplankton density by month

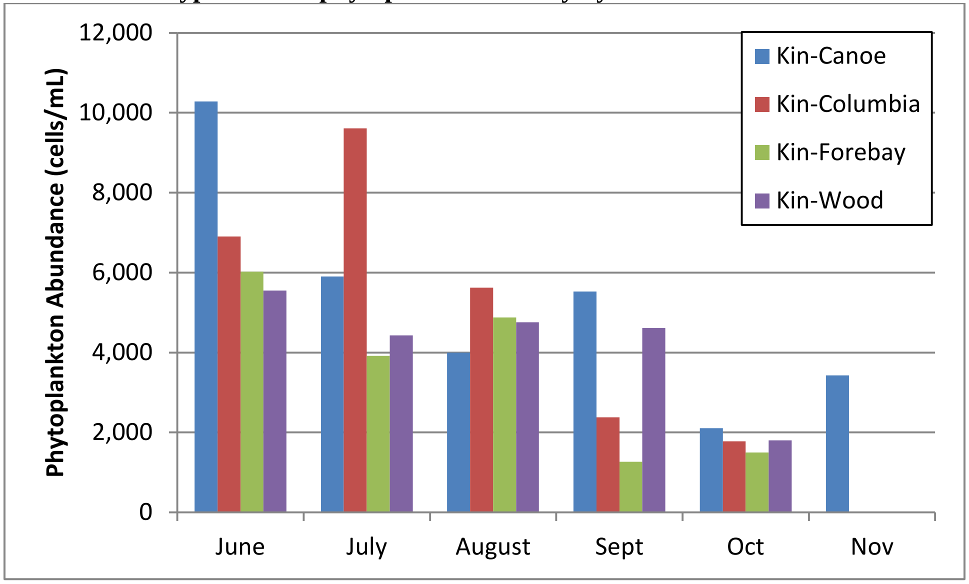
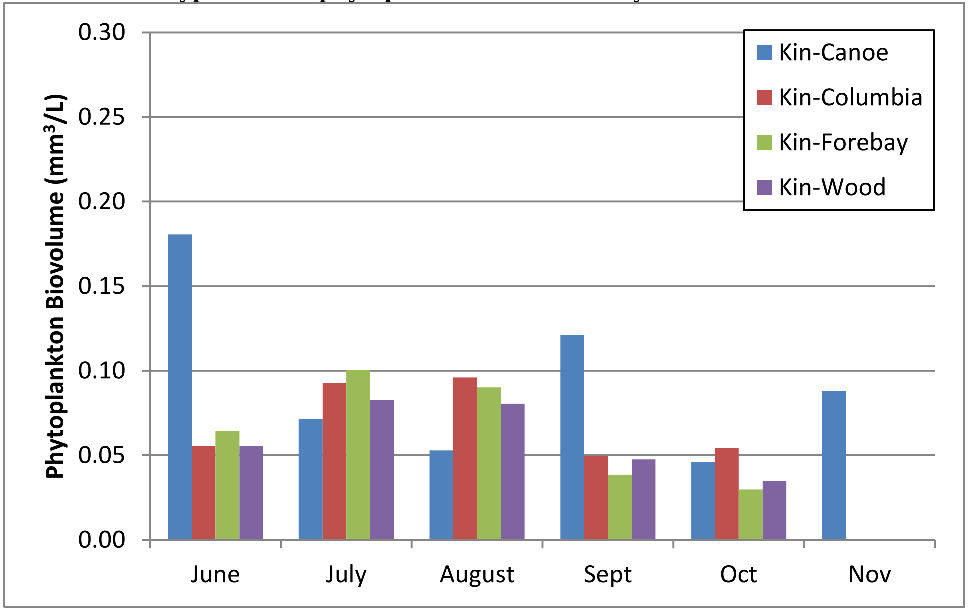


Figure 12 Kinbasket mean hypolimnetic phytoplankton biovolume by month



Revelstoke

The most abundant groups in the hypolimnion of Revelstoke Reservoir in 2012 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 blue-greens. Diatoms, greens and dinoflagellates contributed the least to biovolume (Table 8 and Figure 14). The Upper station had the highest mean cell density and biovolumes of the three Revelstoke stations, followed by the Mid and Forebay stations.

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 2012

Station	Group	May	June	July	August	Sept	Oct	Seasonal Average
Rev-Forebay	Blue-greens	2,646	1,573	9,647	3,317	1,585	744	3,252
	Coccoid Greens, Desmids, etc.	134	122	73	0	49	134	85
	Diatoms	183	24	0	73	24	61	61
	Dinoflagellates	0	0	0	0	0	12	2
	Flagellates	1,695	1,646	7,342	2,390	1,281	1,171	2,588
	Sum of All Groups	**4,659**	**3,366**	**17,062**	**5,781**	**2,939**	**2,122**	**5,988**
Rev-Mid	Blue-greens		4,988	5,903	4,476	3,061	634	3,812
	Coccoid Greens, Desmids, etc.		24	24	98	354	12	102
	Diatoms		24	61	183	134	12	83
	Dinoflagellates		24	12	0	12	24	15
	Flagellates		5,256	4,903	3,305	2,793	781	3,407
	Sum of All Groups		**10,318**	**10,903**	**8,061**	**6,354**	**1,463**	**7,420**
Rev-Upper	Blue-greens		5,561	4,012	5,025	3,939	1,439	3,995
	Coccoid Greens, Desmids, etc.		122	61	12	37	49	56
	Diatoms		85	134	73	49	49	78
	Dinoflagellates		0	0	0	24	0	5
	Flagellates		5,439	3,793	4,500	3,390	1,671	3,759
	Sum of All Groups		**11,208**	**8,000**	**9,610**	**7,439**	**3,207**	**7,893**

Table 8 Revelstoke Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2012

Station	Group	May	June	July	August	Sept	Oct	Seasonal Average
Rev-Forebay	Blue-greens	0.0135	0.0093	0.0444	0.0191	0.0122	0.0060	0.0174
	Coccoid Greens, Desmids, etc.	0.0146	0.0080	0.0029	0.0000	0.0062	0.0092	0.0068
	Diatoms	0.0210	0.0037	0.0000	0.0167	0.0018	0.0038	0.0078
	Dinoflagellates	0.0000	0.0000	0.0000	0.0000	0.0000	0.0049	0.0008
	Flagellates	0.0281	0.0156	0.0535	0.0229	0.0107	0.0229	0.0256
	Sum of All Groups	**0.0773**	**0.0365**	**0.1009**	**0.0588**	**0.0310**	**0.0468**	**0.0585**
Rev-Mid	Blue-greens		0.0200	0.0325	0.0179	0.0271	0.0084	0.0212
	Coccoid Greens, Desmids, etc.		0.0019	0.0019	0.0111	0.0110	0.0010	0.0054
	Diatoms		0.0021	0.0046	0.0191	0.0099	0.0010	0.0073
	Dinoflagellates		0.0098	0.0049	0.0000	0.0049	0.0098	0.0059
	Flagellates		0.0397	0.0381	0.0419	0.0534	0.0145	0.0375
	Sum of All Groups		**0.0734**	**0.0820**	**0.0900**	**0.1062**	**0.0347**	**0.0773**
Rev-Upper	Blue-greens		0.0221	0.0190	0.0230	0.0276	0.0059	0.0196
	Coccoid Greens, Desmids, etc.		0.0077	0.0053	0.0006	0.0058	0.0065	0.0052
	Diatoms		0.0079	0.0121	0.0327	0.0043	0.0049	0.0124
	Dinoflagellates		0.0000	0.0000	0.0000	0.0098	0.0000	0.0020
	Flagellates		0.0452	0.0424	0.0317	0.0362	0.0212	0.0353
	Sum of All Groups		**0.0830**	**0.0788**	**0.0881**	**0.0837**	**0.0384**	**0.0744**

Figure 13 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between May - October 2012 derived from the 15, and 25 meter laboratory composites

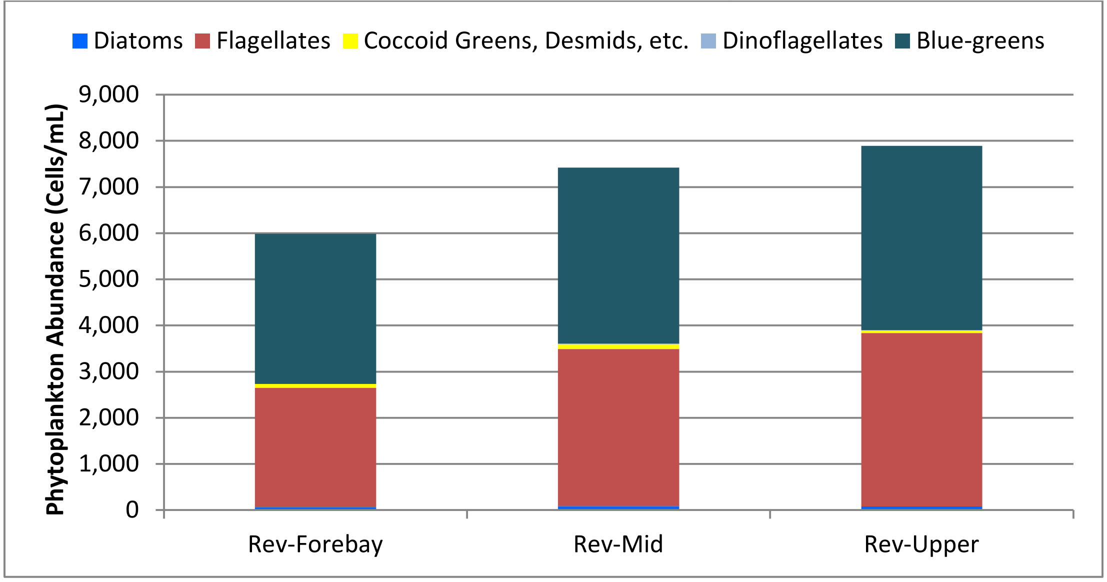


Figure 14 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2012 derived from the 15, and 25 meter laboratory composites

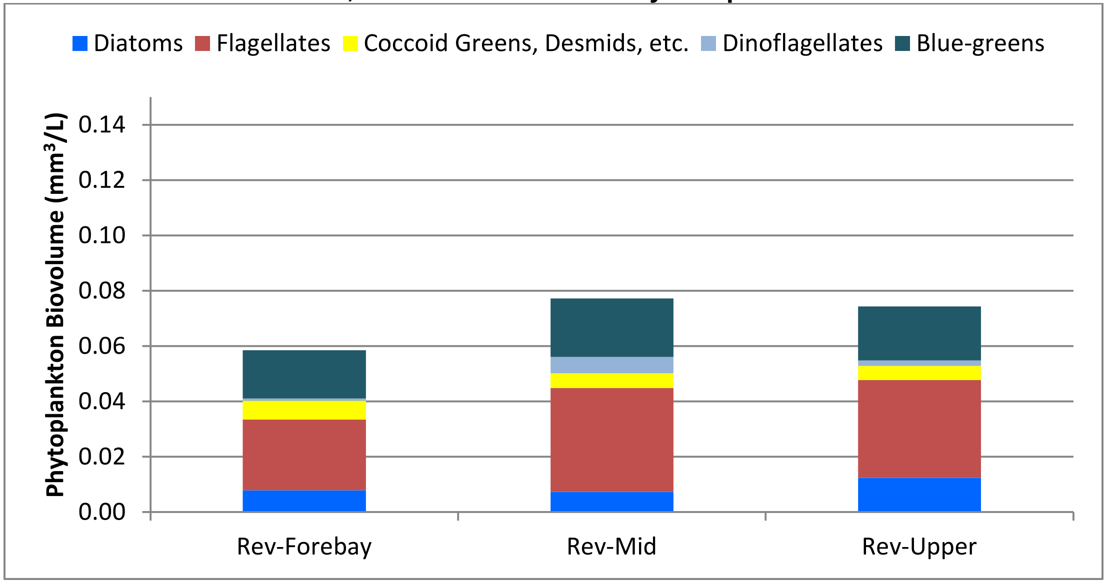


Figure 15 Revelstoke mean hypolimnetic phytoplankton density by month

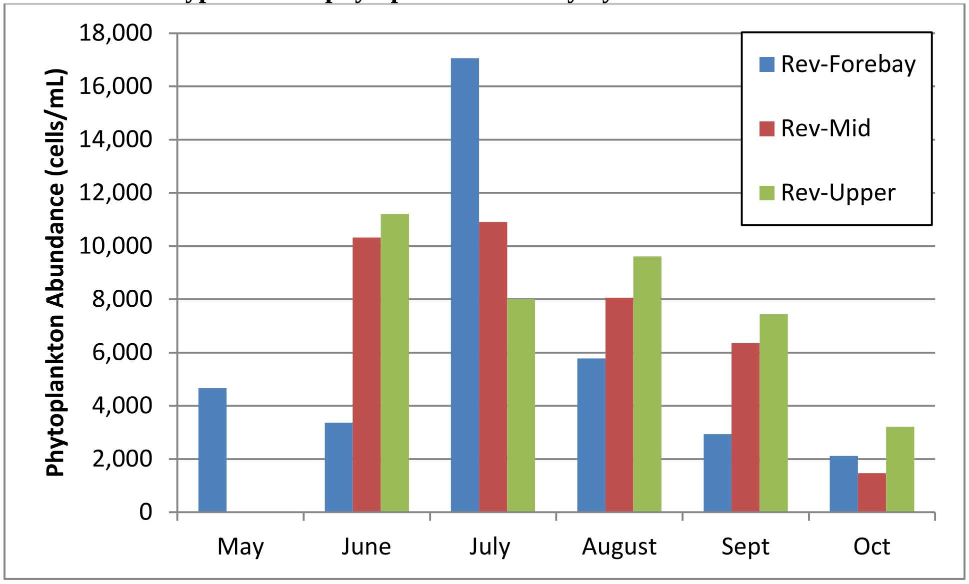
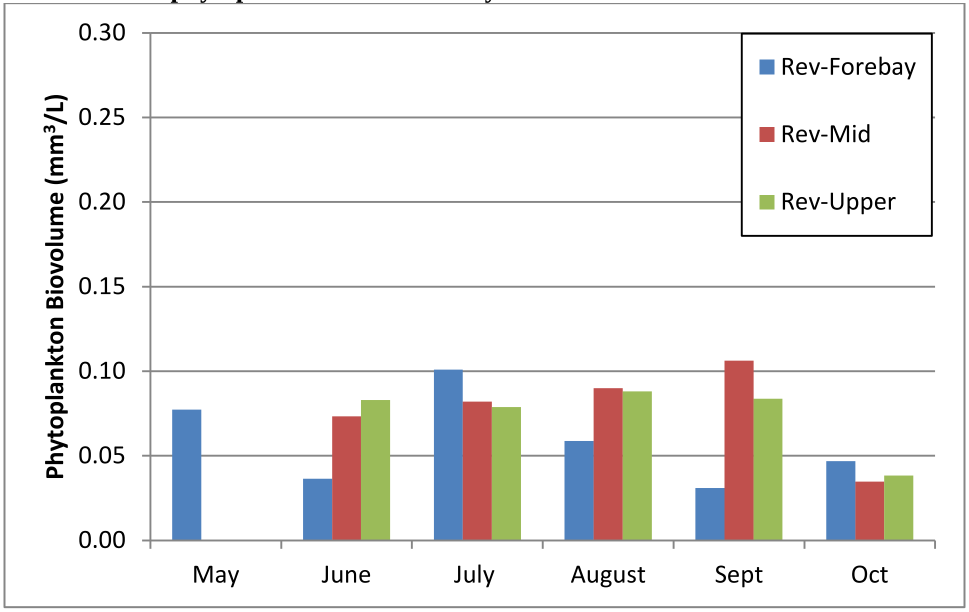


Figure 16 Revelstoke mean phytoplankton biovolume by month



3.3 Vertical Distribution- Phytoplankton Density and Biovolume – 2012

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 2012 sampling season.

Kinbasket

There was little change in phytoplankton density with depth in 2012. Blue-Greens and flagellates dominated the community at all depths (Figure 17).

The biovolume of the phytoplankton community does exhibit difference with depth. The biovolume of the phytoplankton peaks at 5 meters, then decreases with depth. The reduction in biovolume in samples greater than 5 meters in depth is consistent across groups (Figure 18). The reduction in biovolume without the reduction in cell density indicates that as one moves deeper into the water column, the average size of the taxa decreases with depth. The total number of cells may be similar but the large taxa are being replaced by the smaller taxa at the deeper depths.

Figure 17 Average phytoplankton density (Cells/mL), by depth and group, in Kinbasket Reservoir between May - October 2012

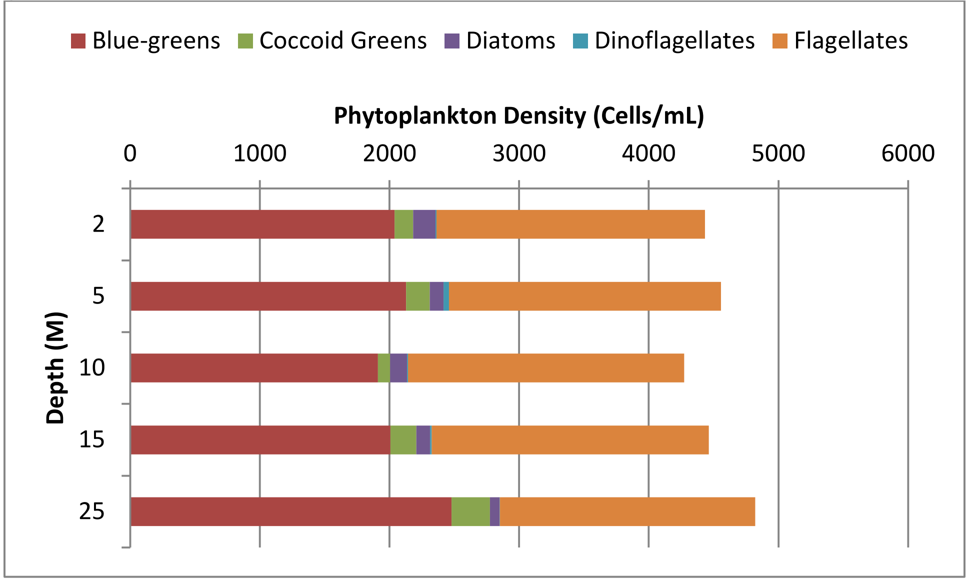
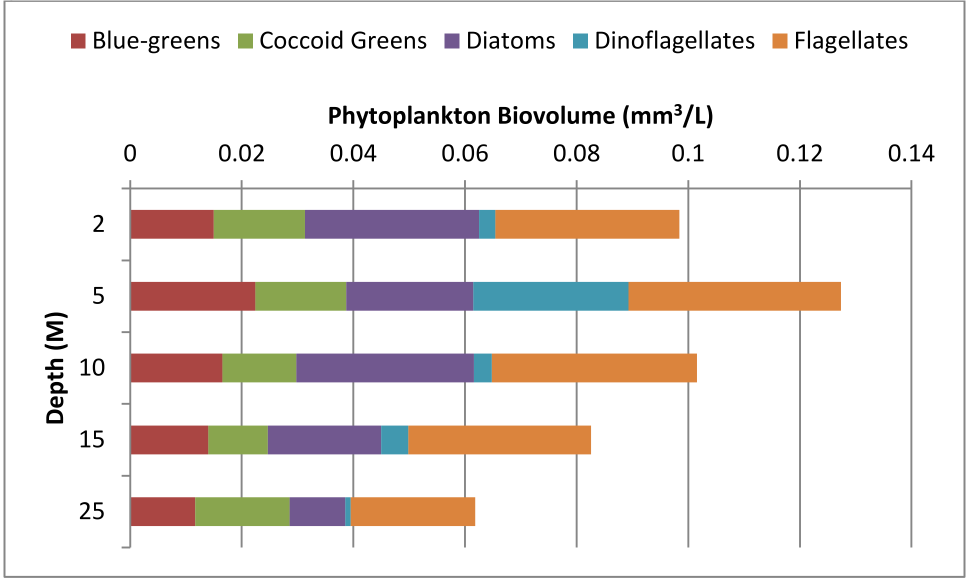


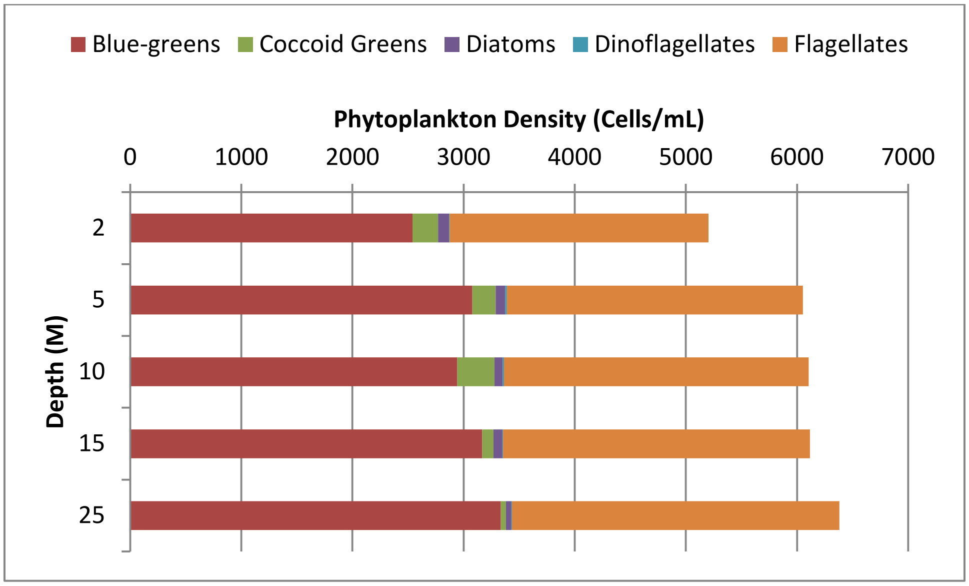
Figure 18 Average phytoplankton biovolume (mm^3/L), by depth and group, in Kinbasket Reservoir between May - October 2012



Revelstoke

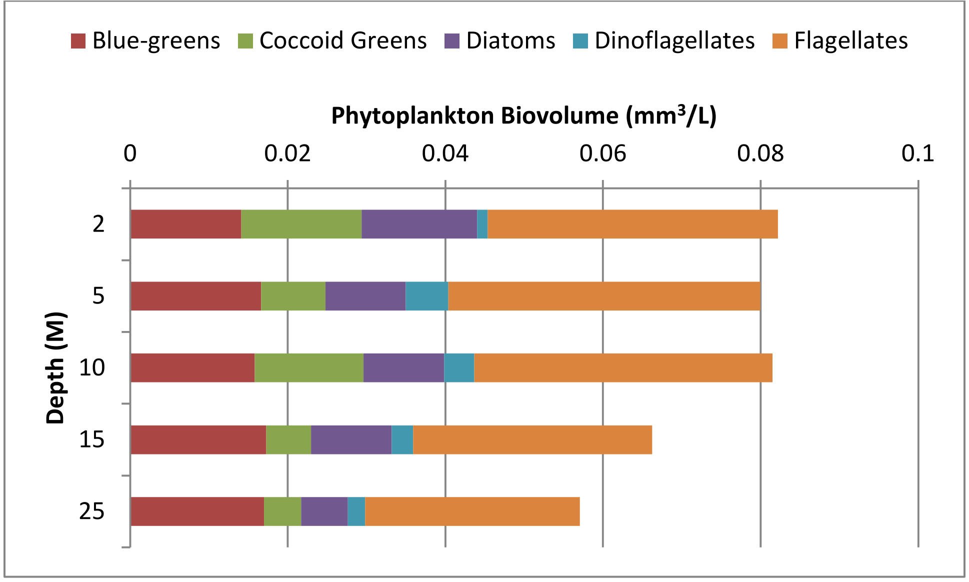
As with Kinbasket, there was little difference in phytoplankton density with depth in Revelstoke Reservoir. The most abundant group at all depths were the blue-greens and flagellates. Dinoflagellate and diatoms were the least abundant groups (Figure 19).

Figure 19 Average phytoplankton density (Cells/mL), by depth, in Revelstoke Reservoir between May - October 2012



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 2012



3.4 Phytoplankton in 2008-2012

To compare the 2008 through 2012 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
	2011[ƚ]	2476	2717	5558	3586	3584
	2012	3823	4541	5522	4490	4594
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
	2012	0.09	0.08	0.13	0.12	0.11

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

ƚ samples were not collected in June or September of 2011 so the averages do not include the values from those months

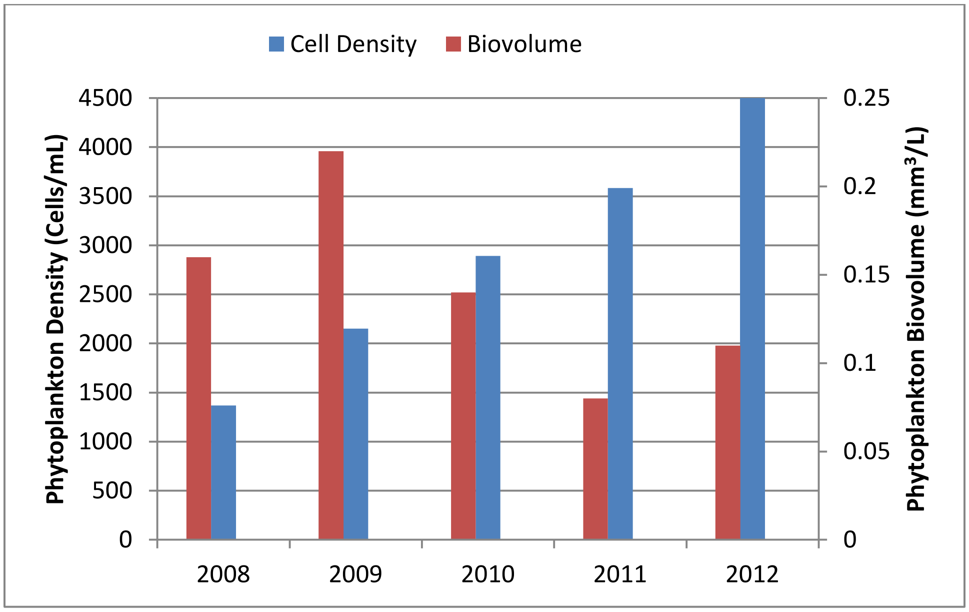


Figure 21 Mean reservoir phytoplankton density and biovolume by year for Kinbasket

Revelstoke

As observed in Kinbasket the mean epilimnetic phytoplankton density has been increasing since 2008. The increase is primarily due to the high densities of small flagellates and Synechococcus sp. observed in these stations in 2011 and 2012 (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
	2012	5708	6425	7561	6565
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
	2012	0.1	0.09	0.08	0.09

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

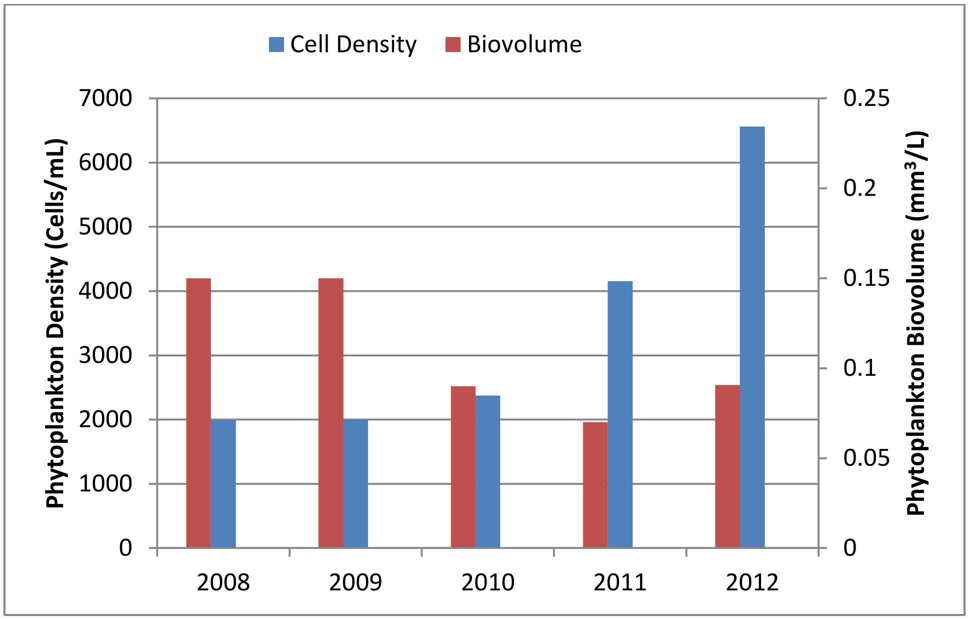


Figure 22 Mean reservoir phytoplankton density and biovolume by year for Revelstoke

3.5 Bacteria and Pico-cyanobacteria Density in 2012

3.5.1 Bacteria.

Kinbasket

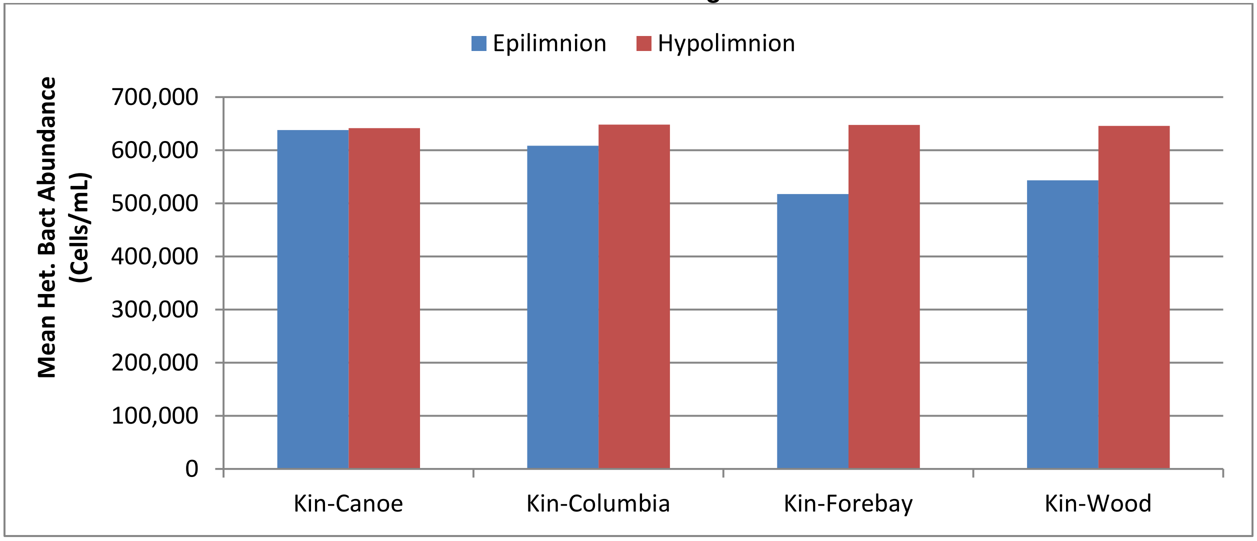
Of the four stations, the Canoe (638,102 cells/mL) and Columbia Arm (608,588 cells/mL)stations had the highest average epilimnetic densities. The Wood, and Forebay stations had mean epilimnetic densities of 543,533 cells/mL and 517,860 cells/mL respectively (Table 9 and Figure 23).

Table 9 2012 Picoplankton densities

		Heterotrophic Bacteria (Cells/mL)						
		June	July	August	Sept.	Oct.	Nov.	Avg.
Epilimnion	Kin-Canoe	691,487	818,657	608,032	683,539	515,039	511,859	638,102
	Kin-Columbia	735,202	536,498	641,811	608,032	521,397		608,588
	Kin-Forebay	532,524	596,109	372,568	576,239	511,859		517,860
	Kin-Wood	866,346	560,343	310,970	842,501	137,503		543,533
	Rev-Forebay	496,758	572,265	490,797	295,074	287,126		428,404
	Rev-Middle	592,135	759,046	487,816	225,528	486,425		510,190
	Rev-Upper	544,447	675,591	623,928	368,594	521,397		546,791
Hypolimnion	Kin-Canoe	774,942	615,980	673,604	568,291	616,775	600,878	641,745
	Kin-Columbia	719,305	687,513	766,994	520,602	546,831		648,249
	Kin-Forebay	663,668	572,265	731,228	715,331	556,369		647,772
	Kin-Wood	635,850	612,006	703,409	723,279	556,369		646,183
	Rev-Forebay	453,043	747,124	554,382	238,444	292,094		457,017
	Rev-Middle	584,187	612,006	649,759	264,275	600,878		542,221
	Rev-Upper	612,006	751,098	602,070	382,504	578,624		585,260

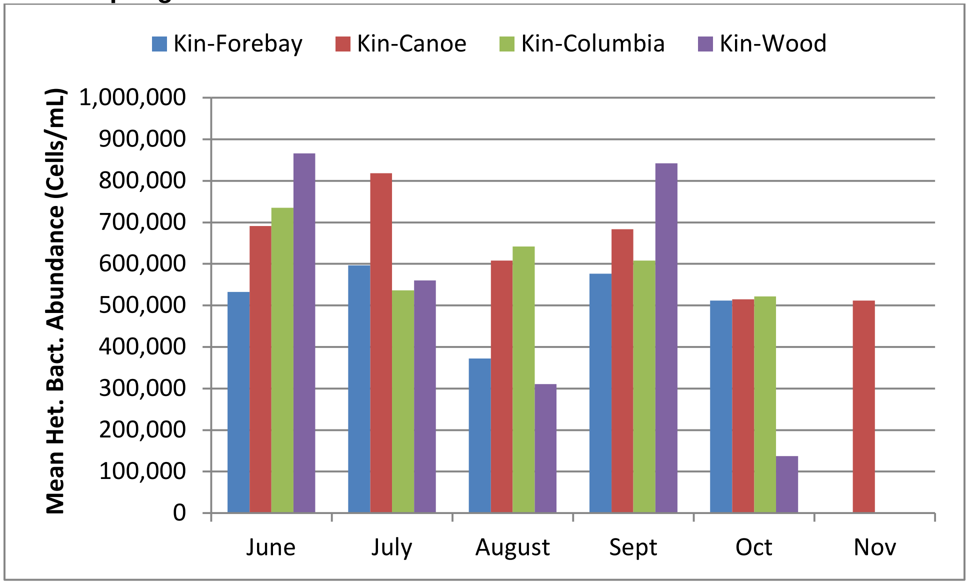
		Pico-cyano Bacteria (Cells/mL)						
		June	July	August	Sept.	Oct.	Nov.	Avg.
Epilimnion	Kin-Canoe	26,494	12,419	16,724	17,552	12,998	8,693	15,813
	Kin-Columbia	13,247	18,546	17,883	19,953	14,406		16,807
	Kin-Forebay	33,117	16,393	14,240	17,883	11,425		18,612
	Kin-Wood	14,406	7,617	20,036	14,158	7,037		12,651
	Rev-Forebay	17,442	14,737	24,093	20,864	17,883		19,004
	Rev-Middle	16,227	25,390	23,016	22,851	26,080		22,713
	Rev-Upper	16,062	13,247	8,279	6,458	6,623		10,134
Hypolimnion	Kin-Canoe	19,374	13,247	10,598	16,724	7,534	11,508	13,164
	Kin-Columbia	9,604	11,591	11,757	11,177	12,005		11,227
	Kin-Forebay	36,926	13,909	8,528	19,374	14,406		18,628
	Kin-Wood	20,533	10,598	27,570	11,425	10,018		16,029
	Rev-Forebay	13,909	12,419	6,209	8,942	10,432		10,382
	Rev-Middle	12,088	11,591	9,024	20,201	11,343		12,849
	Rev-Upper	11,425	11,094	4,305	4,802	4,388		7,203

Figure 23 Average density (Cells/mL) of heterotrophic bacteria at four sampling stations in Kinbasket Reservoir between the months of June through October 2012



The heterotrophic bacteria densities appear to have a bimodal characteristic with a peak in June or July followed by a decline in August and a secondary peak in September (Figure 24). The highest densities observed were in the Wood Arm station. The Wood Arm station also had the highest variability between sampling events.

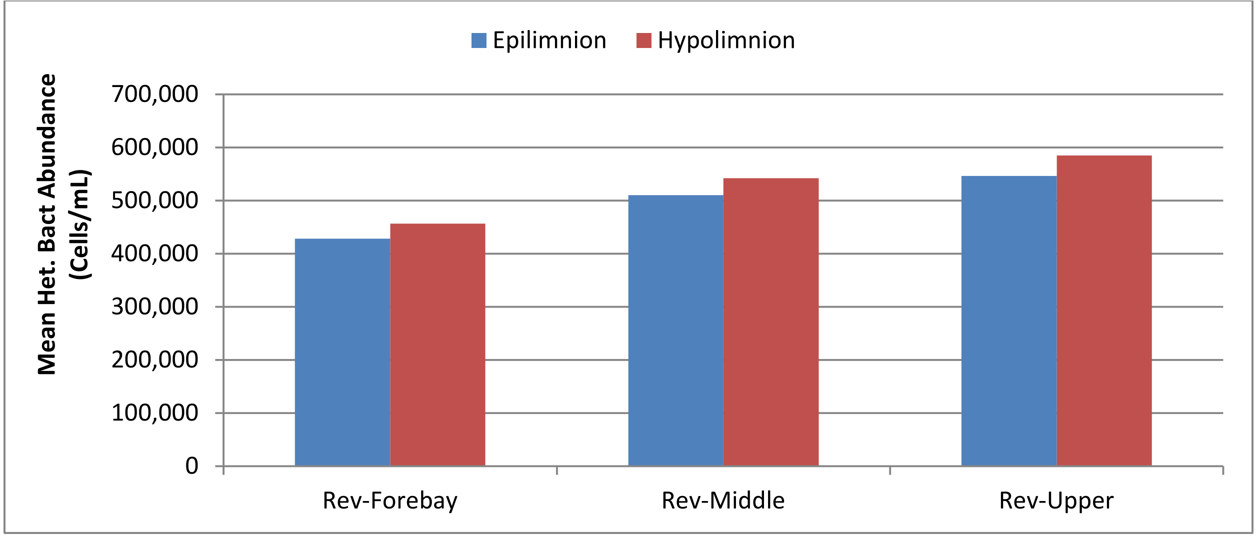
Figure 24 Kinbasket Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at four sampling stations in 2012



Revelstoke

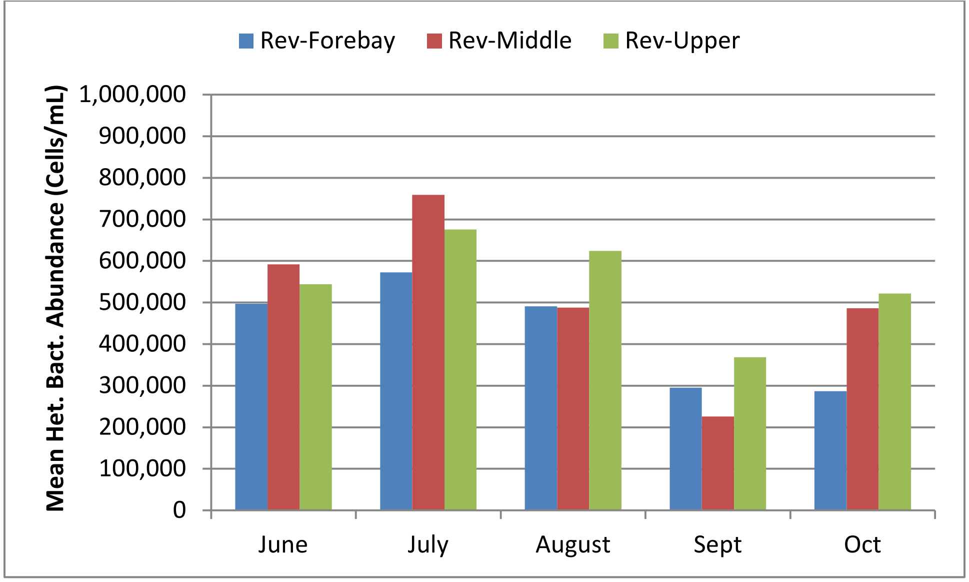
The epilimnetic average of heterotrophic bacteria ranged from 428,404 to 546,791cells/mL (Table 9). These values are slightly lower than those observed in Kinbasket in 2012. The Upper Station had the highest epilimnion and hypolimnion densities (Figure 25).

Figure 25 Average density (Cells/mL) of heterotrophic bacteria at three sampling stations in Revelstoke Reservoir between the months of June through October 2012



The heterotrophic bacteria densities in June through August were relatively stable followed by a decline in September and October (Figure 26). This is similar to the conditions observed in Kinbasket Reservoir. 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 2012



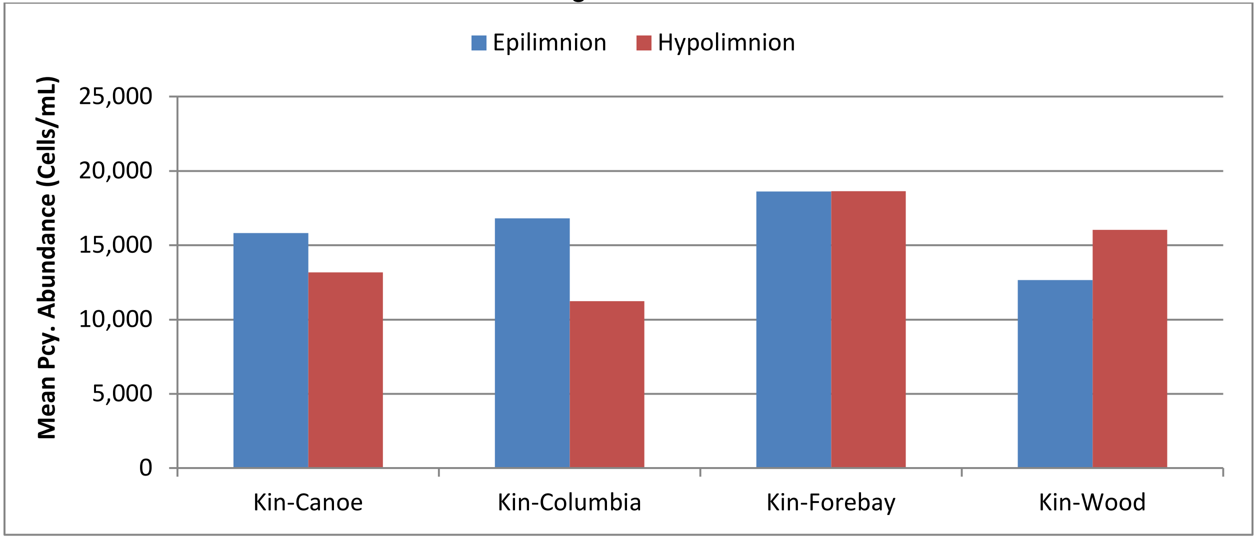
3.5.2 Pico-cyanobacteria.

Kinbasket

Total seasonal average density of epilimnetic pico-cyanobacteria in Kinbasket Reservoir was just under 16,000 cells/mL. The stations had relatively similar average epilimnetic densities (Table 9 and Figure 27). The densities observed in 2012 were considerably lower than the densities observed in 2011 and more in line with the 2010 observbations.

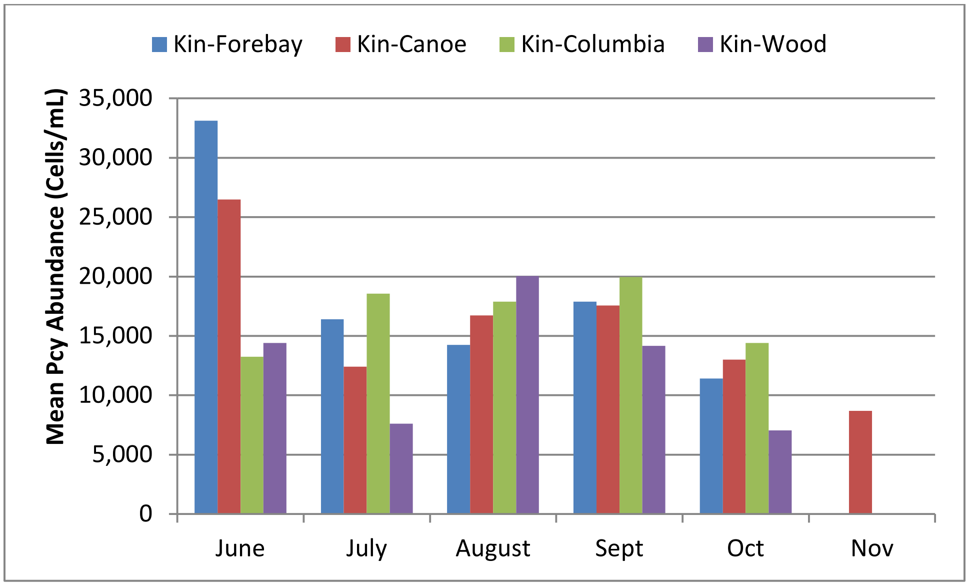
Hypolimnetic total seasonal average density of pico-cyanobacteria averaged just under 15,000 cells/mL. The Columbia sampling station had the lowest average density out of the four stations (Figure 27).

Figure 27 Average density (Cells/mL) of pico-cyanobacteria at four sampling stations in Kinbasket Reservoir between the months of June through October 2012



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. Like the heterotrophic bacteria densities in Kinbasket Reservoir, the pico-cyano densities exhibited a bimodal characteristic with a large peak in June followed by a second smaller peak in August (Figure 28).

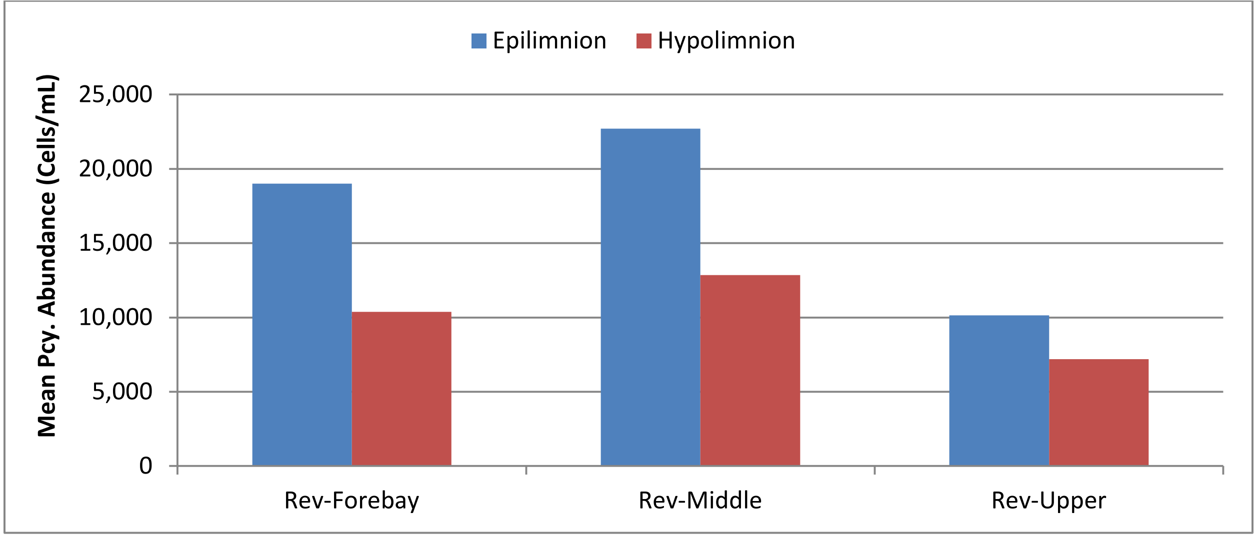
Figure 28 Average monthly density (Cells/mL) of epilimnetic pico-cyanobacteria at four sampling stations in Kinbasket Reservoir



Revelstoke

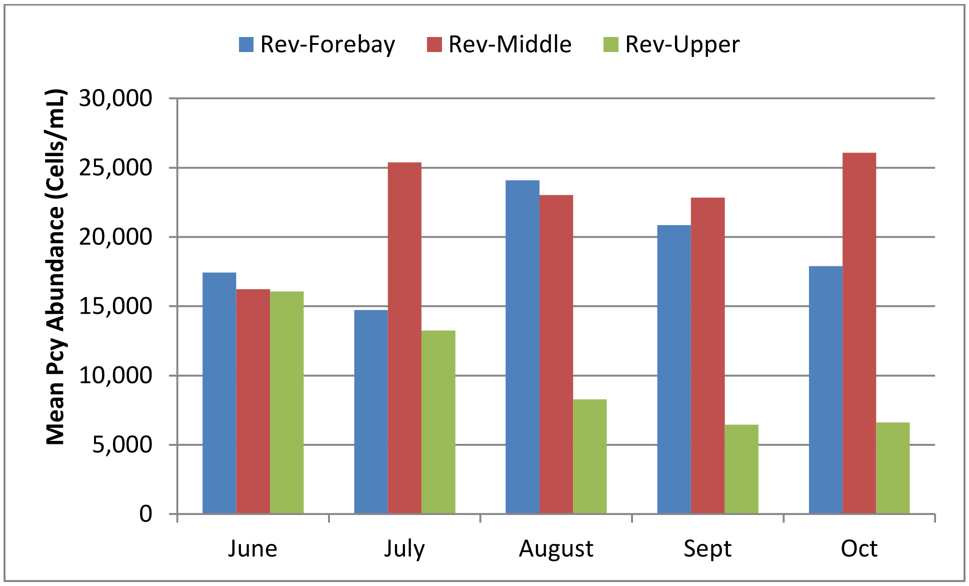
The average density in the epilimnion was approximately 17,284 cells/mL in Revelstoke Reservoir (Table 9). In the hypolimnion the average density was 10,145 cells/mL. The Mid station had the highest average density in both the hypolimnion and epilimnion, followed by the Forebay and Upper station (Figure 29).

Figure 29 Average density (Cells/mL) of pico-cyanobacteria at three sampling stations in Revelstoke Reservoir between the months of June through October 2012



The Forebay and Middle Reservoir stations exhibited an increase in densities from June through July. The densities remained steady through October for these two stations. The Upper station peaked in June and then declined in every subsequent month (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 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 sho rt term predictions of future conditions.

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Appendix A.

Kinbasket and Revelstoke 2012 Taxa List and Number of Occurrences

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
Bacillariophyte	**Diatoms**	Achnanthidium sp.	1	10
		Asterionella formosa	6	7
		Aulacoseira italica		1
		Cyclotella comta	17	9
		Cyclotella glomerata	51	29
		Cyclotella stelligera	1	
		Fragilaria capucina	8	7
		Fragilaria crotonensis	62	33
		Gomphonema sp. (medium)		1
		Hannaea arcus	1	
		Navicula sp. (medium)		1
		Navicula sp. (small)		1
		Nitzschia sp. (medium)	1	4
		Nitzschia sp. (small)	1	1
		Rhizosolenia sp.	2	1
		Stephanodiscus sp. (large)	28	9
		Stephanodiscus sp. (small)	1	1
		Synedra acus	40	27
		Synedra acus var. angustissima		1
		Synedra nana	6	
		Synedra ulna	10	4
Chlorophyte	**Coccoid Greens, Desmids, etc.**	Ankistrodesmus sp.		1
		Aulomonas sp.	2	
		Chlamydocapsa sp.	1	
		Chlamydomonas	5	2
		Chlorella		1
		Coelastrum sp. (cells)	21	18
		Cosmarium sp.	8	1
		Dictyosphaerium (cells)	3	
		Elakatothrix sp.	8	3
		Euglena	6	2
		Geminella sp.		1
		Gleotila sp.	11	1
		Gloeococcus sp.	4	1
		Golenkinia sp.	2	5
		Monomastix sp.	6	4
		Monoraphidium	3	1
		Nephroselmis	32	35
		Oocystis sp. (cells)	20	7

		Paramastix		1
		Phacus (medium)	5	4
		Phacus (small)	1	2
		Planktosphaeria		1
		Scenedesmus sp.	2	
		Scourfieldia	13	15
		Sphaerocystis sp.	10	
		Stichococcus minutissimus	3	6
		Tetraedron	38	37
Chryso- & Cryptophyte	**Flagellates**	Bitrichia sp.	2	1
		Chilomonas sp.	4	4
		Chromulina sp.	19	23
		Chroomonas acuta	69	58
		Chroomonas sp.	1	1
		Chrysochromulina sp.	7	7
		Chrysococcus	83	59
		Chrysolykos sp.		1
		Cryptomonas sp. (large)	1	3
		Cryptomonas sp. (medium)	55	39
		Cryptomonas sp. (small)	2	3
		Dinobryon sp. (medium)	58	42
		Gyromitus sp.	8	8
		Kephyrion sp.	67	51
		Komma sp.	44	57
		Mallomonas sp. (medium)	2	4
		Ochromonas sp.	67	35
		Paranema		1
		Pseudokephrion sp.	13	9
		Small microflagellates	104	82
		Sphaleromantis sp		1
		Trachelomonas sp.	30	17
Cyanophyte	**Blue-greens**	Anabaena sp.	1	
		Aphanothecae sp.	1	
		Chroococcus sp. (cells)	58	39
		Coelosphaerium sp. (cells)	1	
		Limnothrix redekei (cells)	1	
		Lyngbya sp. (cells)		1
		Merismopedia sp. (cells)	27	19
		Microcystis incerta	1	
		Microcystis sp. (cells)	2	1
		Synechococcus sp. (coccoid)	104	81

		Synechococcus sp. (rod)	83	72
		Synechocystis	28	28
Dinophyte	**Dinoflagellates**	Gymnodinium sp. (large)	3	
		Gymnodinium sp. (medium)	25	20
		Gymnodinium sp. (small)	5	4

Appendix 7

Zooplankton Kinbasket and Revelstoke Reservoirs, 2012

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Kinbasket and Revelstoke Reservoirs
Zooplankton, 2012

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March 2013

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1. Introduction

This report summarises the zooplankton data collected in 2012, with comparisons to available data from previous years and some historical data. The study of Kinbasket and Revelstoke Reservoirs macrozooplankton (length >150 µm), 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 Revelstoke and from June to November in Kinbasket Reservoir during 2012 sampling season, 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 May and from Revelstoke in November 2012.

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.

Seven species of Cladocera were present in 2012 (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 *Diaphanosoma brachyurum* (Lievin), *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.

Table 1. List of zooplankton species identified in Kinbasket Reservoir in 2003-2012. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2004	2005	2008	2009	2010	2011	2012
Cladocera								
Alona sp.						r		
Bosmina longirostris	+	+	+	+	+	+	+	+
Chydorus sphaericus			+		+	+		
Daphnia galeata mendotae	+	+	+	+	+	+	+	+
Daphnia rosea	+	+	+	+	+	+	+	+
Daphnia schoedleri	+	+	+	+	+	+	+	+
Diaphanosoma brachyurum		+	+		+	+		+
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	r
Leptodiaptomus sicilis	+	+	+	+	+	+	+	+

3.2 Density and Biomass

For comparison with historical data the average at Mica Forebay station in Kinbasket was used. Zooplankton density values in 2003-2012 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 2012 to 7.22 individuals/L from 7.97 individuals/L in 2011 (Fig. 2). The zooplankton density was numerically dominated by copepods, which averaged 78% of the 2012 community. *Daphnia* spp comprised 16%, and cladocerans other than *Daphnia* 6%. Copepods were the most abundant zooplankton at all four stations. They numerically prevailed during the whole sampling season, with populations peaking in July. The highest copepod density was found in July at Mica Forebay with 16.27 individuals/L. (Fig. 3). The number of Cladocerans varied by season as well as along the reservoir. Cladocerans other than *Daphnia* were the most numerous in July at each sampling station. The highest density was found in July at Mica Forebay with 2.00 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 September with 2.15 individuals/L (Fig.4). The highest density of *Daphnia* was found in September at Mica Forebay with 3.06 individuals/L. The proportion of *Daphnia* density was the highest at Canoe Reach (19%), while at other stations it varied between 14 and 16%. (Fig. 5, Tab. 2)

Table 2. Seasonal average zooplankton density at four sampling stations in Kinbasket Reservoir in 2012. Density is in units of individuals/L; biomass is in units of µg/L.

		Canoe Reach	Mica Forebay	Columbia Reach	Wood Arm
Density	Copepoda	4.67	6.92	4.58	6.59
	Daphnia	1.18	1.43	0.95	1.11
	Other Cladocera	0.31	0.53	0.46	0.34
	Total	6.17	8.89	6.00	8.05
Biomass	Copepoda	8.42	11.66	9.34	10.47
	Daphnia	26.37	22.99	20.99	24.62
	Other Cladocera	0.51	1.11	0.79	0.59
	Total	35.30	35.76	31.12	35.68

Seasonal average total zooplankton biomass in 2012 was 34.51 µg/L (Fig.6). *Daphnia* had the highest proportion of the total biomass in the whole reservoir 69% with 23.87 µg/L. Copepods made up 29% with 9.90 µg/L, while Cladocerans other than *Daphnia* comprised only 2% of the total zooplankton biomass with 0.74 µg/L. The highest total zooplankton biomass of 52.42 µg/L was found at Wood Arm in October, when *Daphnia* comprised 92% of total biomass with 48.24 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. Among the stations the highest seasonal average *Daphnia* biomass was found at Canoe Reach where *Daphnia* contributed to 75% of the zooplankton biomass. The proportion of seasonal average *Daphnia* biomass at Mica Forebay was 64%, at Columbia Reach 67%, while at Wood Arm proportion of *Daphnia* biomass was 69% (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 2003-2012. 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 2012 peak total zooplankton density occurred in July at 14.07 individuals/L while highest biomass was found in August at 49.29 µg/L (Tab. 3, Fig. 4). *Daphnia* was the most numerous in September with 2.15 individuals/L, while the highest *Daphnia* biomass in the season was in October with 41.64 µg/L.

Table 3. Monthly average density and biomass of zooplankton in Kinbasket Reservoir in 2012. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**
	Copepoda	6.97	12.33	5.60	2.61	1.73	1.49
	Daphnia	0.04	0.33	1.71	2.15	1.81	0.42
	Other Cladocera*	0.04	1.41	0.45	0.07	0.16	0.07
	Total Zooplankton	**7.06**	**14.07**	**7.75**	**4.84**	**3.69**	**1.98**
Biomass		**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**
	Copepoda	8.47	20.25	11.62	6.89	4.23	2.00
	Daphnia	0.71	5.90	36.75	38.24	41.64	8.28
	Other Cladocera**	0.06	2.31	0.91	0.33	0.23	0.15
	Total Zooplankton	**9.25**	**28.46**	**49.29**	**45.46**	**46.10**	**10.42**

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

In comparison to data from the previous year, total zooplankton density decreased while biomass increased in 2012. That was a result of increased number of *Daphnia*, which contributed greatly to the zooplankton biomass. *Daphnia* developed strong and numerous populations in 2012, similar to 2005, which was 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 June to November 2012 the proportion of gravid females averaged 0.16. The highest proportions have been found at Columbia Reach 0.38 in July. On average, gravid female carry 12.61 eggs. The number of eggs per water volume averaged 2.17 eggs/L, and the number of eggs per capita averaged 0.62 eggs/individual (Tab. 4).

Table 4. Fecundity data for *D. bicuspidatus thomasi* in Kinbasket Reservoir in 2003-2012. Values are seasonal averages, calculated for samples collected between May - October 2003, 2005, 2009, 2010 and 2011, May – December 2004, July – October 2008 and June – November 2012.

	2003	2004	2005	2008	2009	2010	2011	2012
Proportion of gravid females	0.12	0.05	0.08	0.11	0.17	0.13	0.15	0.16
# Eggs per gravid Female	12.42	12.42	9.67	11.17	13.86	14.31	14.83	12.61
# Eggs per Litre	1.42	0.29	0.47	2.58	1.68	1.25	1.28	2.17
# Eggs per Capita	0.25	0.25	0.1	0.18	0.48	0.25	0.40	0.62

In Kinbasket Reservoir *Daphnia* gravid females were present from June to November in 2012 (Fig. 11). The proportion of gravid females averaged 0.08 (Tab. 5). The seasonal average number of eggs per gravid female was 2.11. Across the sampling season the number of eggs per water volume averaged 0.12 eggs/L and the number of eggs per capita averaged 0.17 eggs/individual.

Table 5. Fecundity data for *Daphnia* spp. in Kinbasket Reservoir in 2003-2012. Values are seasonal averages, calculated for samples collected between May - October 2003, 2005, 2009, 2010 and 2011, May – December 2004, July – October 2008 and June – November 2012.

	2003	2004	2005	2008	2009	2010	2011	2012
Proportion of gravid females	0.07	0.03	0.03	0.19	0.19	0.12	0.09	0.08
# Eggs per gravid Female	1.80	2.11	1.59	1.91	2.04	1.52	2.08	2.11
# Eggs per Litre	0.16	0.03	0.1	0.13	0.18	1.14	0.07	0.12
# Eggs per Capita	0.15	0.05	0.05	0.37	0.48	0.23	0.25	0.17

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 2012 (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 brachyurum* (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 2003-2012. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2008	2009	2010	2011	2012
Cladocera						
Acroperus harpae	r					
Alona sp.	r			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 brachyurum			r			r
Holopedium gibberum	+	+	+	+	+	+
Leptodora kindtii	+	+	+	+	+	+
Scapholeberis mucronata	r	r	r	r	r	r
Copepoda						
Diacyclops bicuspidatus	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+	+	+
Leptodiaptomus sicilis	+	+	+	+	+	+

4.2 Density and Biomass

The seasonal average zooplankton densities observed in 2003, 2008-2012 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 69% of the zooplankton density and 25% of the zooplankton biomass during the studied period in 2012. *Daphnia* accounted for 10% of the density and 41% of the biomass during the same time period, while other cladocerans comprised 21% of density and 34% of zooplankton biomass (Fig. 13 and 14).

The seasonal average zooplankton density in 2012 (May to October) was 4.70 individuals/L. Copepods were the most abundant with 3.23 individuals/L. Annual average density of *Daphnia* was 0.47 individuals/L, while density of other Cladocerans (mainly *Bosmina* and *Holopedium*) was 1.01 individual/L. (Tab. 7, Fig. 13). Total zooplankton biomass, averaged for the whole reservoir was 20.78 µg/L. Copepods contributed 25% of the total zooplankton biomass with annual average biomass of 5.23 µg/L. *Daphnia* and other cladocerans made up 41% and 34%, with 8.50 µg/L, and 7.05 µg/L of the total zooplankton biomass (Tab. 7; Fig. 14).

Table 7. Annual average zooplankton abundance and biomass in Revelstoke Reservoir 2003-2012. Data are averaged for May to October in 2003, 2009, 2010, 2011 and 2012, and July to October in 2008.

		2003	2008	2009	2010	2011	2012
Density	Copepoda	5.49	7.08	4.96	6.63	3.53	3.23
	Daphnia	2.64	0.77	0.72	0.47	0.25	0.47
	other Cladocera	2.12	1.00	0.73	1.17	0.81	1.01
	Total	**10.25**	**8.85**	**6.41**	**8.27**	**4.59**	**4.70**

		2003	2008	2009	2010	2011	2012
Biomass	Copepoda	10.79	17.32	8.02	9.83	5.35	5.23
	Daphnia	51.56	14.75	12.30	7.56	4.23	8.50
	other Cladocera	6.61	4.69	4.22	7.37	6.47	7.05
	Total	**68.96**	**36.76**	**24.54**	**24.76**	**16.05**	**20.78**

The seasonal average zooplankton densities in Revelstoke Reservoir did not change in comparison to the previous year. In 2011 seasonal average zooplankton density was 4.59 individuals/L and in 2012 4.70 individuals/L. The highest zooplankton density averaged for the whole reservoir was in July with 7.72 individuals/L (Fig. 15). Seasonal average zooplankton biomass in 2012 increased in comparison to the previous year (Tab. 7). The highest zooplankton biomass averaged for the whole reservoir was found in July with 39.90 µg/L. Among the stations, the highest total zooplankton density and biomass were seen at Rev Middle in July with 17.12 individuals/L and 98.59 µg/L (Fig. 16 and 17).

During 2012 sampling season Copepods were the most numerous in May with 4.48 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 summer, than decreased in August, and increased again in September. *Daphnia* density increased at the end of the sampling season, while number of other Cladocera peaked in July (Fig. 15). Other Cladocerans were composed mainly of *Holopedium* and *Bosmina*, averaging 0.59 and 0.41 individuals/L respectively, in the whole reservoir. In July 2012, at station Mid Lake the number of other cladocerans was the highest in the season due to a peak of *Holopedium* with 5.98 individuals/L. In terms of biomass, regardless to their small size, other cladocerans contributed 34% to the total zooplankton biomass. Their biomass was less then 2 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 24.93 µg/L and 66.86 µg/L, and in July at Dam Forebay when the biomass of other cladocerans reached 12.43 µg/L (Fig. 17).

Number of *Daphnia* was low during the entire sampling season in 2012. It was less than 1 individual/L at each station except in September and October at station Mid Lake when *Daphnia* density increased to 2.80 individuals/L and 1.25 individuals/L respectively. Although *Daphnia* were present in samples during the entire season, they accounted for 0.5 to 26% of the zooplankton community from May to October. Its density was relatively low averaging 0.01 to 2.80 individual/L at all three stations from May to October (Fig. 16). However, *Daphnia* biomass was the highest of three zooplankton groups averaging 8.50 µg/L of the sampling season (Fig. 14). The highest *Daphnia* biomass was found at Rev Middle station with 46.95 µg/L in September, when *Daphnia* accounted for 76% 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, made up the majority of the biomass in September.

During 2012 peak total zooplankton density occurred in July with 7.72 individuals/L (Tab. 8, Fig. 15). The peak total zooplankton biomass occurred also in July with 39.90 µg/L, when other cladocerans biomass reached its peak with 26.50 µg/L comprising 66% 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 2012. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
	Copepoda	4.48	4.01	3.98	3.16	3.16	1.41
	Daphnia	0.03	0.08	0.38	0.41	1.04	0.56
	Other Cladocera*	0.18	0.95	3.36	0.39	0.35	0.26
	Total Zooplankton	**4.69**	**5.04**	**7.72**	**3.96**	**4.54**	**2.22**
Biomass		**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
	Copepoda	6.00	5.28	8.21	4.76	5.28	2.34
	Daphnia	0.20	1.60	5.19	6.63	17.47	14.38
	Other Cladocera**	0.58	8.73	26.50	0.80	0.72	0.64
	Total Zooplankton	**6.78**	**15.61**	**39.90**	**12.19**	**23.48**	**17.36**

*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 2012. Gravid females in Revelstoke Reservoir comprise 0-35% of the female population in 2012 (Fig. 18). From May to October the proportion of gravid females averaged 0.16. The highest proportions have been found in June at the Rev Upper station 0.35. On average, gravid female carry up to about 14.80 eggs (Tab. 9). Across the sampling season the number of eggs per water volume averaged 1.06 eggs/L. The number of eggs per capita averaged 0.49 eggs/individual.

Table 9. Fecundity data for *D. bicuspidatus thomasi* in Revelstoke Reservoir in 2003-2012. Values are seasonal averages, calculated for samples collected between July and October in 2008 and May to October in 2003, 2009 - 2012.

	2003	**2008**	**2009**	**2010**	**2011**	**2012**
Proportion of gravid females	0.19	0.18	0.15	0.13	0.16	0.16
# Eggs per gravid Female	15.64	11.18	15.17	17.36	18.51	14.80
# Eggs per Litre	3.18	1.54	1.06	1.18	0.65	1.06
# Eggs per Capita	0.88	0.54	0.89	0.31	0.60	0.49

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 0.08 in 2012 (Tab. 10). The seasonal average number of eggs per gravid female was 2.36. Across the sampling season the number of eggs per water volume averaged 0.09 eggs/L, and the number of eggs per capita averaged 0.21 eggs/individual over the study period in 2012.

Table 10. Fecundity data for *Daphnia* spp. in Revelstoke Reservoir 2003-2012. Values are seasonal averages, calculated for samples collected between July and October in 2008 and May to October in 2003, 2009 - 2012.

	2003	**2008**	**2009**	**2010**	**2011**	**2012**
Proportion of gravid females	0.11	0.20	0.13	0.09	0.09	0.08
# Eggs per gravid Female	2.67	2.66	2.00	1.76	2.41	2.36
# Eggs per Litre	0.32	0.16	1.15	0.07	0.05	0.09
# Eggs per Capita	0.35	0.46	0.28	0.18	0.27	0.21

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. increased in 2012 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. increased in the 2012 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.

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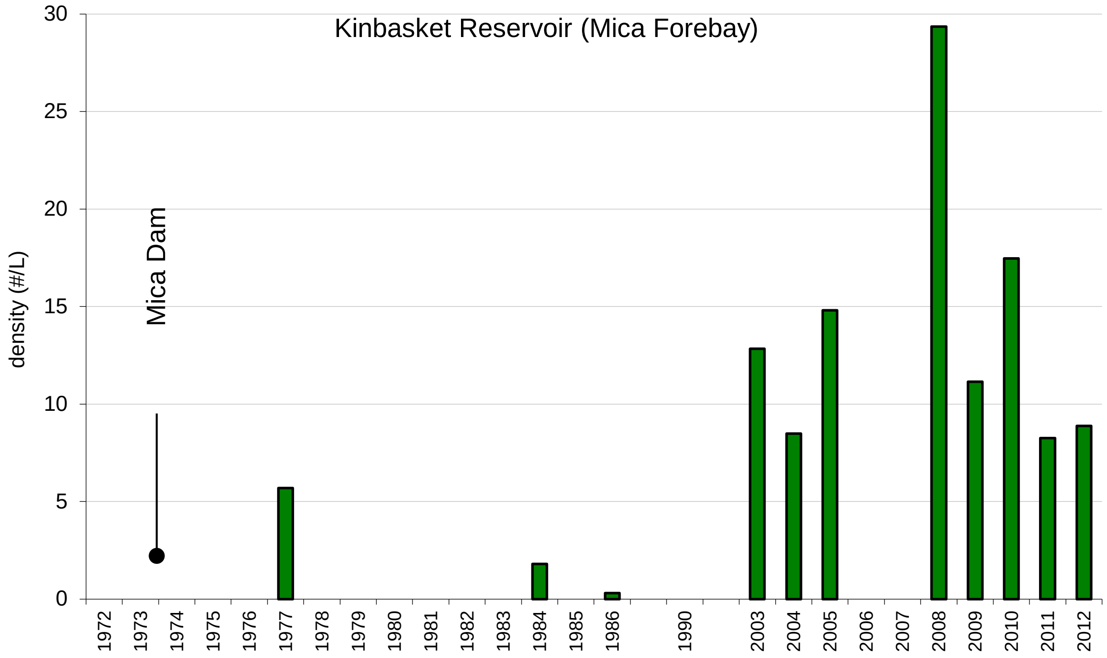


Figure 1. Zooplankton density 1977-2012 at Mica Forebay in Kinbasket Reservoir.

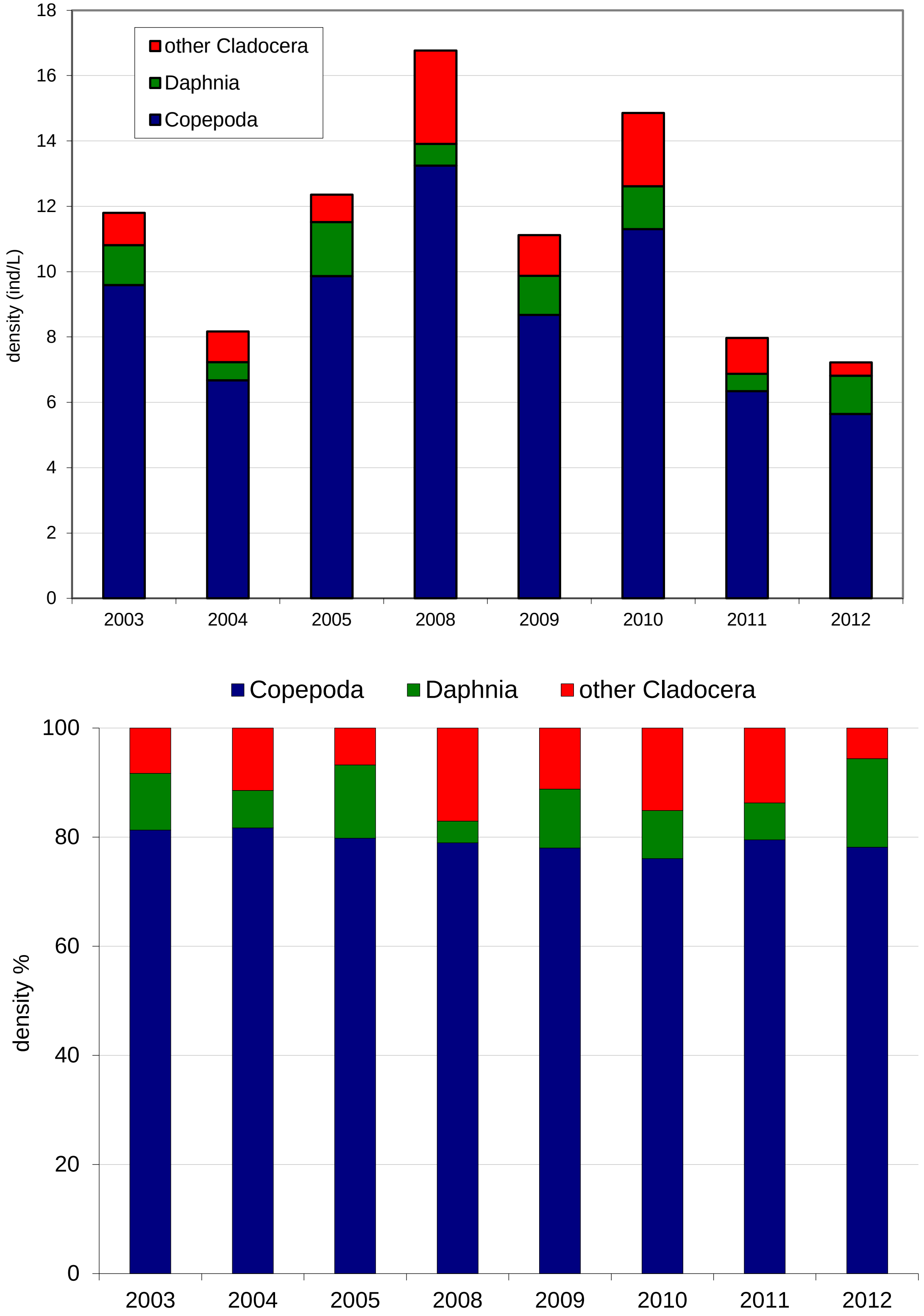
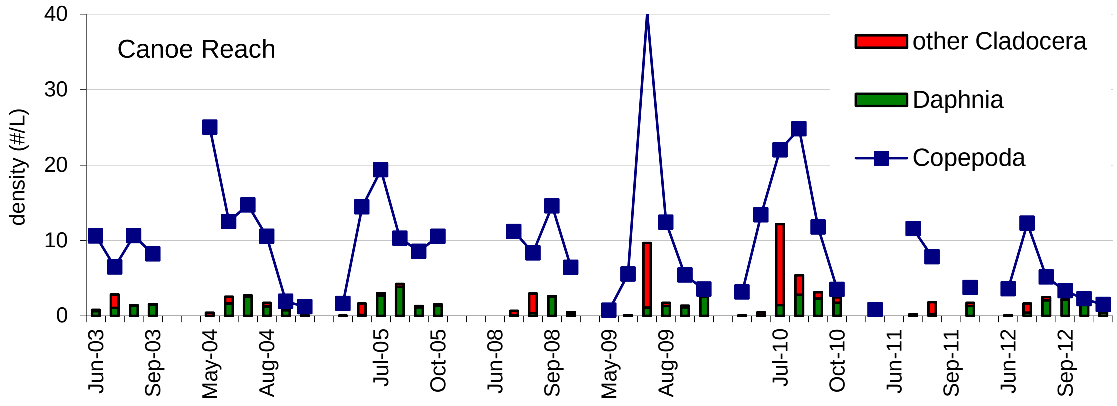


Figure 2. Seasonal average zooplankton density in Kinbasket Reservoir 2003-2012.


Canoe Reach
density (#/L)
40
30
20
10
0
other Cladocera
Daphnia
Copepoda
Jun-03
Sep-03
May-04
Aug-04
Jul-05
Oct-05
Jun-08
Sep-08
May-09
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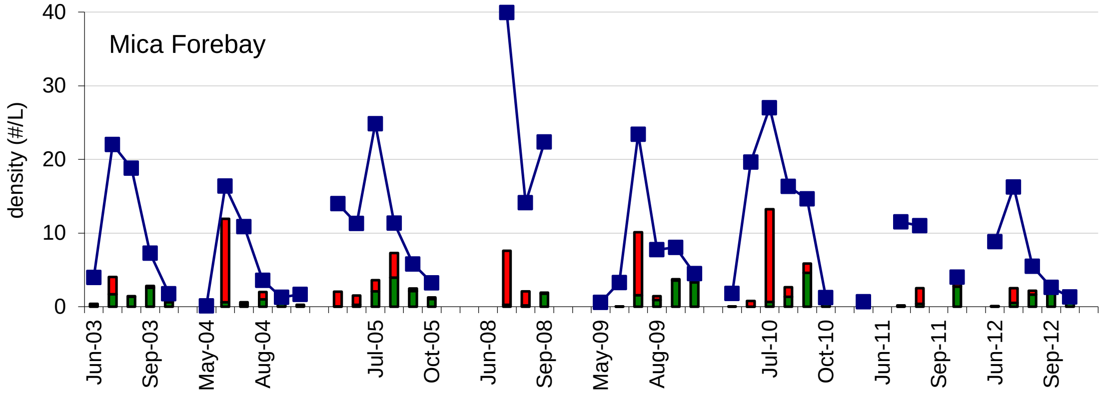
Jun-11
Sep-11
Jun-12
Sep-12


Mica Forebay
density (#/L)
40
30
20
10
0
Jun-03
Sep-03
May-04
Aug-04
Jul-05
Oct-05
Jun-08
Sep-08
May-09
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Jun-11
Sep-11
Jun-12
Sep-12

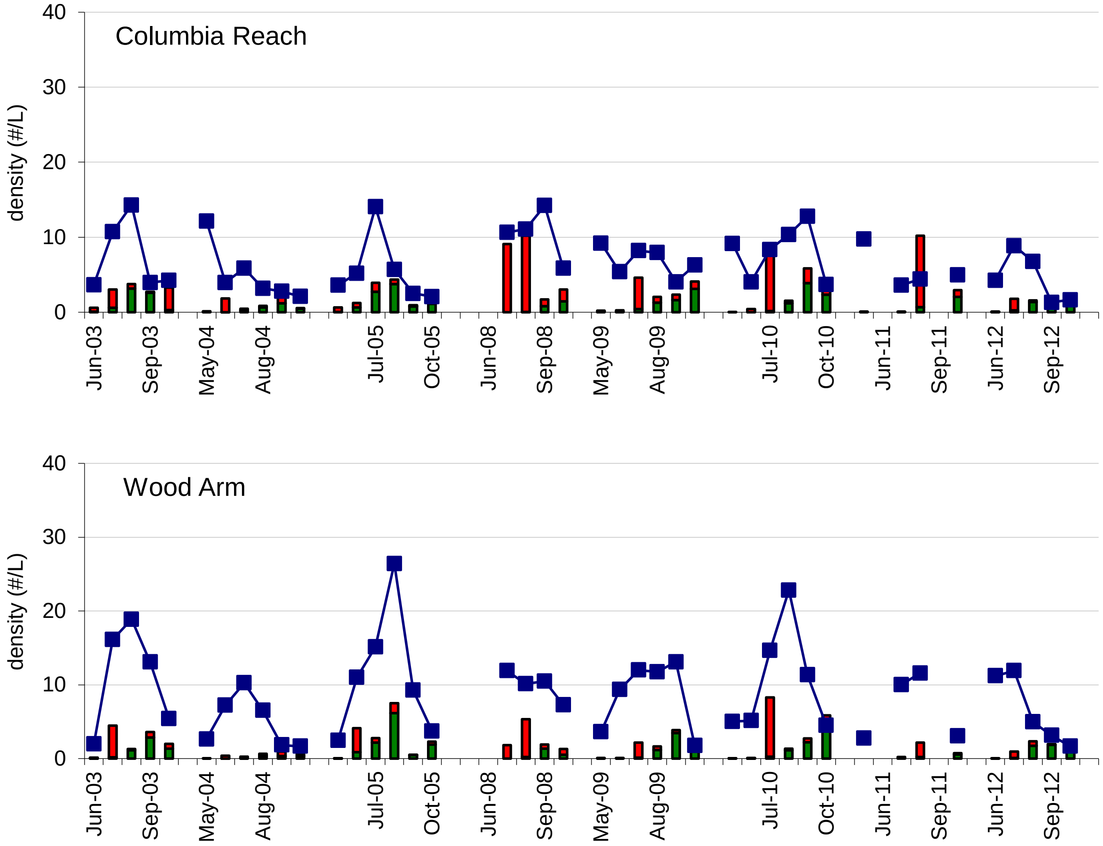

Figure 3. Density of cladoceran and copepod zooplankton in Kinbasket Reservoir in 2003-2012.

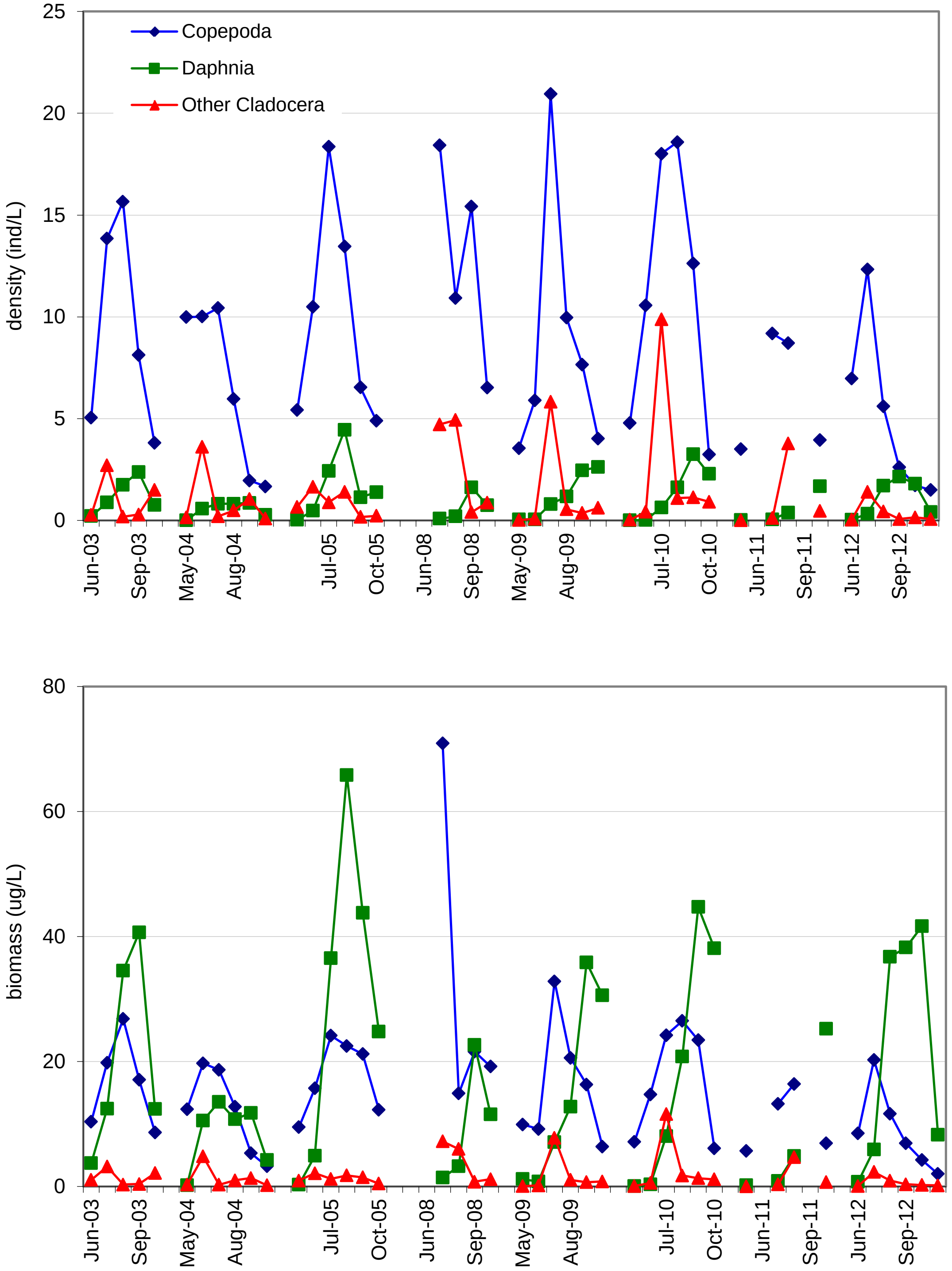

Figure 4. Monthly zooplankton density averaged for the whole Kinbasket Reservoir in 2003-2012.

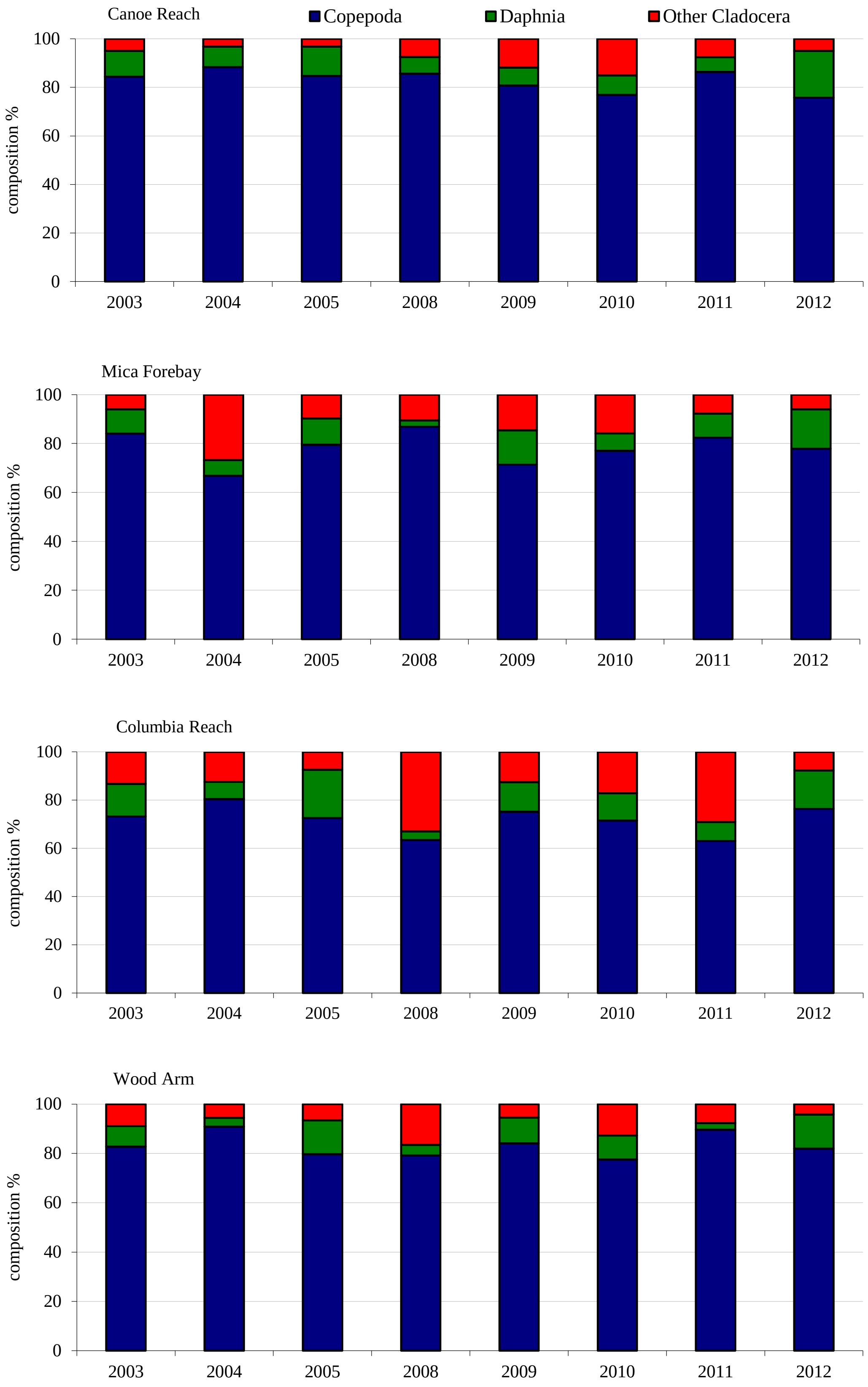

Figure 5. Seasonal average % of zooplankton density composition at four stations in Kinbasket.

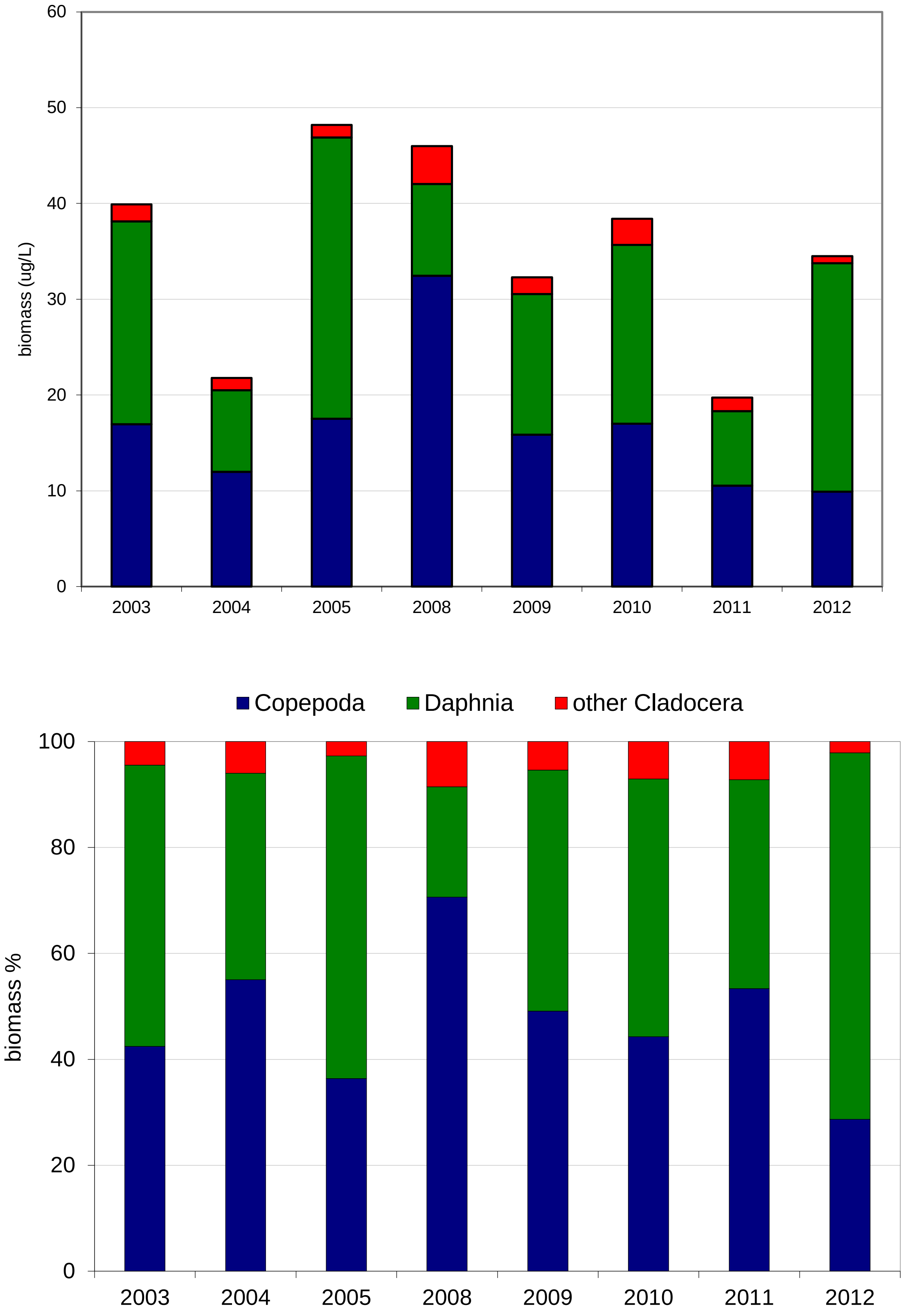

Figure 6. Seasonal average zooplankton biomass in Kinbasket Reservoir 2003-2012.

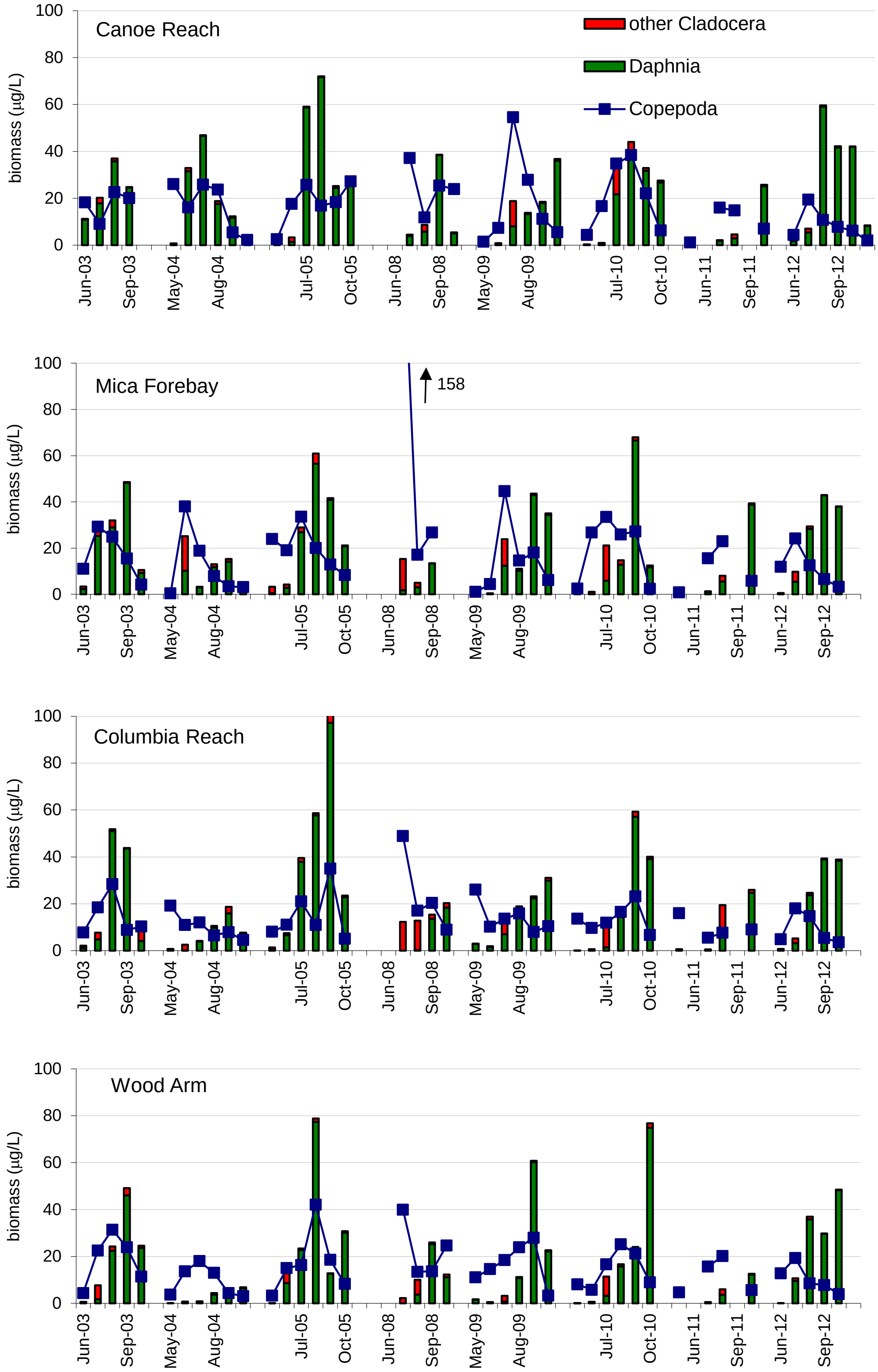

Figure 7. Biomass of cladoceran and copepod zooplankton in Kinbasket Reservoir in 2003-2012.

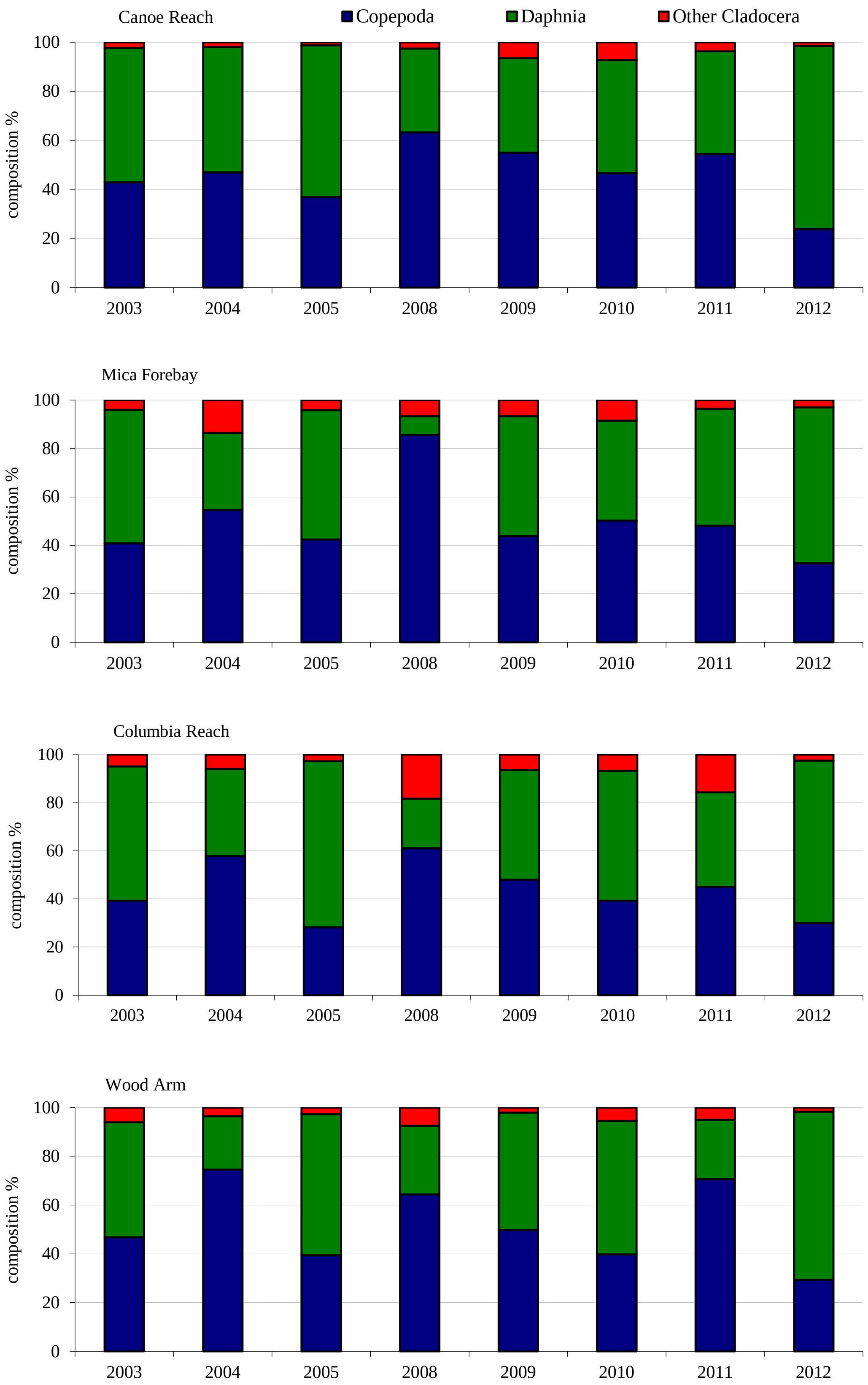

Figure 8. Seasonal average % of zooplankton biomass composition at four stations in Kinbasket.

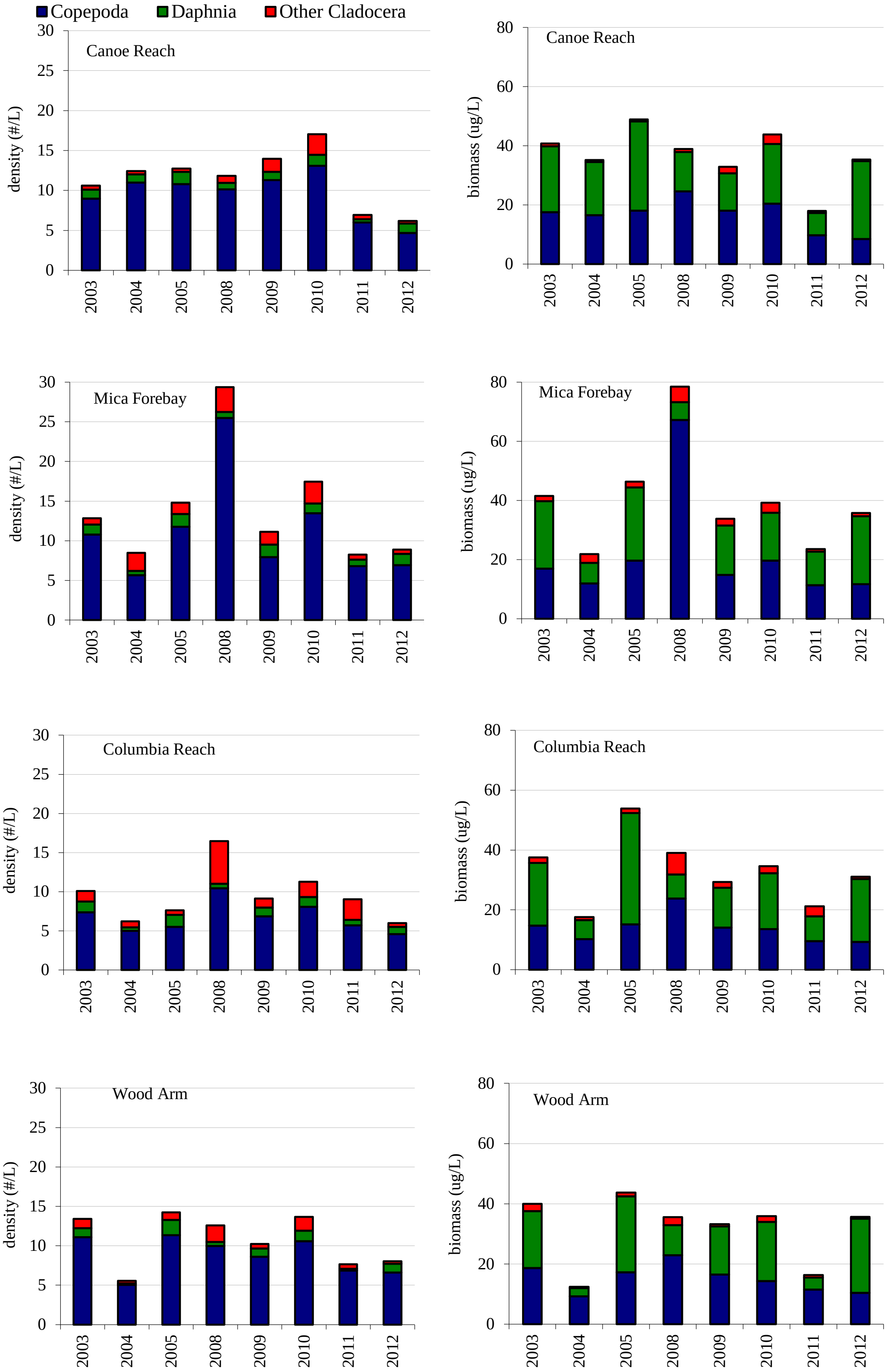

Figure 9. Annual average zooplankton density (left) and biomass (right) at four stations in Kinbasket.

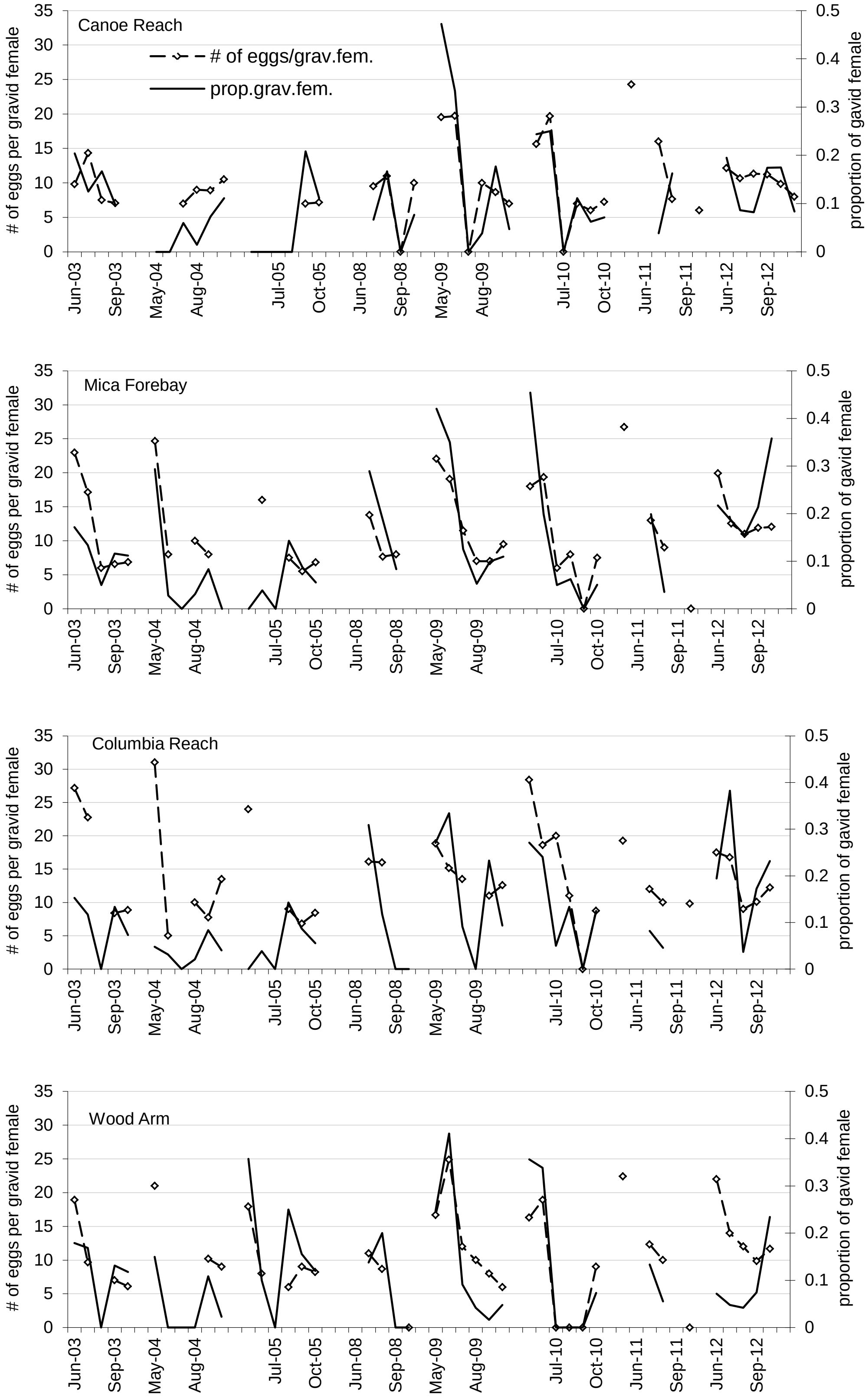

Figure 10. Fecundity features of Diacyclops bicuspidatus in Kinbasket Reservoir in 2003-2012.

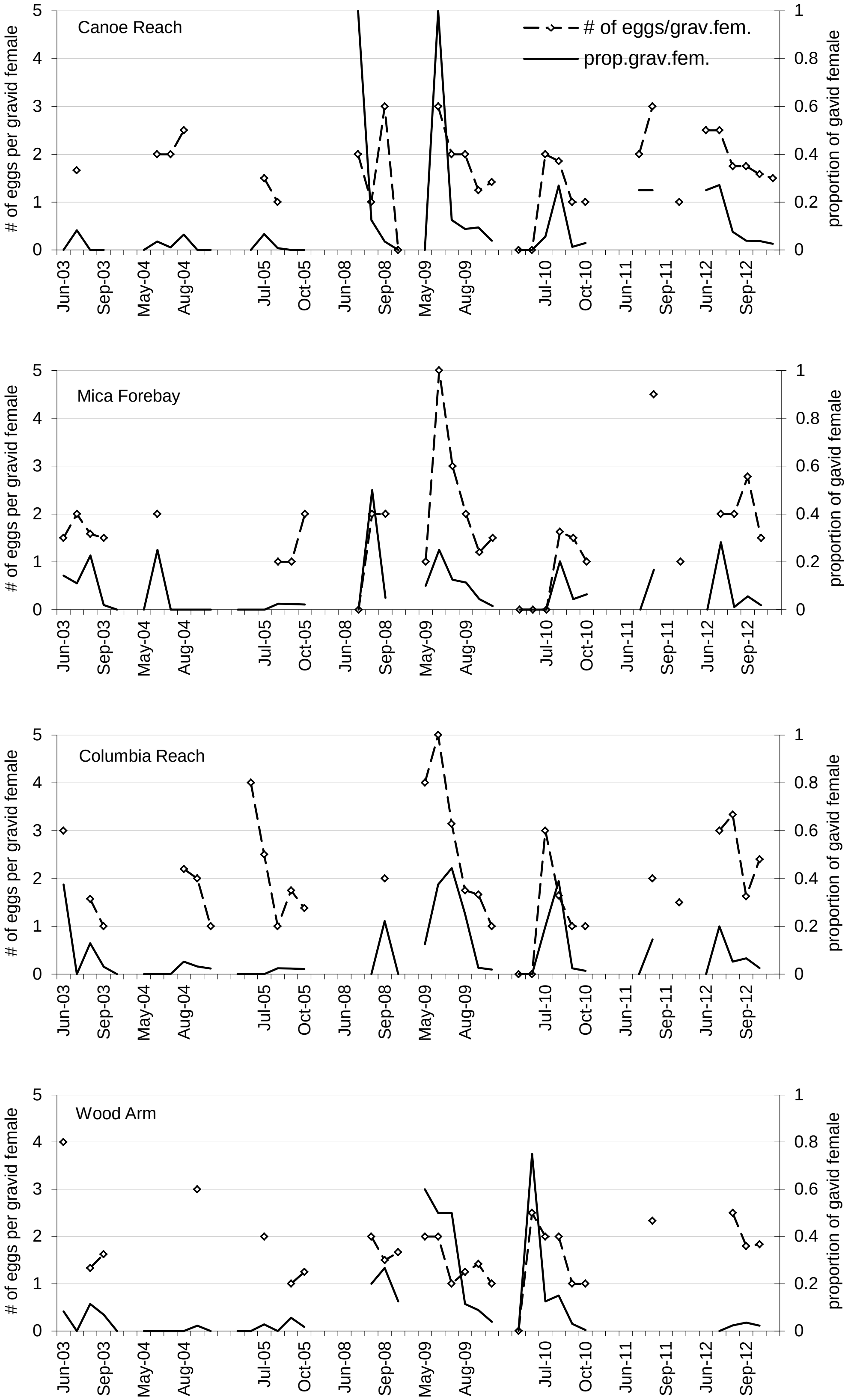

Figure 11. Fecundity features of Daphnia spp. in Kinbasket Reservoir in 2003-2012.

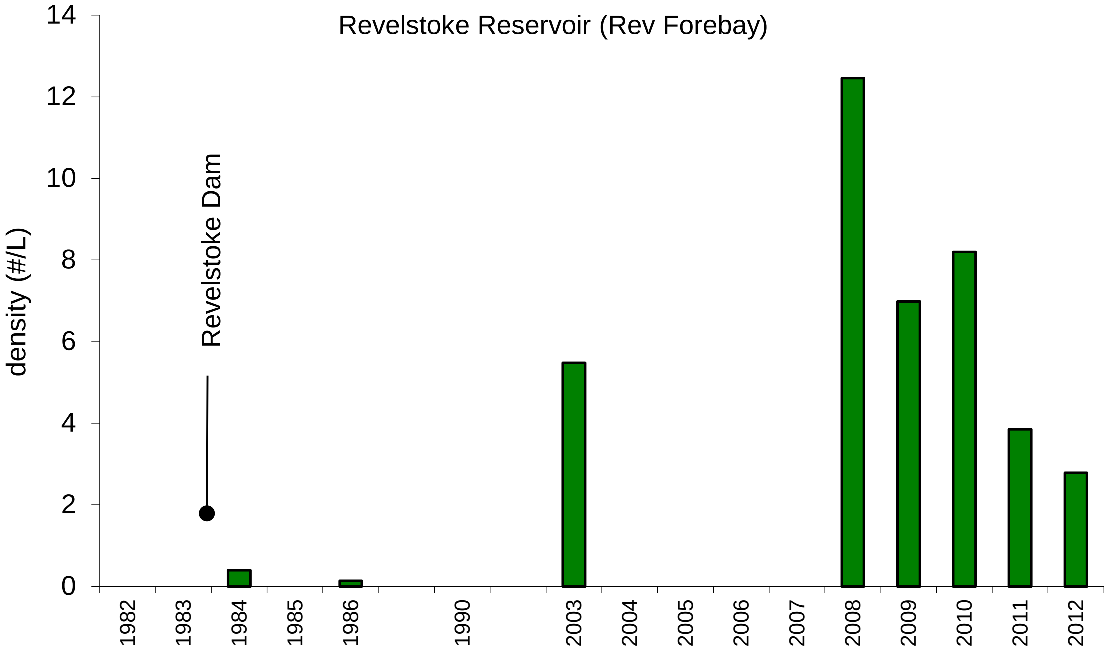

Figure 12. Zooplankton density 1984-2012 at Rev Forebay in Revelstoke Reservoir.

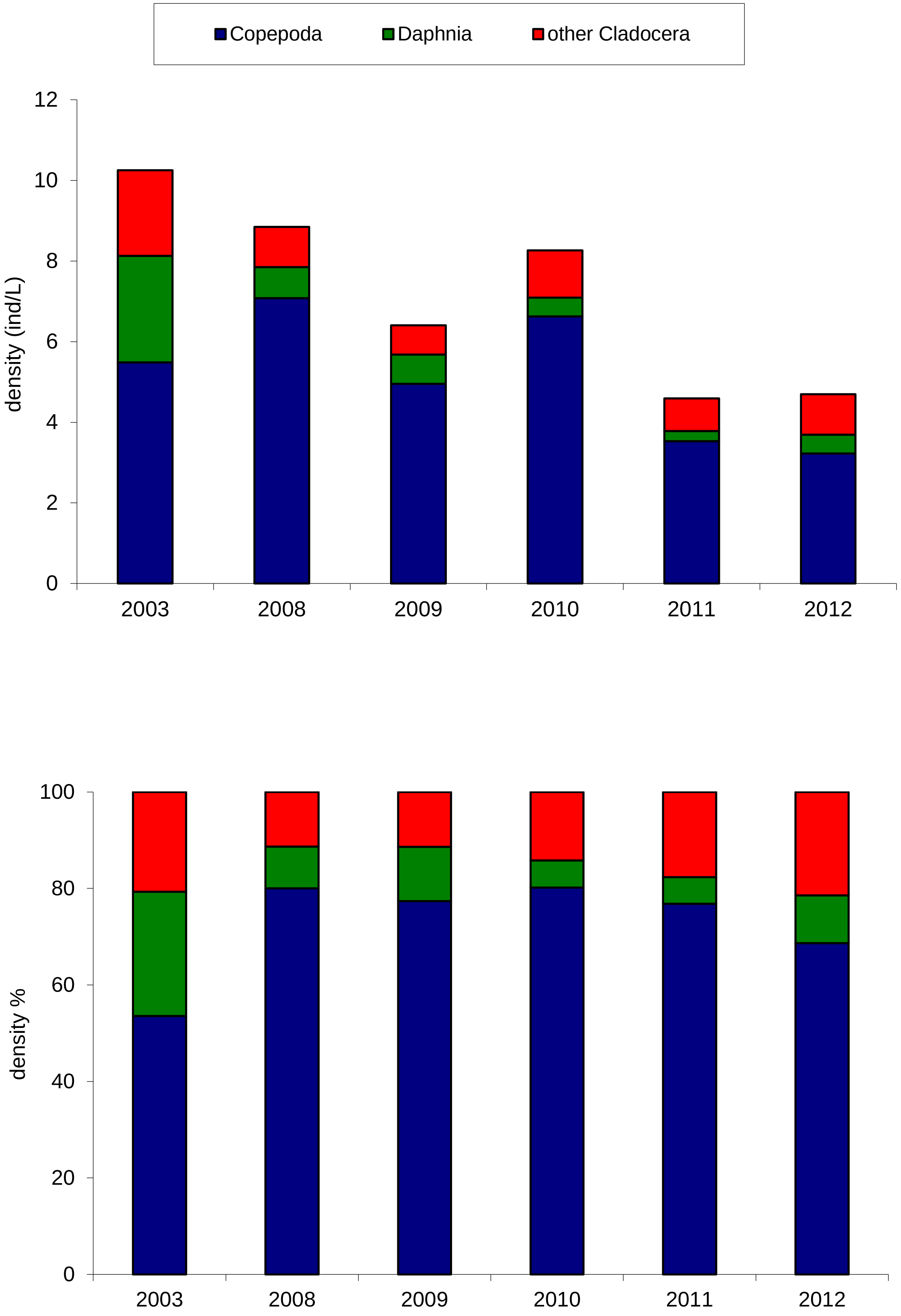

Figure 13. Seasonal average composition of zooplankton density in Revelstoke Reservoir in 2003, 2008 – 2012.

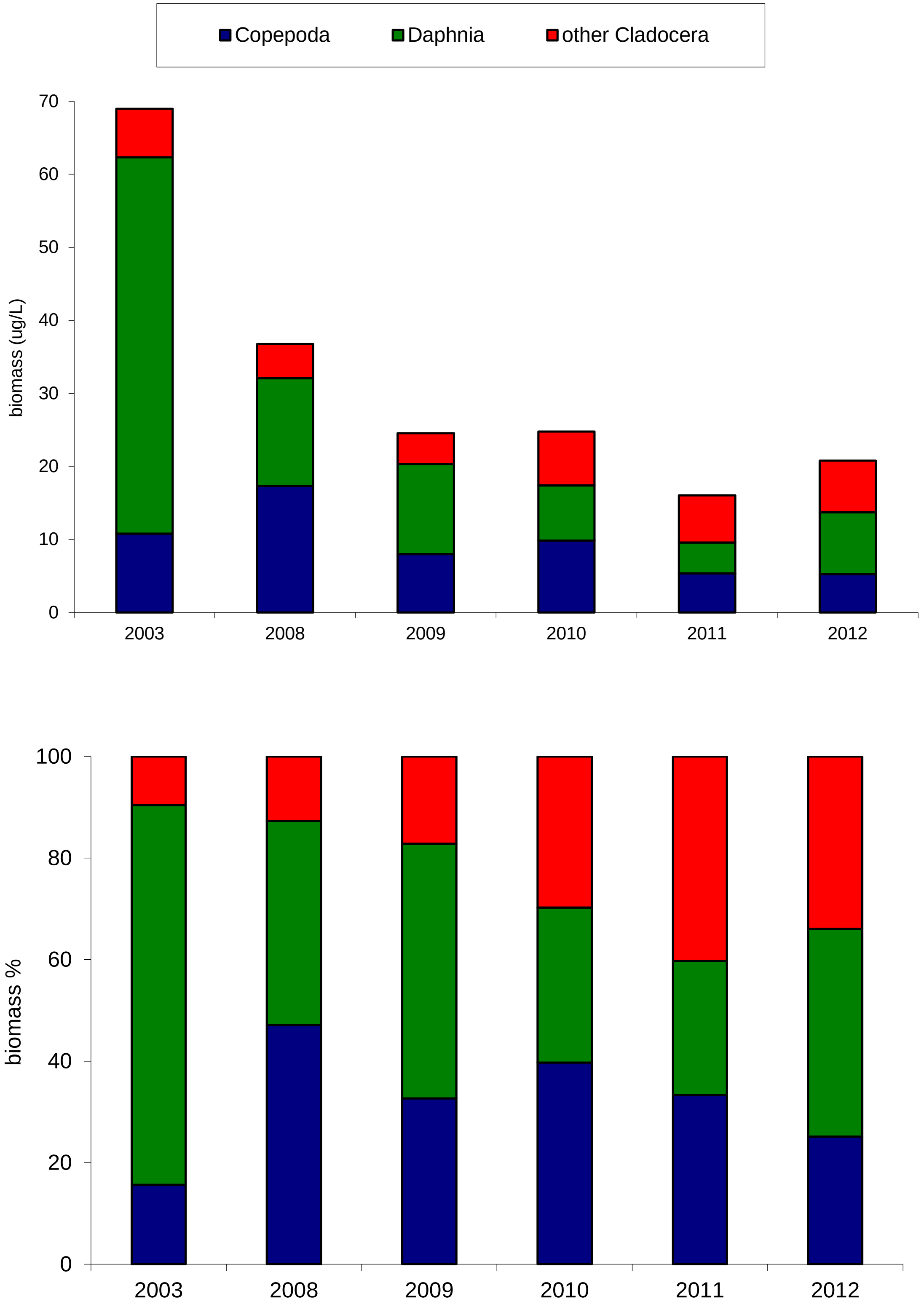

Figure 14. Seasonal average composition of zooplankton biomass in Revelstoke Reservoir in 2003, 2008 – 2012.

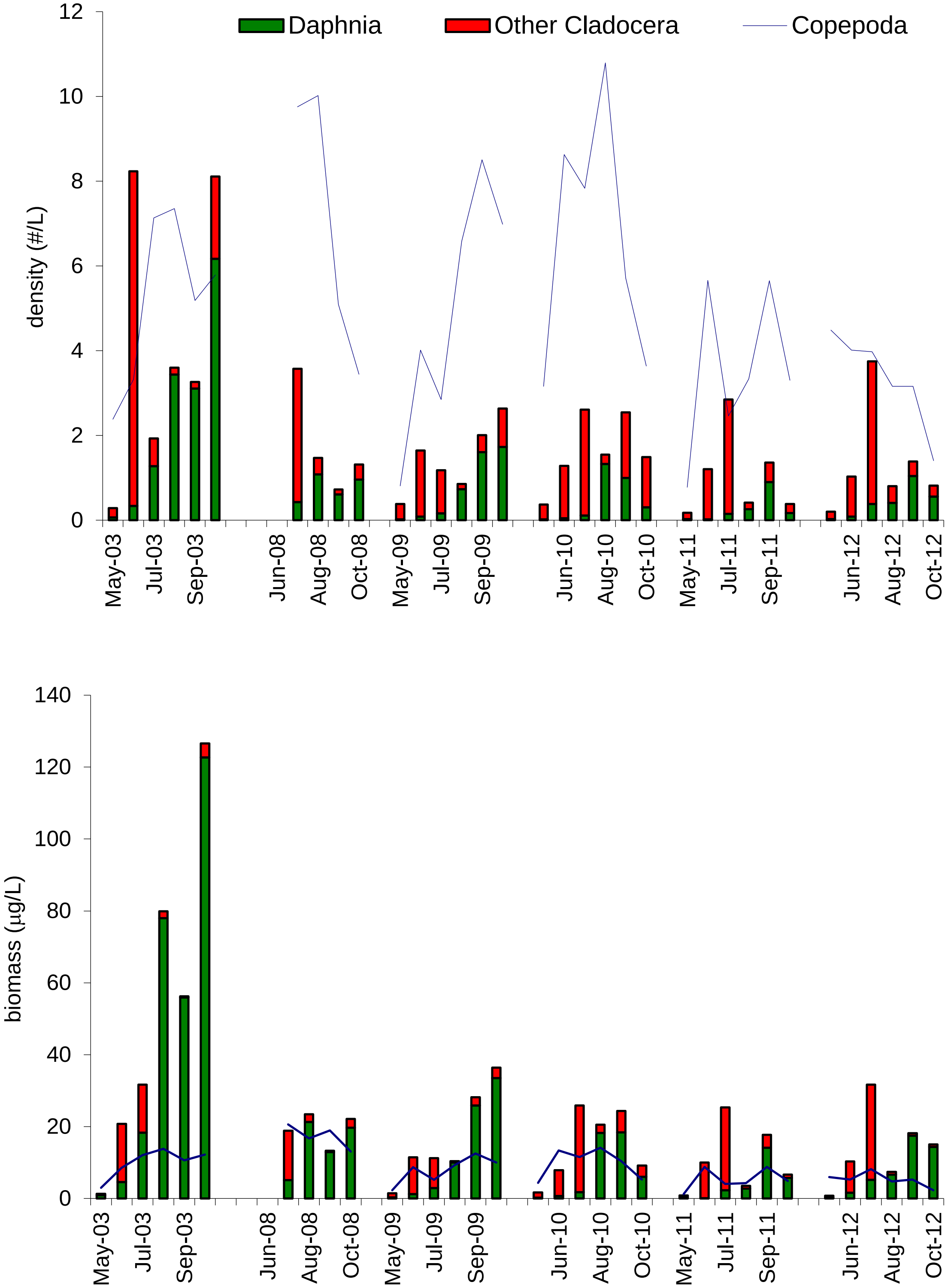

Figure 15. Monthly average zooplankton density (top) and biomass (bottom) in Revelstoke Reservoir.

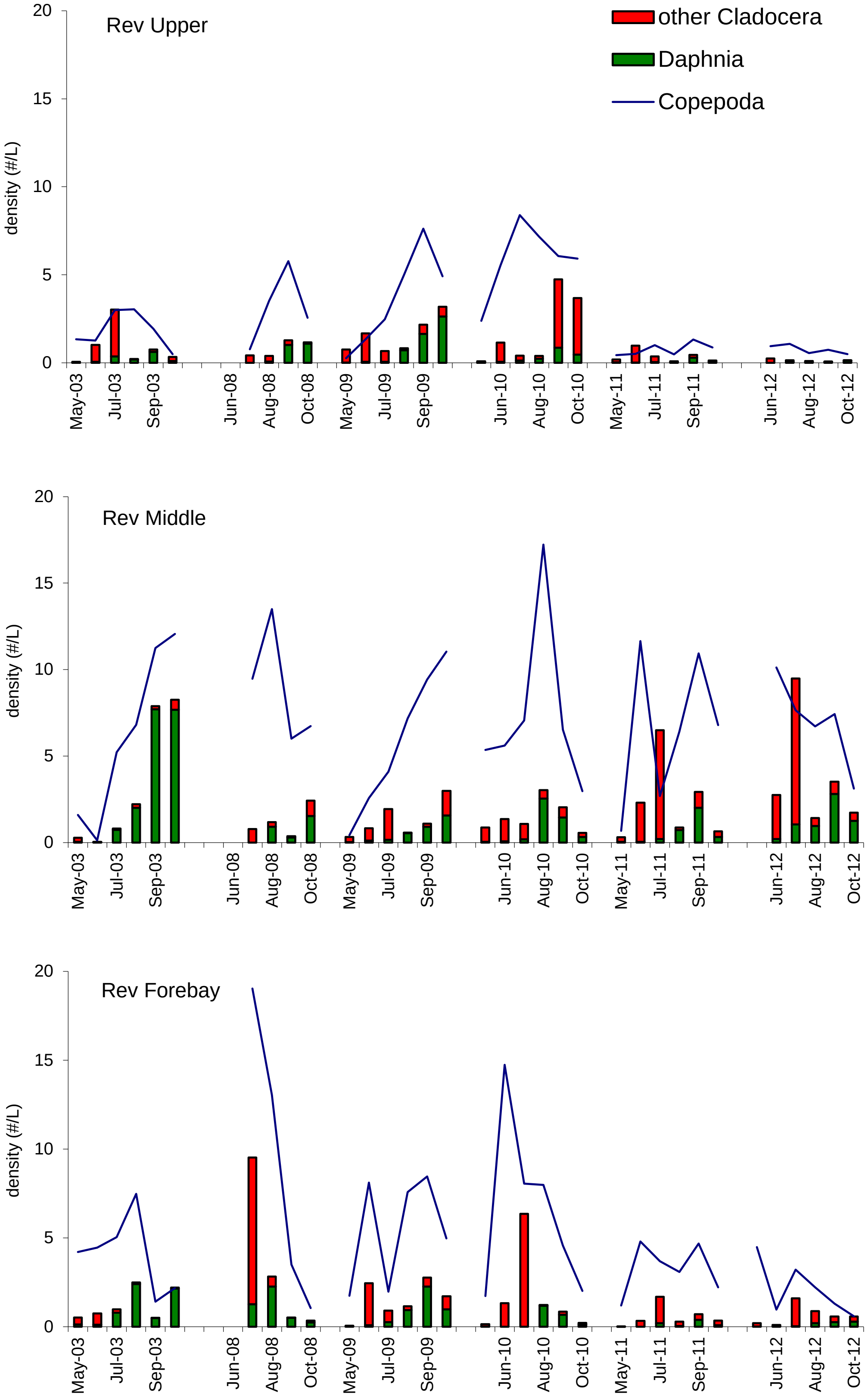

Figure 16. Zooplankton density at 3 stations in Revelstoke Reservoir 2003, 2008 – 2012.

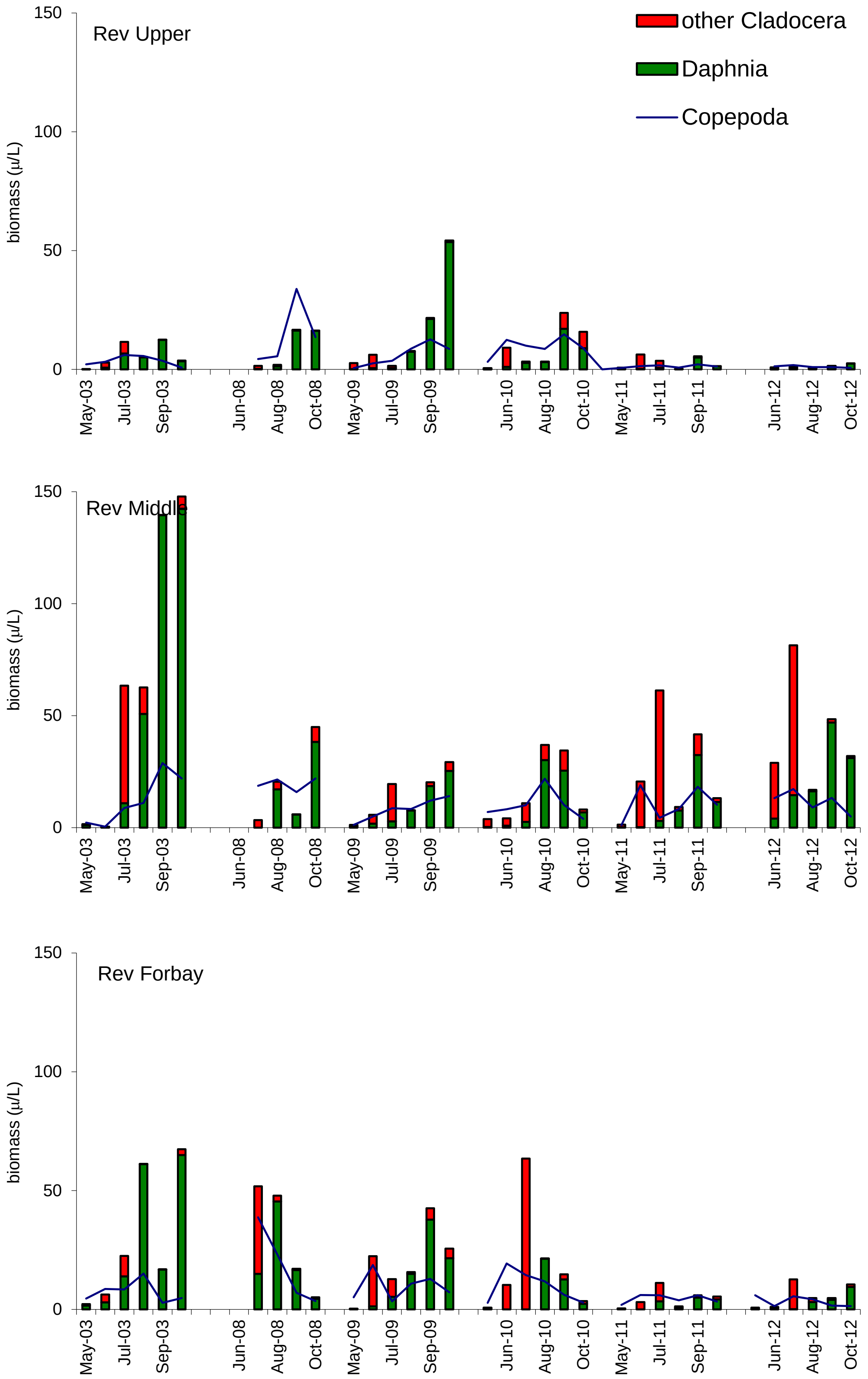

Figure 17. Zooplankton biomass at 3 stations in Revelstoke Reservoir 2003, 2008 – 2012.

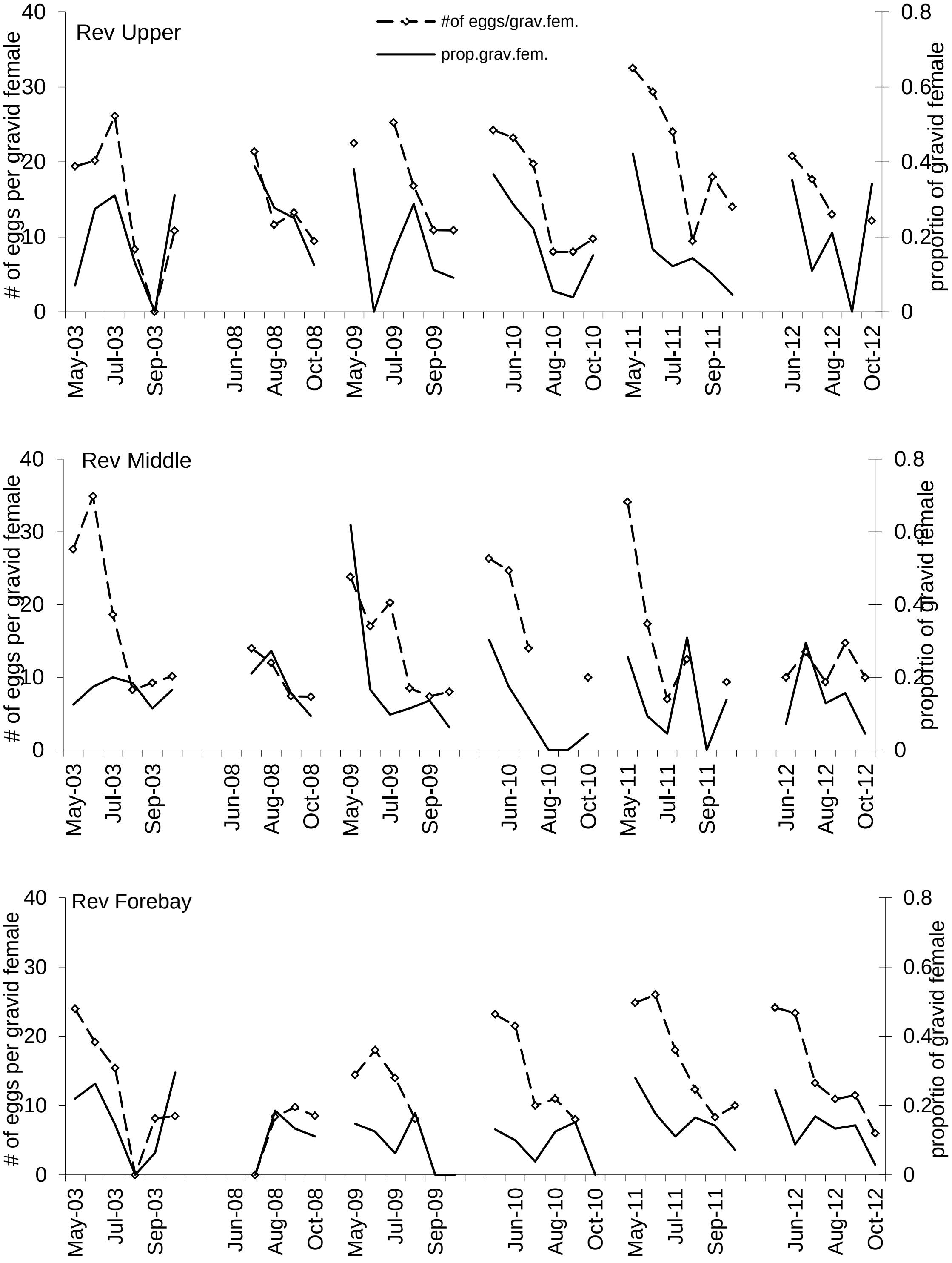

Figure 18. Fecundity features of *Diacyclops bicuspidatus* in Revelstoke Reservoir in 2003, 2008-2012.

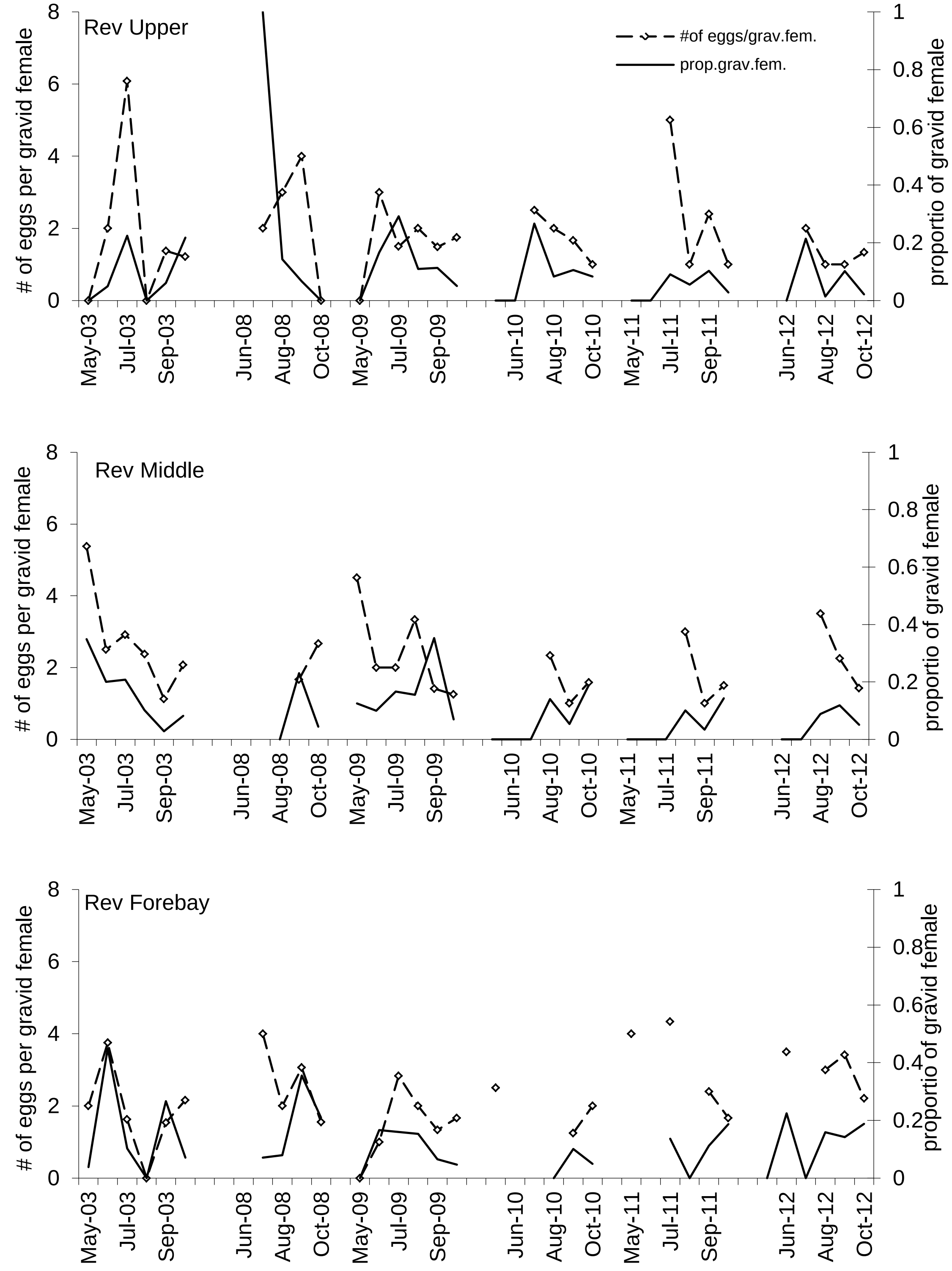

Figure 19. Fecundity features of *Daphnia spp.* in Revelstoke Reservoir in 2003, 2008-2012.

Appendix 8

Moorings
Kinbasket and Revelstoke Reservoirs, 2012

Roger Pieters and Greg Lawrence
University of British Columbia

Moorings,
Kinbasket and Revelstoke Reservoirs, 2012

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

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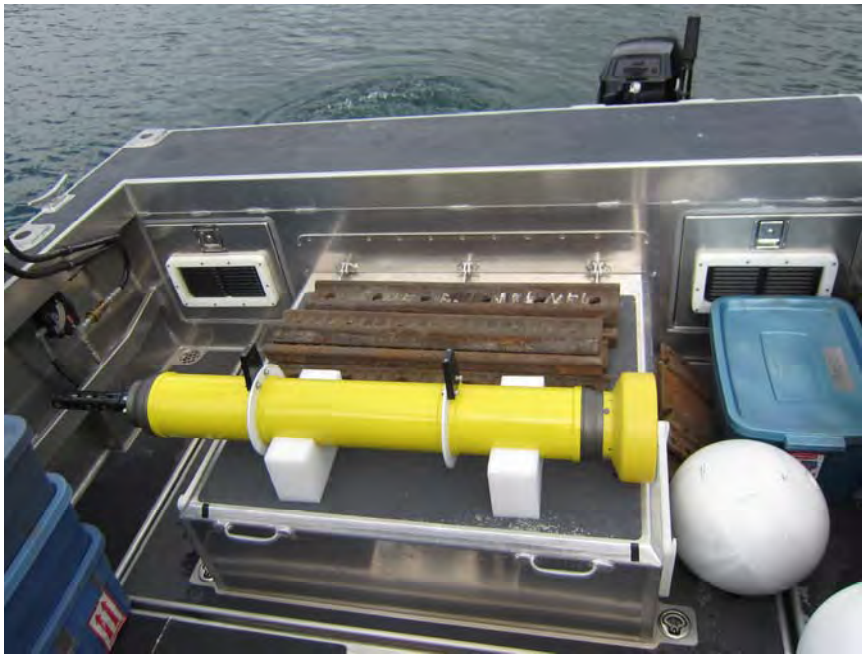

Profiler (yellow) and floats (white) in back of the boat, 11 Sep 2012

Prepared for

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

November 18, 2014

Contents

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1. Introduction

This report introduces the collection of data from moored temperature recorders at fixed sites in Kinbasket and Revelstoke Reservoirs for the B.C. Hydro project “CLBMON-56 Addendum #1 to CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring Program - Mica Project Units 5 and 6 Addendum.” The overall plan and goals are briefly summarized, and data from trial moorings in the forebay of Revelstoke Reservoir in the summer of 2012 are described.

The goal of the ongoing CLMBON-3 project has been to collect long-term data describing basic processes needed to understand reservoir limnology, to investigate long-term trends in pelagic conditions, and to improve our understanding of the effect of reservoir operation on ecosystem function. To address the effect of the addition of two turbines to the Mica powerhouse (Mica 5 and Mica 6), the CLBMON-56 addendum will collect data from moorings of temperature recorders at fixed locations. We propose two base stations, one each in the forebay of Revelstoke and Kinbasket Reservoirs. The goal is to collect data from these base stations throughout the duration of the project. Additional stations are planned, for example, to collect temperature data from the mid and upper stations in Revelstoke Reservoir. These moorings can then be moved in subsequent years to examine processes in different reaches of Kinbasket Reservoir.

Data from moored temperature recorders will complement data gathered by CTD (conductivity-temperature-depth) surveys for CLBMON-3, conducted on average once a month from May to October (Pieters and Lawrence 2014). Temperature recorders will provide data with high temporal resolution, observing reservoir behaviour between the monthly CTD surveys. Data from the moorings will provide information about how rapid changes in inflows and outflows affect a variety of processes such as internal seiches, interflows, and transport of water into the photic zone. These processes are important, for example, to the replenishment of nutrients needed for pelagic productivity in the photic zone (Pieters and Lawrence 2012). Work for CLBMON-56 will include measurement of wind and other meteorological data at the surface of the reservoir; wind and cooling can drive mixing of the surface layer, as well as internal seiches and upwelling, all important to understanding pelagic productivity.

2. Methods

A trial of four different types of moorings was undertaken in the forebay of Revelstoke Reservoir during the summer of 2012. The type of moorings and their duration are summarized in Table 2.1, and their locations are given in Table 2.2.

Table 2.1 Moorings in Revelstoke Forebay, 2012

Name	Date	Description
Rev FB BOOM	18 Jul – 11 Oct 2012	Line hanging from log boom near dam
Rev FB SUB	16 Aug – 11 Oct 2012	Subsurface mooring
Rev FB SPAR	16 Aug – 11 Oct 2012	Spar mooring
Rev FB PROF	11 Sep – 11 Oct 2012	Profiler

Table 2.2 Location of moorings, 2012

Name	UTM Easting(11U)/Northing	Latitude/ Longitude
Rev FB BOOM	416,518E 5,656,309N	51° 3.134 N 118° 11.464 W
Rev FB SUB	416,942E 5,657,543N	51° 3.804 N 118° 11.119 W
Rev FB SPAR	416,846E 5,657,294N	51° 3.668 N 118° 11.197 W
Rev FB PROF	417,057E 5,657,845N	51° 3.968 N 118° 11.024 W

Temperature recorders consisted of Onset Hobo Water Temp Pro V2 (HWTP) recorders and Seabird SBE56 recorders. The characteristics of the temperature recorders are given in Table 2.3. Because of their low cost, HWTP recorders were typically used every 2 m while the more accurate, but more expensive SBE56 recorders were used every 20 m. To assess movement of the moorings, several RBR Duo TD recorders were also used to measure both temperature and pressure (depth).

Table 2.3 Temperature recorders

Instrument	Resolution	Accuracy	Time response	Typical annual sample rate	Max depth
HWTP	0.02°C	±0.2 °C	5 min	15 min	120 m
SBE56	0.0001°C	±0.002 °C	0.5 sec	10 sec	1500 m
RBR Duo	0.00005 °C	±0.002 °C	~1 sec	5 sec	200 m*

* Limited by the pressure sensor

The SUB, SPAR and BOOM moorings used 5/8 inch Samson Quick Splice single-braid bi-polymer olefin line (specific gravity 0.94, 7.0 kg/100m, average strength 3000 kg). This line was chosen to be buoyant, have good handling, low abrasion and little stretch.

Each the moorings (except for the mooring hung from the log boom at the dam) made use of an Interocean Model 111 acoustic release. The release is located just above the anchor, and upon receiving a coded acoustic signal the release disconnects from the anchor, the float carries the mooring and release to the surface allowing for recovery of the mooing without the anchor. This makes it possible to deploy the moorings from a smaller boat without the need for a crane to recover the moorings. These releases have an extended-life battery option, enabling deployments for up to one year.

A schematic of the four types of moorings is shown in Figure 2.1, and are described as follows:

REV FB SUB This is a subsurface mooring; the float is below the water surface. In Revelstoke there is little water level variation so that the float can be located a few meters below the surface, depending on water clarity, the float can usually be seen from the boat. The float consists of two 14 inch (36 cm) hard shell trawl floats which together provide approximately 80 lbs (36 kg) of floatation at the top of the mooring, balanced by 160 lbs (72 kg) of steel anchor at the bottom. As the temperature recorders are anchored at the bottom, they do not rise and fall with water level changes, but remain at a fixed elevation. Use of a subsurface float means the mooring is much less likely to be snagged by surface debris or moved by any ice that may form. Instruments are concentrated in the upper part of the mooring, both above and below the level of the intake (~ 30 m depth), see Figure 2.1.

REV FB BOOM The short line attached to the log boom near the dam is meant to record temperature in the near surface which is not sampled by REV FB SUB. This line rises and falls with water level changes. A steel weight of approximately 35 lbs (16 kg) was attached at the bottom to keep the line vertical.

REV FB SPAR The spar buoy consists of a 8 ft (2.4 m) aluminum pole holding three close-cell foam floats with a combined floatation of ~120 lbs (54 kg). The spar is held upright by 5.5 m of ¼ inch chain weighing ~11 lbs (5 kg) attached directly to the spar, and by a weight of 25 lbs (11 kg) at 34 m. This mooring tested whether the spar was suitable as a platform for measuring wind at the water surface; a wind monitor was not attached in 2012. There were, however, several temperature recorders below the spar, which duplicated data collected by REV FB BOOM.

REV FB PROF In addition to traditional temperature recorders, an experimental tethered autonomous profiler was also moored in Revelstoke forebay. The profiler consisted of a Teledyne Webb Apex APF9I float. These type of floats are normally deployed in the open ocean where they reside at depth (e.g. 1000 m), rise on a regular basis (e.g. every 10 days) to collect a profile of temperature, conductivity and other parameters; on reaching the surface, the data and GPS location of the float is telemetered by ARGO satellite. There are thousands of these floats throughout the oceans collecting data that would otherwise be very costly to gather by boat. Most of these ocean profilers are treated as expendable, lasting about three years.

We were able to purchase three Apex floats through the NSERC Research Tools and Instruments program. The three floats were specifically designed to slide up and down on a low friction tether consisting of nylon coated stainless steel wire held taut by 80 lbs (36 kg) of subsurface floatation at the top and 160 lbs (72 kg) of anchor at the bottom. This makes these profilers suitable for mooring in lakes and reservoirs. Since the float does not rise all the way to the surface, it does not have satellite communications, and instead data is recorded within the float. The float is capable of collected daily CTD profiles for more than one year. Once recovered, the data is uploaded, and the batteries are changed for another deployment. These floats each have a Seabird SBE 41cp CTD and a Seapoint turbidity meter.

3. Results

All four trial moorings were successfully deployed, recovered and uploaded. The mooring hung from the log boom in the forebay of Revelstoke Dam (REV FB BOOM) was the first to be deployed (18 Jul 2012), giving the longest record of the four moorings (Table 2). Temperature data measured by instruments attached to this mooring are shown in Figure 3. All graphs are plotted in days of 2008, the year the CLBMON-3 project began.

Near the surface (0.5 m depth), the temperature generally varied from 15 °C to just over 20 °C, while at the deepest sensor (26.5 m), the temperature generally varied between 8 and 12 °C. On top of this seasonal pattern there are other variations on a variety of time scales, the most notable of which is large changes in temperature every 14 to 23 days. For example, the temperature at 0.5 m dropped from 18.4 °C at 16:00 22 August 2012 (day 1696.67) to 12.1 °C after 17 hours, shown in the inset in Figure 3.1. This reduced temperature at 0.5 m lasted about 3 days. Likewise there are also large increases in deeper temperature: for example at 18.5 m, the temperature of 11.1 °C on 15 August 2012 (day 1689.67) rose to 16.7 °C in 12 hours. This increased temperature at 18.5 m lasted just over 1 day. These variations indicate internal wave activity, the origin of which will be discussed in a future report.

The subsurface mooring (REV FB SUB) was installed on 16 Aug 2012 (day 1690), a month later than REV FB BOOM. The temperatures measured by instruments on the REV FB SUB mooring are shown in Figure 3.2; temperature recorders were at nominal depths (relative to full pool) of 4.4 to 124 m. As in REV FB BOOM, the surface shows gradual seasonal cooling modulated by internal waves. The temperature at 124 m is comparatively steady, rising very slowly by ~0.1 °C/month, similar to that observed in other deep lakes.

The spar mooring (REV FB SPAR) was installed at the same time as the subsurface mooring to measure near surface temperatures. The temperatures measured at 5 depths using this mooring are shown in Figure 3.3. The temperature at 0.5 m rises to just over 19 °C in mid-August. The peaks in temperature at 0.5 m record the daily heating of the surface by the sun.

The profiler (REV FB PROF) was deployed a month later, on 11 September 2012, sampling every 4.9 hours, and collecting a total of 146 profiles. Temperature, raw salinity and turbidity data are shown as contour plots in Figure 3.4. The black bars mark the 1% light level determined from the profile data (Pieters and Lawrence 2014a). The depth of the reservoir outlet is marked with an arrow.

The profiler data suggests that interflow water spends some time in photic zone. To see this, begin with salinity, which indicates the origin of the water (Figure 3.5b). The water below 80 m is relatively unchanged since the spring (cf Pieters and Lawrence 2014a,

Figure D8); this quiescent deep water is slightly more saline (<64 mg/L), and turbidity increases particularly near the bottom, suggestive of settling debris.

During spring and early summer, inflow from Kinbasket Reservoir was relatively low, and inflow to Revelstoke Reservoir was dominated by inflow of relatively fresh snowmelt from local tributaries (Pieters and Lawrence, 2014b). This resulted in relatively low salinity (<60 mg/L) throughout the top 60 m of the reservoir until mid-July (Pieters and Lawrence, 2014a). By October, remnants of this low salinity water are observed near the surface, and as a band around 60 m depth (Figure 3.5b).

In mid-July a big change occurs with a the sudden increase in deep outflow from Kinbasket Reservoir, from close to zero to over 1500 m^3/s. This cool, slightly higher salinity (>60 mg/L), and higher turbidity water forms an interflow along the length of the reservoir centered around 30 m depth (for further detail see Pieters and Lawrence 2012, 2014abc).

From the profile surveys, the nutrients in the interflow appeared to short circuit through Revelstoke Reservoir, namely these nutrients appeared to pass through the reservoir below the 1% light level directly to the outlet. However, the one month record of profiler data indicated two periods when part of the interflow was within the photic zone: about a third of the interflow depth was in the photic zone for about 3 days from 11 – 14 September 2012, and about a quarter of the interflow depth was in the photic zone for about 5 days (30 September to 4 October 2012). This suggests that nutrients in the interflow may be able to contribute to pelagic productivity.

Temperatures from all four moorings were compared at selected depths, and were found to be generally similar (Figure 3.5). Near surface data (4.5m), available from all four moorings, was quite similar (Figure 3.5a). At 20 m the temperature was around 9 °C at the start of the record in mid-July, warming to about 11 °C near the end of August and beginning to cool again in early September. On top of this general trend were occasional brief increases to almost 16 °C; temperatures were sometimes dissimilar during these changes (Figure 3.5b). At 30 m, close to the depth of the outlet, the temperature was quite steady with only one warmer period (Figure 3.5c). Larger changes in temperature were observed at 60 m (Figure 3.5d), while temperature at 80 and 100 m showed gradual warming throughout the record (Figure 3.5e,f). Differences between moorings are likely due to their slightly different locations.

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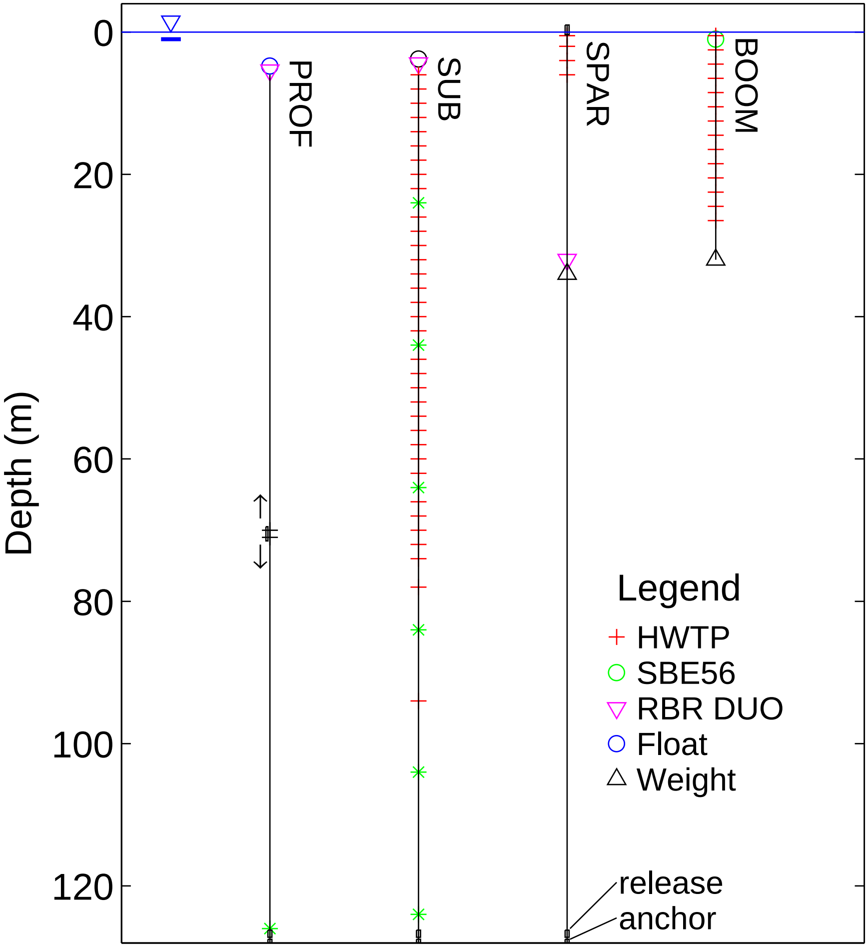
Figure 2.1 Revelstoke Forebay Moorings, 2012



/ocean/rpieters/kr/moor/schem/moorschemRevFB2012.m fig= 1 2014−Oct−01

Figure 3.1 REV−FB−BOOM, Jul 18 − Oct 11, 2012

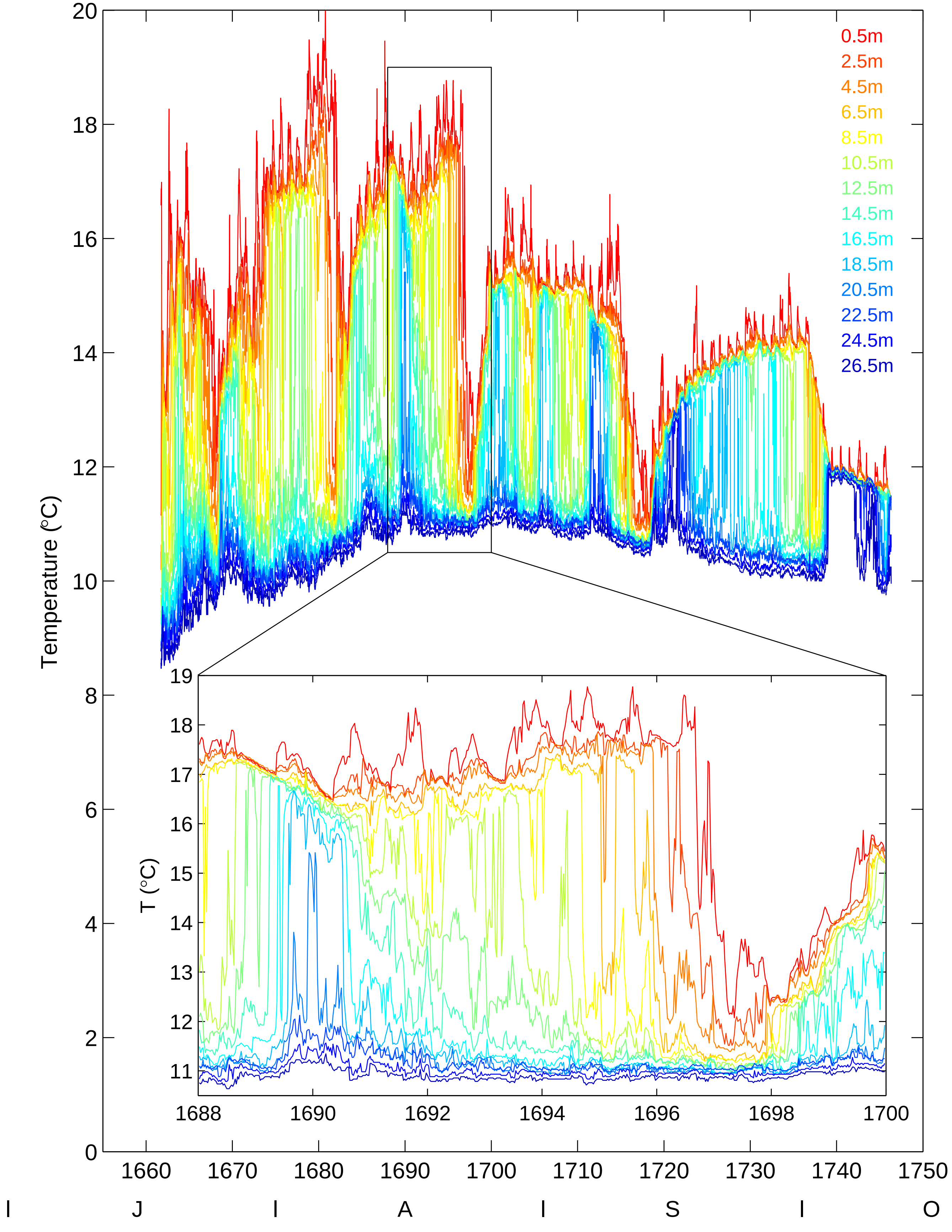


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Figure 3.2 REV−FB−SUB, Aug 16 − Oct 11, 2012

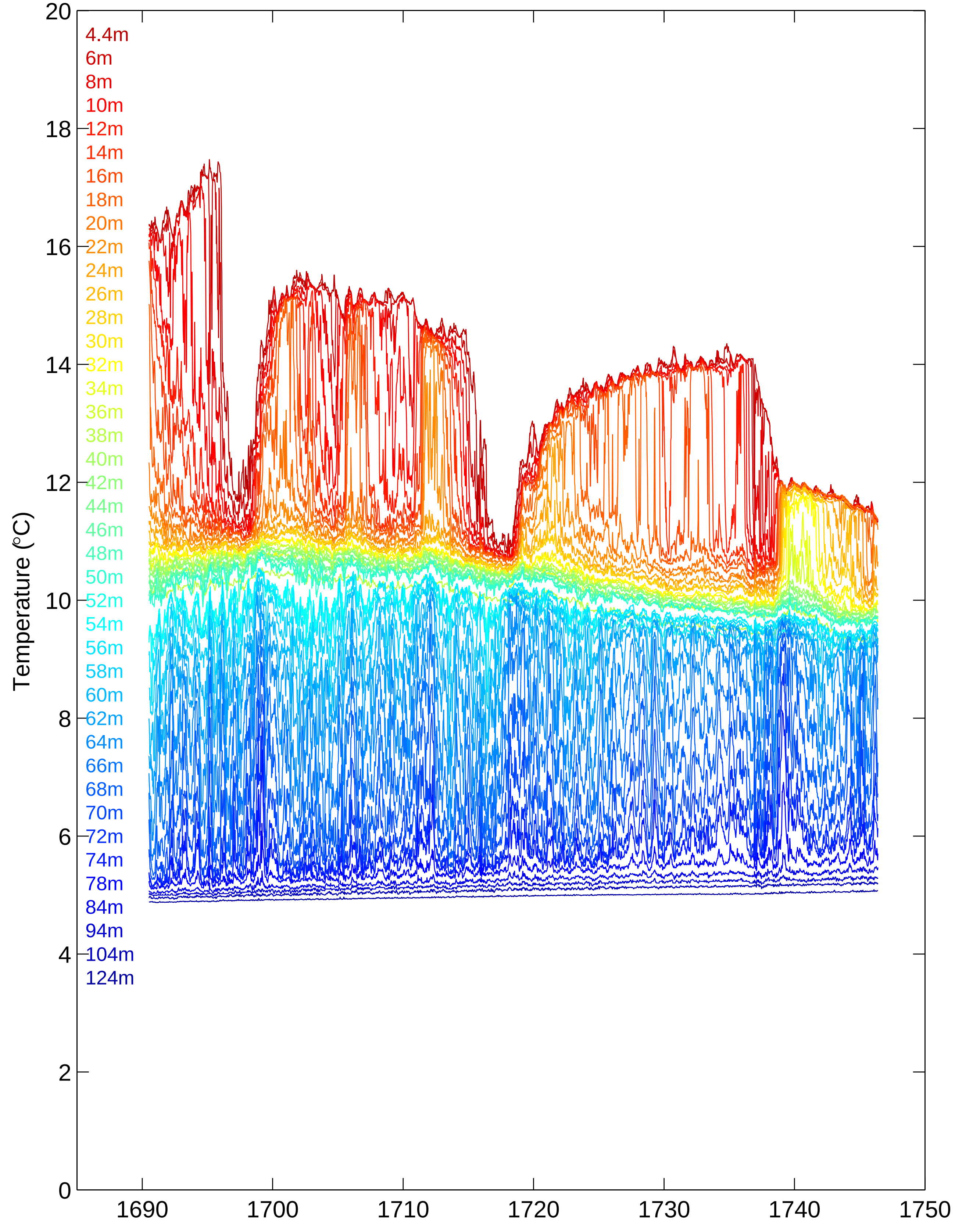

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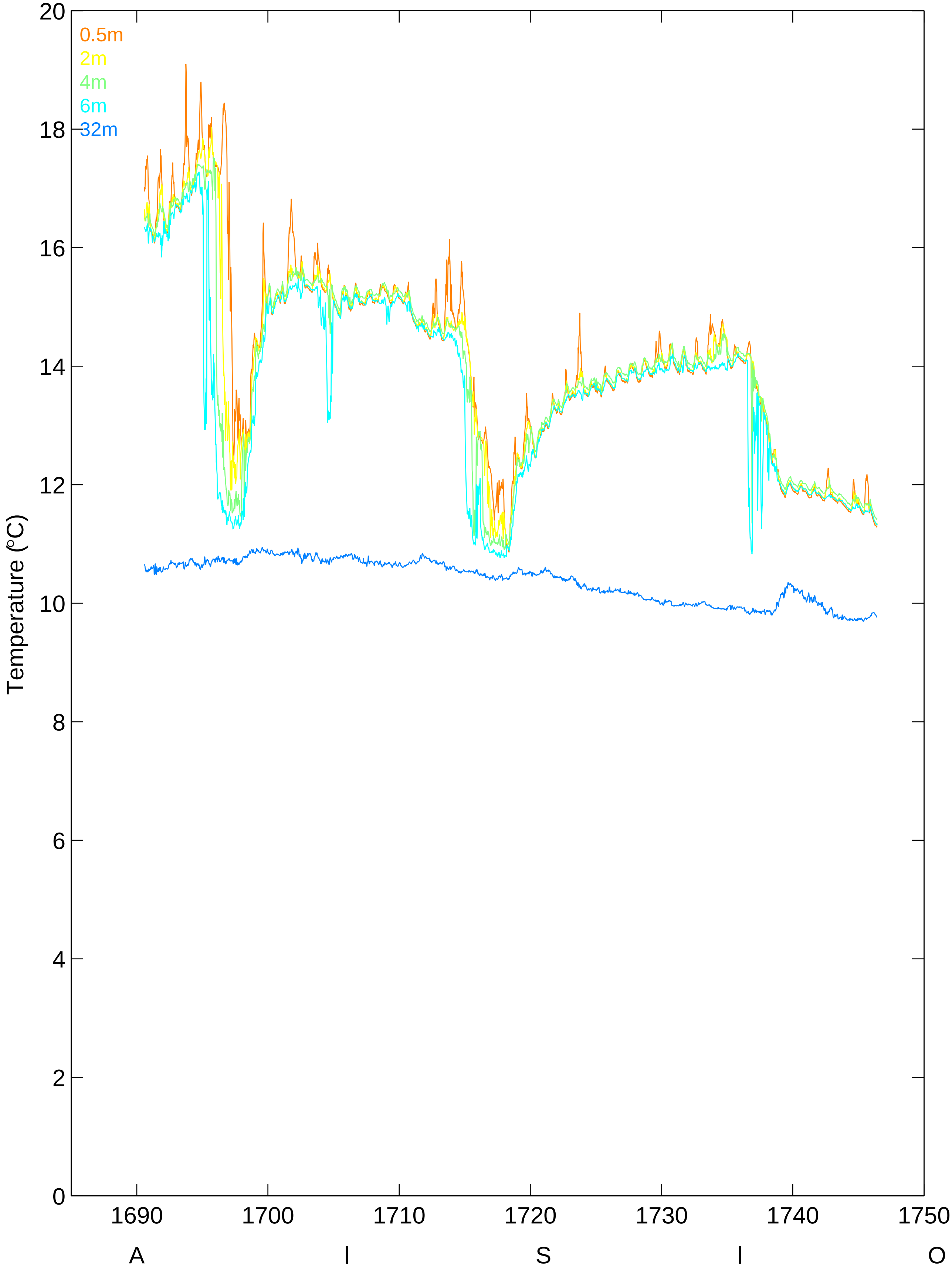
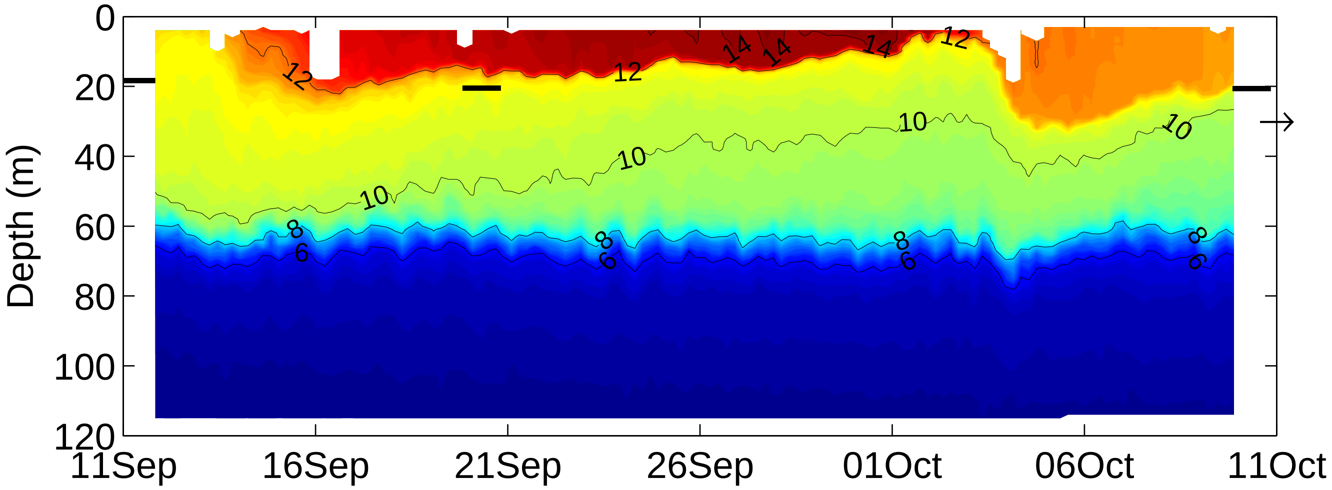
Figure 3.3 REV−FB−SPAR, Aug 16 − Oct 11, 2012



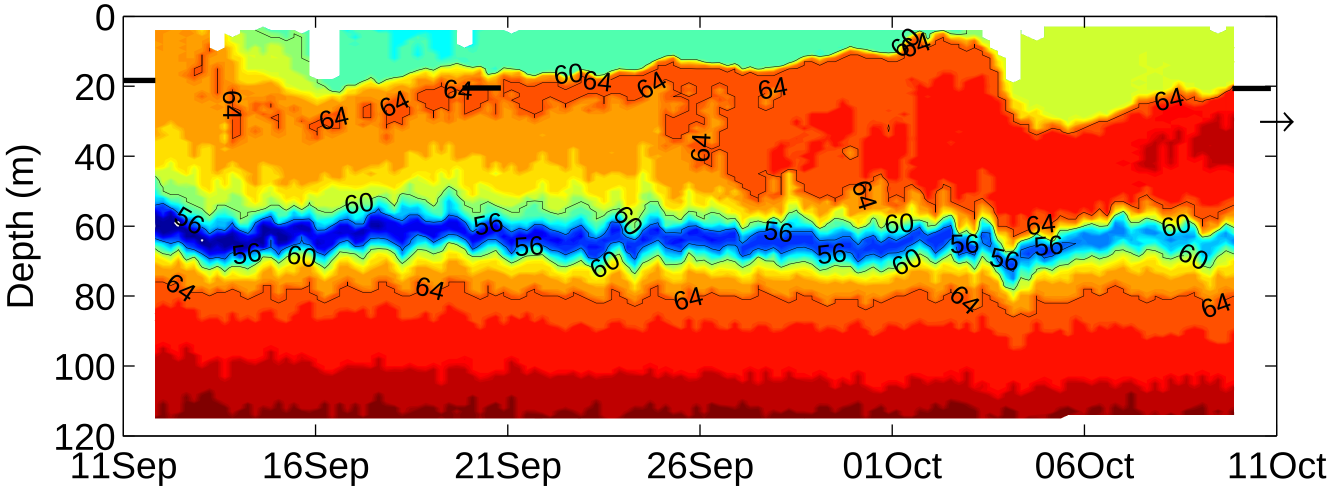
/ocean/rpieters/kr/moor/plot12/plotline30.m fig= 3 2014−Oct−28

Figure 3.4 REV−FB−PROF, 11Sep−11Oct, 2012 (day 1716−1746)

(a) T (°C)



(b) S (mg/L)



(c) Turbidity (NTU)

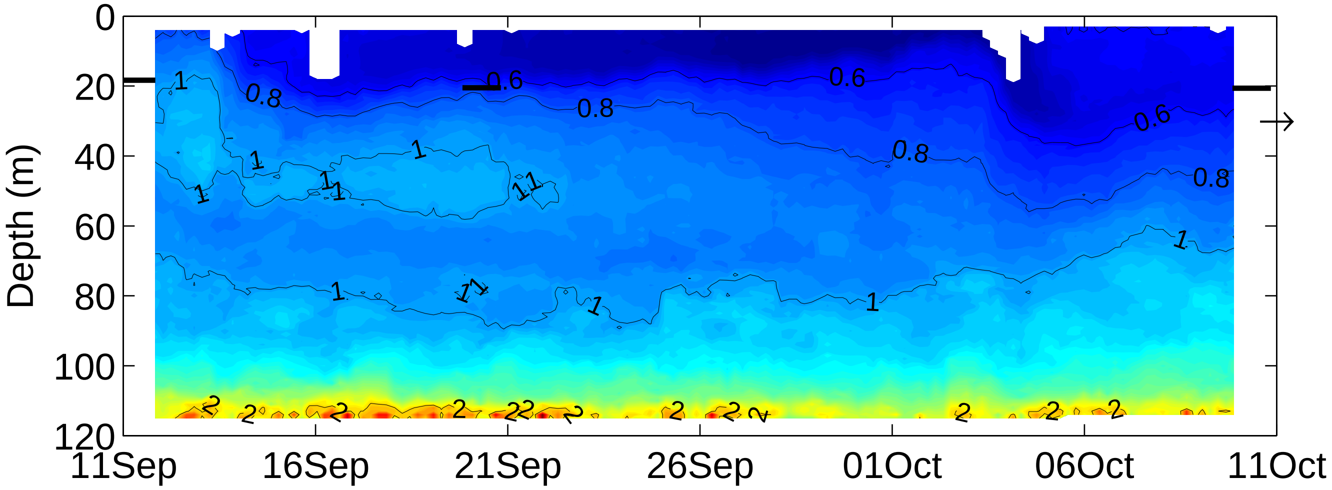


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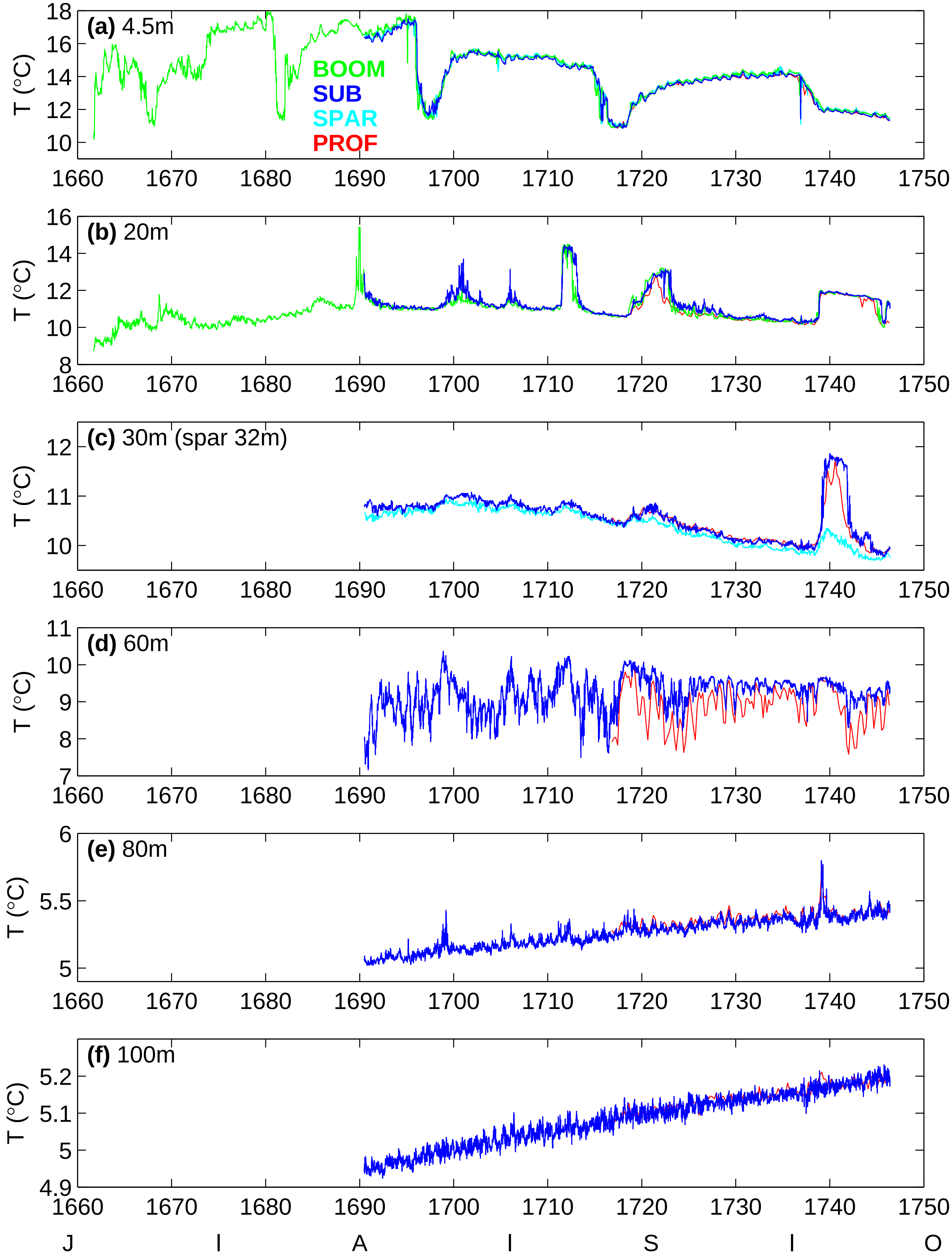
Figure 3.5 Comparison at selected depths, Revelstoke Forebay, 2012



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