Columbia River Project Water Use Plan

Kinbasket Fish and Wildlife Information Management Plan

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring

Implementation Year 6

Reference: CLBMON-3 and CLBMON-56

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring –*Year 6 and Year 2 (2013)*

Study Period: 2013

K.E. Bray
BC Hydro

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Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring
Year 6 (2013) Progress Report


Mica Dam and Forebay, May 2013

Prepared by:
Karen Bray
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:

Brandt, D. 2016. Phytoplankton populations in Kinbasket and Revelstoke Reservoirs, Upper Columbia Basin, British Columbia - 2013. Prepared for BC Hydro, Water Licence Requirements. 36 pp. + apps. Appendix 5 *in* Bray, K.E. 2016. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 6 (2013). BC Hydro, Environment. Study No. CLBMON-3 and CLBMON-56.

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Field Crew
Beth Manson, BC Hydro
Pierre Bourget, BC Hydro
Petra Wykpis, Ministry of Environment
Allison Hebert, Ministry of Environment

Study Team
Dr. Roger Pieters, University of British Columbia
Dale Sebastian, Ministry of Forests, Lands and Natural Resource Operations, Retired
Tyler Weir, Ministry of Forests, Lands and Natural Resource Operations
Shannon Harris, Ministry of Environment
Eva Schindler, Ministry of Forests, Lands and Natural Resource Operations
Dr. Ken Ashley, Ashley and Associates

Specialised Analyses
Darren Brandt, Advanced Eco-Solutions
Dr. Lidija Vidmanic, Limno Lab

BC Hydro Personnel
Morgan McLennan, Mica Generating Station
Judy Bennett, Mica Generating Station
Gene Blackman, Construction Services, Mica
Jim Van Denbrand, Fleet Services
James Crossman, Environment, Castlegar
Eva Boehringer, Environment, Castlegar

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APPENDICES

1.0 Introduction

This report summarises the Year 6 (2013) 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 an eight year study focussing on fine scale measurement of temperature in Kinbasket and Revelstoke Reservoirs to further refine data on circulation, and thus, production. The second year of this study was implemented in 2013 and annual results are included together with CLBMON-3 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 met on March 6-7, 2013, to discuss progress on the management questions, evaluate the sampling program to date, and set the 2013 (Year 6) 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).

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 sixth annual report presents a study overview followed by individual progress reports for the physical processes and biological components of the 2013 sampling year as per previous progress reports (Bray 2014, 2013, 2012; BC Hydro 2011a; BC Hydro 2010). Also included is the second annual report for CLBMON-56. More specific information pertaining to individual year monitoring results is contained in these reports.

In Year 6 (2013) regular reservoir monthly sampling began in April and concluded early in September due to logistical issues (Figure 1). Sampling protocols remained unchanged from the previous year (Table 1) although a change of analytical laboratory for water quality was necessary (see Appendices 2 and 4).

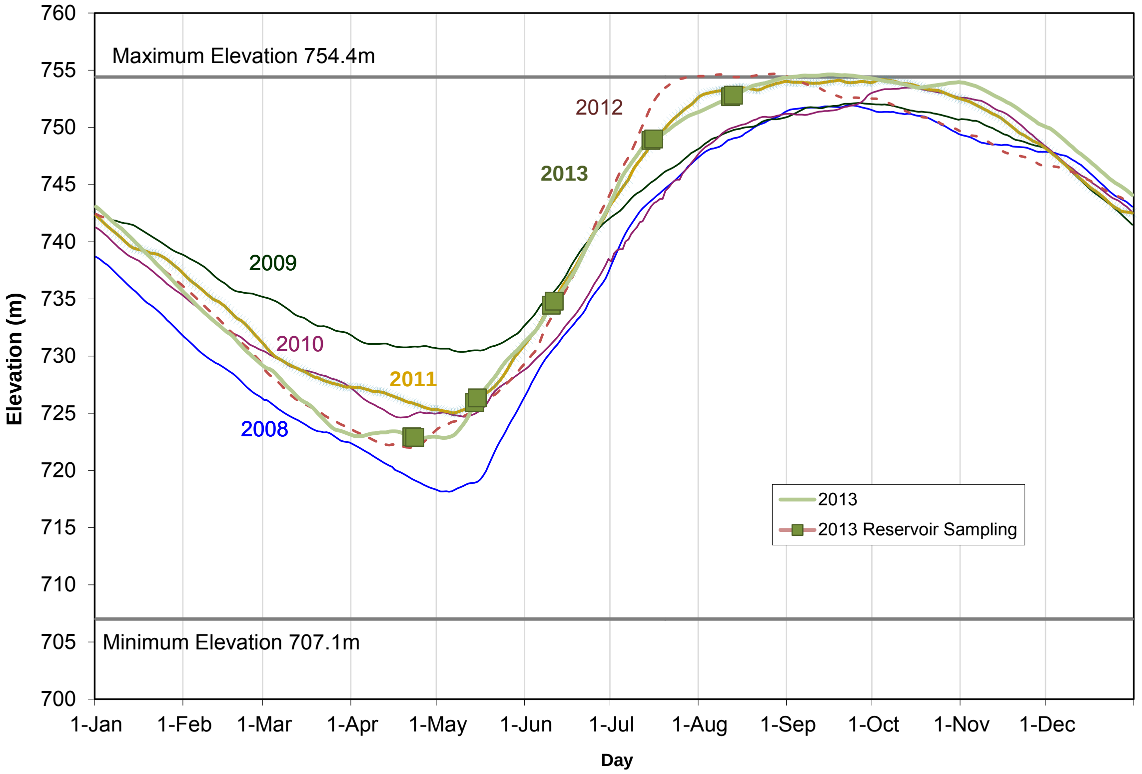

Figure 1. Kinbasket Reservoir elevation and sampling dates, 2013. Elevations for 2008-2012 are shown for comparison.

Table 1. Summary of Kinbasket and Revelstoke Reservoirs field sampling program 2013.

Parameter (Analyses)	**Sampling Frequency**	**Method**	**Depths**	**Stations** **(approx. max depth)**								
				KIN Forebay	**KIN Canoe**	**KIN Wood Arm**	**KIN Col Reach**	**KIN Mid Pool**	**REV Upper**	**REV Middle**	**REV Forebay**	**Tribs**
Weather Station (temp, ppt, BP, RH, PAR, wind)	Hourly/daily	Fixed Data logger		Mica dam crest							Rev Dam crest	
Profile (DO, temp, cond, chl a, PAR, turbidity) +secchi	**Apr-Sep** Monthly (6)	Seabird +Secchi	0 to 60m+ (to within 5 m of bottom)	√	√	√	√	√	√	√	√	
Water Chem - Reservoir (TP, SRP, TDP, cond, NO2+NO3, alk, pH, turb) (silica)	**Apr-Sep** Monthly (6)	Bottle, tube	2,5,10,15,20, 40, 60, 80m and 5m off bottom 0-20m for Si	√	√	√	√		√	√	√	
Water Chem - Tributary (TP, SRP, TDP, cond, NO2+NO3, pH, alk, turb, temp)	5 reference tribs once in A/S/O/N and twice in M/J/J +Beaver	Bucket	Surface grab									√
Temperature	Tidbits, hourly	Reference trib sites*	Add tribs in fall									√
Phytoplankton	**Apr-Sep** Monthly (6)	Bottle	2, 5, 10, 15, 25 m Dropped 20 and 30m	√	√	√	√		√	√	√	
Bacteria	**Apr-Sep** Monthly (6)	Bottle	Two composites of 2,5,10m and 15,20,25m	√	√	√	√		√	√	√	
Zooplankton	**Apr-Sep** Monthly (6)	Wisconsin net 2 hauls per site	0-30m	√	√	√	√		√	√	√	
C^{14}	**June-Sep** Monthly (4)	3 size fractions	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

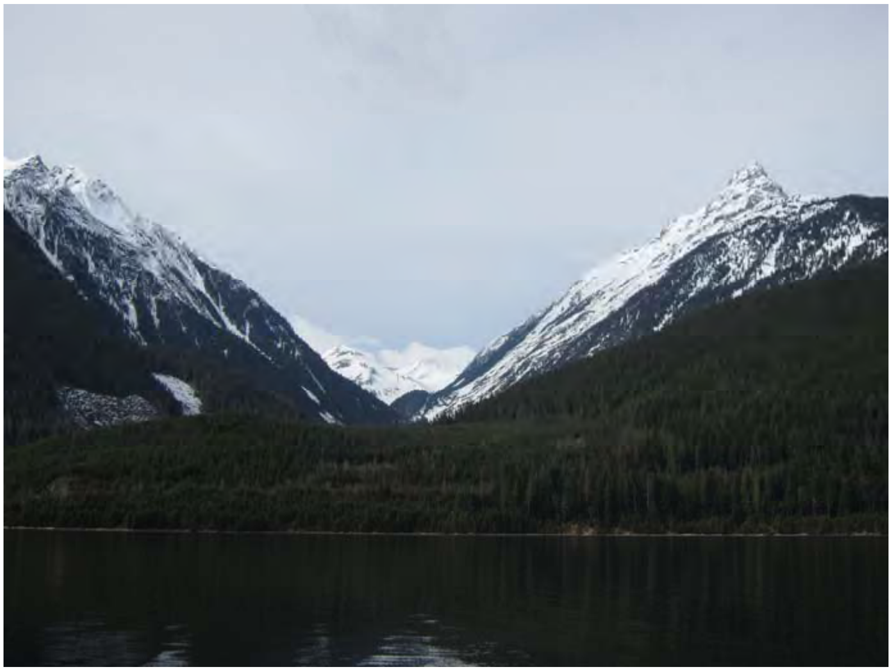
Hydrology of Kinbasket and Revelstoke Reservoirs, 2013

Roger Pieters, Alyssia Law, and Greg Lawrence
University of British Columbia

Hydrology of Kinbasket and Revelstoke Reservoirs, 2013

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

[1] Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C. V6T 1Z4
[2] Civil Engineering, University of British Columbia, Vancouver, B.C. V6T 1Z4



Revelstoke Reservoir, 26 April 2013

Prepared for

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

January 14, 2016

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1. Introduction

The hydrology of Kinbasket and Revelstoke Reservoirs is described, focusing on flow in 2013. This report updates Pieters et al (2014) 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 southeast, the Columbia River enters the Columbia Reach of Kinbasket Reservoir about 15 km downstream of Donald Station.

To the northwest, 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/yr)	~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 1944-2013 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 1944-2013. 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 1944-2013 was 171 m^3/s.

The daily flows are shown in Figure 3.2 for selected years (1993-1994, 1999-2013) which include the years with hydroacoustic surveys of kokanee abundance (1993, 1994, 2003-2013). Also shown for comparison in each panel is the daily mean flow for 1944-2013. 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 1971-2013 from BC Hydro. The WSC data from "Columbia River above Nagle Creek" were used for 1947-1975 and the BC Hydro data were used for 1976-2013.

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 had a large single peak of roughly 1600 m^3/s from early June to mid-July (Figure 4.1b). 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). During snowmelt in spring, the outflow from the Reservoir is generally low, and most of the freshet inflow is stored in the reservoir. However, once the reservoir has almost filled, outflow is increased, thereby releasing the tail of the freshet and resulting in an increase in flow during the late summer. A second broad peak occurs during the winter as water is released for hydroelectric generation.

The discharge from Mica Dam for selected years (1993-1994, 1999-2013) is shown in Figure 4.2. While the flow over the years shown has generally followed the mean, the flow from mid-May to mid-July was often below average with long stretches close to zero. In some years, outflow was also below average through late summer and early fall, e.g. 2008, 2009, 2010 and 2013.

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 1986-2013, data were available from WSC station 08ND025, entitled "Revelstoke Project Outflow".

Results

The daily discharge for 1955-2013 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 under 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, 1999-2013) 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

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 2013 are compared in Figures 6.5 to 6.10, 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. Note also that the 2013 record is based on raw data from WSC, in which some winter data is missing.

Table 6.1 Gauged tributaries flowing into the Columbia River

Station #	Station Name	Year	Drainage Area (km^2)	Annual Mean Flow* (m^3/s)	Yield (m/yr)
08NB019	Beaver River near the Mouth	1985-2013	1150	41.2	1.13
08NB014	Gold River above Palmer Creek	1973-2013	427	18.1	1.34
08ND012	Goldstream River below Old Camp Creek	1954-2013	938	38.7	1.30
08ND013	Illecillewaet River at Greeley	1963-2013	1170	52.6	1.42

*The mean given is to 2010.

7. Kinbasket Reservoir Water Level

Data

Daily water level data were available for 1974-2013 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 1980-2013 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 1974-2013. 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 1977-2013.

The water level in Kinbasket Reservoir for selected years (1993-1994, 1999-2013) 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, the water level was slightly below average from March to June, but rose to above average (including surcharge) for July to September. Similarly in 2013, the water level was slightly below average from March to May, but was above average for the remainder of the year with brief surcharge in September 2013.

Figure 7.3 shows the annual minimum and maximum water level for Kinbasket Reservoir, 1977-2013. 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 2008-2013). The minimum and maximum water levels are shown in Figure 7.3b. 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. Also shown are the dates at which the reservoir reached minimum pool in late April, and 90% of full pool in late July (Figure 7.3c). From 2008-2011, the minimum water level occurred significantly later than average.

8. Revelstoke Water Level

Data

Daily water level data were available for 1984-2013 from the BC Hydro station located in the Revelstoke forebay.

Results

Figure 8.1a shows the water level of Revelstoke Reservoir for 1984-2013. 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 1988-2013. 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, 1999-2013) is shown in Figure 8.2, together with the mean post-impoundment level averaged from 1988-2013. The water levels generally followed the post-impoundment mean levels. The last two years have seen drawdowns below normal minimum, for example in January, and November 2013.

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 1976-2013. 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, 1999-2013) is shown without smoothing in Figure 9.2. The flow in recent years, 2008 to 2013, 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. The Columbia River at Donald is the main inflow (Q_{in}) to Kinbasket Reservoir, and the outflow from Mica Dam is the main inflow to Revelstoke Reservoir.

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 1989-2013. 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, 1999-2013). 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 River at Donald. The Columbia River 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 River 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 2013

The El-Nino/Southern Oscillation ENSO index (Wolter, 2012) and the size of winter snow packs (BCRFC, 2013) 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% Local flow above average in late June and early July.
2013	Weak La Nina (Jun-Aug 2013) Columbia Region Snow basin Index (April 1st), 103% Flow average

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

The summer, including those of 2008 to 2013, 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 7.2.2) and little outflow (Figure 4.2.2d). 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 8.2.2), 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, there was a large freshet peak from late June to mid-July (Figure 6.9). In 2013, despite the strong onset of freshet in mid-May, local inflow was approximately average through the remainder of the year.

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 4.2.2). This increased flow from Kinbasket to Revelstoke makes up for the decline in local freshet inflow to Revelstoke; as a consequence, the discharge from Revelstoke is similar in both periods (Figure 5.2.2; Figure10.4.2).

Acknowledgements

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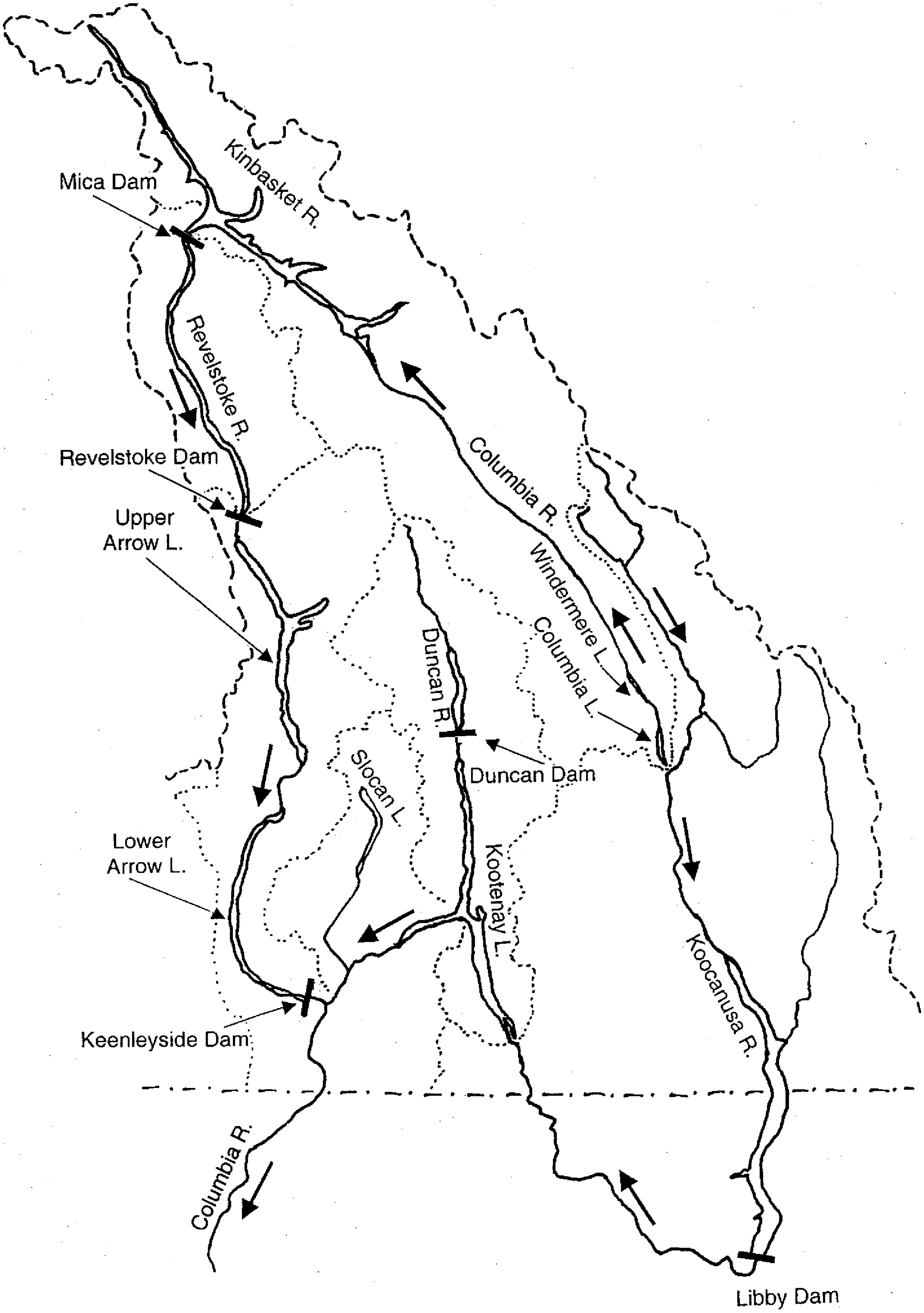


Figure 1.1. Upper Columbia River Basin

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

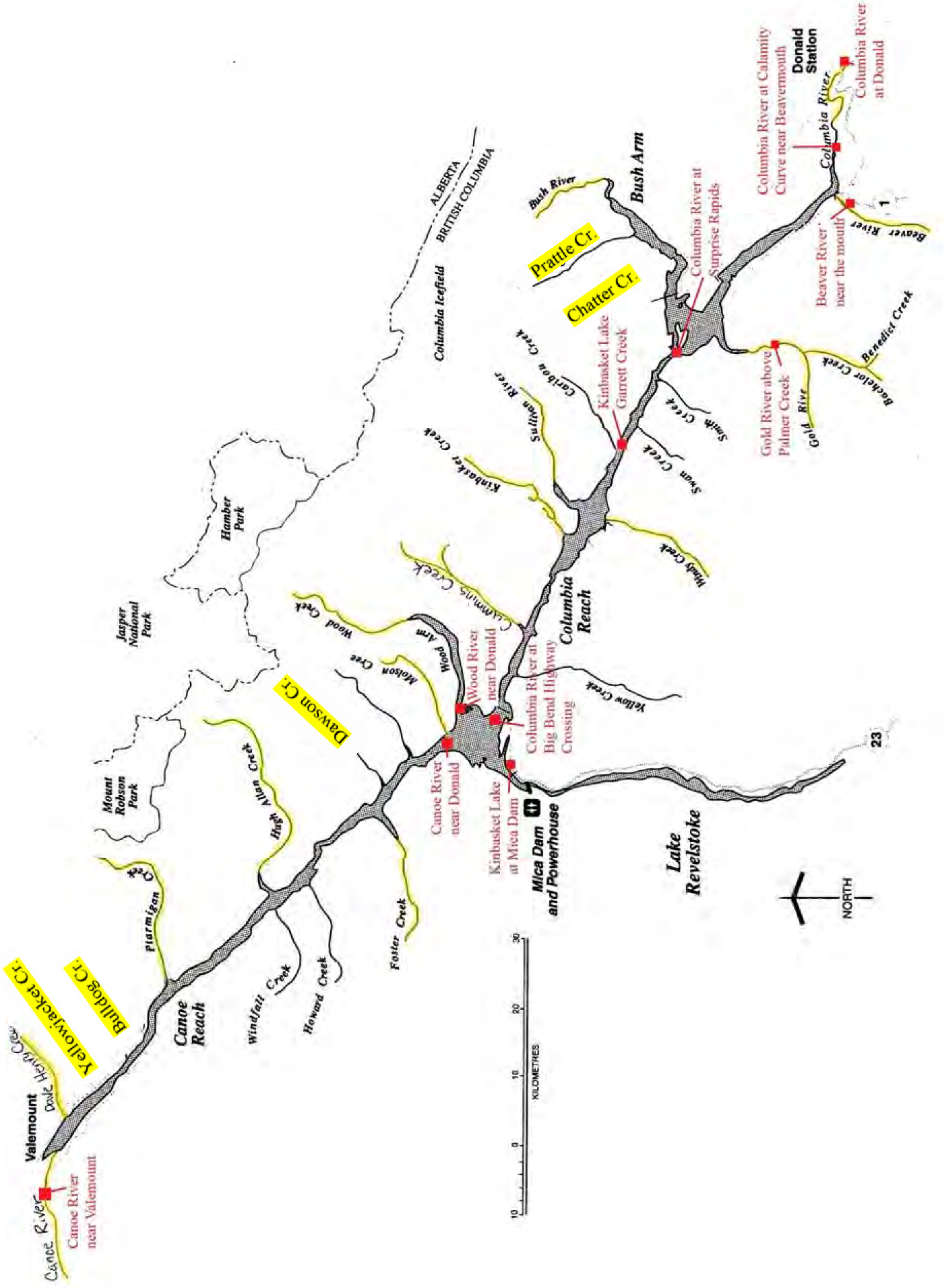
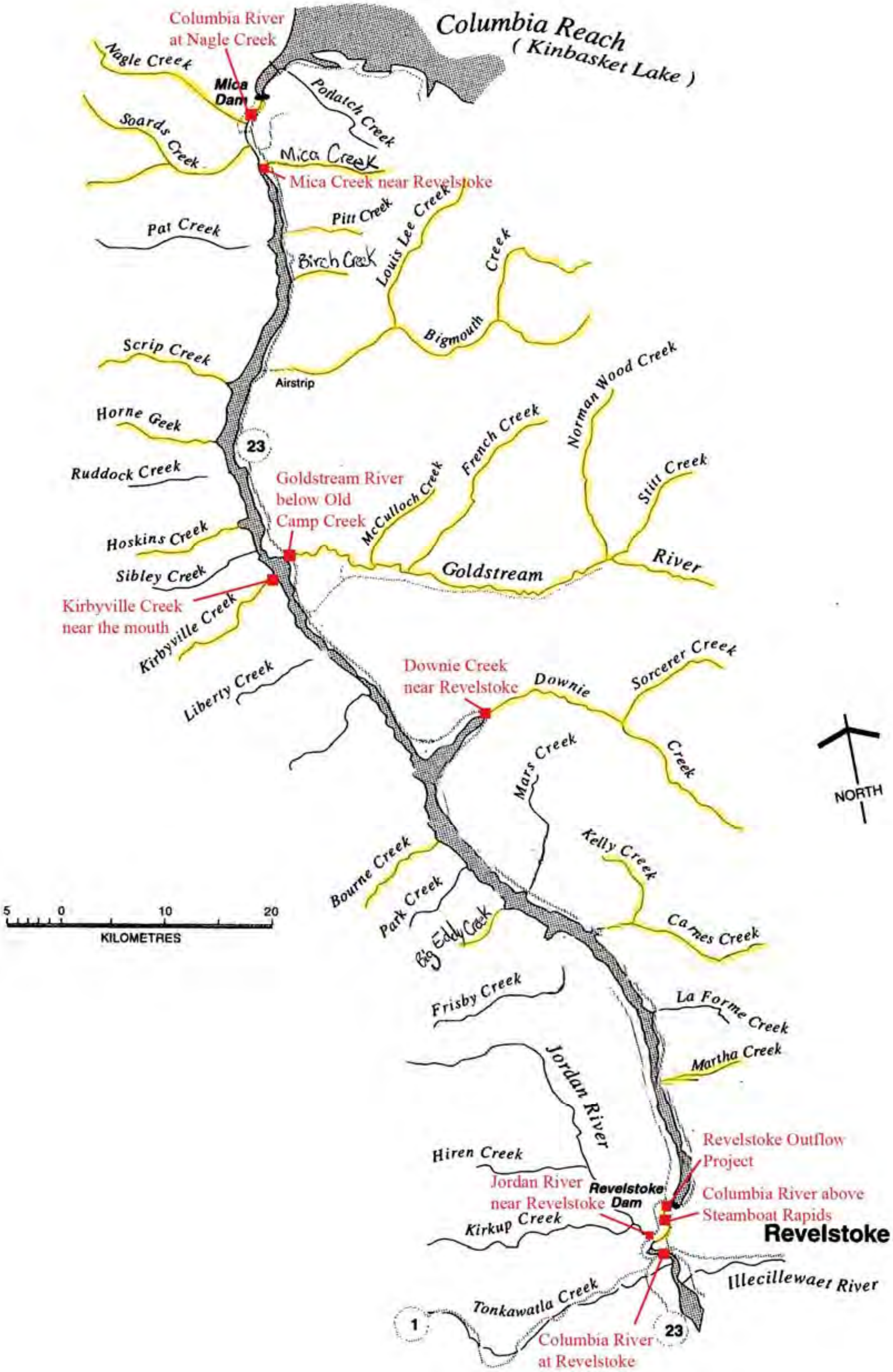


Figure 1.3 Revelstoke Reservoir with gauging stations (RED) and sampled tributaries (YELLOW).



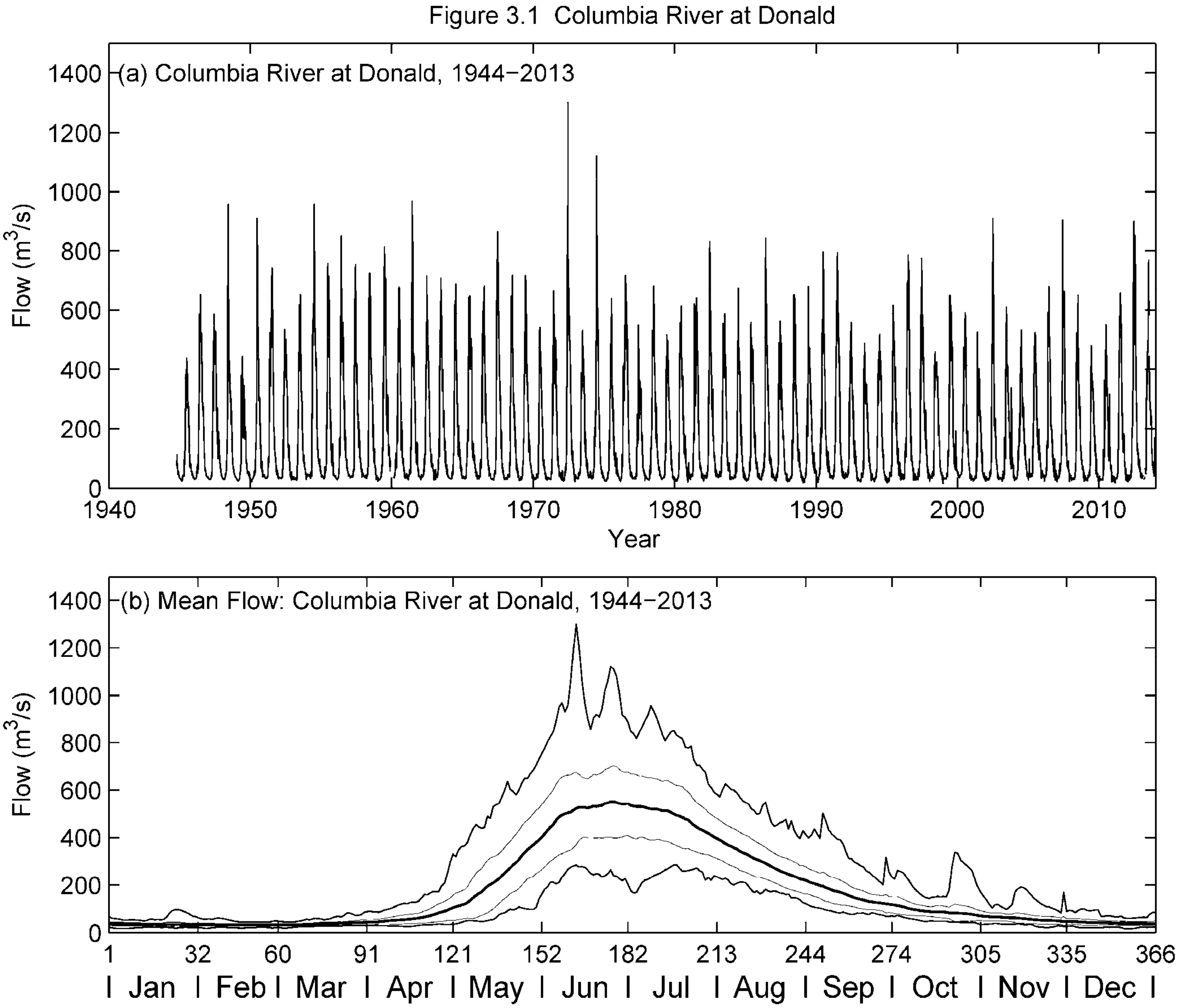


Figure 3.1. **(a)** WSC station 08NB005, "Columbia River at Donald", 1944-2013. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

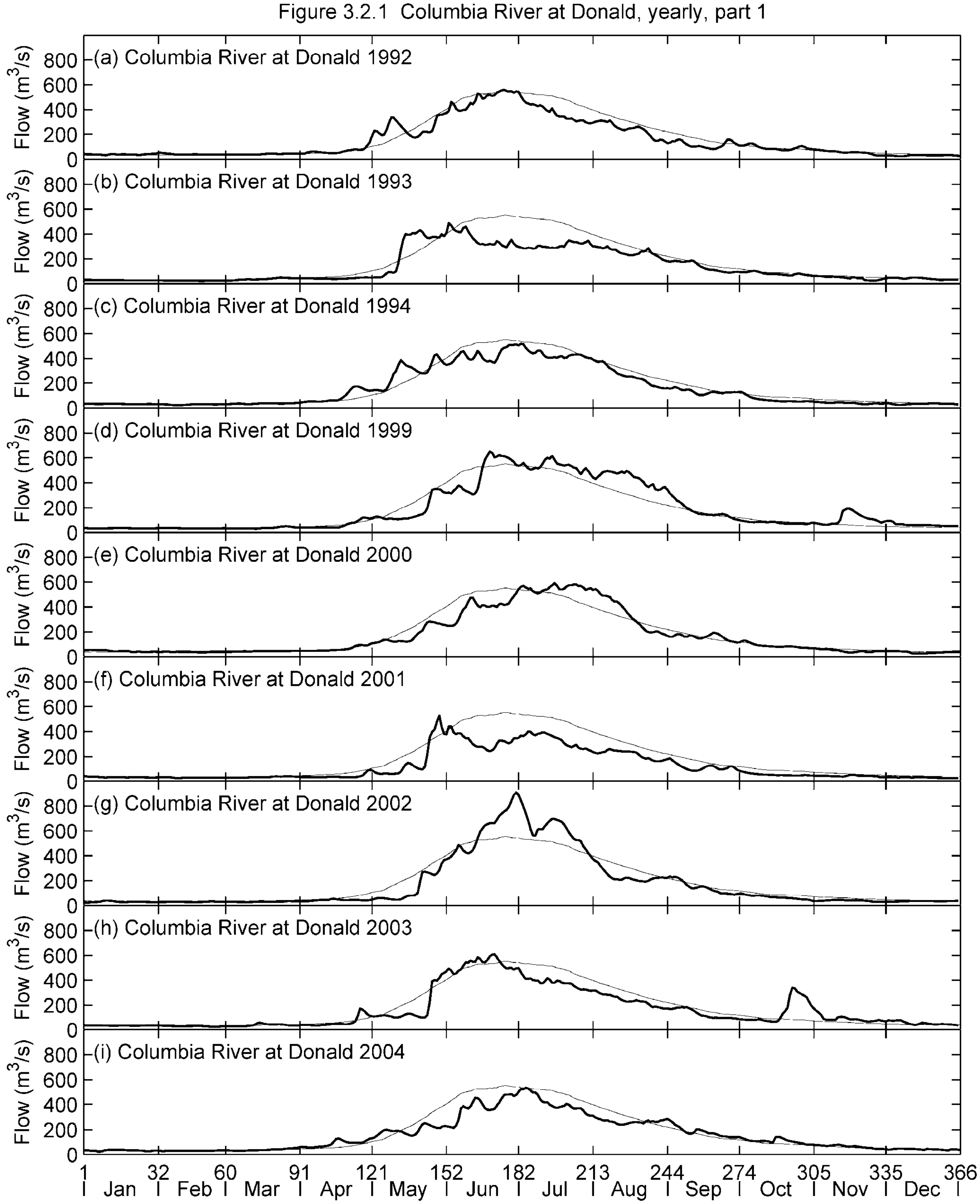


Figure 3.2.1. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2013 (light line) is shown for comparison.

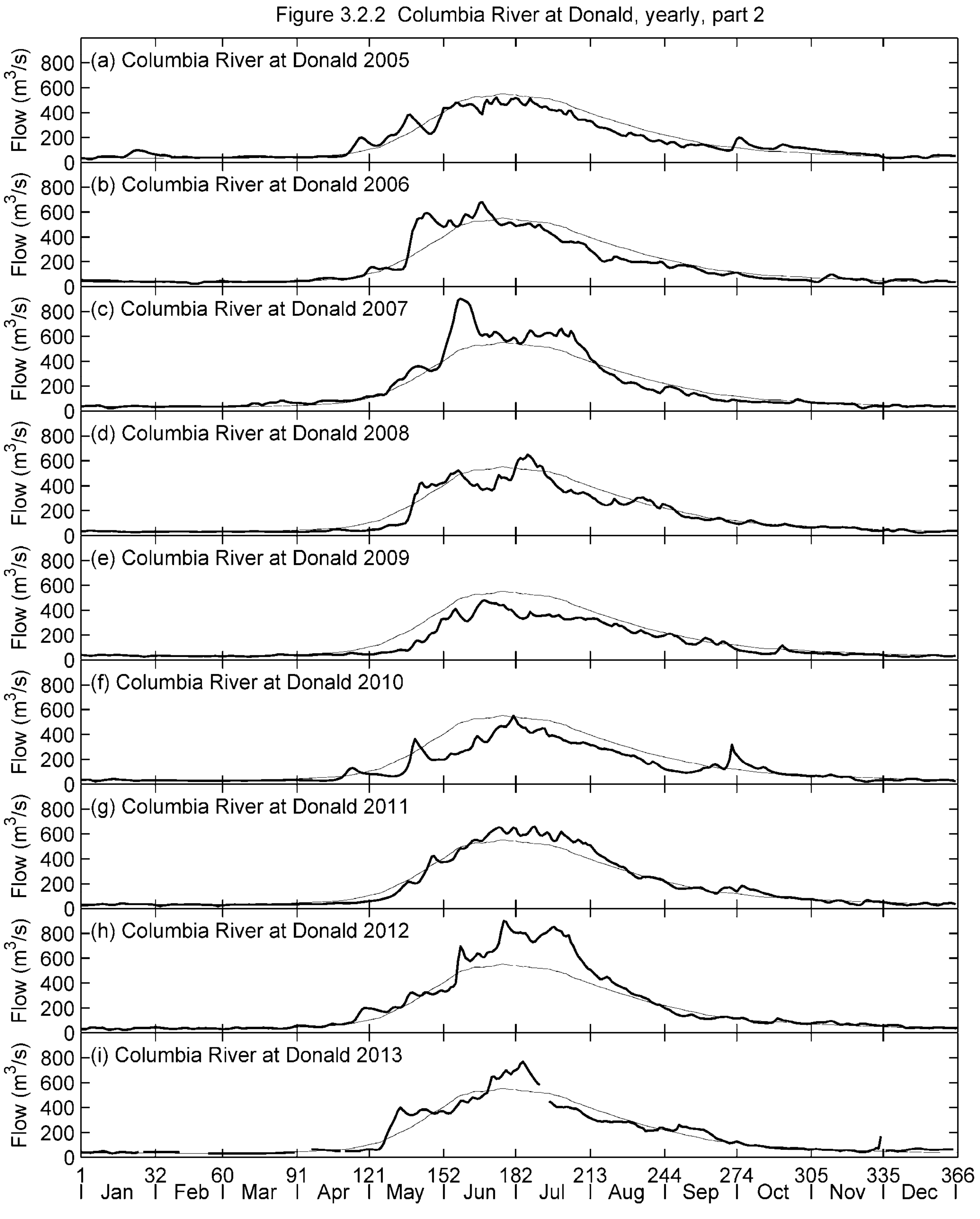


Figure 3.2.2. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2013 (light line) is shown for comparison.

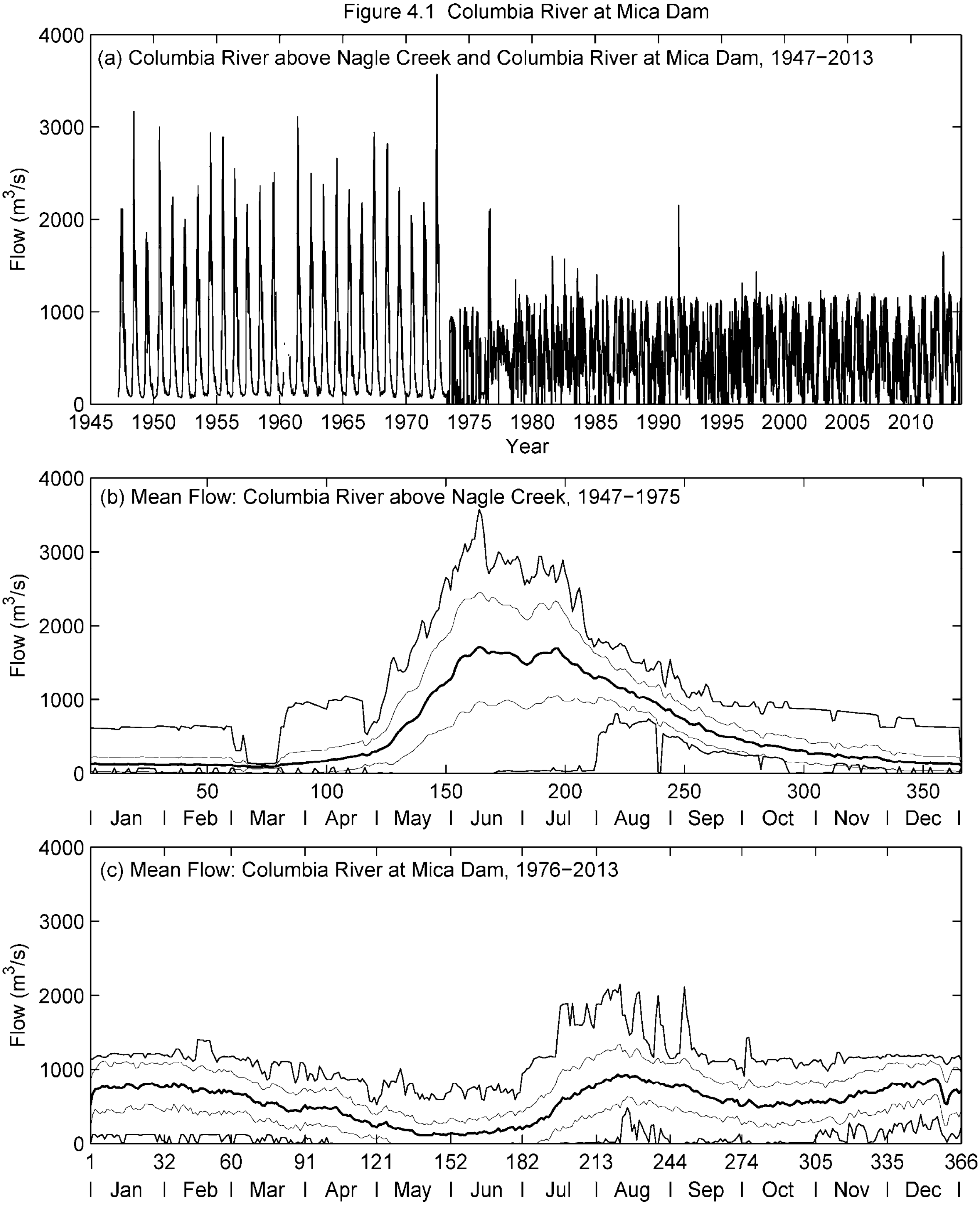


Figure 4.1. **(a)** WSC station 08ND007, "Columbia River above Nagle Creek", 1947-1975 and BC Hydro station "Columbia River at Mica Dam Outflow", 1976-2013. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

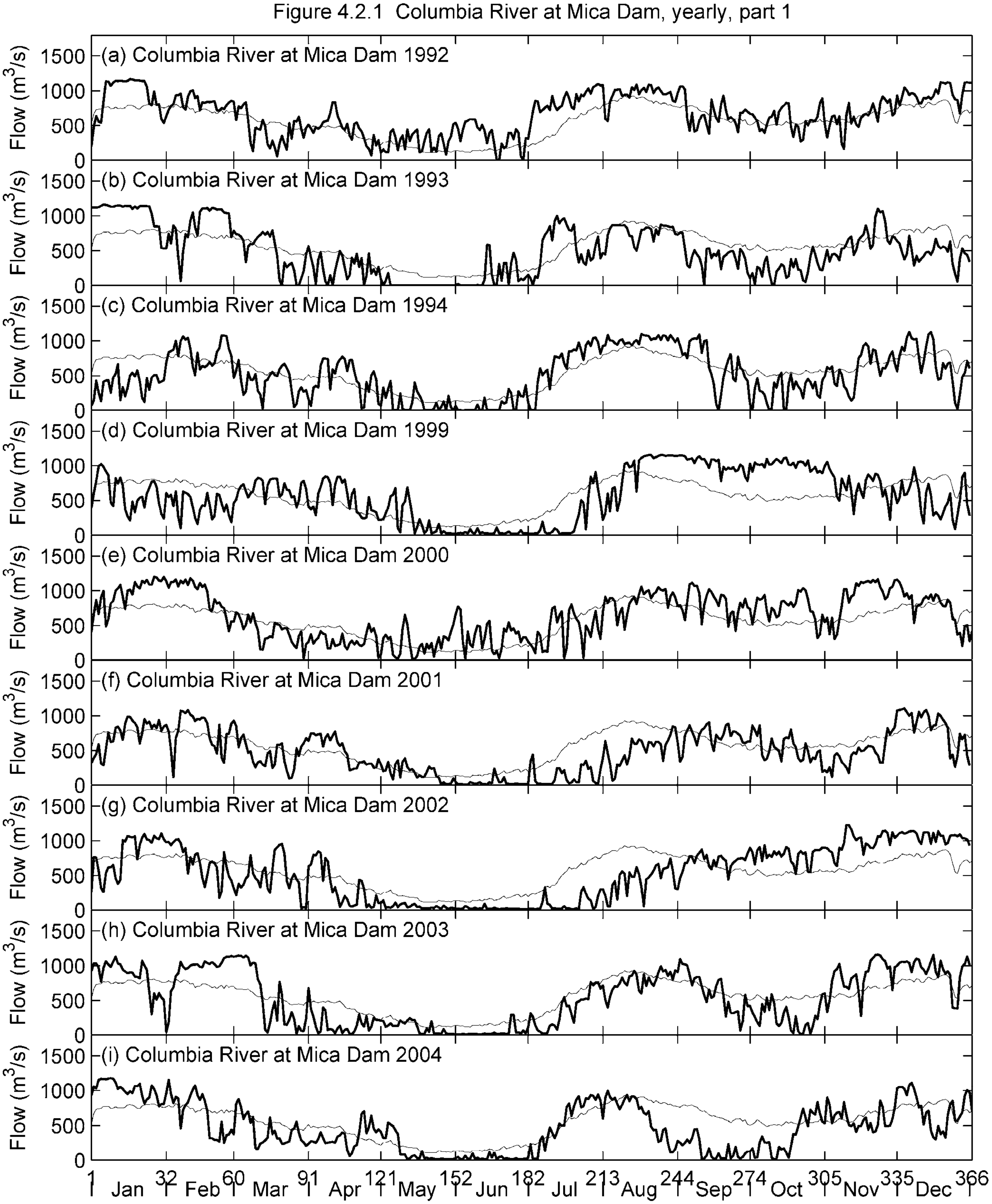


Figure 4.2.1. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2013 (light line) is shown for comparison.

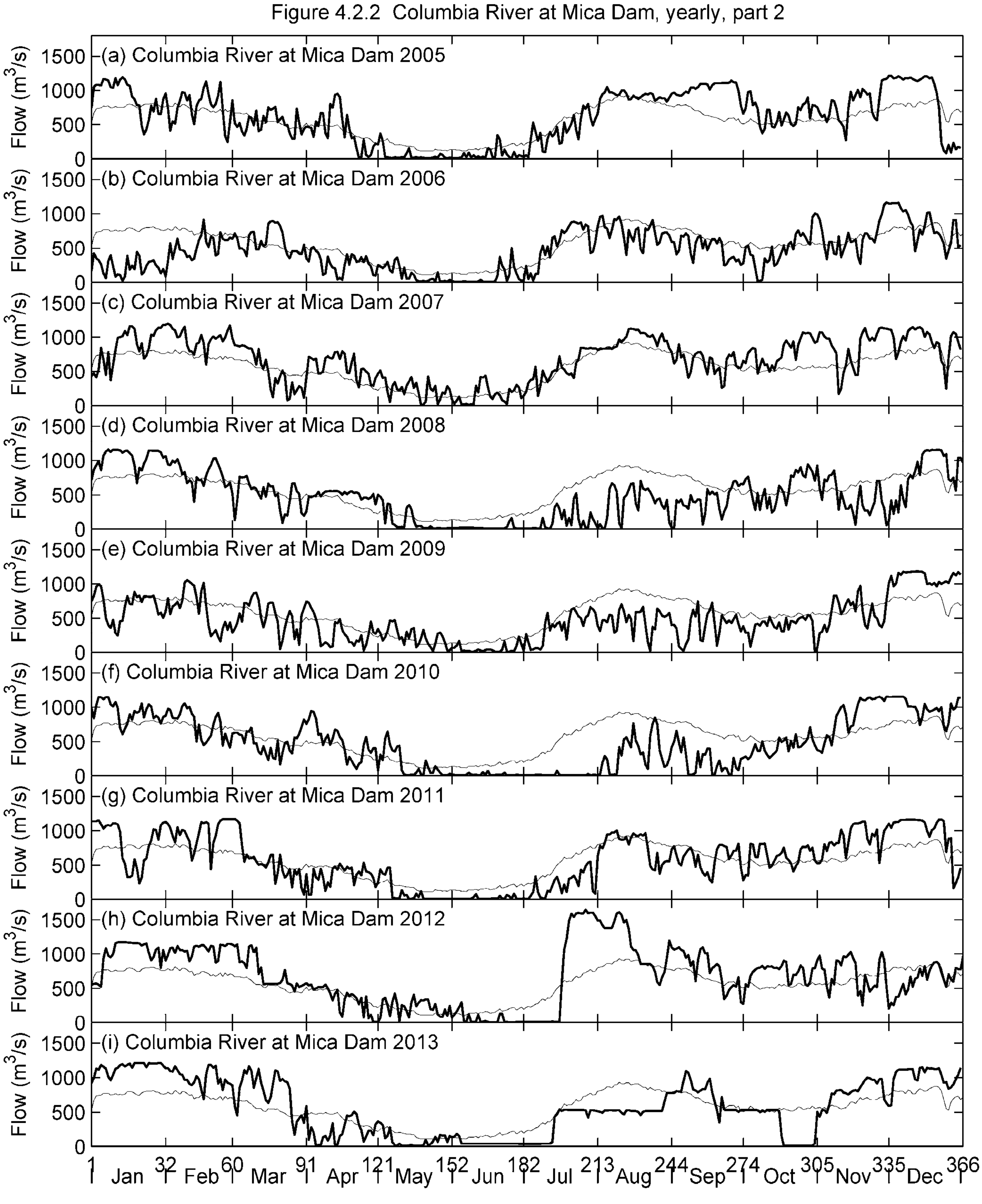


Figure 4.2.2. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2013 (light line) is shown for comparison.

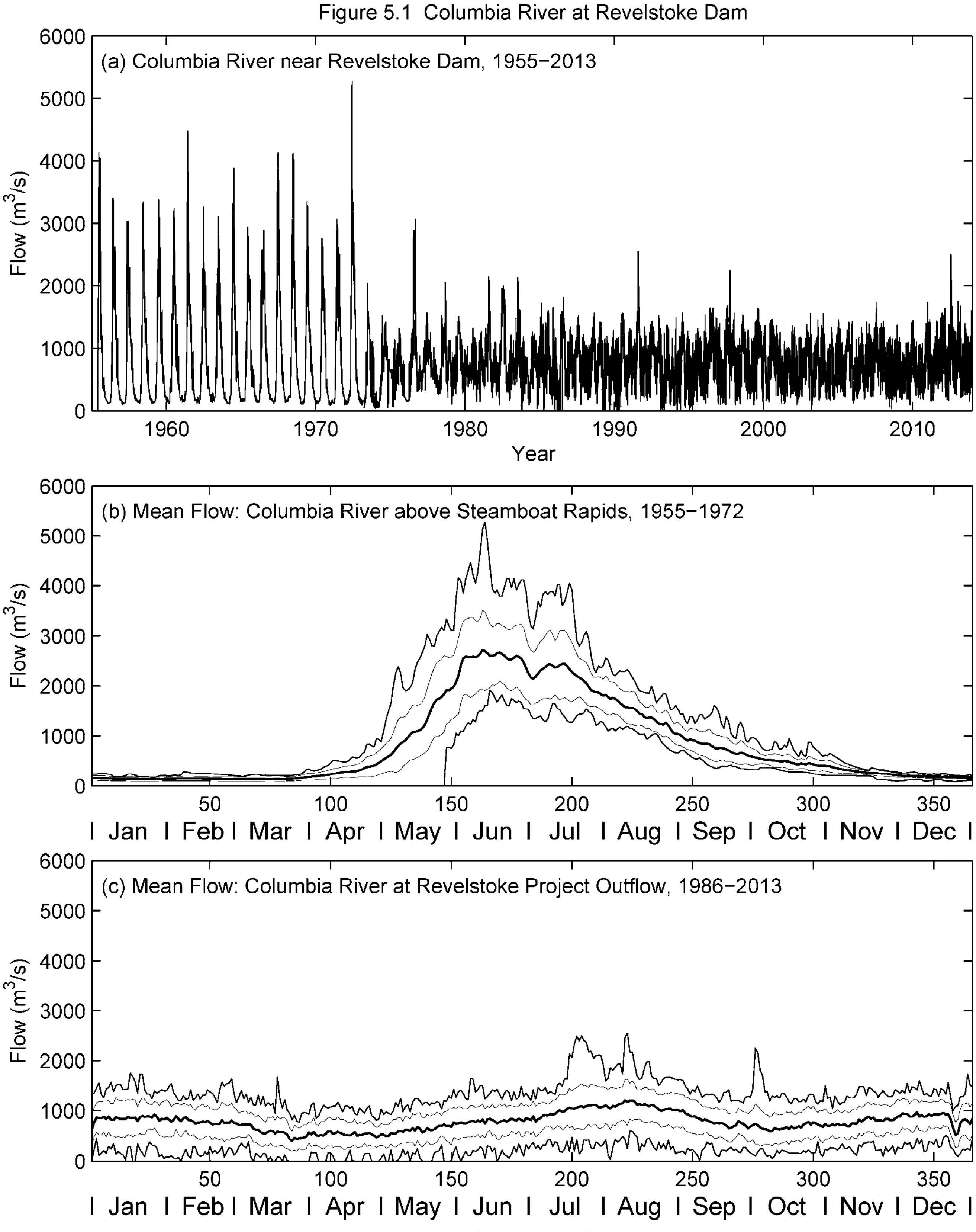


Figure 5.1. **(a)** WSC station 08ND011, "Columbia River above Steamboat Rapids", 1955-1985 and WSC station 08ND025, "Revelstoke Project Outflow", 1986-2013. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

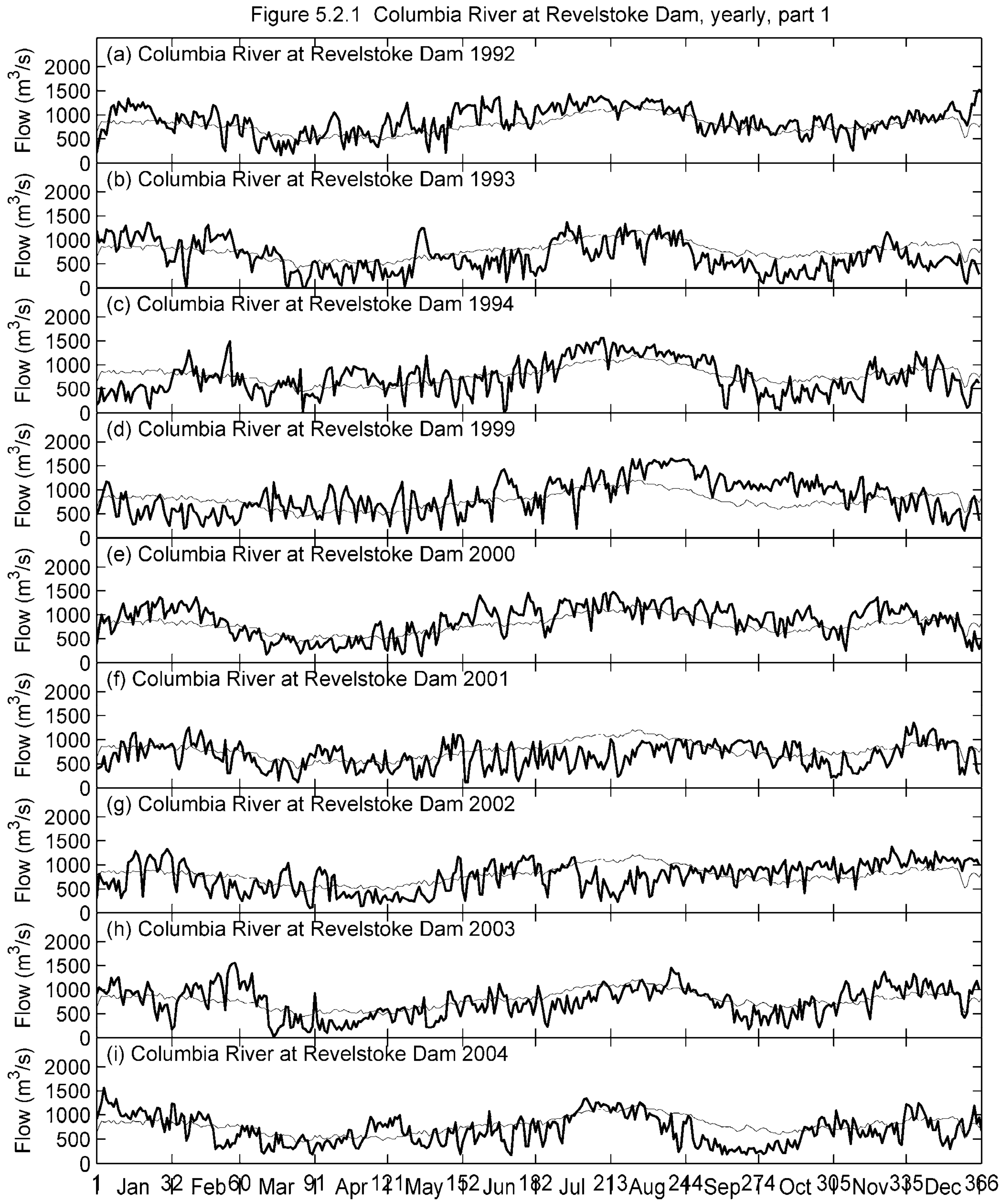


Figure 5.2.1. WSC station 08ND025, “Revelstoke Project Outflow”, selected years (heavy line). Mean flow for 1986-2013 (light line) is shown for comparison.

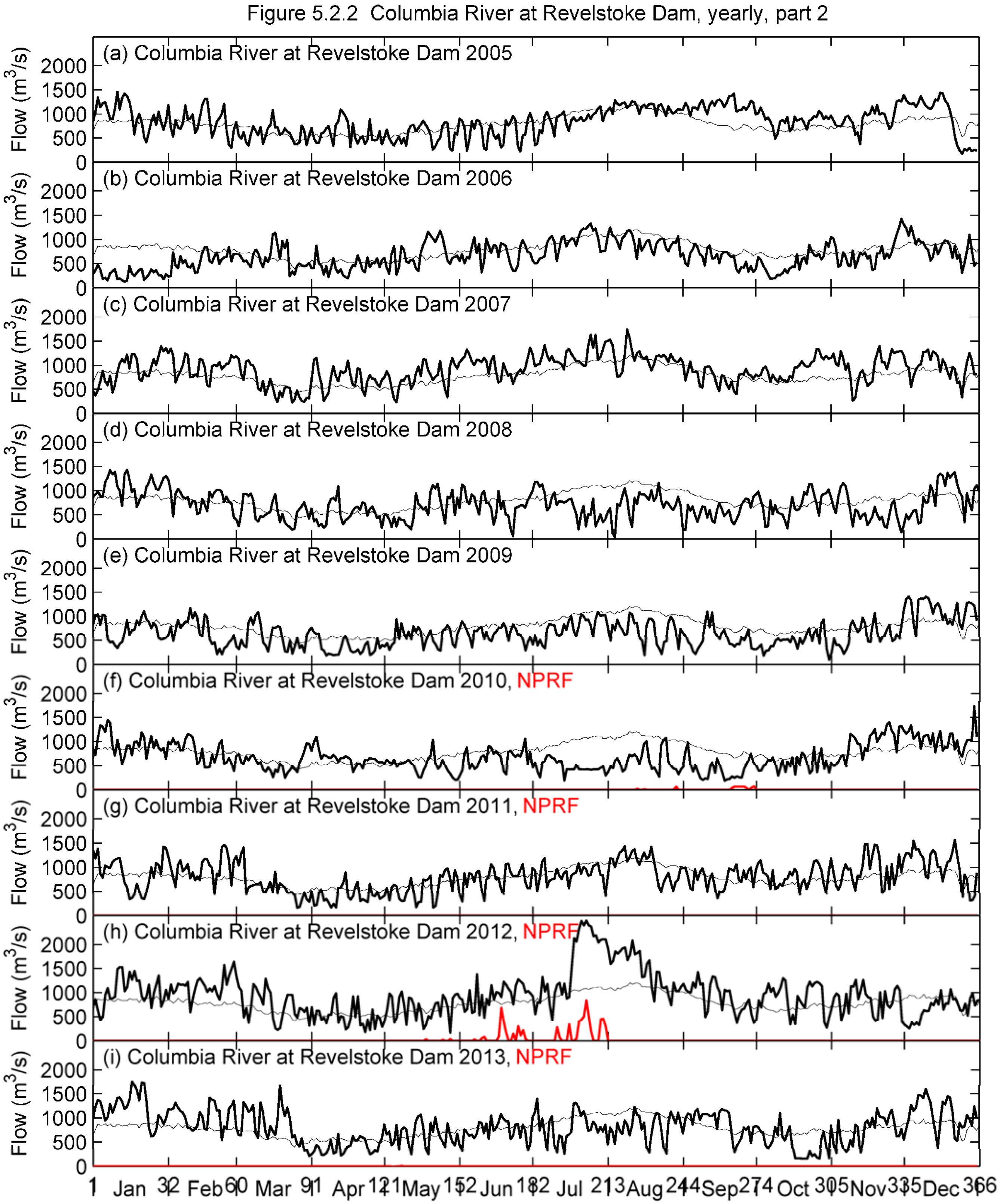


Figure 5.2.2. WSC station 08ND025, "Revelstoke Project Outflow", selected years (heavy line). Mean flow for 1986-2013 (light line) is shown for comparison. NPRF (RED) marks non-power flow (spill).

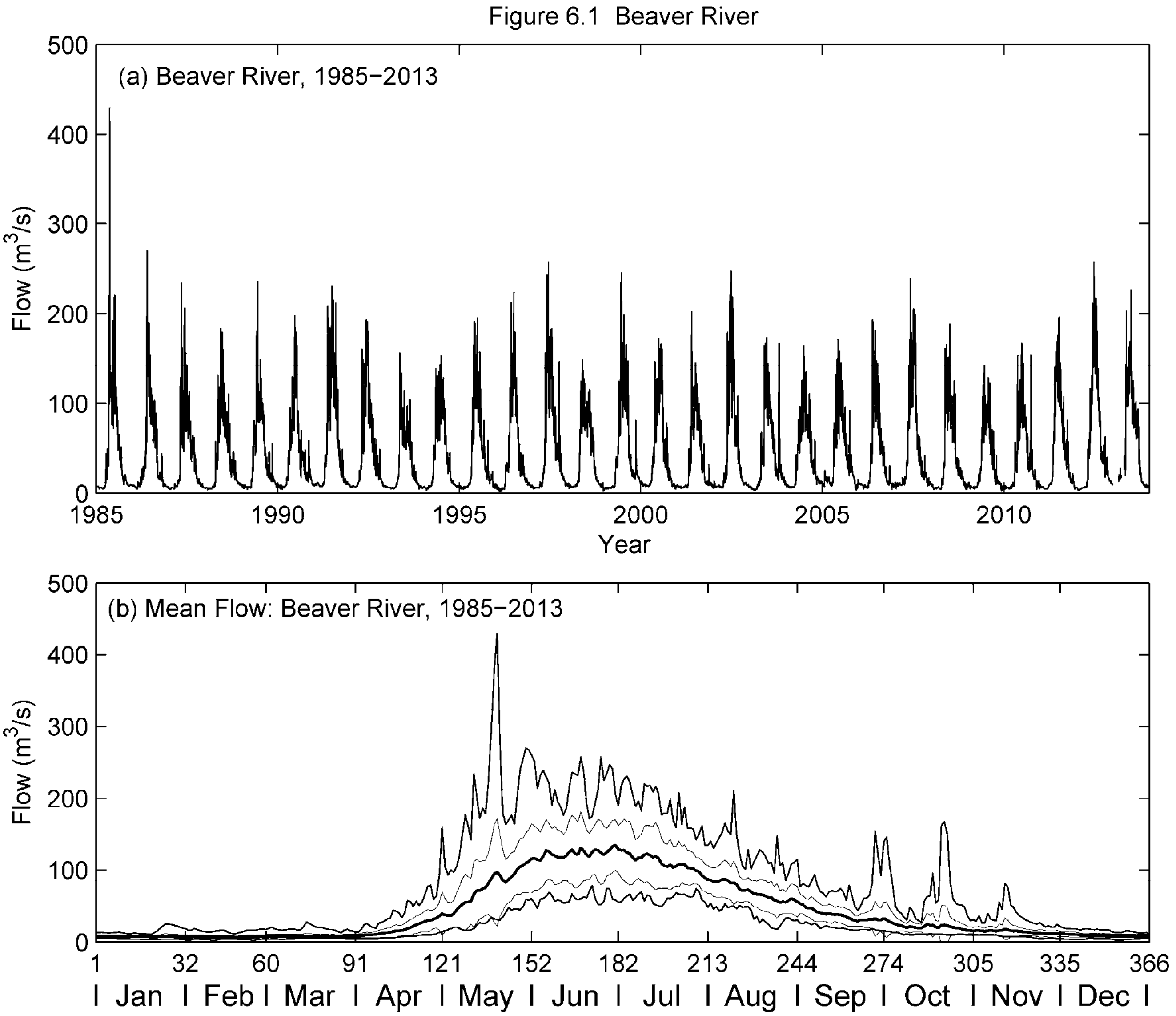


Figure 6.1. **(a)** WSC station 08NB019, "'Beaver River near the Mouth", 1985-2013. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

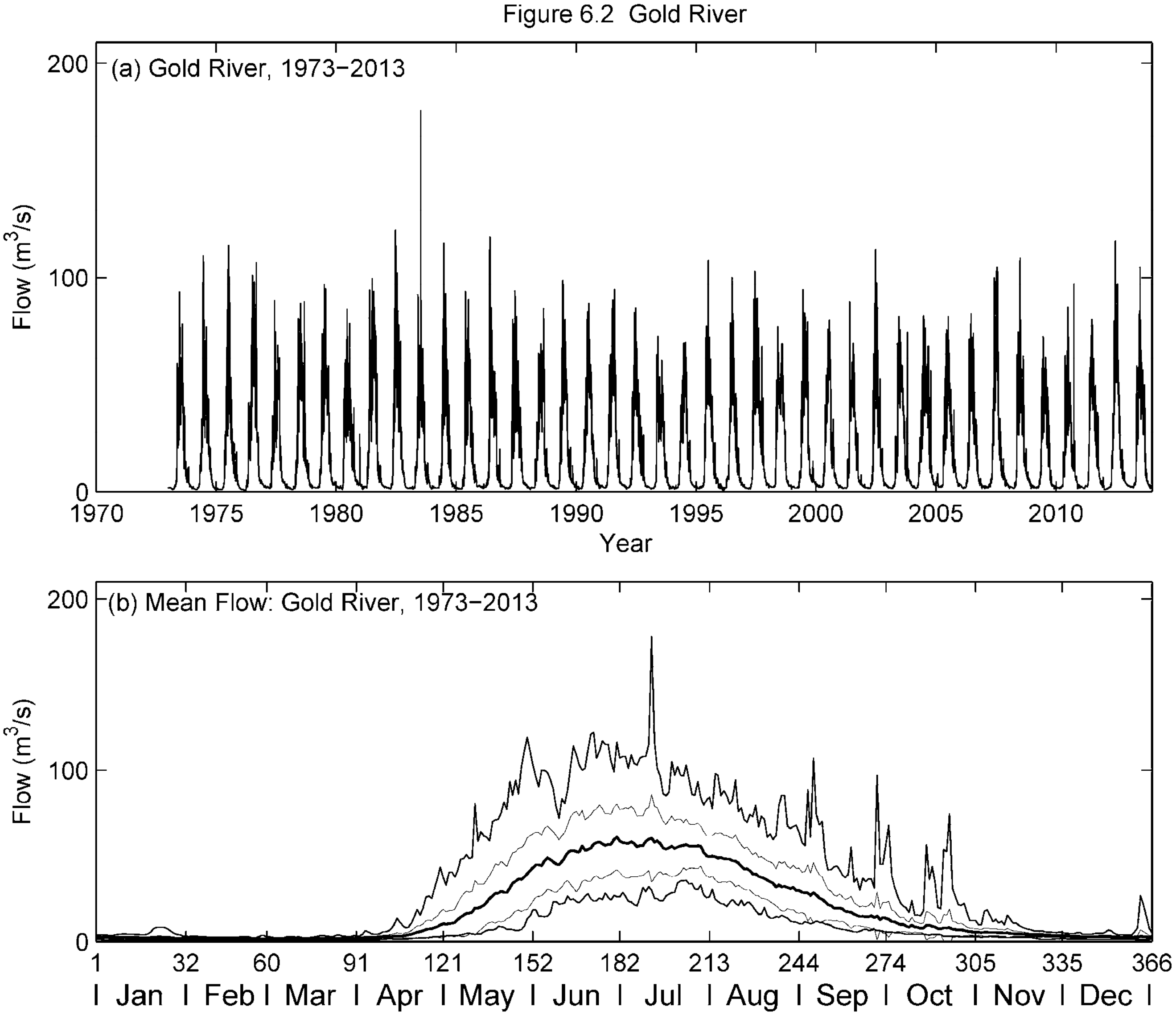


Figure 6.2. **(a)** WSC station 08NB014, "Gold River above Palmer Creek", 1973-2013. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

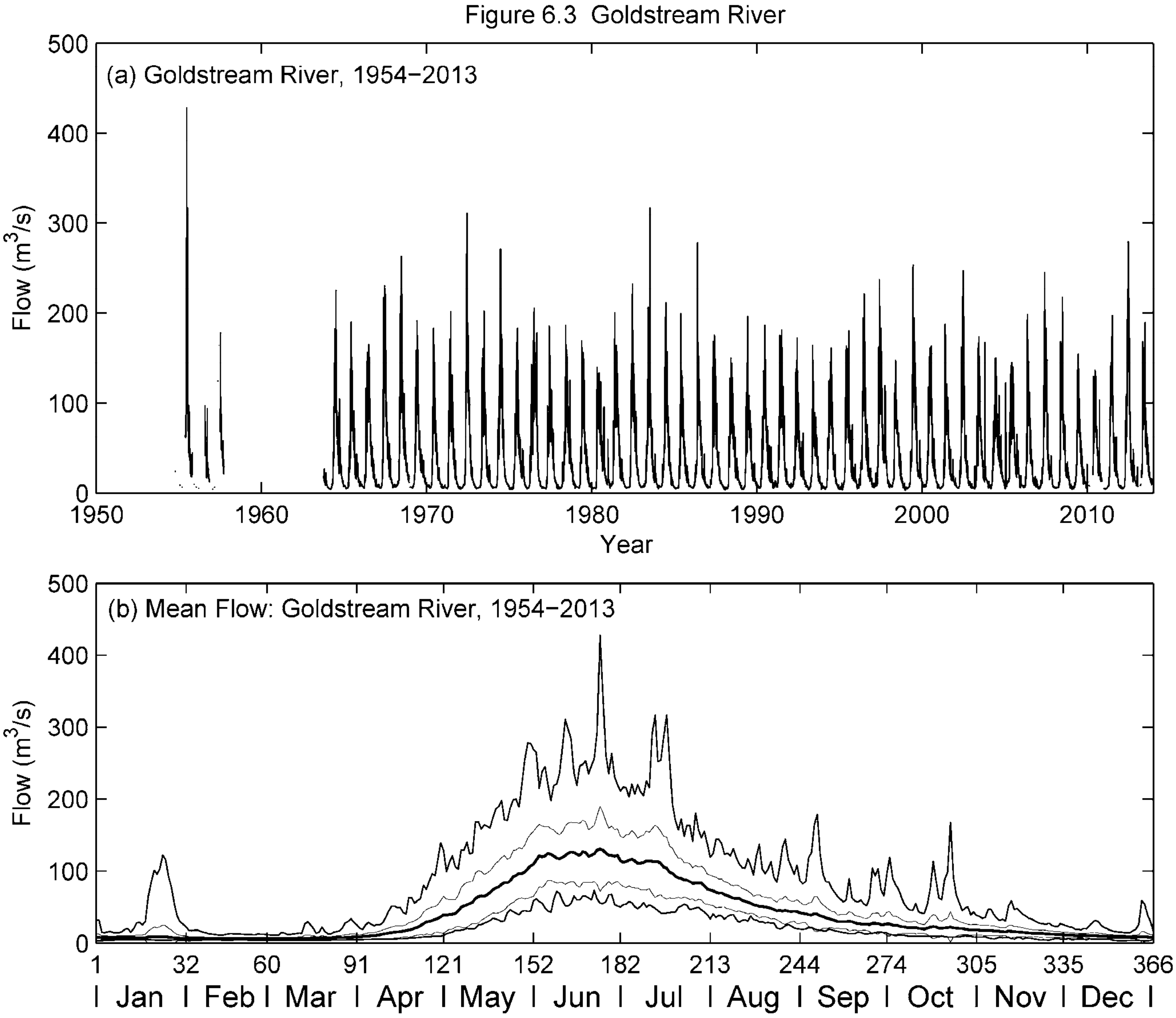


Figure 6.3. **(a)** WSC station 08ND012, “Goldstream River below Old Camp Creek”, 1954-2013. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

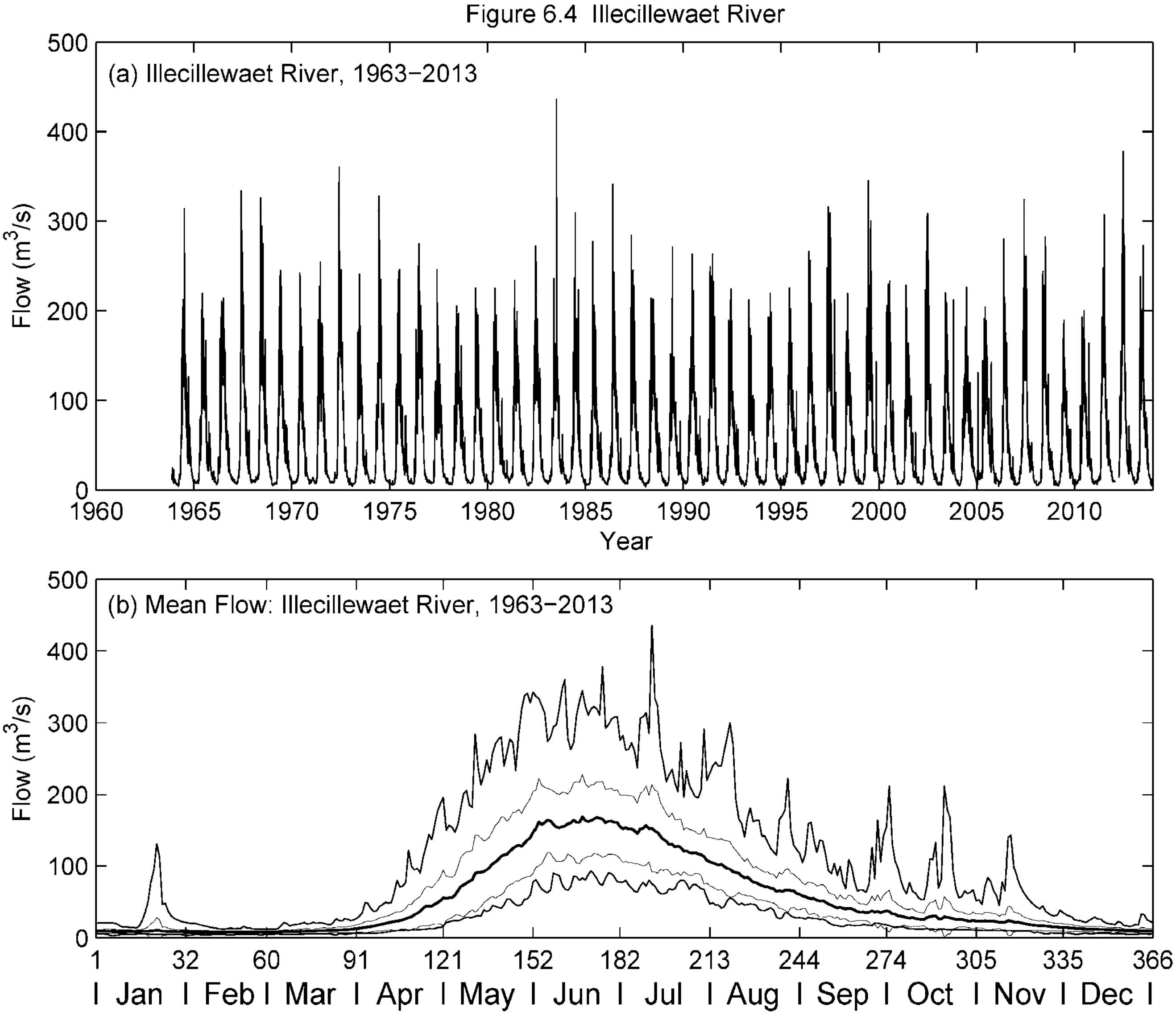


Figure 6.4. **(a)** WSC station 08ND013, "Illecillewaet River at Greeley", 1963-2013. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

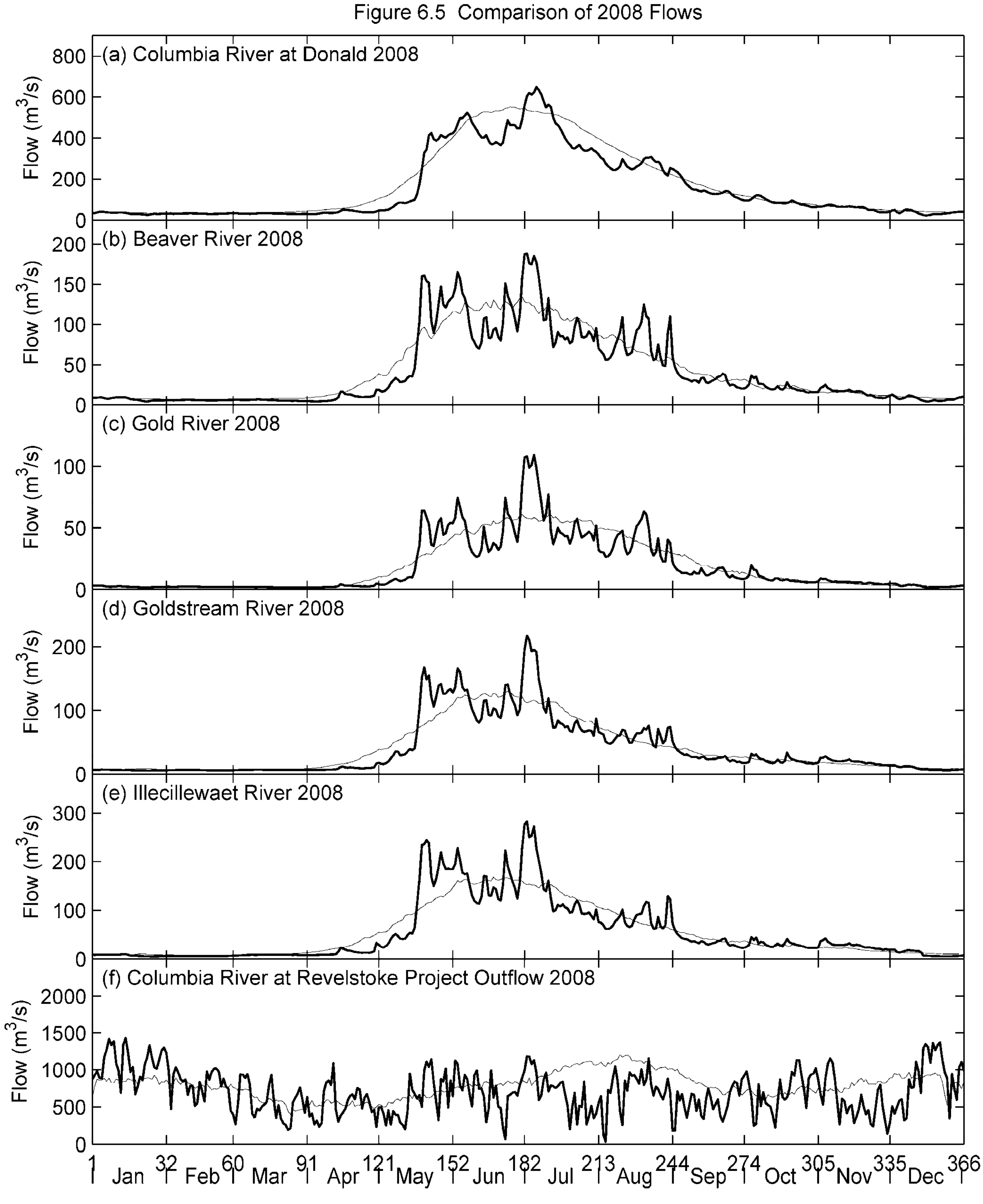


Figure 6.5. Comparison of flows in 2008 for the stations indicated (heavy line). Mean flows for **a)** 1944-2013 **b)** 1985-2013 **c)** 1973-2013 **d)** 1954-2013 **e)** 1963-2013 **f**) 1986-2013 (light line).

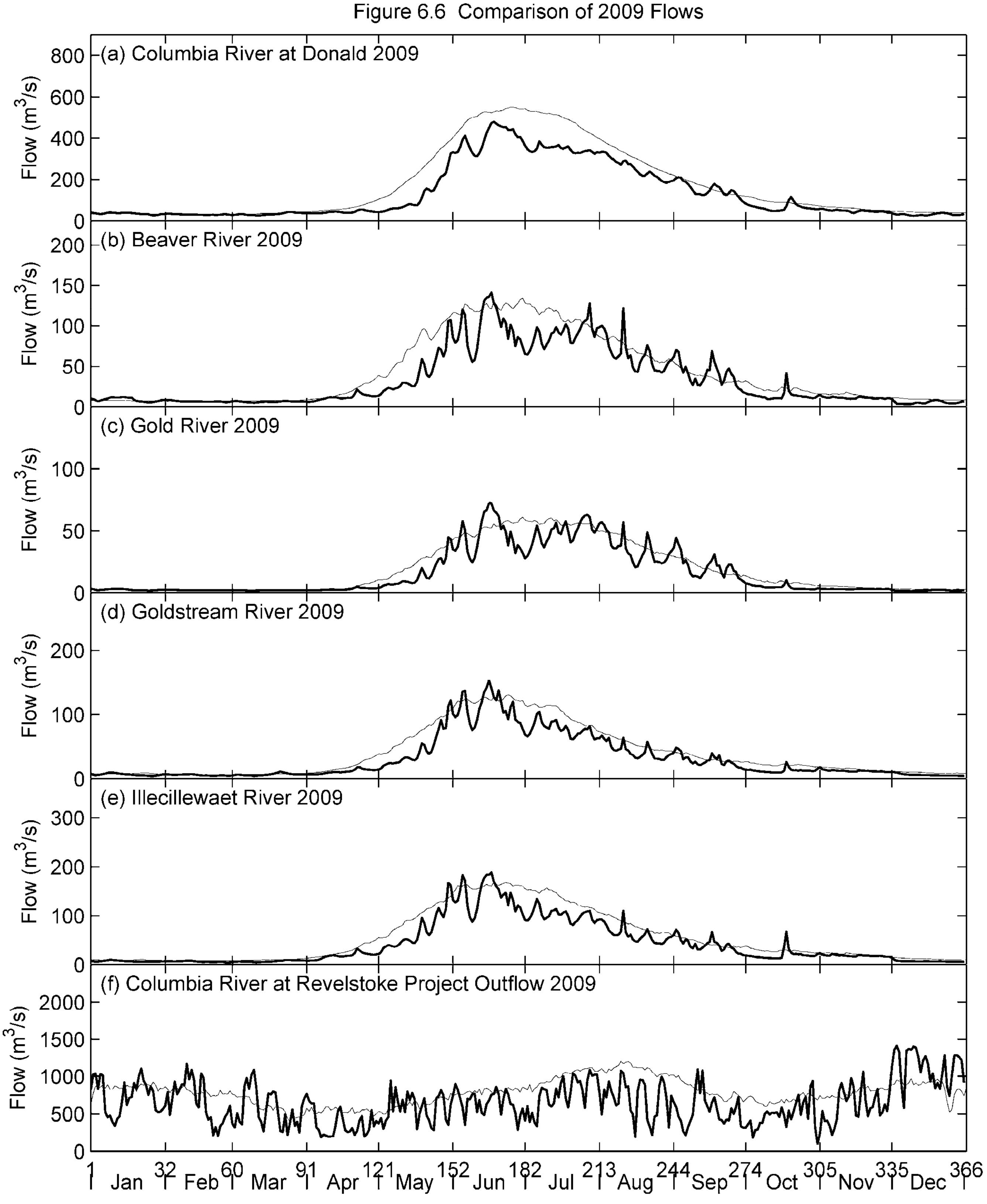


Figure 6.6. Comparison of flows in 2009 for the stations indicated (heavy line). Mean flows for **a)** 1944-2013 **b)** 1985-2013 **c)** 1973-2013 **d)** 1954-2013 **e)** 1963-2013 **f**) 1986-2013 (light line).

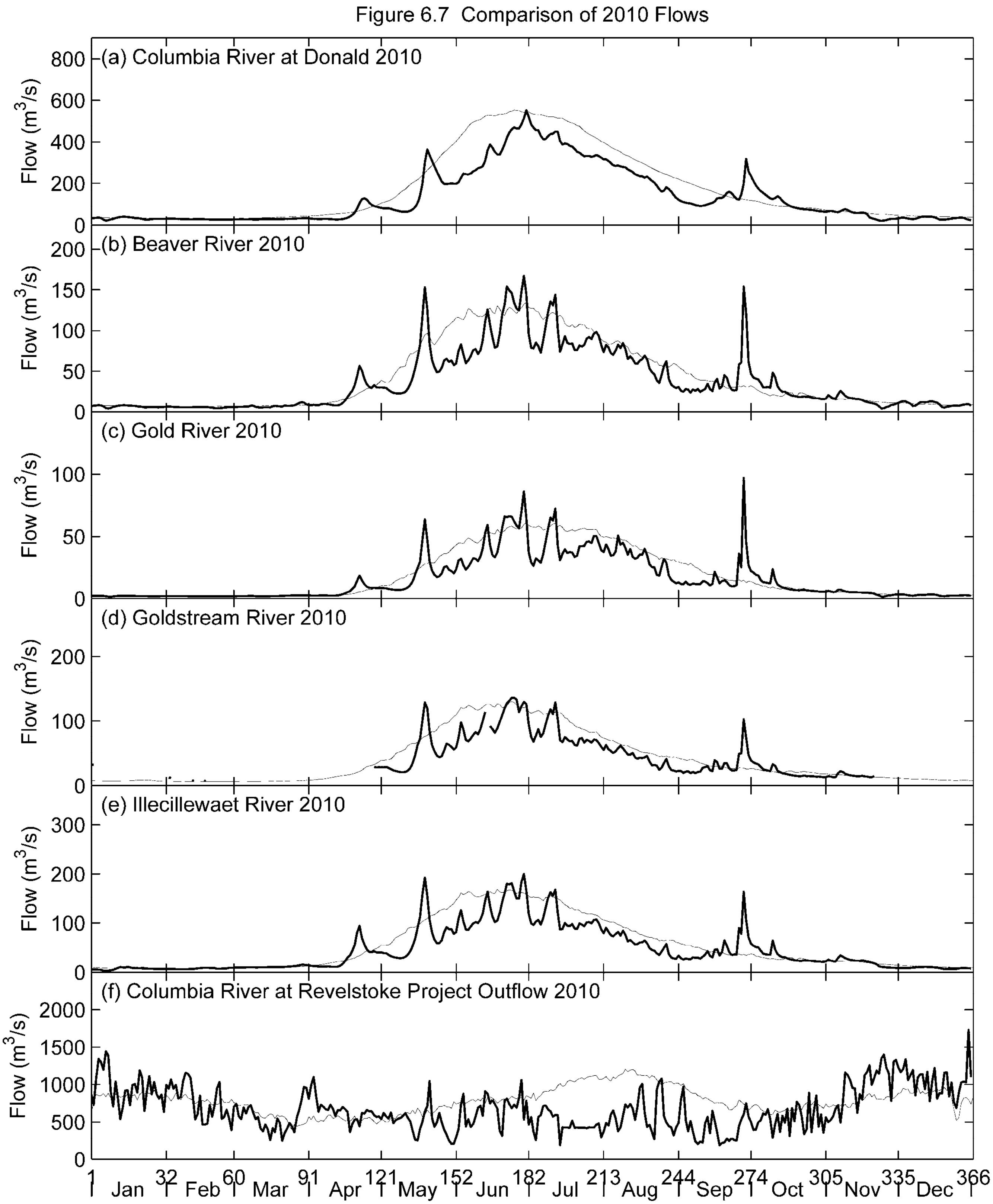


Figure 6.7. Comparison of flows in 2010 for the stations indicated (heavy line). Mean flows for **a)** 1944-2013 **b)** 1985-2013 **c)** 1973-2013 **d)** 1954-2013 **e)** 1963-2013 **f**) 1986-2013 (light line).

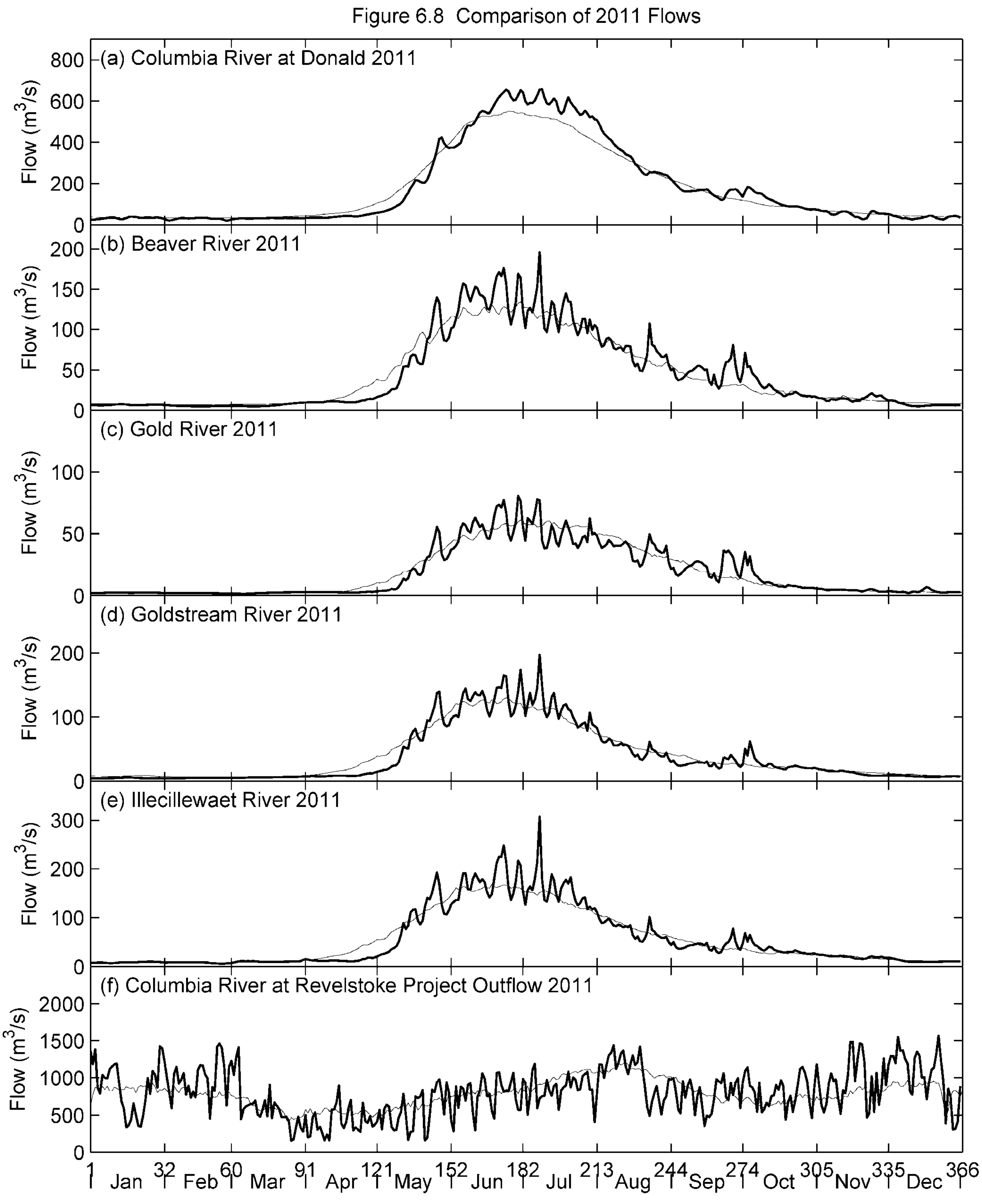


Figure 6.8. Comparison of flows in 2011 for the stations indicated (heavy line). Mean flows for **a)** 1944-2013 **b)** 1985-2013 **c)** 1973-2013 **d)** 1954-2013 **e)** 1963-2013 **f**) 1986-2013 (light line).

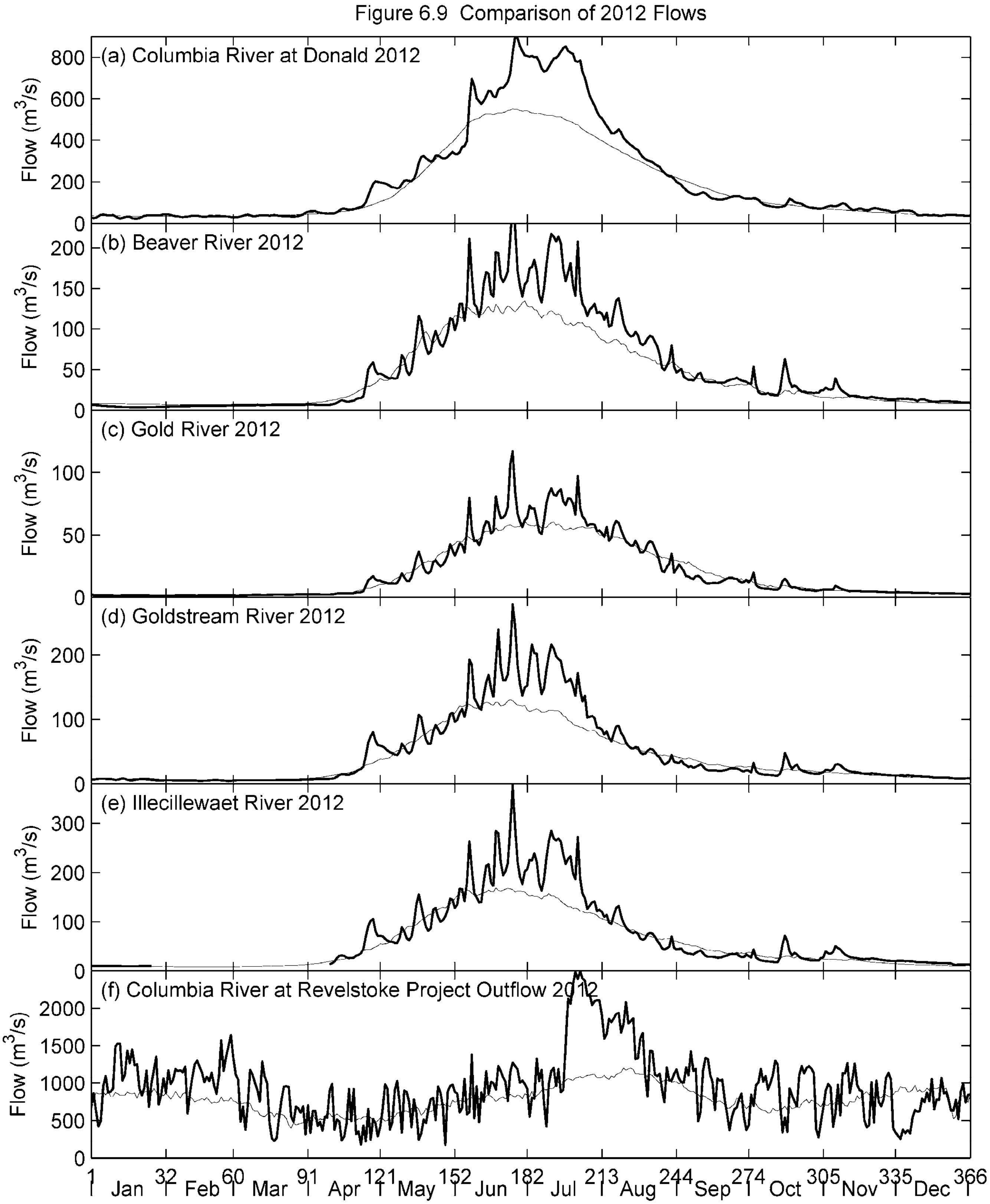


Figure 6.9. Comparison of flows in 2012 for the stations indicated (heavy line). Mean flows for **a)** 1944-2012 **b)** 1985-2012 **c)** 1973-2012 **d)** 1954-2012 **e)** 1963-2012 **f**) 1986-2012 (light line).

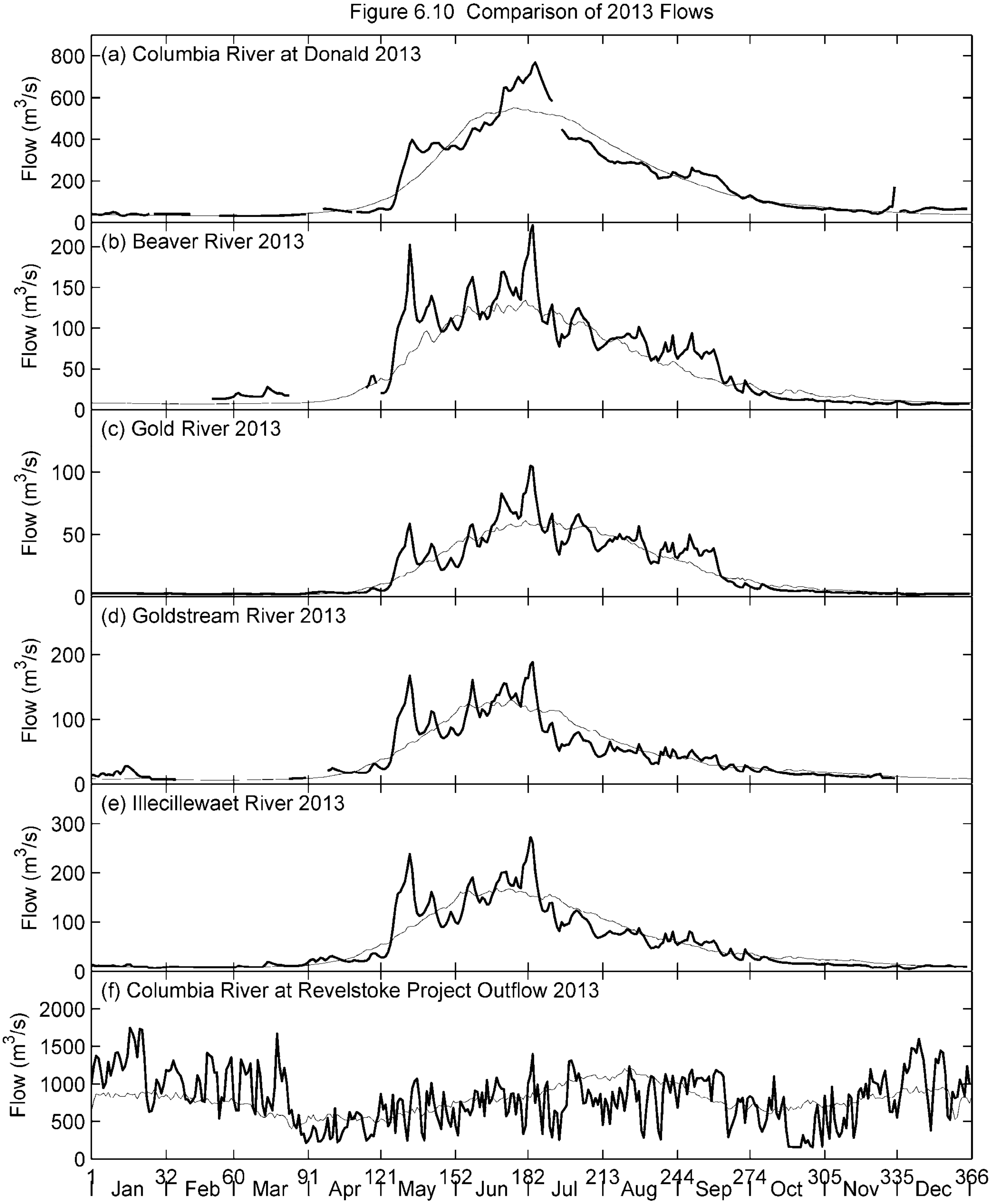


Figure 6.10. Comparison of flows in 2013 for the stations indicated (heavy line). Mean flows for **a)** 1944-2013 **b)** 1985-2013 **c)** 1973-2013 **d)** 1954-2013 **e)** 1963-2013 **f)** 1986-2013 (light line).

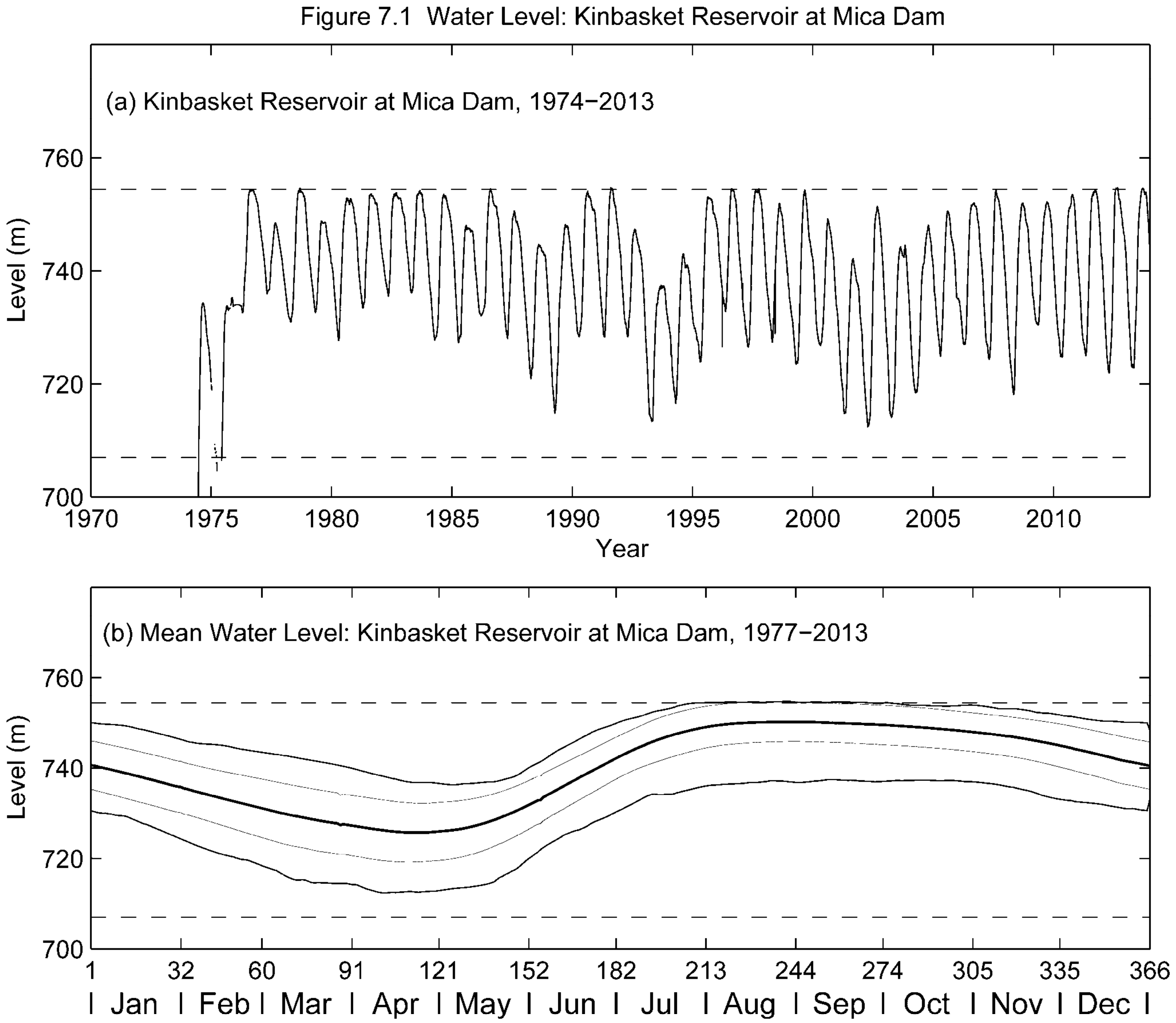


Figure 7.1. (a) WSC station 08ND017 "Kinbasket Lake at Mica Dam", 1974-2013. **(b)** Mean daily water level for 1977-2013. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

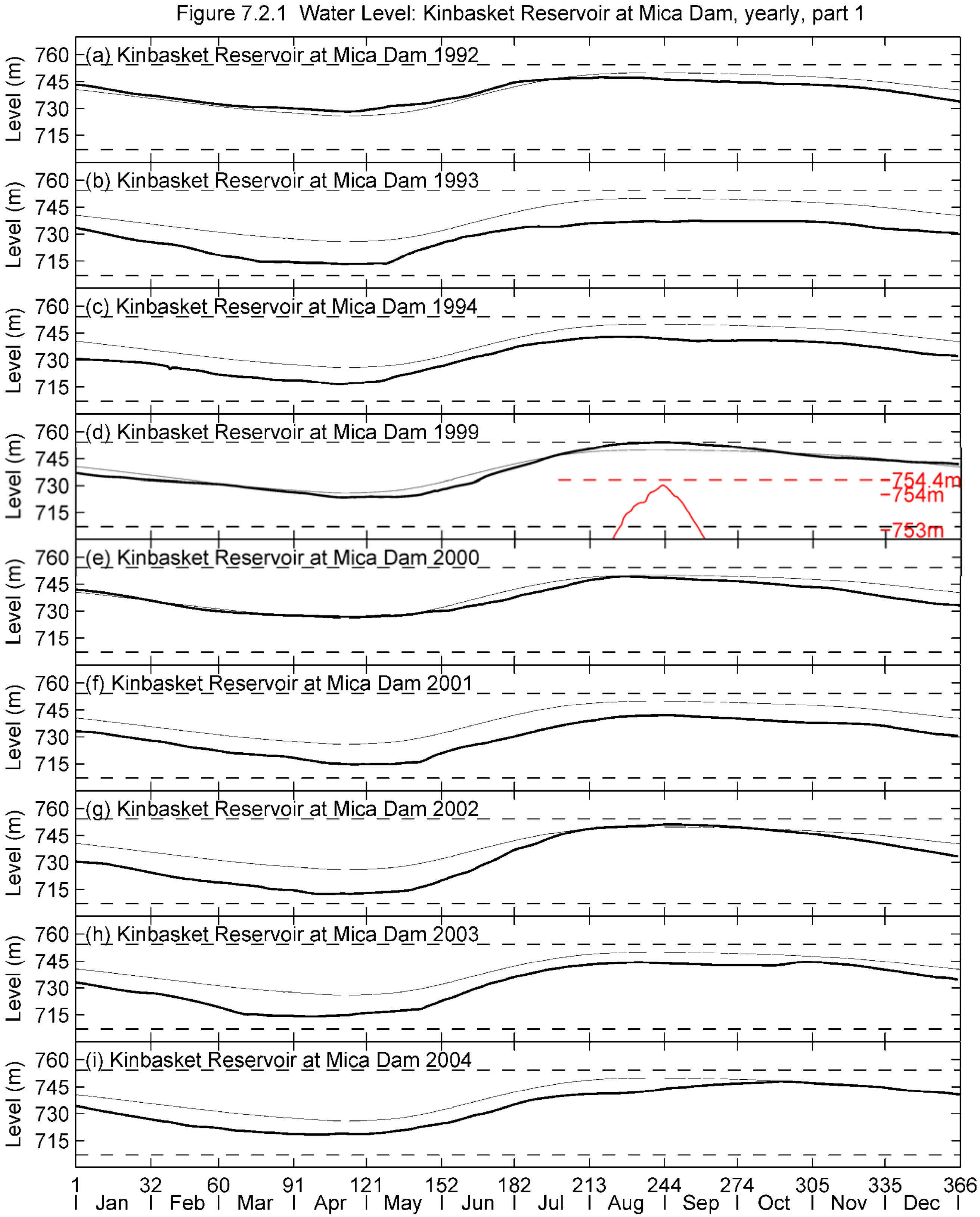


Figure 7.2.1. Water levels for WSC station 08ND017 "Kinbasket Lake at Mica Dam", selected years (heavy line). Mean daily water level for 1977-2013 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

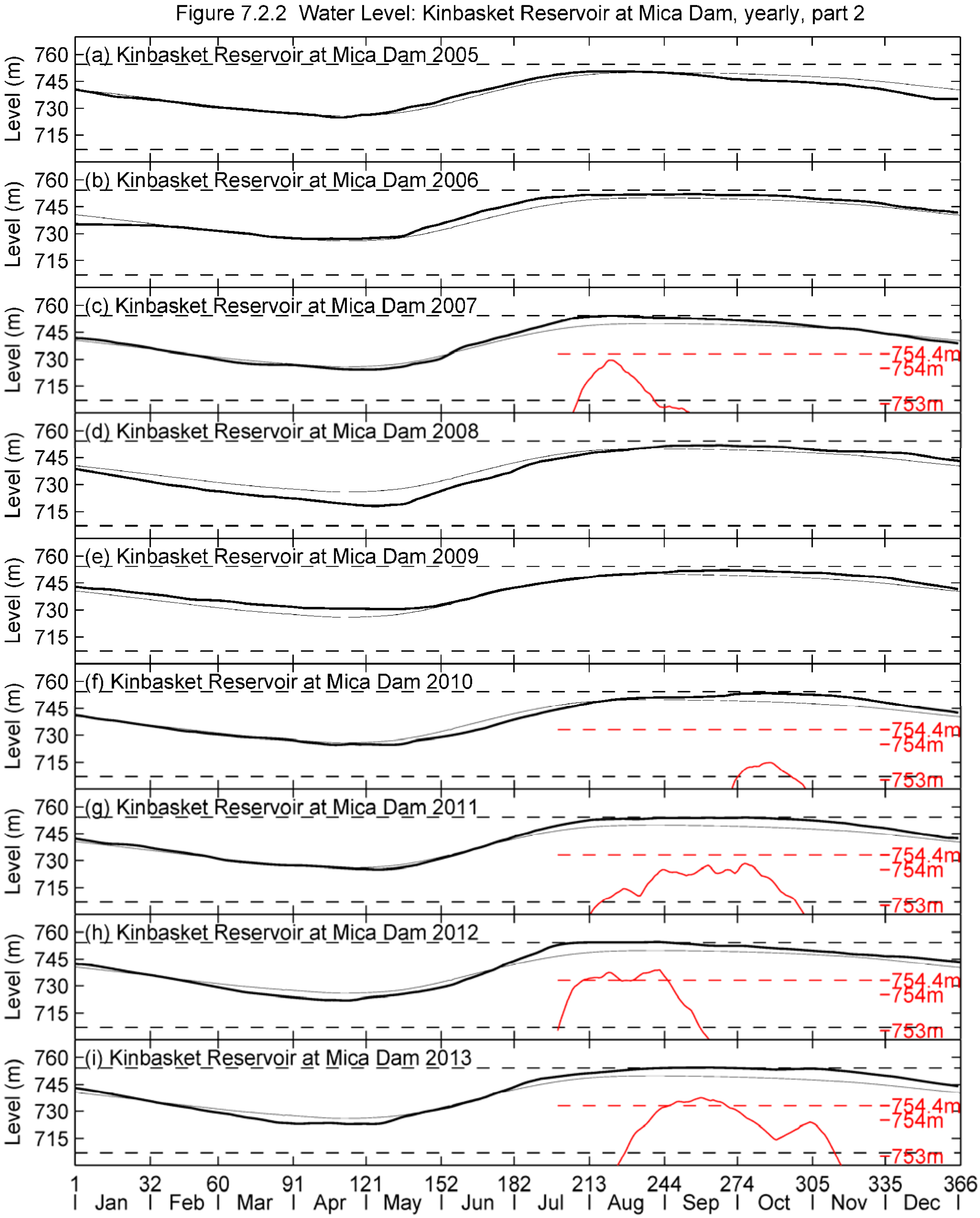


Figure 7.2.2. Water levels for WSC station 08ND017 “Kinbasket Lake at Mica Dam”, selected years (heavy line). Mean daily water level for 1977-2013 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

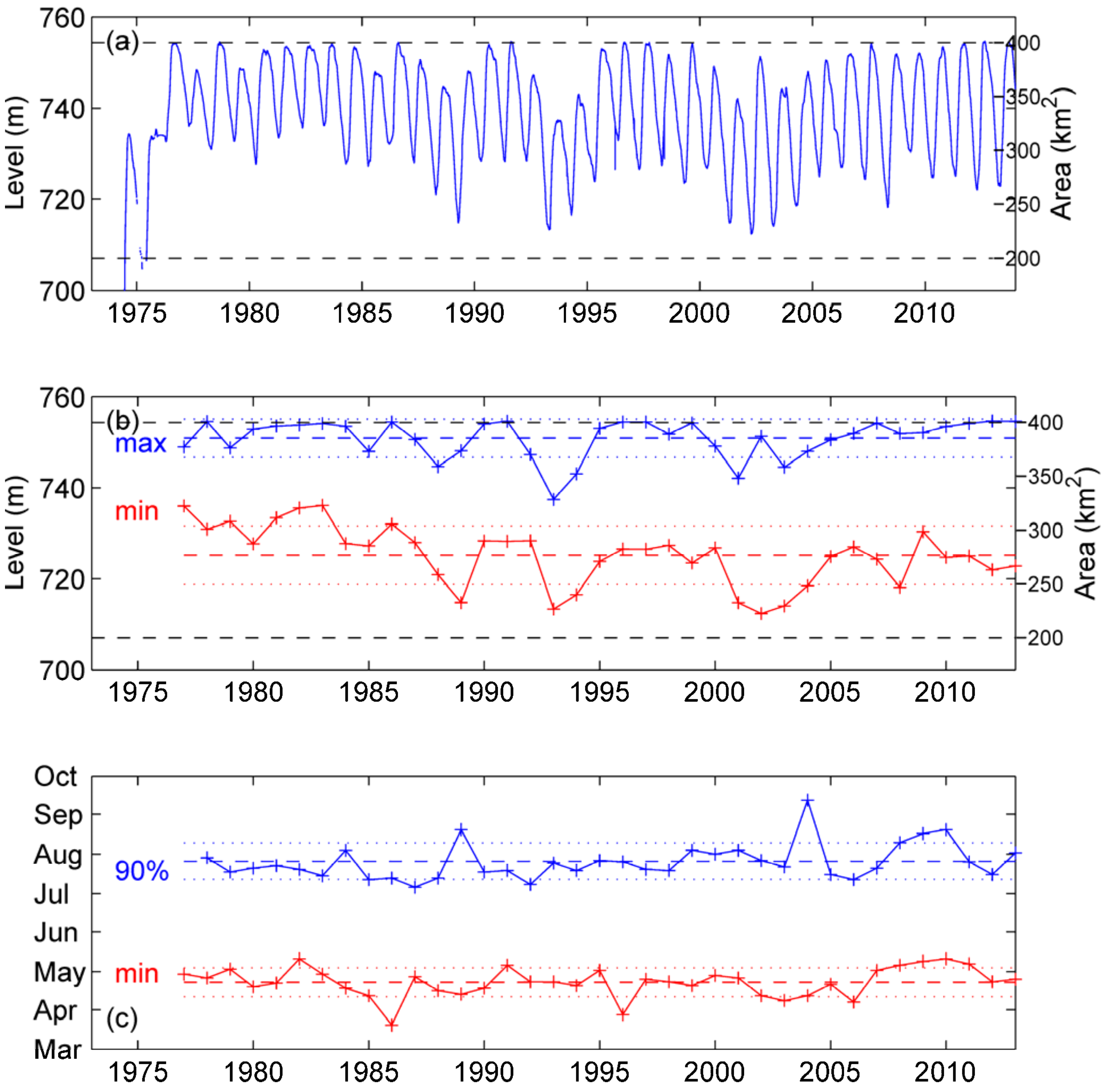


Figure 7.3 (a) Water level in Kinbasket Reservoir, 1973-2013. Black dash lines mark normal minimum and maximum water level. (b) Minimum (red) and maximum (blue) water level for 1977-2013. (c) Date of minimum (red), 90% maximum (blue) water level for 1977-2013. The time to 90% full is shown because the 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.

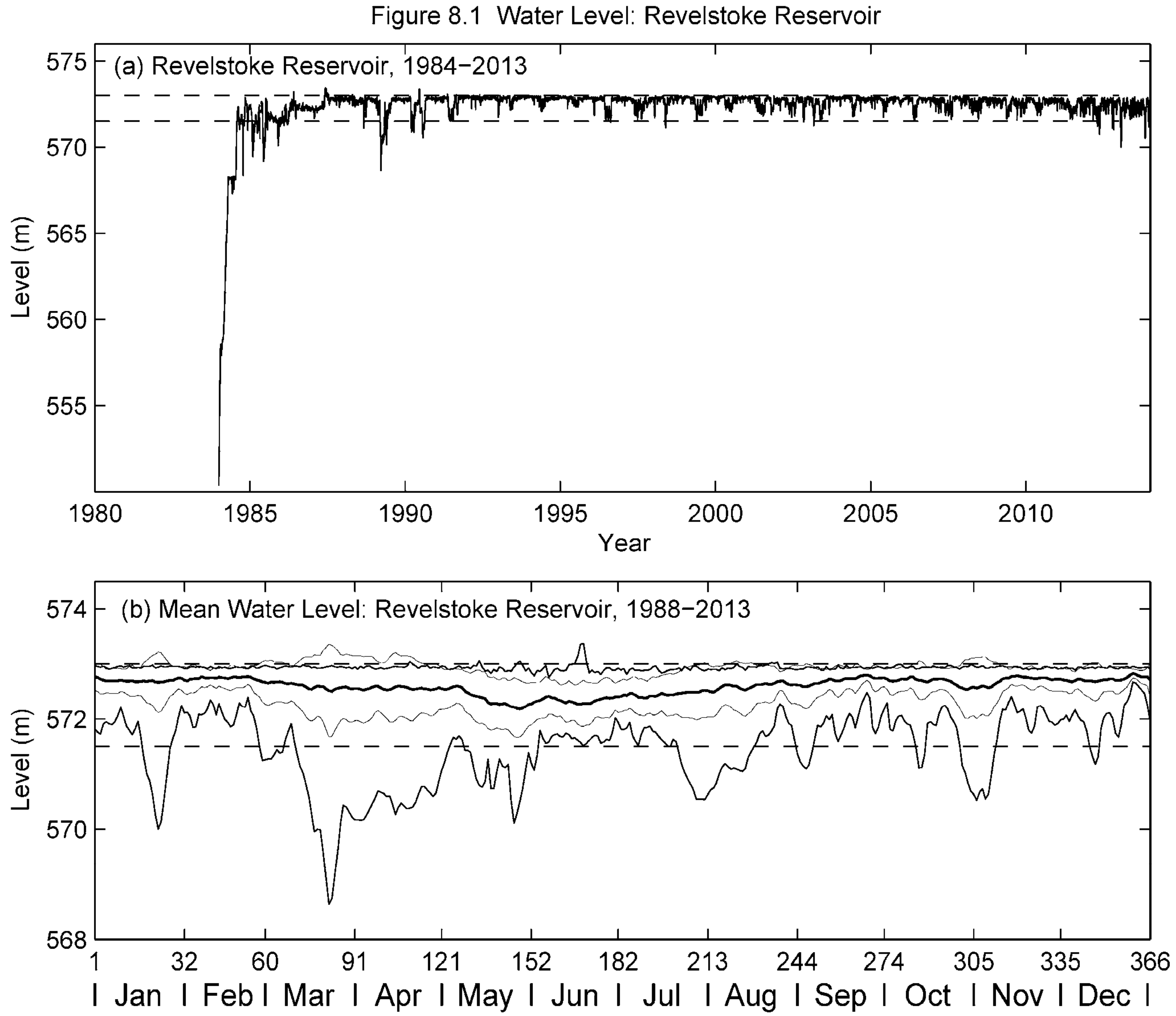


Figure 8.1. (a) BC Hydro station "Revelstoke Lake Forebay", 1984-2013. **(b)** Mean daily water level for 1988-2013. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

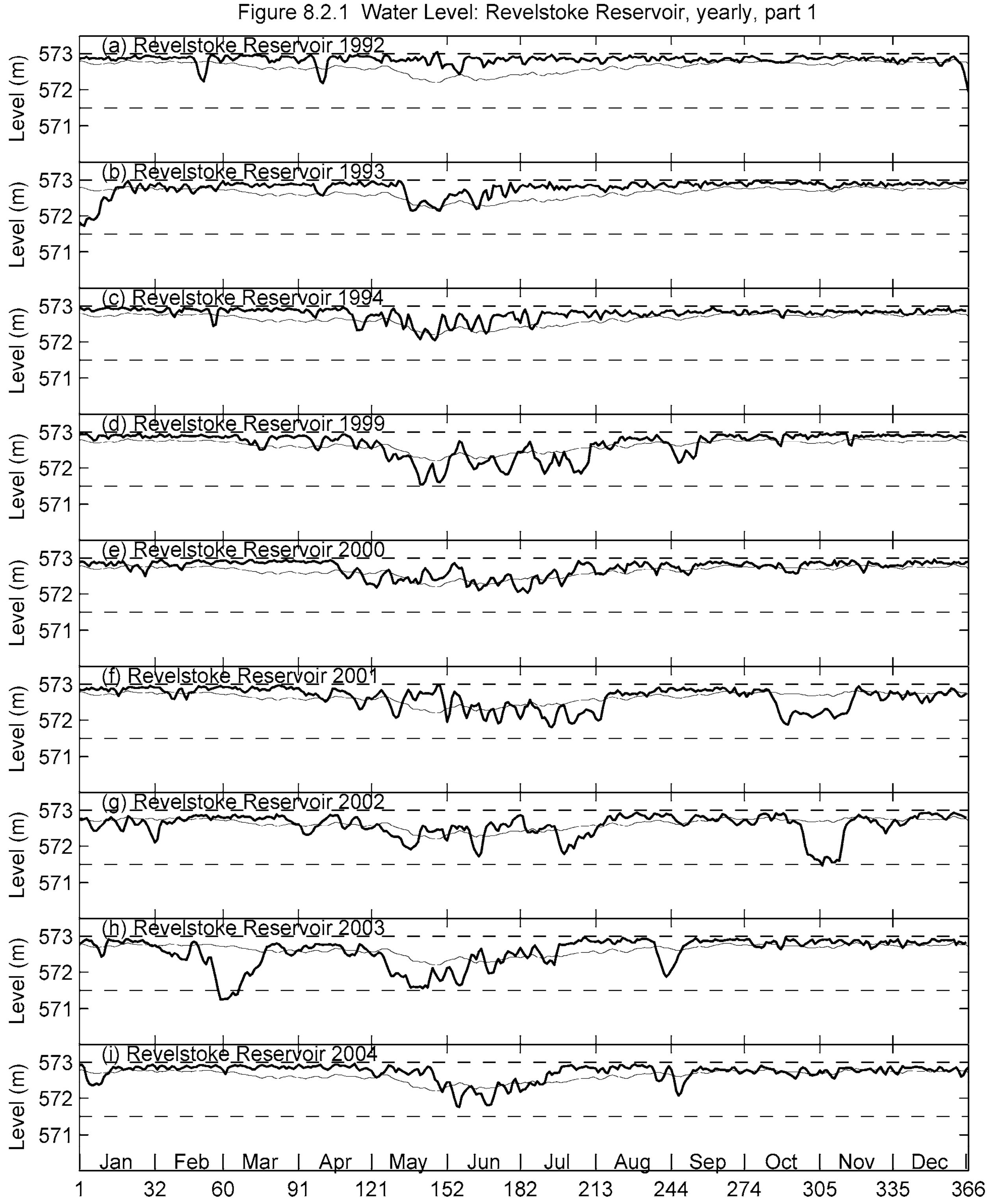


Figure 8.2.1. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2013 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

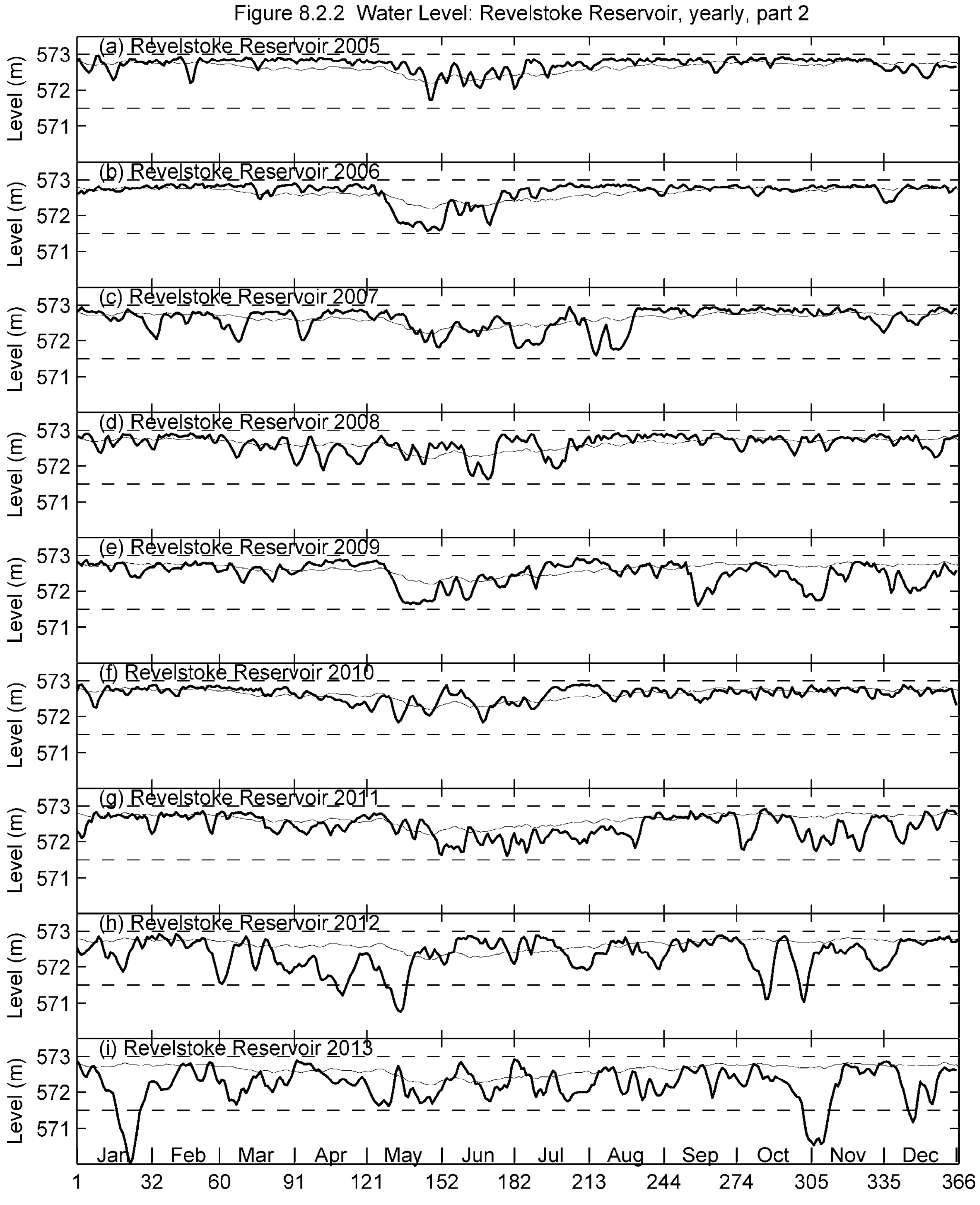


Figure 8.2.2. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2013 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

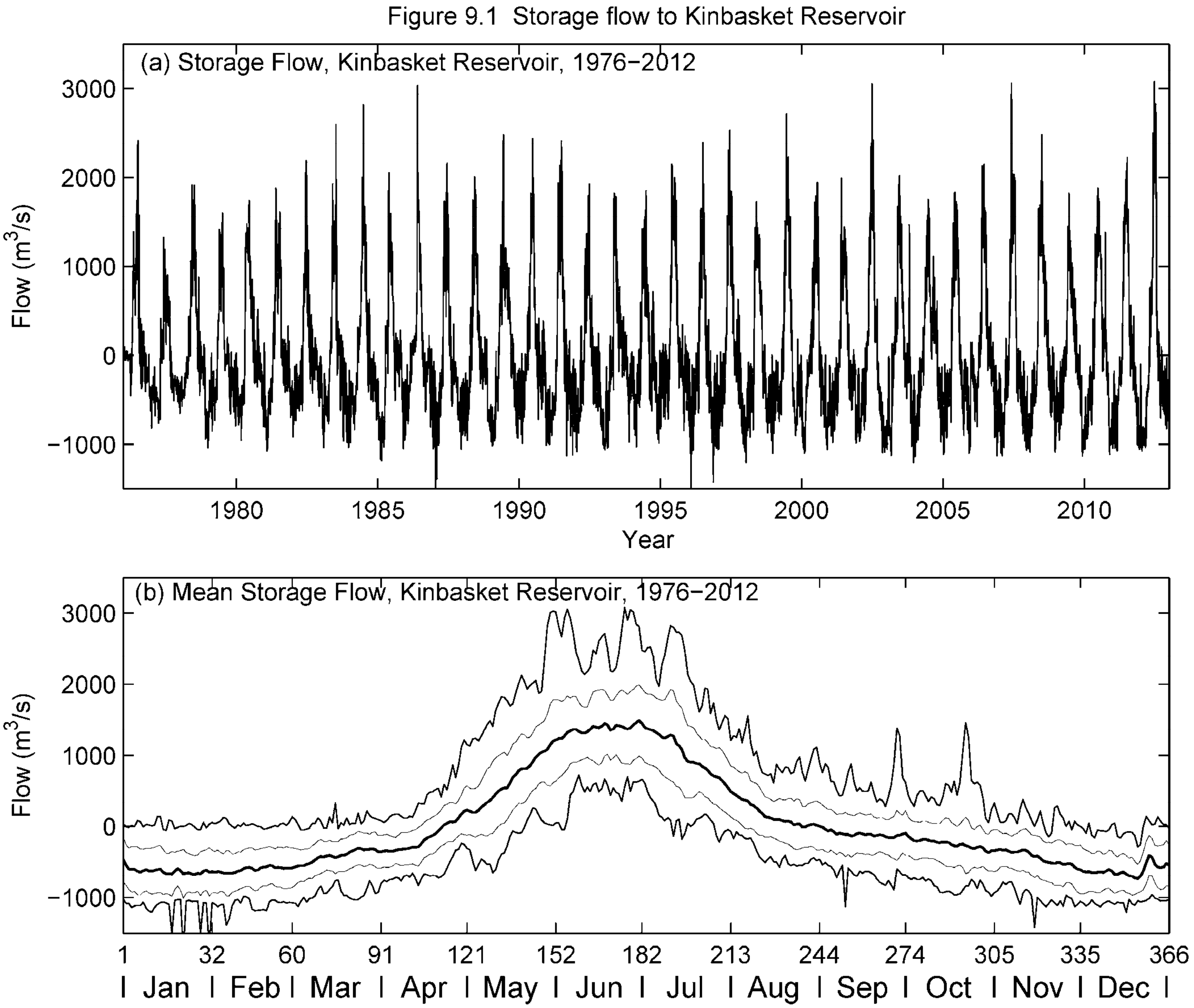


Figure 9.1. **(a)** Storage flow to Kinbasket Reservoir, 1976-2013. **(b)** Mean daily storage flow for 1976-2013. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

Figure 9.2.1 Kinbasket storage flow, yearly, part 1

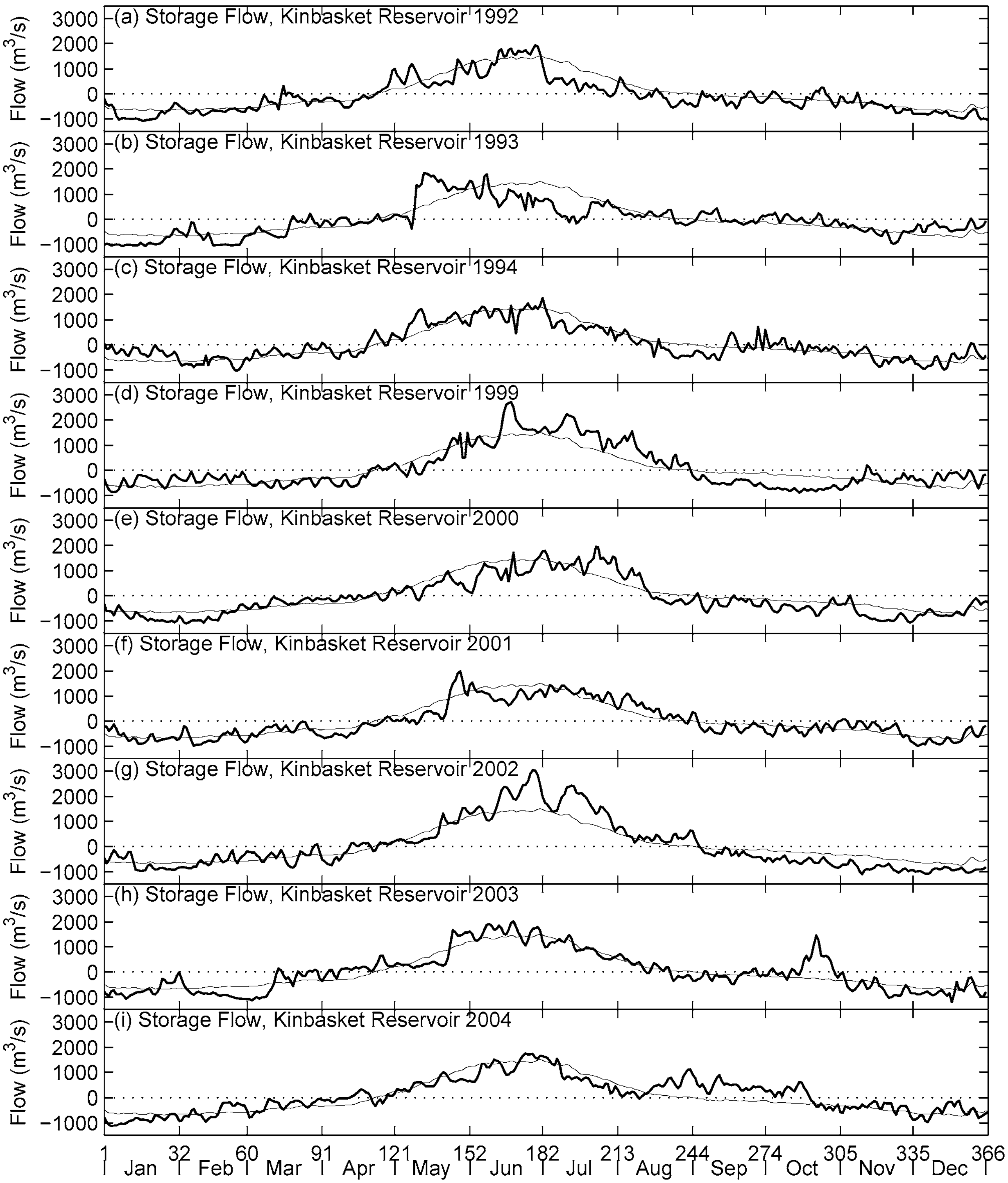


Figure 9.2.1. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2013 (light line) is shown for comparison.

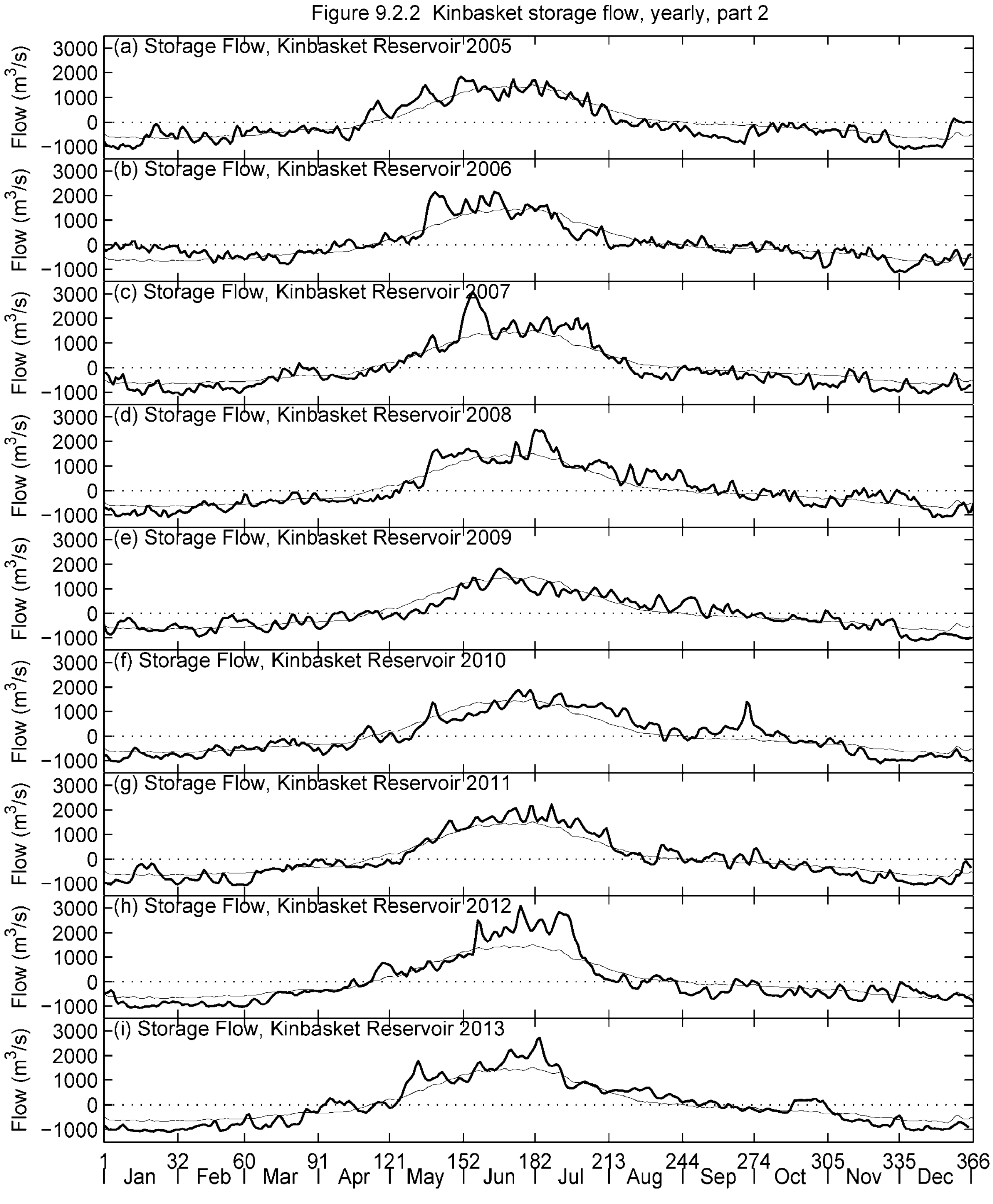


Figure 9.2.2. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2013 (light line) is shown for comparison.

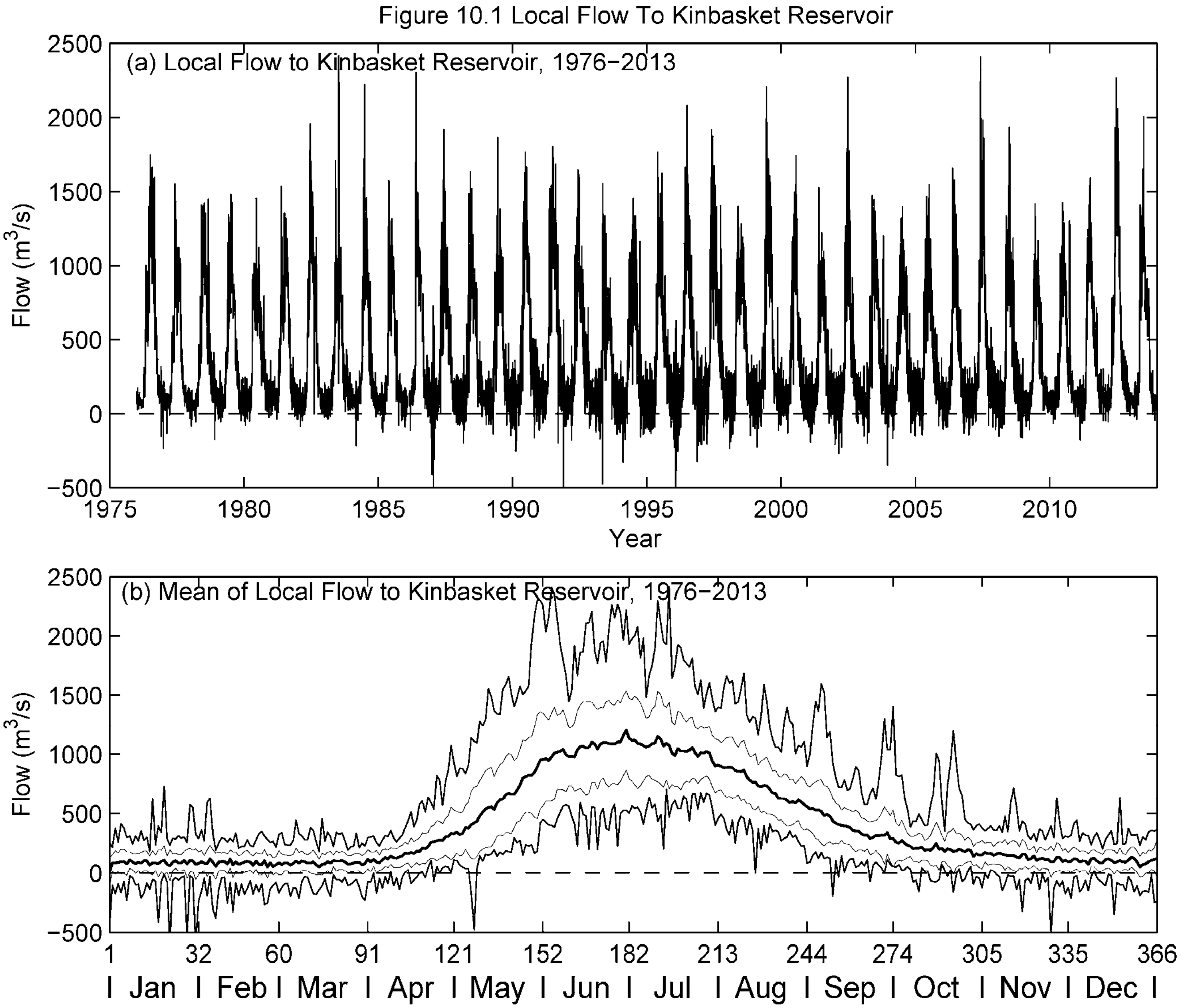


Figure 10.1. **(a)** Local flow to Kinbasket Reservoir, 1976-2013. **(b)** Mean daily local flow for 1976-2013. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

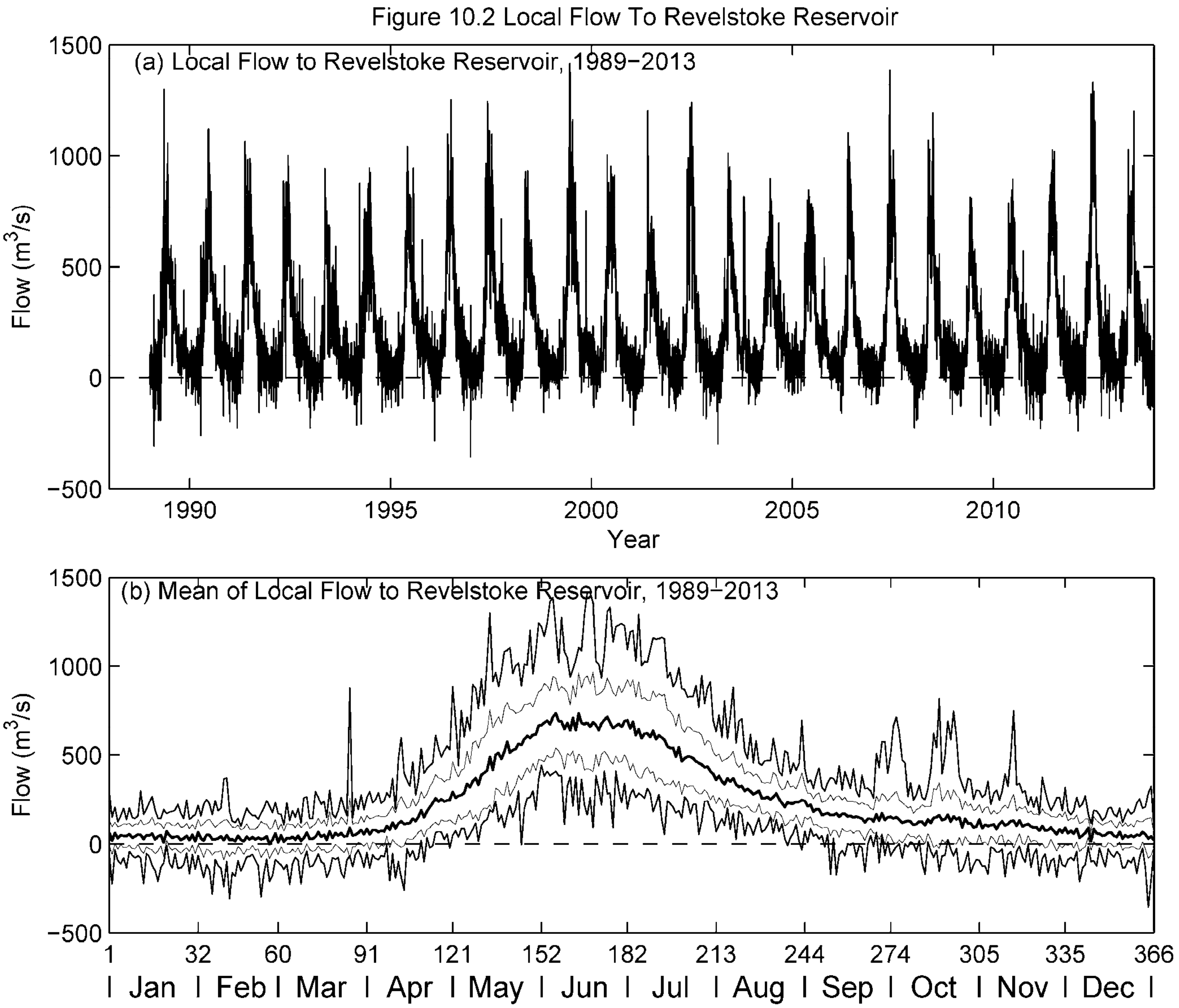


Figure 10.2. (a) Local flow to Revelstoke Reservoir, 1976-2013. **(b)** Mean daily local flow for 1976-2013. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

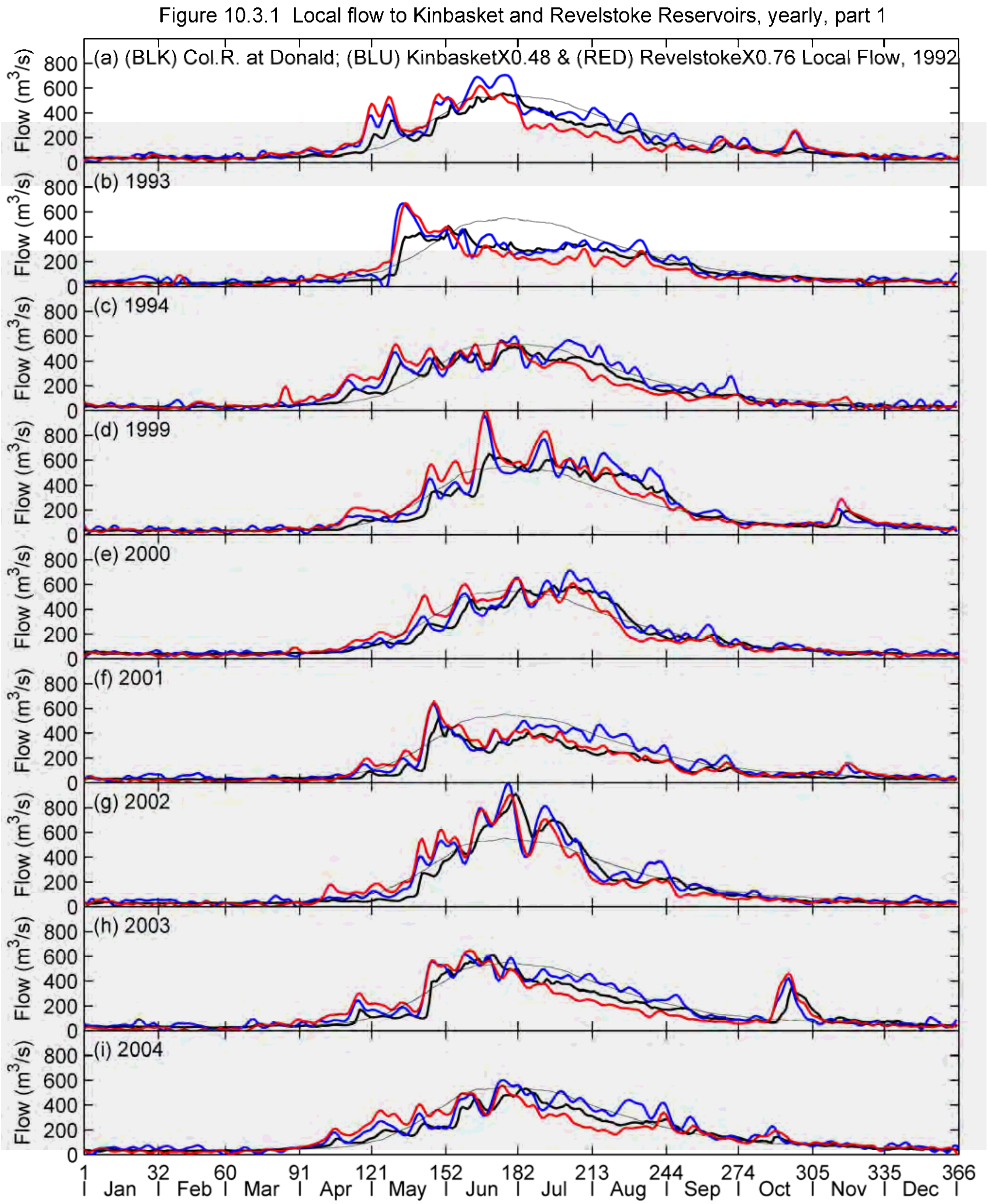


Figure 10.3.1. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2013 (light line) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

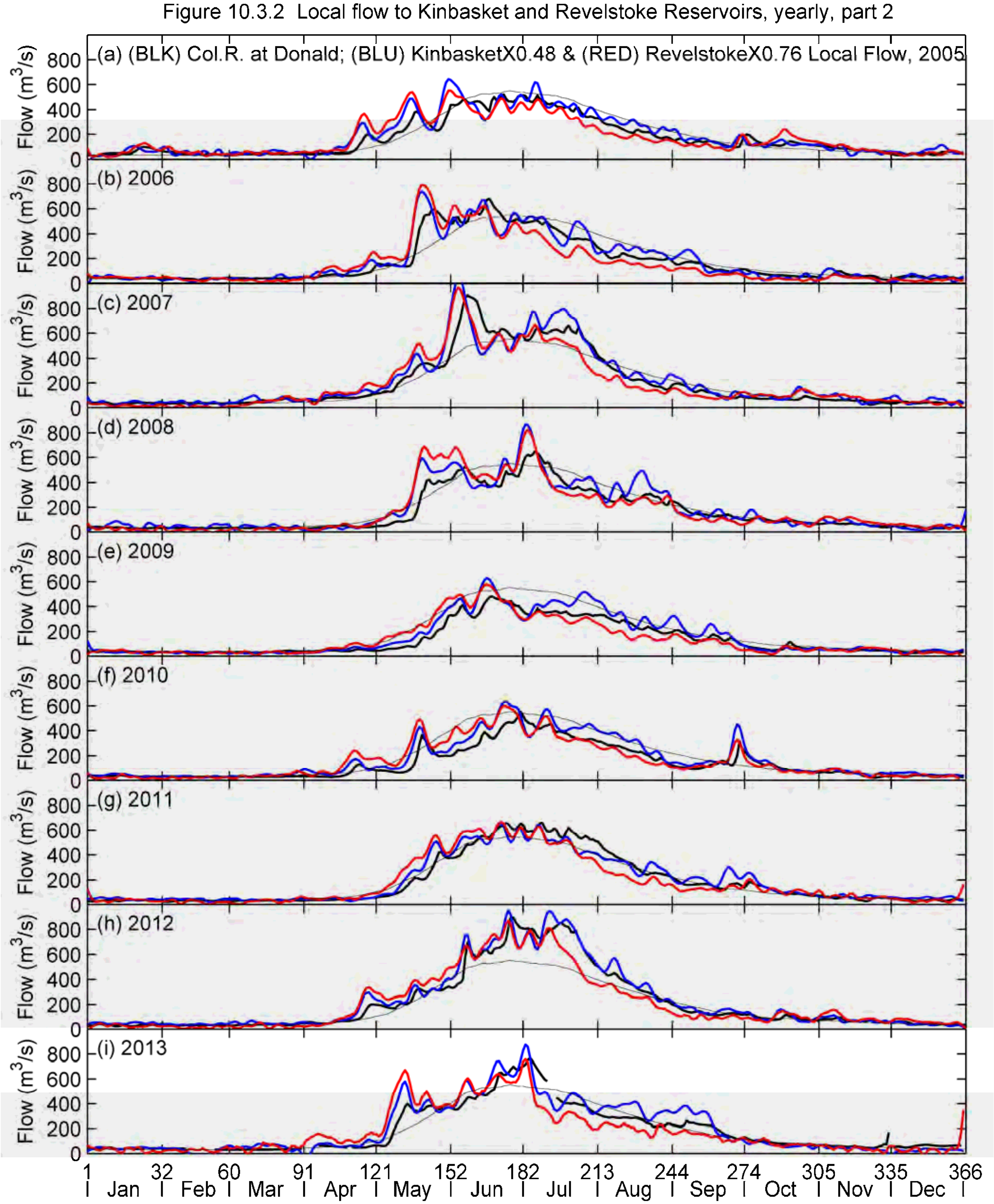


Figure 10.3.2. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2013 (light line) are shown for comparison.

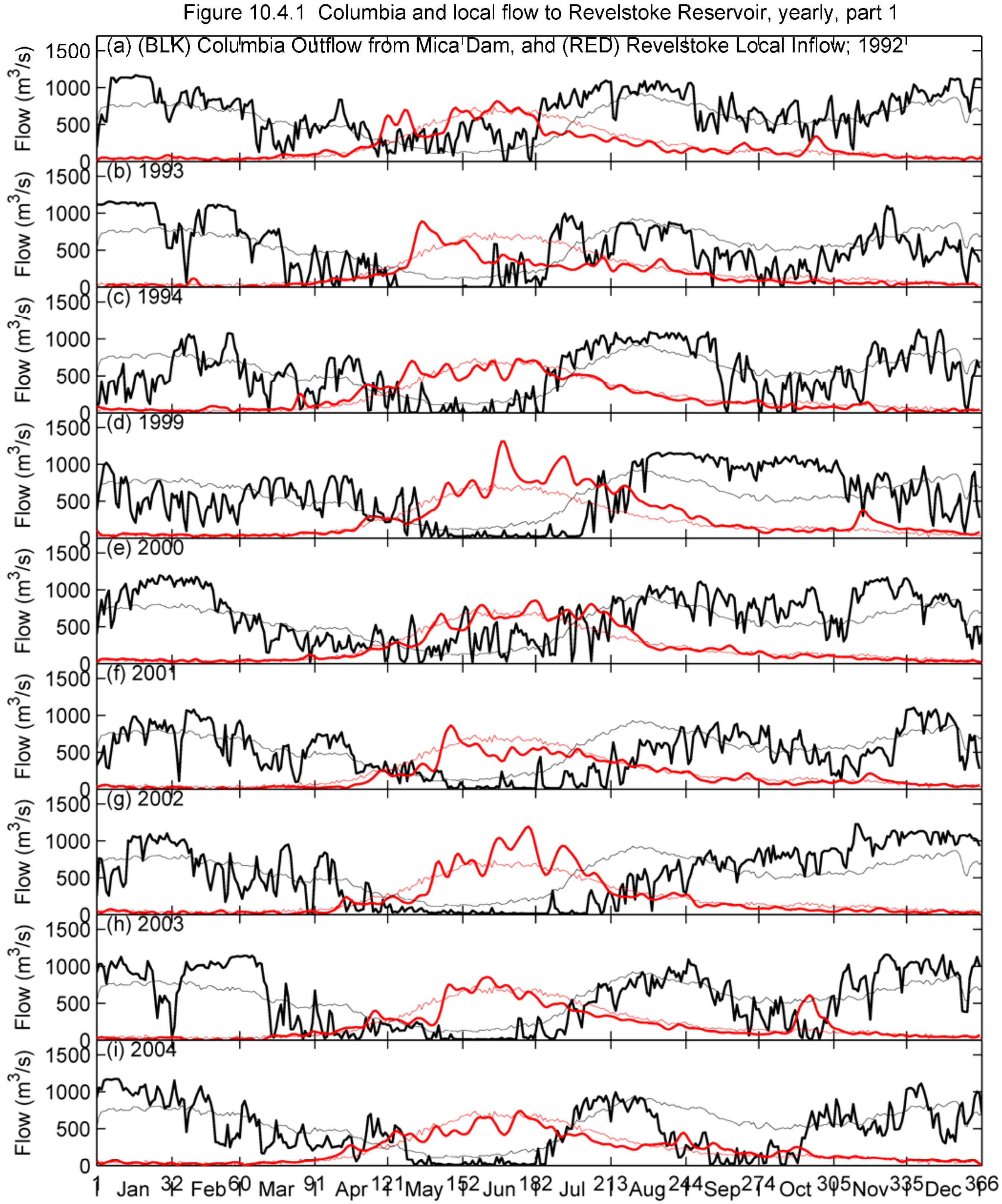


Figure 10.4.1. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison.

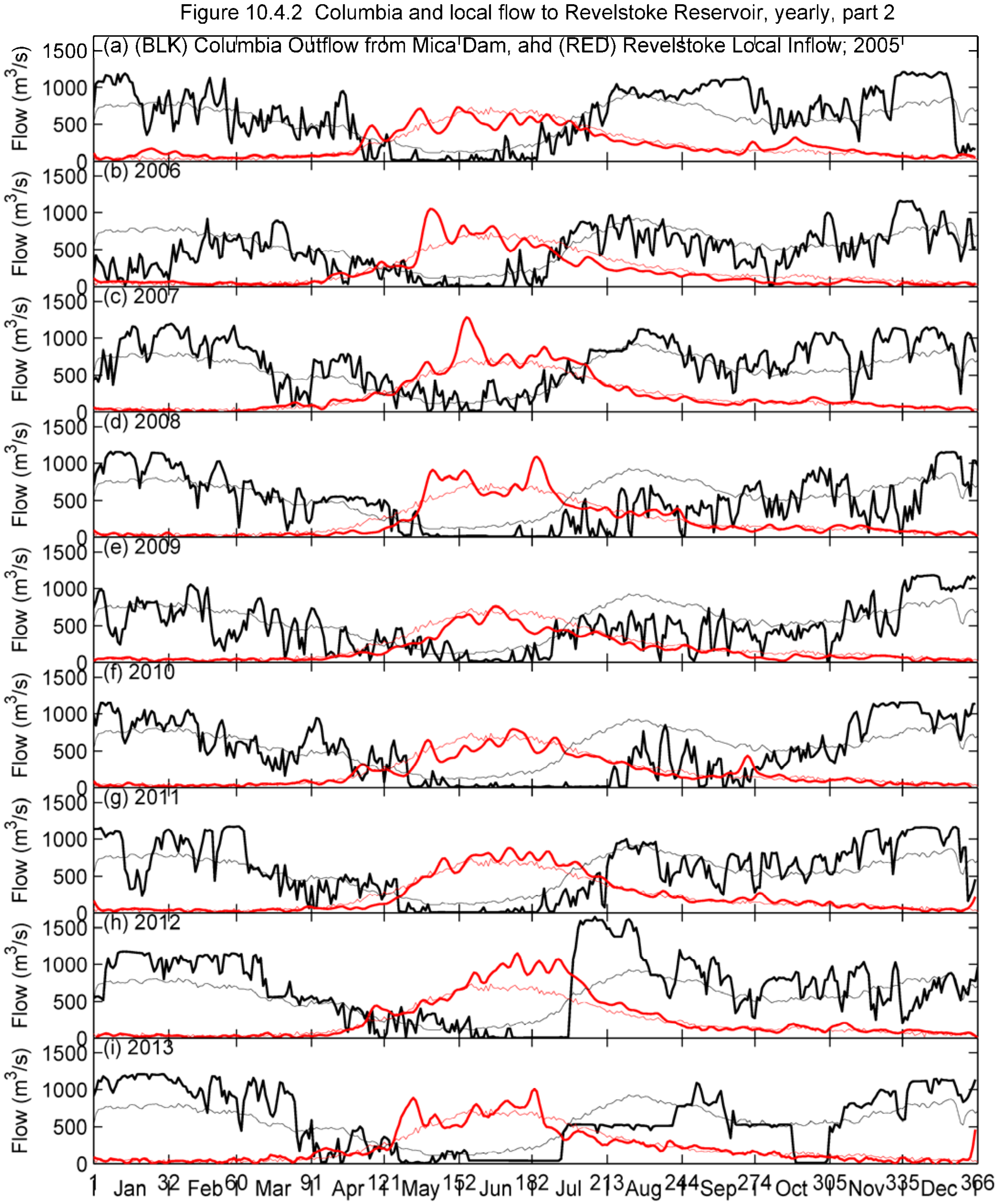


Figure 10.4.2. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

Appendix 1 Gauging Stations in the Kinbasket/ Revelstoke Drainage

Type*	**Station #**	**Abbr**	**Station Name**	**Year**	**Drainage Area[1] (km^2)**	**Mean Flow[1] (m^3/s)**	**Yield (m/yr)**
Columbia River							
Q	08NA045		Columbia River near Fairmont Hot Springs	1944-1996	891	10.4	0.37
WL	08NA004		Columbia River at Athalmer	1944-1984	1340	-	-
ND	08NA027		Columbia River near Athalmer	-	-	-	-
Q	08NA052		Columbia River near Edgwater	1950-1956	3550	58.7	0.52
Q	08NA002		Columbia River at Nicholson	1903-present	6660	107	0.51
Q	08NB005	coldo	Columbia River at Donald	1944-present	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-present	-	-	-
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-present	-	-	-
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-present	-	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-present	-	-	-
Local Flow in Kinbasket Lake							
Q	08NB019	beavr	Beaver River near the Mouth	1985-present	1150	41.9	1.15
Q	08NB014	goldr	Gold River above Palmer Creek	1973-present	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-present	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-present	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)

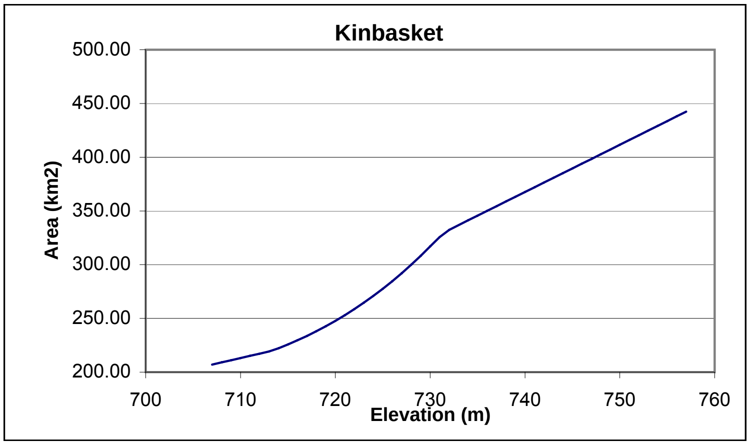
Revelstoke Reservoir Elevations

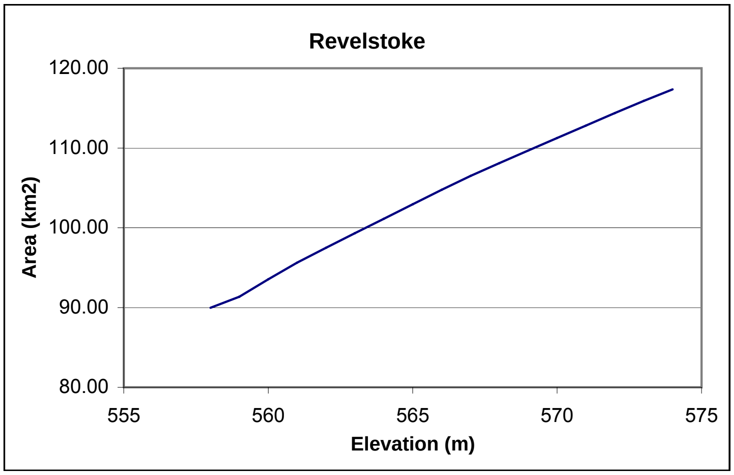
Elevation (ft)	Elevation (m)	Storage (Mm^3)	Area (km^2)	Comments
1894.0	577.6			Crest of dam
1885.0	574.6	5449.4	118.2	DSI, Dam Safety Incident level when spill gates are open. Expected maximum reservoir level during the PMF inflow event (7100 m3/s, 250,000 cfs)
1880.0	573.0	5264.8	116.0	Nmax, Normal 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, 2013

Roger Pieters, Alyssia Law, and Greg Lawrence
University of British Columbia

Tributary Water Quality
Kinbasket and Revelstoke Reservoirs, 2013

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

[1] Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C. V6T 1Z4
[2] Civil Engineering, University of British Columbia, Vancouver, B.C. V6T 1Z4

Revelstoke Reservoir below Mica Dam, 29 Aug 2013

Prepared for

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

January 14, 2016

Contents

List of Figures

1. Introduction

We report on water quality data collected from tributaries to Kinbasket and Revelstoke Reservoirs in 2013. 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:

1. Reference tributaries, sampled from May to November. Regular sampling of reference tributaries began in 2009 (Pieters et al. 2011-2014); here we report on the data from the reference tributaries in 2013.
2. Surveys of many tributaries at a given time. Sampling of tributary surveys were undertaken across both reservoirs in June and August 2008 (Pieters et al, 2010), and on 7-8 July 2009 (Pieters et al, 2011), but a survey was not conducted in 2010, 2011 or 2012 due to lack of helicopter availability. Here we report on the survey of tributaries conducted on 6 May 2013.

2. Methods

Reference Tributary sample collection

There are five reference tributaries: Columbia River at Donald, Goldstream River, Kinbasket Reservoir (Mica Dam) outflow, Revelstoke Reservoir (Revelstoke Dam) outflow, and Beaver River. In the past, the first four were sampled by BC Hydro, and the Beaver River was sampled by Environment Canada. In 2013, BC Hydro began sampling the Beaver River as well.

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.

The Beaver River was sampled at the east gate of Glacier National Park by Environment Canada, representing about half of the total drainage of the Beaver River. Sampling of the Beaver River by BC Hydro was begun in 2013, at sampling sites near the confluence with Kinbasket Reservoir, and varying with water level (Appendix 2).

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

Tributary survey Sample Collection

Surveys were completed by helicopter from 6-9 May 2013 except when tributaries were easily accessible by road, particularly along the east side of Revelstoke Reservoir where samples were collected from Highway 23. The 2013 survey included four new tributaries to Kinbasket Reservoir (Waitabit, Bluewater, Quartz and Succour Creeks) all between Bush pool and Donald Station. The 2013 survey also included one new tributary to the north end of Revelstoke Reservoir, Pat Creek.

Sample Processing

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 Maxxam Analytics, 4606 Canada Way, Burnaby, British Columbia. Note that in previous years (2008-2012) samples were analyzed by the Cultus Lake Salmon Research Laboratory, Department of Fisheries and Oceans, 4222 Columbia Valley Highway Cultus Lake, British Columbia. In all years, samples were analyzed for the water quality parameters listed in Table 1. Laboratory methods are summarized in Appendix 1. The tributaries sampled are listed in Appendix 2. Data are given in Appendix 3. A problem was found with alkalinity data prior to 2013; this report shows corrected alkalinity for all years (see Appendix 1 for detail).

Table 1 Parameters measured

Parameter	Units	Symbol	Detection Limit (Maxxam)
pH		pH	
Conductivity (C25)	µS/cm	Cond	1 µS/cm
Nitrate and Nitrite (NN)	µg/L N	NN	2 ug/L
Soluble Reactive Phosphorus (SRP)	µg/L P	SRP	1 ug/L
Total Dissolved Phosphorus (TDP)	µg/L P	TDP	2 ug/L
Total Phosphorus (TP)*	µg/L P	TP	2 or 20 ug/L
Turbidity (Turb)	NTU	Turb	0.1 NTU
Alkalinity (Alk)	mg$CaCO_3$/L	Alk	0.5 mg$CaCO_3$/L
Water Temperature (T)	^oC	T	

*A color/turbidity correction for TP is only available for 2008-2012 data.

Sample Coverage

The approximate drainage areas of the sampled tributaries (Appendix 2) were used to estimate the percentage of the local and total drainage that was sampled by the survey

(Tables 2 and 3). For Kinbasket Reservoir, ~39% of the local drainage was sampled. Kinbasket Reservoir can be divided into three regions, Columbia Reach, Canoe Reach and Wood Arm. Of these approximately half of the drainage area was sampled in both the Columbia and Canoe Reaches, and ~37% from the drainage of Wood Arm (Table 2). The total drainage for Kinbasket Reservoir includes not only the local inflow but the flow from the Columbia River at Donald Station. Of the total drainage to Kinbasket Reservoir, 71% was sampled (Table 3).

For Revelstoke Reservoir, ~76% of the local drainage area was sampled. Revelstoke Reservoir can be divided into Upper and Lower Revelstoke of which approximately 85% and 56% were sampled, respectively (Table 2). Of the total drainage to Revelstoke Reservoir, which includes the outflow from Mica Dam, 95% was sampled (Table 3).

Table 2 Percentage of the local drainage sampled in 2013

KINBASKET RESERVOIR

Drainage area local to Kinbasket Reservoir	11,790 km^2
Drainage area of all tributaries sampled (except Columbia at Donald)	~5,600 km^2
Percent Sampled	47%
Drainage area local to Columbia Reach	7,540 km^2
Drainage area of all sampled tributaries to Columbia Reach	~3,700 km^2
Percent Sampled	49%
Drainage area local to Canoe Reach	3,290 km^2
Drainage area of all Sampled tributaries to Canoe Reach	~1,550 km^2
Percent Sampled	47%
Drainage area local to Wood Arm	956 km^2
Drainage area of all Sampled tributaries to Wood Arm	350 km^2
Percent Sampled	37%

Table 2 con't Percentage of the local drainage sampled in 2013

REVELSTOKE RESERVOIR	
Drainage area local to Revelstoke Reservoir	4,900 km^2
Drainage area of all sampled tributaries (except Columbia River at Mica Outflow)	3,700 km^2
Percent Sampled	76%
Drainage area local to Upper Revelstoke Reservoir	~3,300 km^2
Drainage of all Sampled tributaries to Upper	~2,800 km^2
Percent Sampled	85%
Drainage area local to Lower Revelstoke Reservoir	~1,600 km^2
Drainage of all Sampled tributaries to Lower	~900 km^2
Percent Sampled	56%

Table 3 Percentage of the total drainage sampled in 2013

KINBASKET RESERVOIR	
Columbia River at Donald	9,710 km^2
Drainage area of all sampled tributaries	~5,600 km^2
Total sampled	~15,310 km^2
Drainage area of Kinbasket Reservoir	21,500 km^2
Percent sampled	71%

REVELSTOKE RESERVOIR	
Columbia River at Mica Dam	21,500 km^2
Drainage area of all sampled tributaries	~3,700 km^2
Total sampled	~25,200 km^2
Drainage area of Revelstoke Reservoir	26,400 km^2
Percent Sampled	95%

3. Reference Tributaries

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 2013 are shown in Figures 3.1.1 through 3.1.5, respectively. River flow is shown in Figures 3.1.1a-3.1.5a; 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 3.1.1b-3.1.5b. 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 July 2009. The conductivity, shown in Figures 3.1.1c-3.1.5c, declined through the freshet to about half by mid-summer. Turbidity (Figures 3.1.1d-3.1.5d) was highly variable while pH remained slightly alkaline (Figures 3.1.1e-3.1.5e).

Even more than conductivity, nitrate and nitrite (NN) concentrations declined by 6, 12, and 7 times from May to mid-summer in 2013 in the Goldstream, Columbia at Donald, and Beaver, respectively (Figure 3.1.5f). For example, on 8 May 2013, the Goldstream River had 564 µg/L NN which declined to 91.2 µg/L by 8 Jul 2013 (Figure 3.1.5f); there were similar declines in previous years (Figures 3.1.1f to 3.1.4f).

Note the peak in nitrate occurs at the beginning of freshet; much of this nitrate is thought to come from the snow, that received atmospheric deposition of nitrogen over the winter. The subsequent decrease in nitrate results as the supply of nitrate from the snowpack and from shallow soil water pools is depleted before the end of freshet (Sebestyen *et al.*, 2008).

In previous years, the concentrations of soluble reactive phosphorus (SRP) were low, near the detection level (1 ug/L). The concentration of SRP remained low in 2013, though a few slightly higher values were observed (to 6.8 ug/L), which may be related to the change in lab (Figure 3.1.5g).

Concentrations of total dissolved phosphorus (TDP) for the three natural tributaries were low (<16 µg/L) and relatively constant (Figure 3.1.1h-3.1.5h) with the exception of a single reading of 45.7 µg/L on 10 Sept 2013 in the Columbia at Donald (Figure 3.1.5h).

Total phosphorus (TP) was high and variable (Figure 3.1.1i-3.1.5i) with a peak of 217 µg/L on 6 May 2013 in Beaver River (figure 3.1.5i), at which time the turbidity was also elevated (63 NTU).

The NN:TDP ratio (by weight) was > 10 through much of the year suggesting tributary nutrients are phosphorus limited. However, there were notable exceptions for all three tributaries, particularity in summer. The NN:TDP ratios were particularly low in the

Columbia at Donald through much of summer of 2012 with NN:TDP ratios < 10 persisting until late October (Figure 3.1.4j), and all three tributaries had low nitrate in August and September 2013 (Figure 3.1.5j). Low tributary nitrate during summer may result in nitrogen and phosphorus co-limitation.

In Figures 3.2.1 to 3.2.5, the water quality parameters for the Columbia River at Donald are shown again for each year 2009 to 2013 respectively, 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). Note that Revelstoke Reservoir backs all the way to the foot of Mica dam; as a result, samples of outflow which are taken from the riverine section below the dam can be influenced by Revelstoke Reservoir when outflow from Mica is low, such as typically occurs during early summer (Figures 3.2.1a-3.2.5a).

As in previous years, the temperature of the outflows from the dams were cold as a result of the deep intakes (< 12 ºC, Figure 3.2.5b). There were a few exceptions for the Mica outflow, for example in July and August 2010, when the temperature was warmer; at low flow, the temperature below Mica Dam may have been influenced by Revelstoke Reservoir (Figure 3.2.2b).

The conductivity of the outflow from Mica and Revelstoke Dams was relatively steady in 2013, with the occasional lower value during low outflow from Mica Dam as in previous years (Figures 3.2.1c-3.2.5c). The turbidity of the outflow from both Mica and Revelstoke was very low, generally < 2 NTU (Figures 3.2.1d-3.2.5d). The average turbidity in 2013 was 0.7 and 0.4 NTU, respectively (Figure 3.2.5d), similar to previous years. Like the tributaries, the pH was relatively constant and slightly alkaline (Figures 3.2.1e-3.2.5e). There were some lower values below Mica Dam from mid-May to mid-July, again corresponding with low outflow.

Nitrate and nitrite concentrations (NN) were relatively constant in the outflow from Mica dam, and with the exception of some higher values in spring, varied around 100 µg/L through the summer (Figures 3.2.1f-3.2.5f). In the outflow from Revelstoke, NN was relatively constant throughout the year, varying from 85-150 µg/L (Figures 3.2.1f-3.2.5f).

For both Mica and Revelstoke outflows, SRP concentrations were close to the detection limit, generally below 4 µg/L (Figures 3.2.1g-3.2.5g). Both TDP (Figures 3.2.1h-3.2.5h) and TP (Figures 3.2.1i-3.2.5i) were low and relatively constant in the outflow of both dams. The NN:TDP ratio for the Mica and Revelstoke outflows exceeded 10 throughout the year, suggesting nutrients from these sources are phosphorus limited (Figures 3.2.1j-3.2.5j).

Intensive sampling of the reference tributaries began in 2009. Comparison of the 2009 through 2013 data is shown for April to November in Figure 3.3.1 (Columbia River at Donald), Figure 3.3.2 (Goldstream River), Figure 3.3.3 (Beaver River) Figure 3.3.4 (Mica Dam/Kinbasket Reservoir Outflow) and Figure 3.3.5 (Revelstoke Outflow). As data were available for Beaver River throughout the year, Figure 3.3.3 is plotted from January to December. Overall the water quality parameters show similar trends. The main exception was for Kinbasket outflow from May through July, 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 increased to winter levels by December (Figure 3.3.3d).

4. Tributary Surveys

The results of three surveys are described:

- 25 June and 5 August 2008,
- 7-8 July 2009, and
- 6-9 May 2013.

Selected parameters (pH, C25, NO23, TDP and TP) are shown on maps for Kinbasket Reservoir (Figures 4.1.1 to 4.1.5) and Revelstoke Reservoir (Figures 4.2.1 to 4.2.5). Data are given in Appendix 3c.

Kinbasket Reservoir In May 2013, the pH of Kinbasket tributaries ranged from 7.13 (Bulldog Creek) to 8.29 (Prattle Creek), see Figure 4.1.1. These values were slightly higher than those collected from late June to early August in 2008 and 2009, which ranged from 6.58 (Bulldog Creek 2009) to 8.16 (Bush River 2008). In all three sets (2008, 2009, and 2013), the tributaries of Canoe Reach generally had lower pH than those of the other regions. Not including the slightly lower values in the Canoe Reach, the range of pH in the tributaries to Kinbasket Reservoir was comparable to that of the tributaries entering the Arrow Reservoir, 7.2 to 8.1 (Pieters et al. 2003).

During the May 2013 survey, the conductivity at 25º (C25) varied from 36.1 µS/cm (Bulldog Creek) to 259 µS/cm (Prattle Creek), Figure 4.1.2. The conductivity of the Columbia River at Donald Station was 258 µS/cm. Note the conductivity was considerably higher than in the previous two surveys (ranging from 24 to 160 µS/cm), being collected at the start of freshet (see for comparison the year round data for Beaver Creek, Figure 3.3.3c and Section 5). Similar to the pH, the conductivity was generally lower in Canoe Reach and higher in tributaries to Wood Arm and on the east side of the Columbia Reach. The range of conductivity was similar to that observed in tributaries to the Arrow Reservoir, 36 to 203 µS/cm (Pieters et al. 2003).

In May 2013, the concentration of nitrate and nitrite (NN) ranged from 226 µg/L (Columbia River at Donald Station) to 929 µg/L (Bulldog Creek), much higher than in the previous surveys which ranged from 39 to 113 µg/L, Figure 4.1.3. This increase in nitrate at the start of freshet is comparable to that for Beaver River (Figure 3.3.3d) and is discussed in Section 5. The mid-summer range of NN values was comparable to the range in tributaries to Lower Arrow Reservoir (including the Narrows) of 3 to 133 ug/L, and lower than the range NN to the Upper Arrow, which included several large tributaries such as the Illecillewaet (260 µg/L) and Incomappleux (280 µg/L) (Pieters et al. 2003).

The total dissolved phosphorus (TDP) concentrations in May 2013 were moderate in all areas of the reservoir, ranging from <2.0 µg/L in several tributaries along the eastern side of the Columbia Reach to 4.4 µg/L (Foster Creek), Figure 4.1.4. This range of TDP concentration was similar to that in 2008 and 2009 (1.5 to 10.7 µg/L). TDP in the Columbia River at Donald Station was at the lowest end of the range at <2.0 µg/L. For comparison, the mean annual TDP in tributaries to the Arrow Lakes Reservoir ranged from the detection limit (2.0 µg/L) to 20 ug/L in tributaries to Lower Arrow (Pieters et al. 2003).

In May 2013, total phosphorus (TP) was highly variable, with concentrations ranging from 4.6 µg/L (Molson Creek) to 1650 µg/L (Sullivan River), Figure 4.1.5. During the survey, the TP concentration in the Columbia River at Donald Station was 14.4 µg/L. For comparison the range of average TP concentrations of tributaries to Arrow Reservoir was 7.4 to 52 µg/L (Pieters et al. 2003), and the maximum observed TP was 294 ug/L for the Incomappleux (at which time TDP was only 7 ug/L).

Particulate phosphorus can be estimated as the difference between total and total dissolved phosphorus, PP = TP - TDP. In glacially dominated systems, with high turbidity, much of the total phosphorus may be extracted from the particulate minerals (e.g. apatite) by the digestion (Appendix 1). As a result, for tributaries with high PP, it is likely that much of this phosphorus is of low biological availability.

Concentrations of soluble reactive phosphorus (SRP, also known as orthophosphate) were low in May 2013, ranging from 1.4 µg/L (Molson Creek) to 5.4 µg/L (Canoe River). SRP in the Columbia River at Donald Station was 2.2 µg/L. This is comparable to the range of SRP observed in tributaries to Arrow Reservoir (1 to 6.8 µg/L).

In May 2013, the alkalinity of the tributaries to Kinbasket Reservoir ranged from a low of 7.5 mg/L (Bulldog Creek) to 156 mg/L (Succour Creek). During the survey, the alkalinity of the Columbia River at Donald Station was 114 mg/L. As with pH, the alkalinity was generally lower in Canoe Reach.

Turbidity varied significantly, from very clear (1.1 NTU, Molson Creek) to extremely turbid (1830 NTU, Sullivan River). The turbidity in 2013 was much higher than in the previous surveys, when the upper limit was 96 NTU (Bush River). The turbidity of the Columbia River at Donald station was also high, 45 NTU. Turbidity was high for many of the tributaries entering the eastern side of the Columbia Reach, especially Sullivan River, and Wood River, though Foster Creek on the western side of the Columbia Reach also had high turbidity.

In May 2013 the temperature of the tributaries ranged from 3.5 ºC (Quartz Creek) to 10 ºC (Columbia River at Donald). The temperature of the tributaries sampled 7-8 July 2009 ranged from 6 to 15 ºC. These values are similar to those observed in the Arrow Reservoir (Pieters et al. 2003).

Revelstoke Reservoir Revelstoke Reservoir can be divided into two reaches: Upper Revelstoke, that part of the Reservoir above Downie Creek, and Lower Revelstoke including Downie Creek.

In May 2013, the pH of tributaries to Revelstoke Reservoir was close to neutral and ranged from slightly acidic (6.66, Nagle Creek) to slightly alkaline (7.88 in the Columbia River above Jordan), Figure 4.2.1. During the survey, the pH of the Columbia River at Mica Dam was 7.77. As in 2008 and 2009, the range of pH in the tributaries to Revelstoke Reservoir was slightly lower than that for Kinbasket.

In May 2013, the conductivity (C25) of tributaries to the Revelstoke Reservoir ranged from 21.8 μS/cm (Nagle Creek) to 149 μS/cm (Columbia River above Jordan), Figure 4.2.2. The Columbia River at Mica Dam had a conductivity of 95.9 μS/cm. These values are higher than those observed in summer 2008 and 2009, but this range in conductivity was also lower than that seen in both Kinbasket and Arrow Reservoirs.

In May 2013, the concentration of nitrate and nitrite (NN) ranged from 42 μg/L (Carnes Creek) to 882 μg/L (Big Eddy Creek), Figure 4.2.3. As in Kinbasket, the values were higher than those observed in the summer 2008 and 2009 surveys. The NN concentration of the Columbia River at Mica Dam was 294 μg/L, which likely reflects local tributary values as the inflow from Kinbasket was low prior to sampling (Figure 3.5.2a). The concentrations of NN in tributaries to the Revelstoke Reservoir were more varied than those from Kinbasket, and were generally comparable to those from Arrow Reservoir.

Total dissolved phosphorus (TDP) concentrations in May 2013 ranged from <2.0 μg/L (Scrip Creek and Columbia River above Jordan) to 3.8 μg/L (Mica Creek), Figure 4.2.4. The TDP concentration in the Columbia River at the Mica Dam outflow was 2.1 μg/L. Unlike previously surveyed years, the range of TDP concentrations in tributaries to Revelstoke Reservoir was slightly lower than that to Kinbasket Reservoir.

Total phosphorus (TP) in May 2013 ranged from 2.1 μg/L (Columbia River above Jordan) to 78.7 μg/L (Goldstream River), Figure 4.2.5. The TP concentration in the Columbia River at Mica Dam was 6.1 μg/L.

Turbidity was highly variable in May 2013, ranging from exceptionally clear (0.18 NTU, Columbia River above Jordan) to relatively turbid (35 NTU, Goldstream River). The turbidity of the Columbia River at Mica Dam was low, 2.0 NTU. There were fewer tributaries with high turbidity in Revelstoke Reservoir than in Kinbasket Reservoir. The temperature of the tributaries ranged from 3.0 to 6.0 ºC from 6-9 May 2013, as expected for the time of year.

Soluble reactive phosphorus (SRP) concentrations were low in May 2013, ranging from <1.0 µg/L (Columbia River above Jordan) to 4.9 µg/L (Downie Creek). The SRP concentration of the Columbia River at Mica Dam was 1.8 µg/L during the tributary survey and averaged 1.2 µg/L from May to November, 2013.

The alkalinity of the tributaries flowing into Revelstoke Reservoir ranged from 4 mg/L CaCO3 (Nagle Creek) to 64 mg/L CaCO3 (Columbia River above Jordan). The alkalinity of the Columbia River at Mica Dam outflow was 40 mg/L CaCO3. These values were lower than the range of alkalinity values for Kinbasket tributaries.

5. Discussion

Caution should be applied to the survey results as they are based on few samples. Most of the tributaries to Kinbasket and Revelstoke Reservoirs are remote and difficult to access, making it prohibitive to collect enough samples from each site to show the seasonal variation. A more complete indication of seasonal variability is provided by the reference tributaries.

Seasonal variability is illustrated by 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 3.4.1. 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 begin to increase again. Also shown for reference are SRP, TDP, TP, pH, NH_3 and water temperature.

Figure 3.4.2 compares the seasonal evolution of the flow, C25 and NN in the Illecillewaet River 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 3.4.2b). The decline in NN occurs more gradually through May and June to very low values in July and August (Figure 3.4.2c). 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).

6. 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, and much of the 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. Nitrate in the outflow from Kinbasket and Revelstoke Reservoirs was approximate 100 μg/L. For comparison, nitrate in the outflow from Arrow Reservoir was 200 μg/L (Pieters et al. 2003).

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. The N:P ratio was well above 10 for the outflow from both reservoirs.

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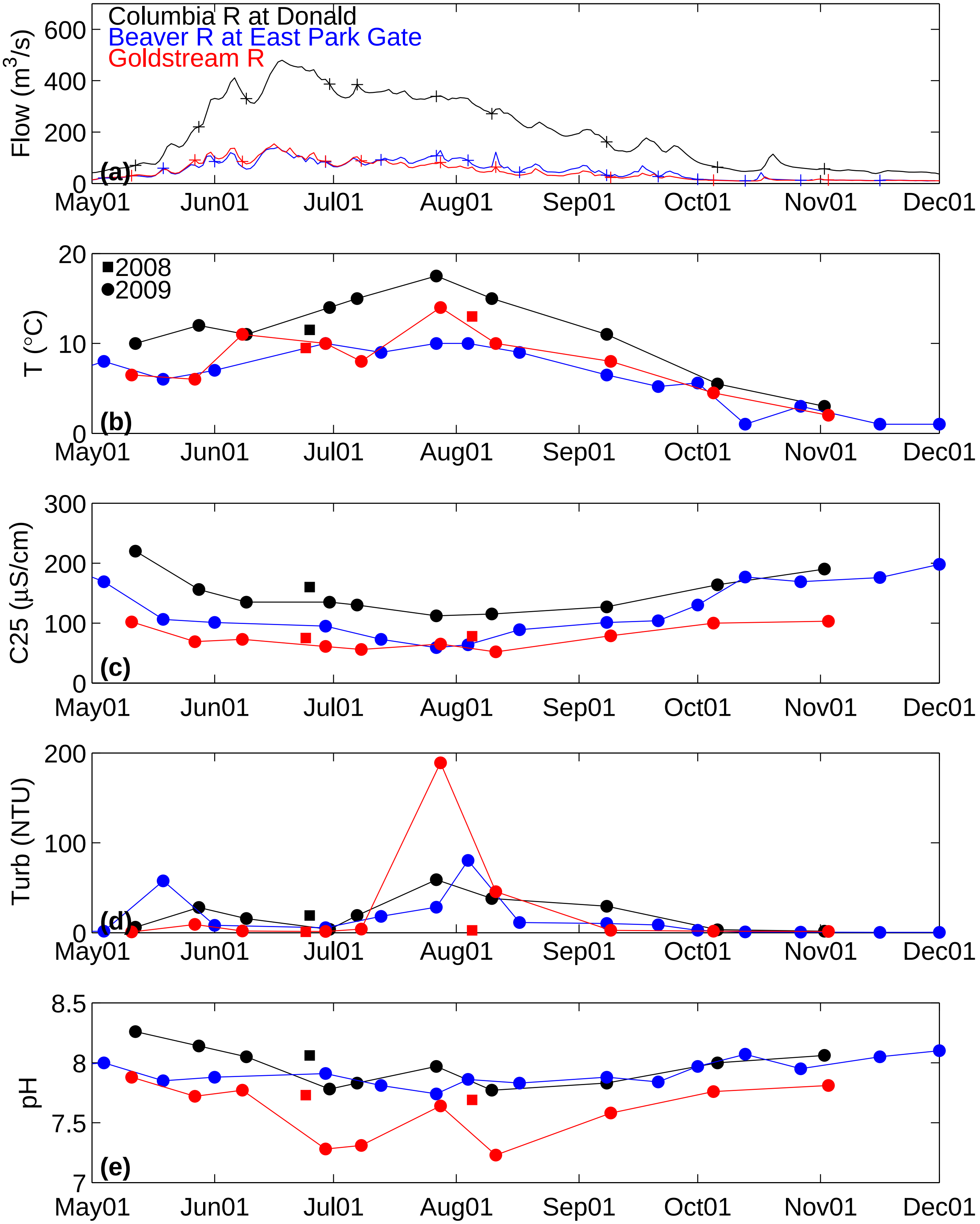
Figure 3.1.1 Flow and water quality of reference tributaries, 2009



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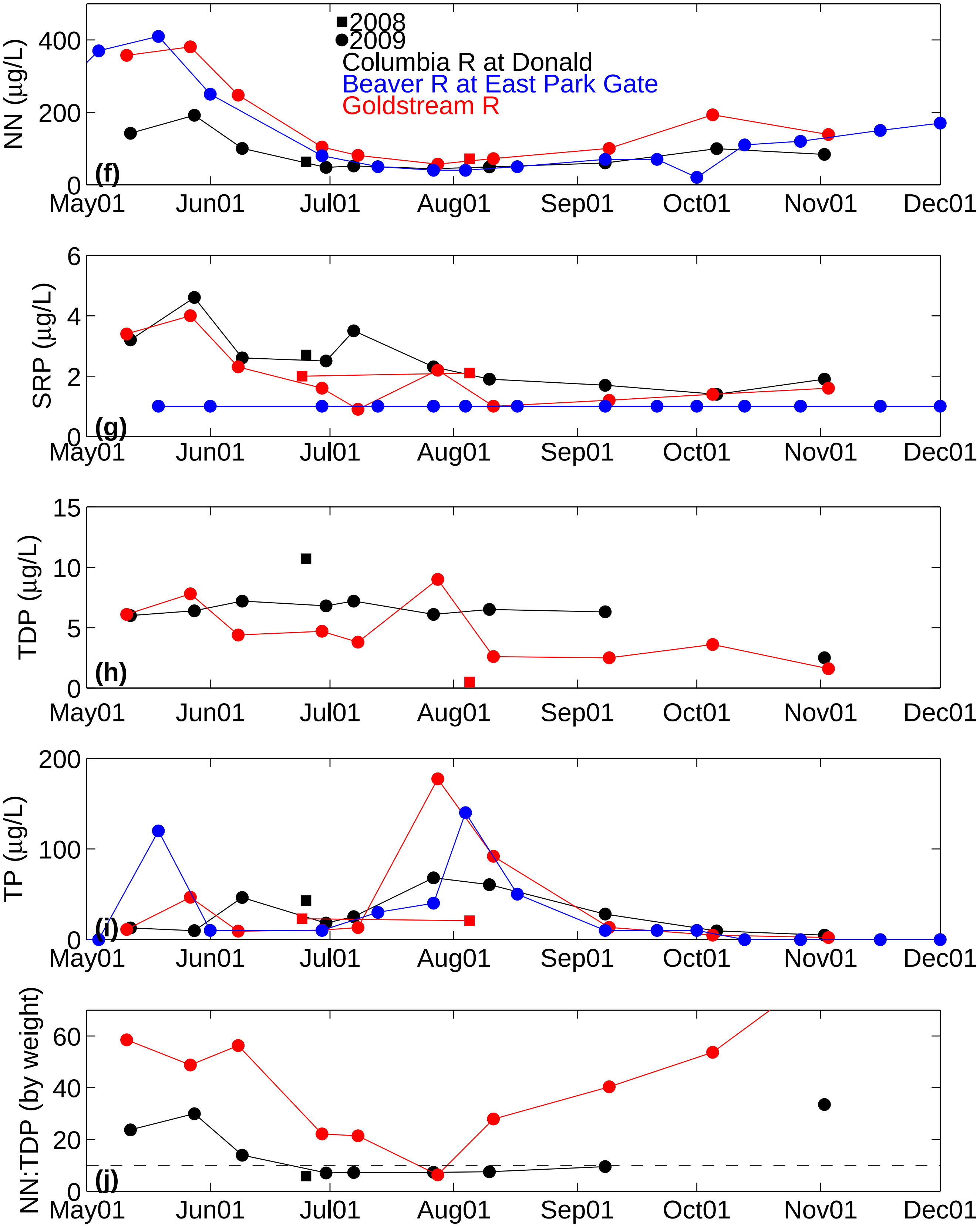

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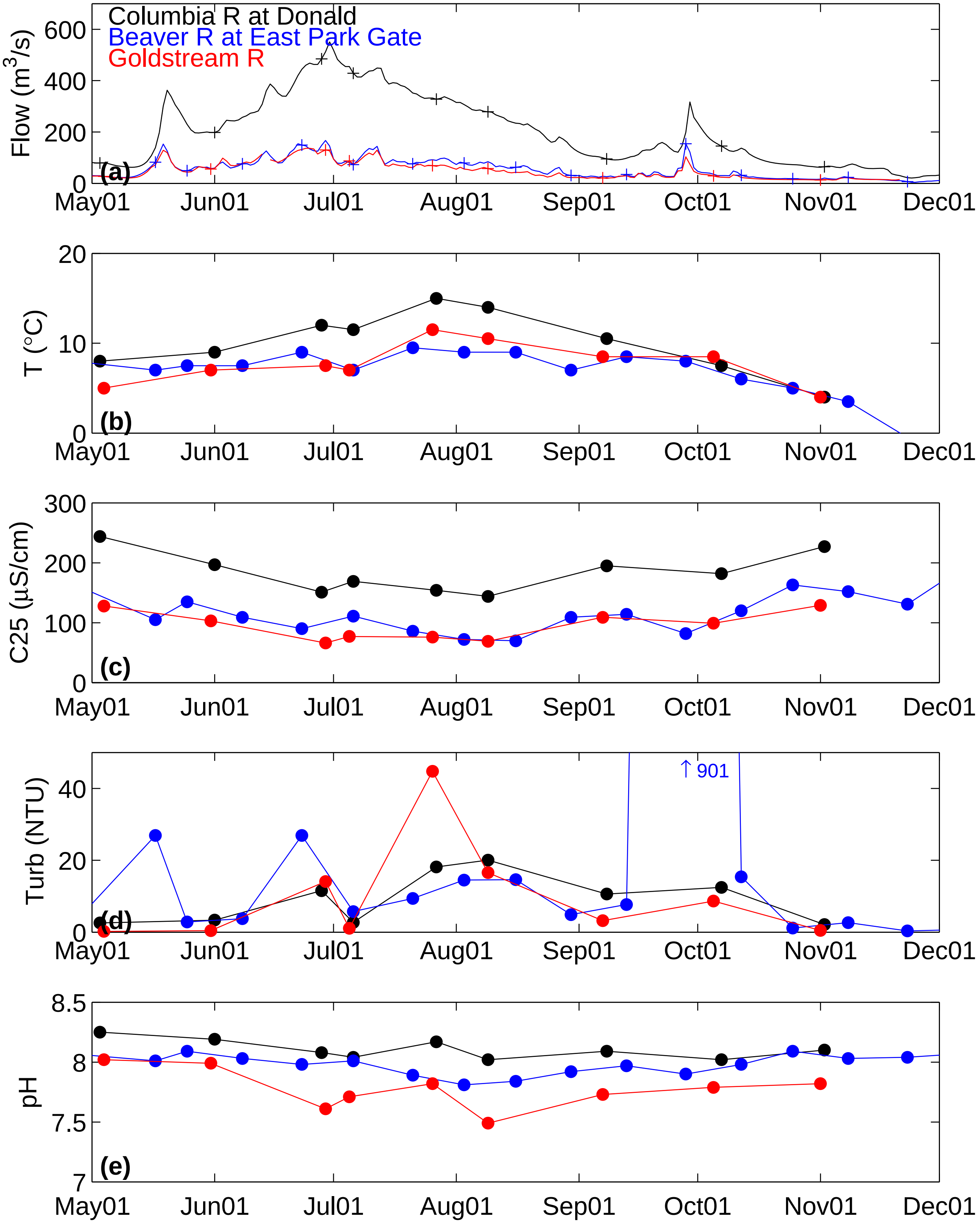

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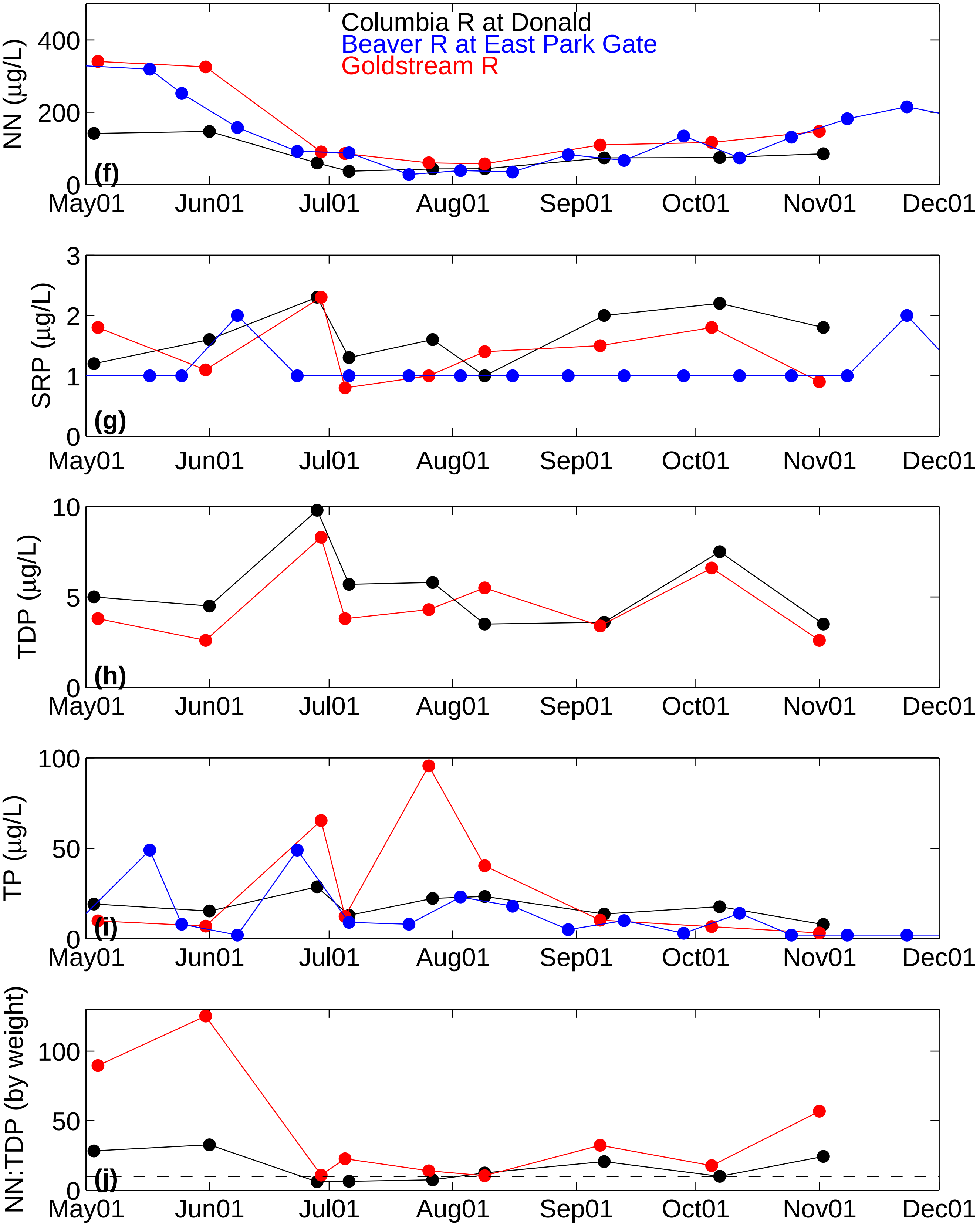

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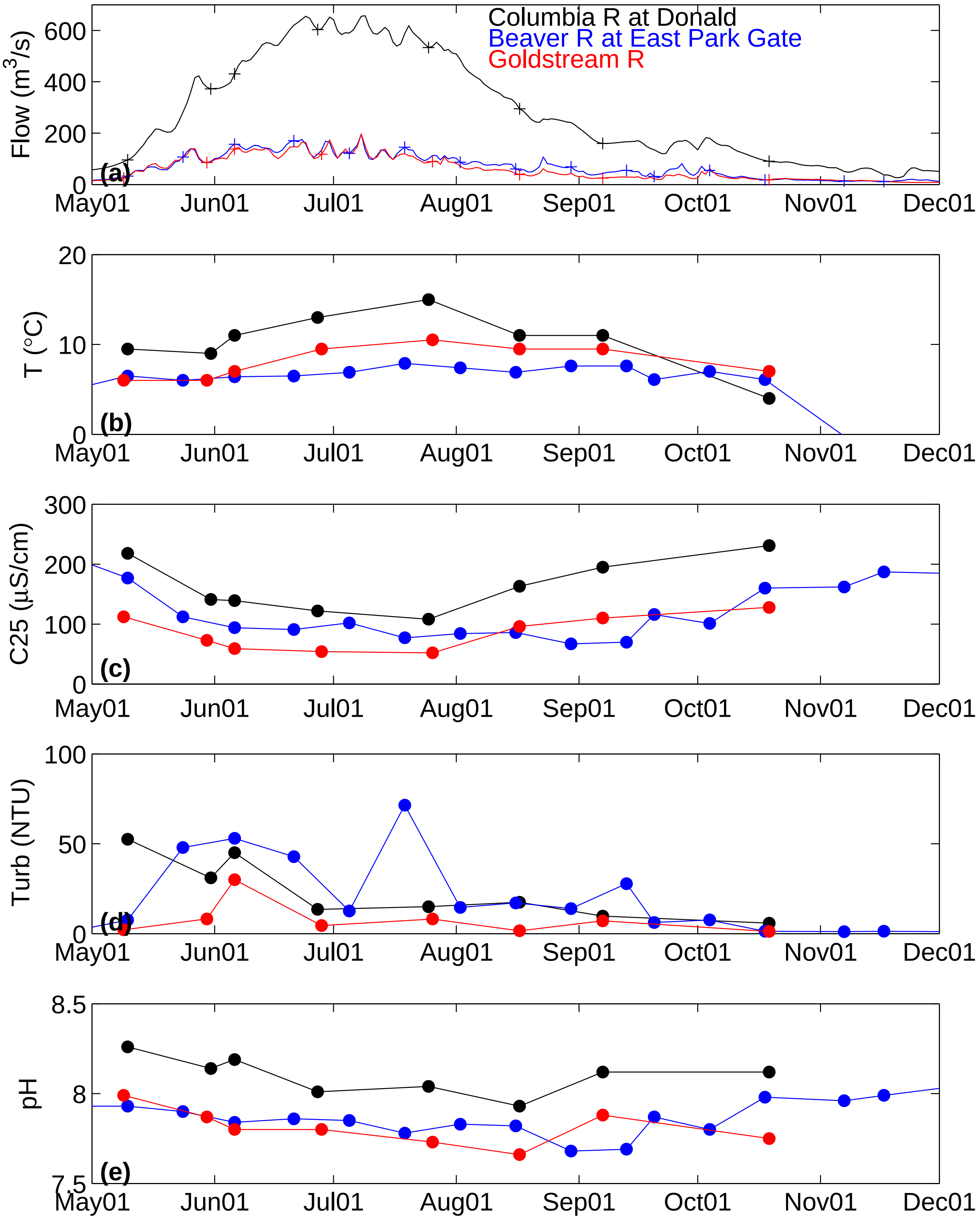

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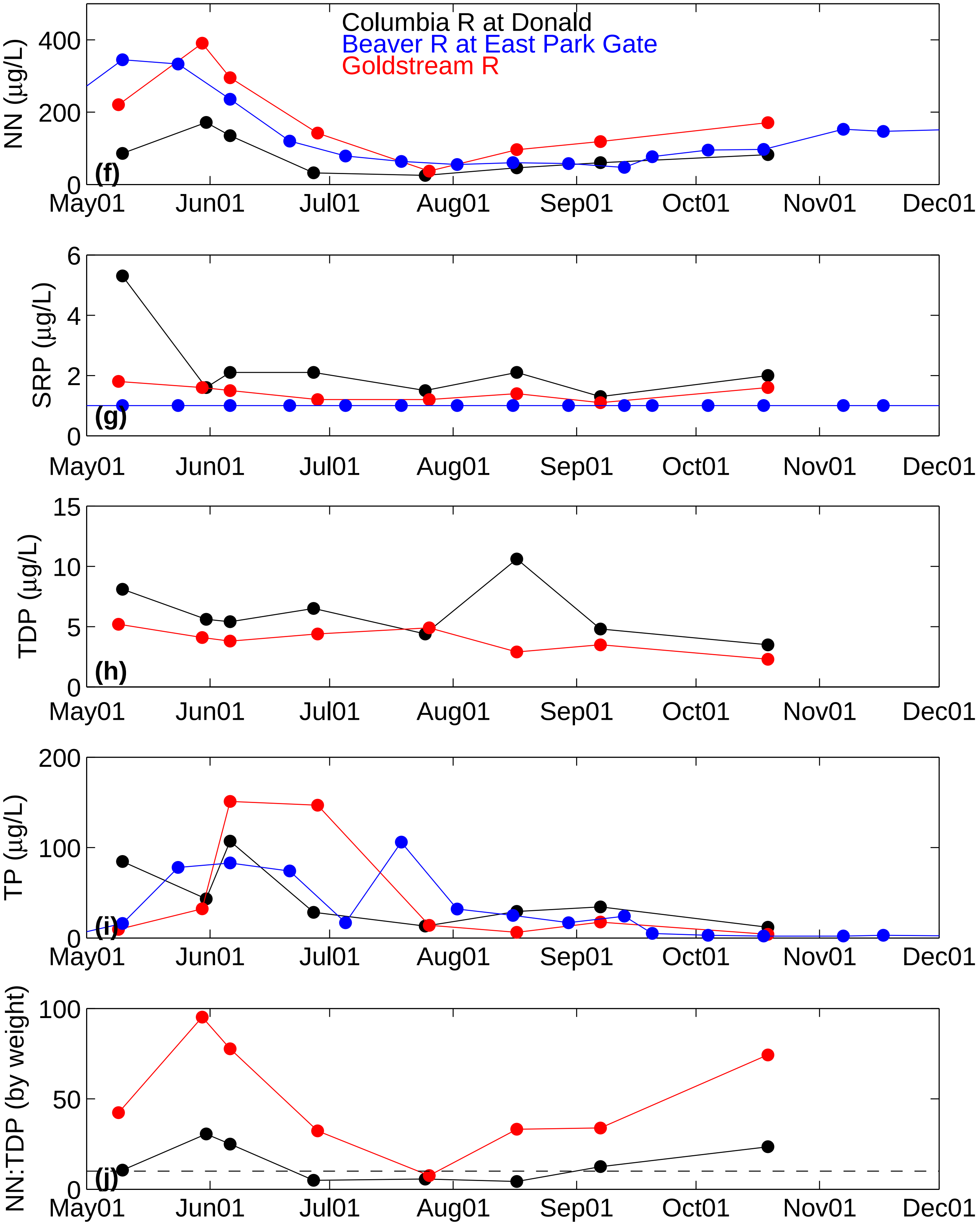

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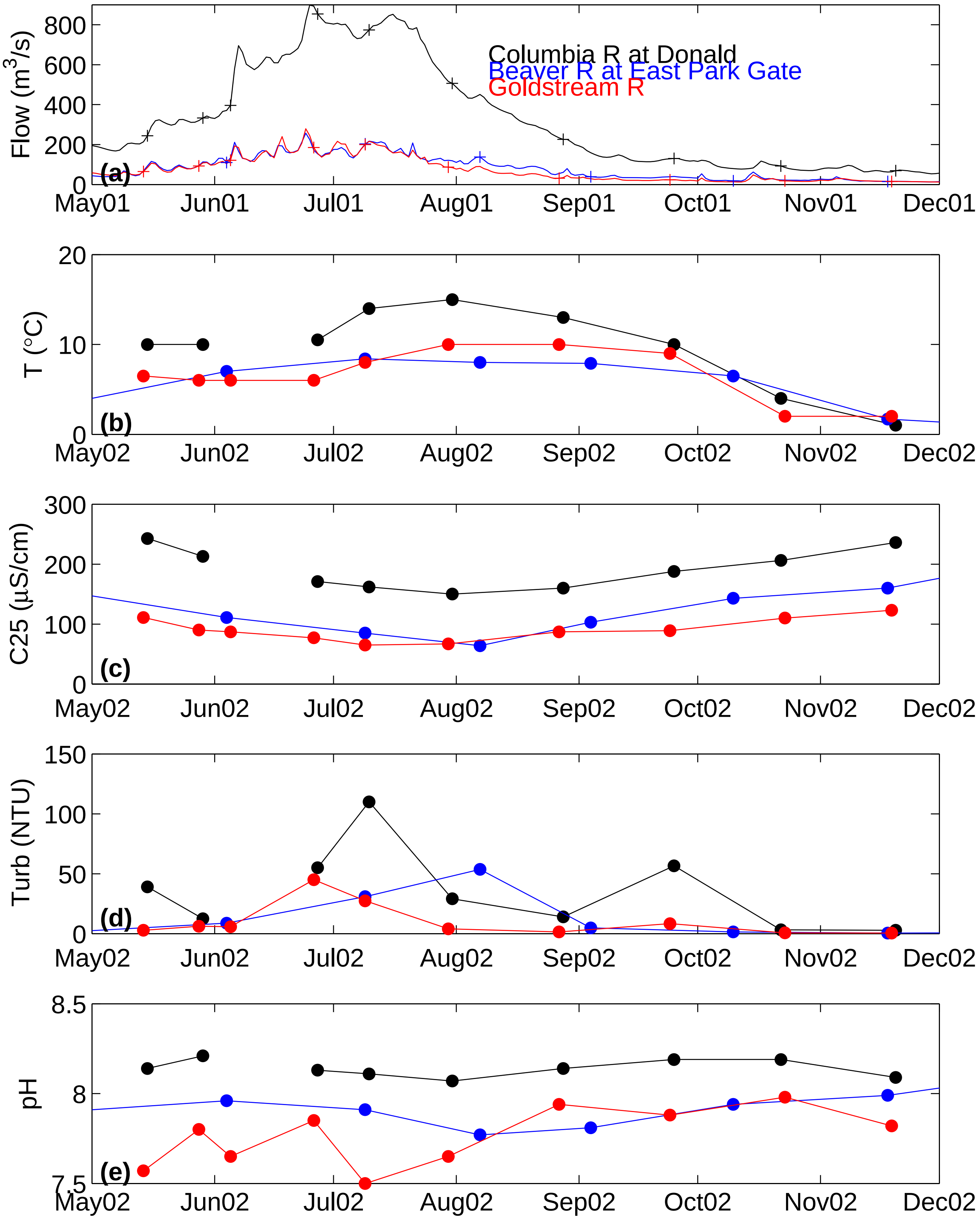
Figure 3.1.4 Flow and water quality of reference tributaries, 2012



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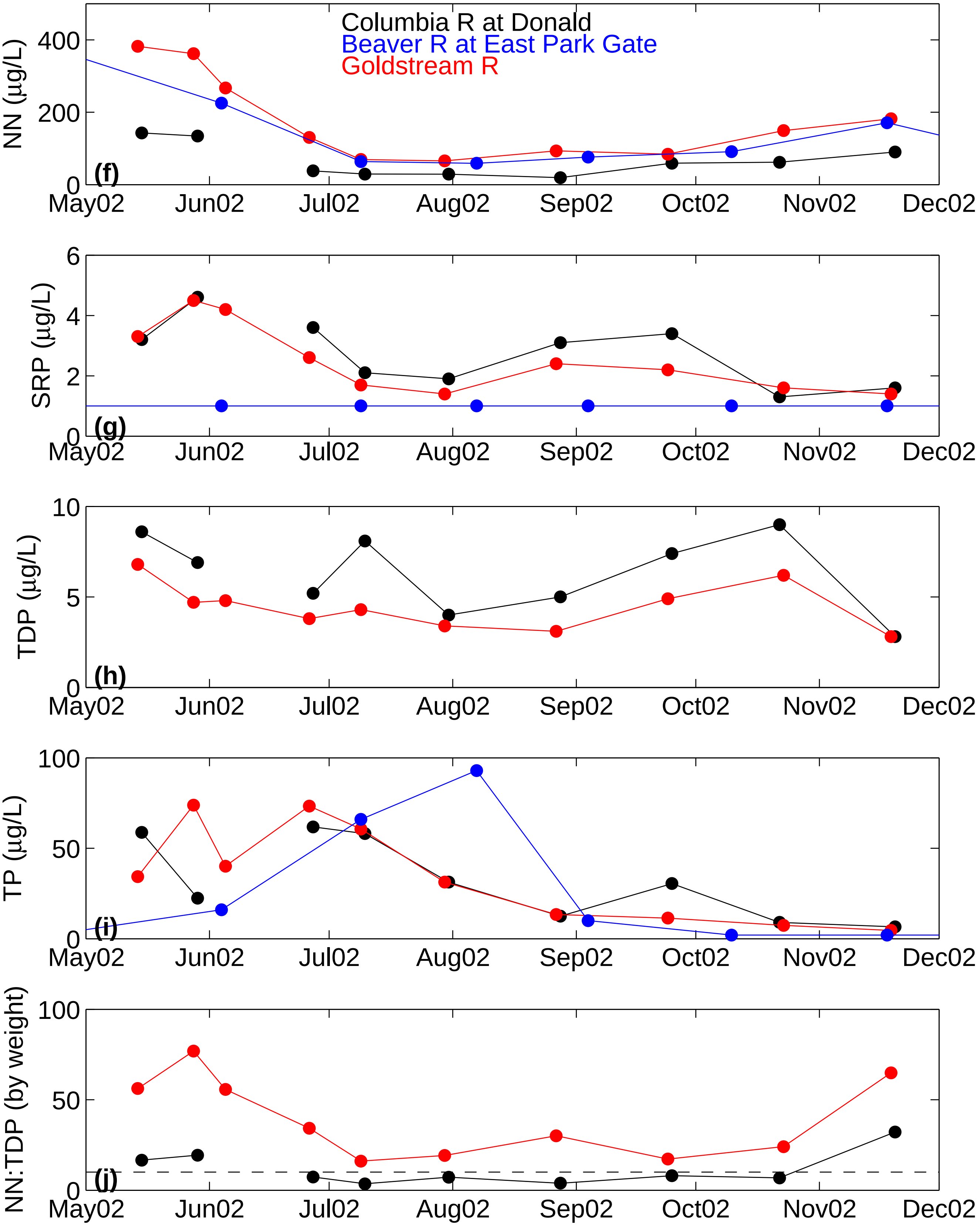

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Figure 3.1.5 Flow and water quality of reference tributaries, 2013

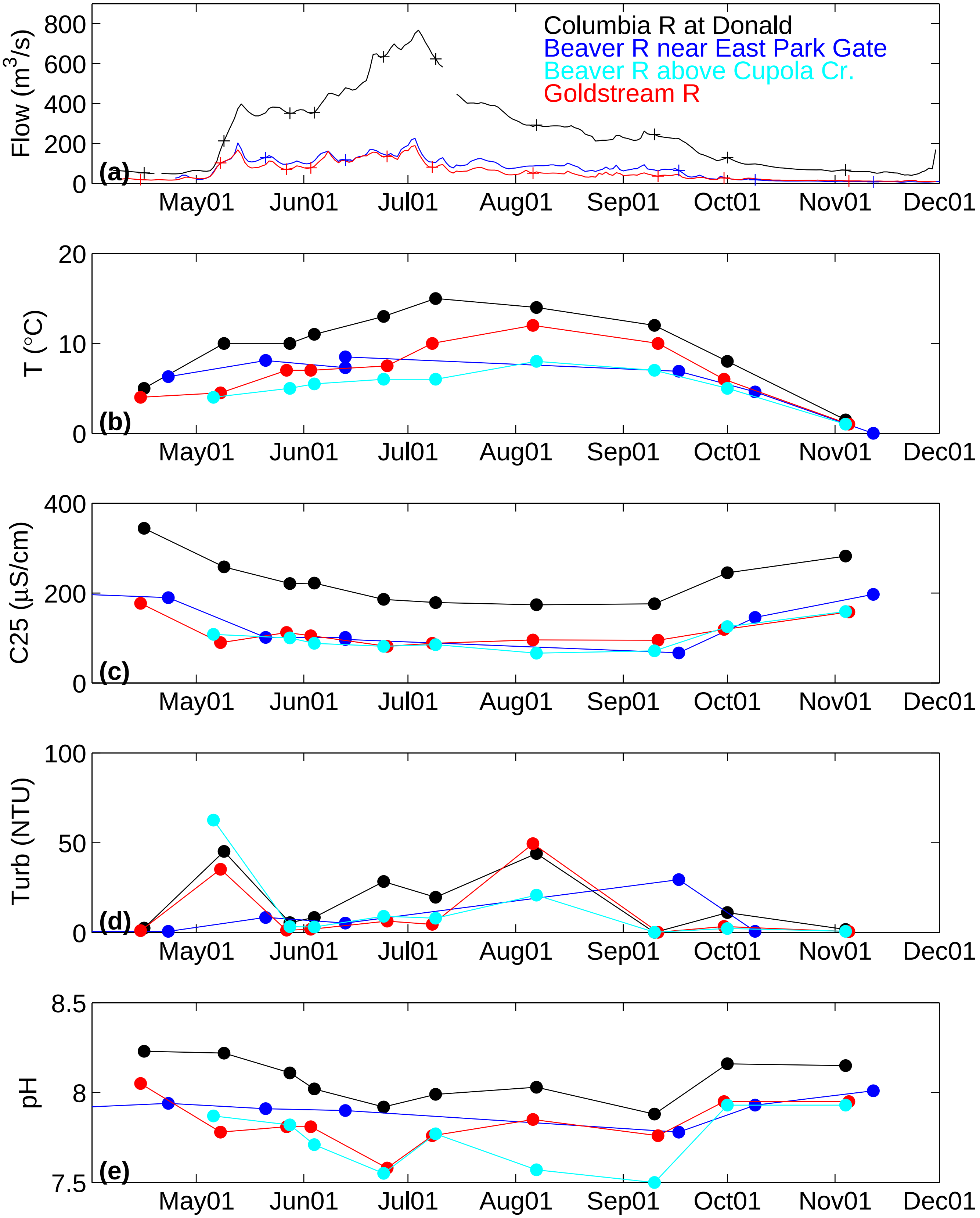

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Figure 3.1.5 con't Flow and water quality of reference tributaries, 2013

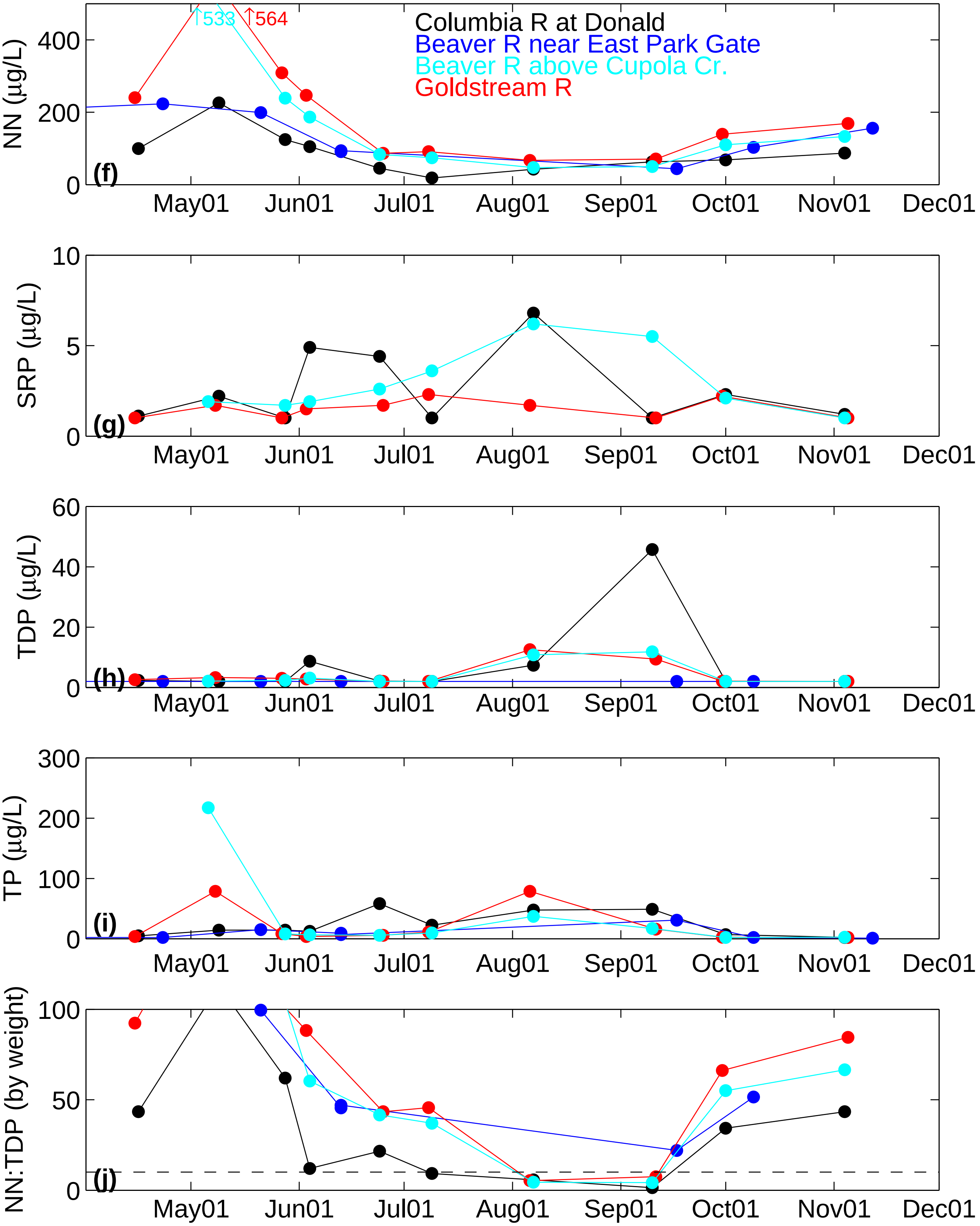

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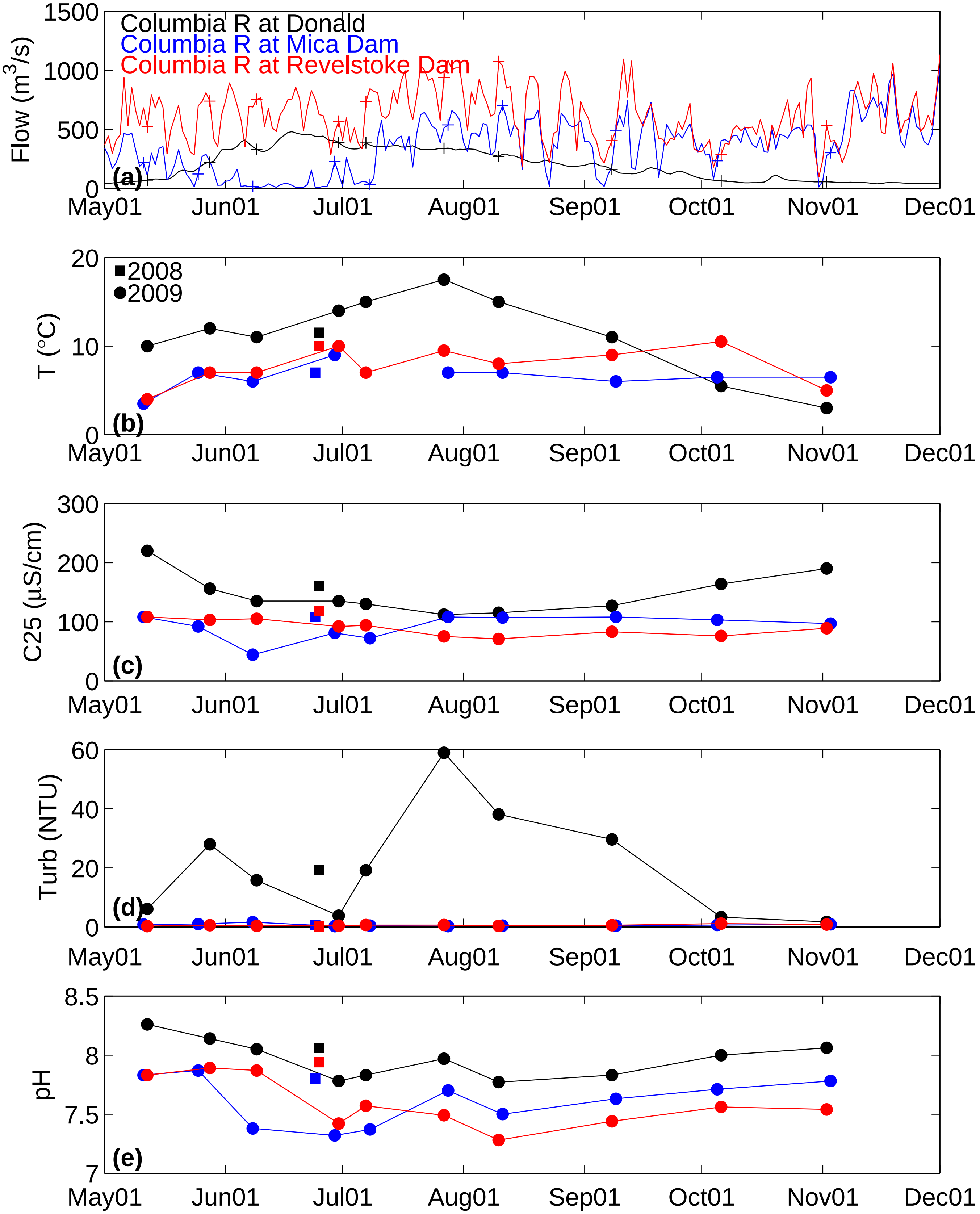
Figure 3.2.1 Flow and water quality of Columbia River, 2009



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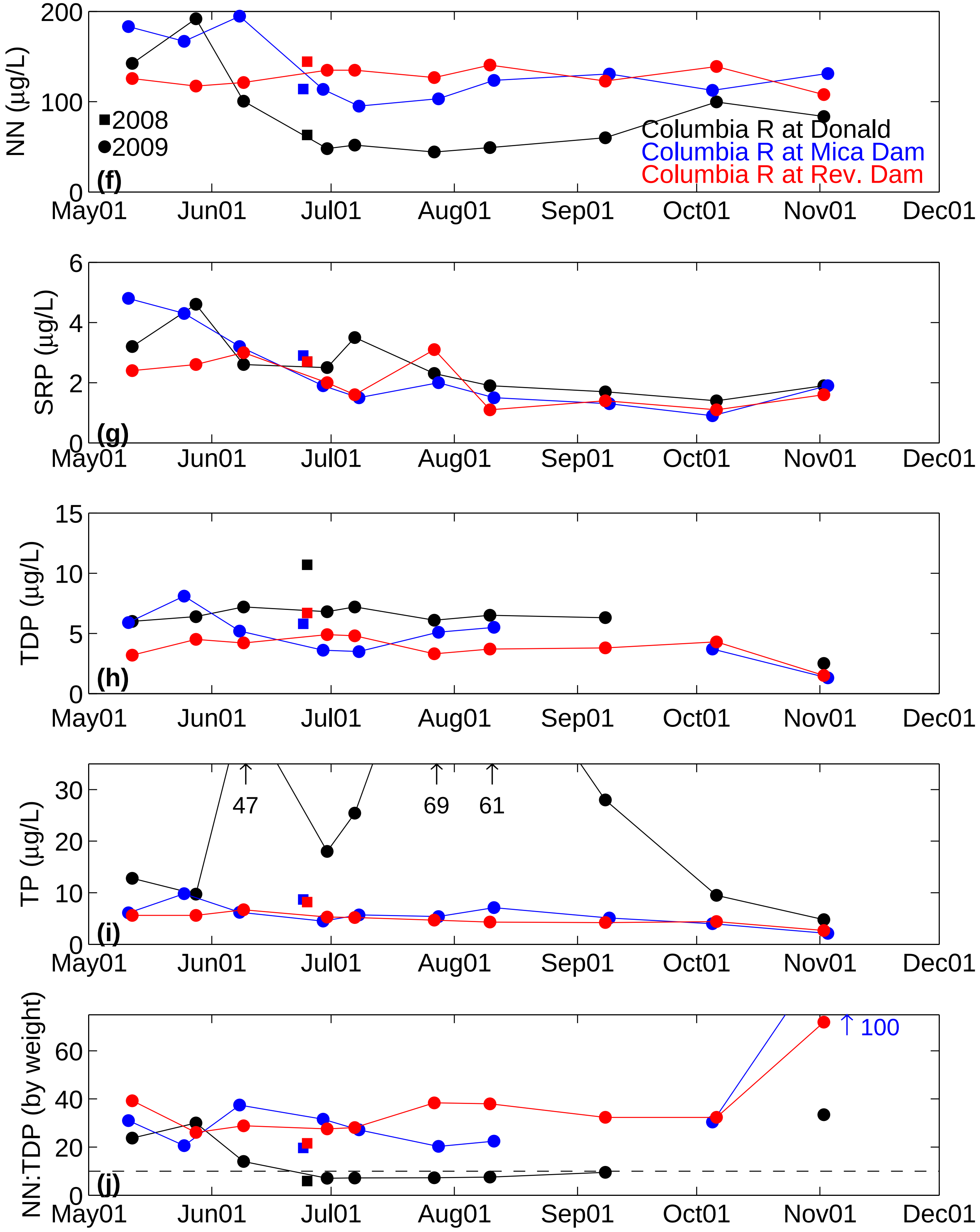

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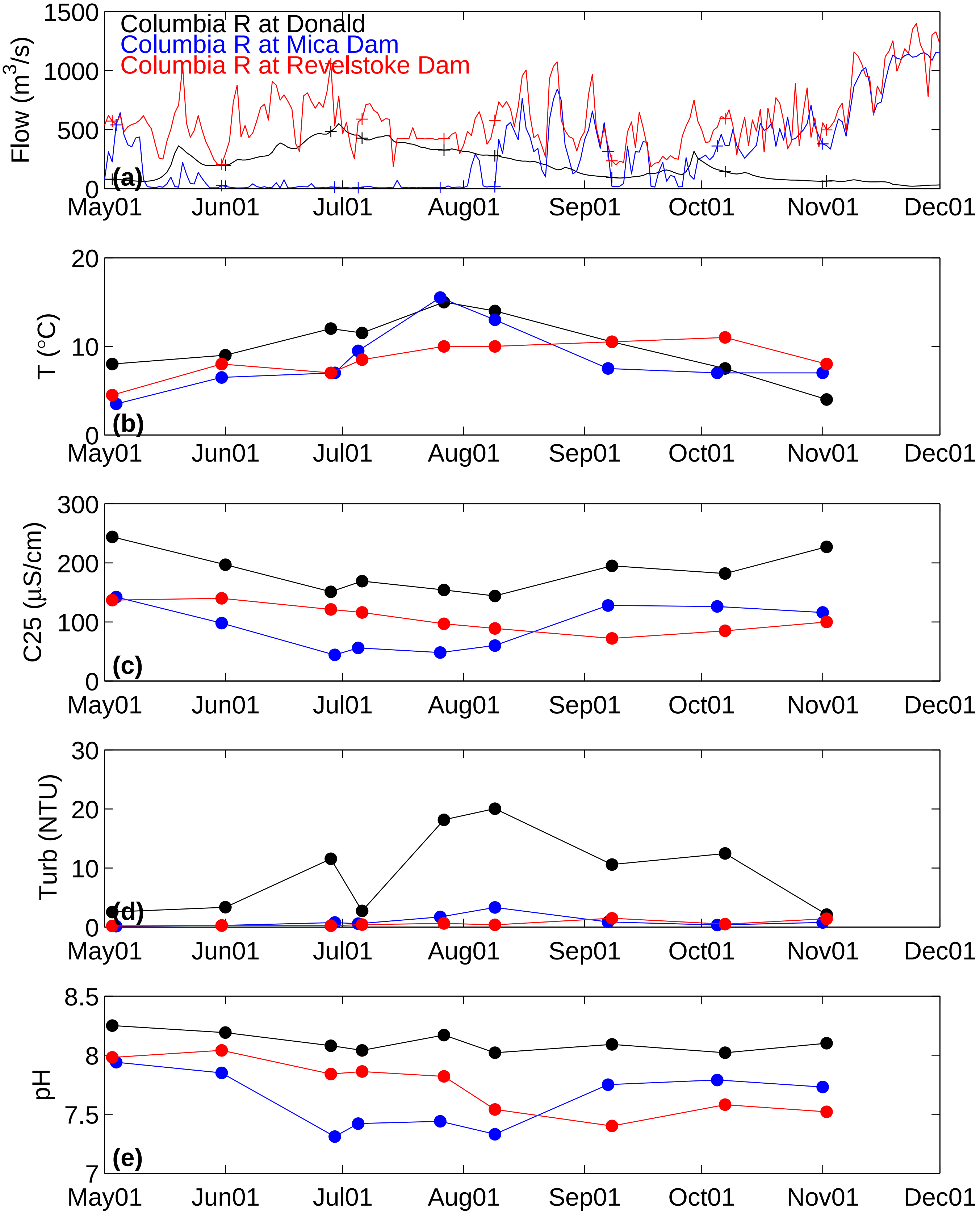
Figure 3.2.2 Flow and water quality of Columbia River, 2010



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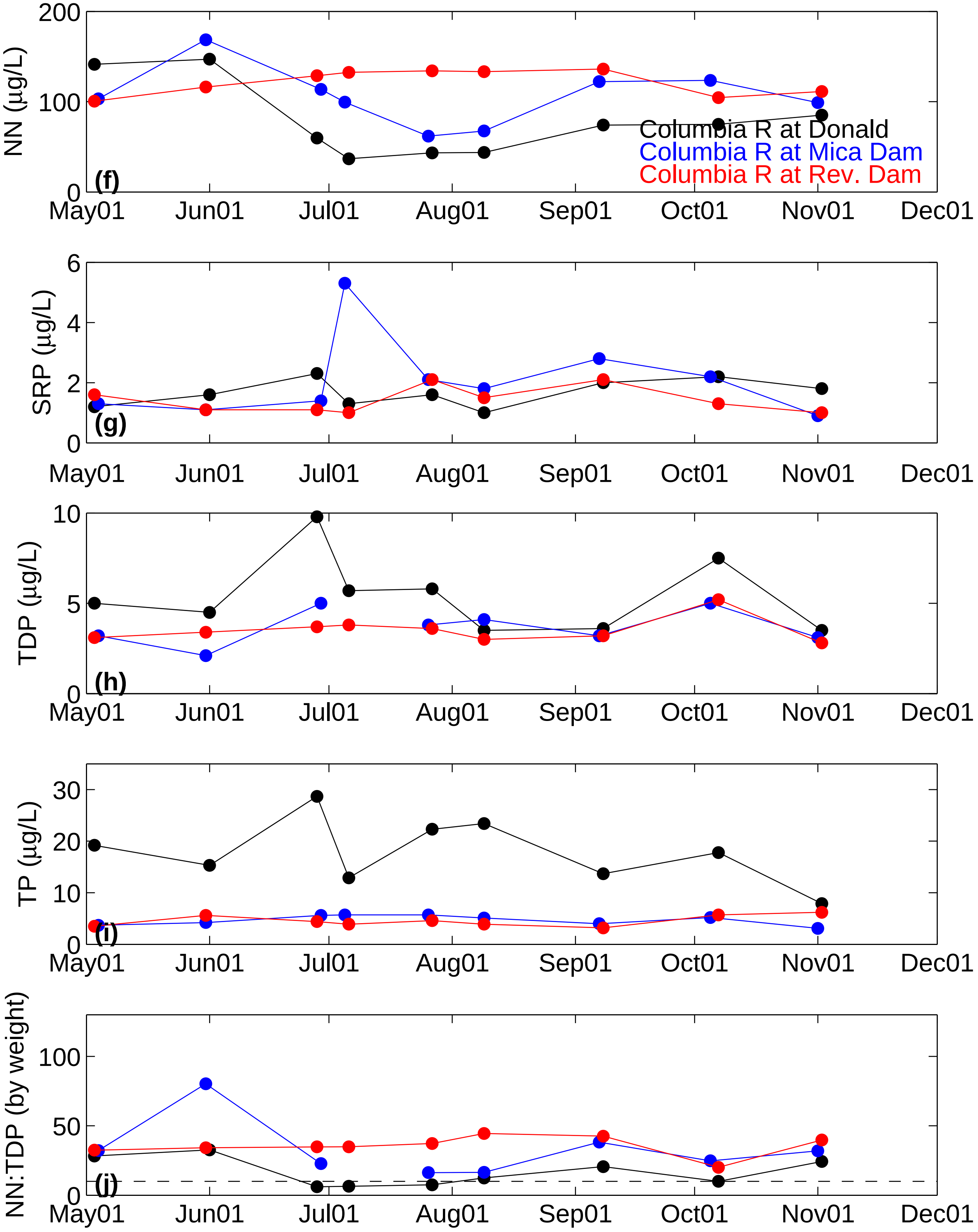

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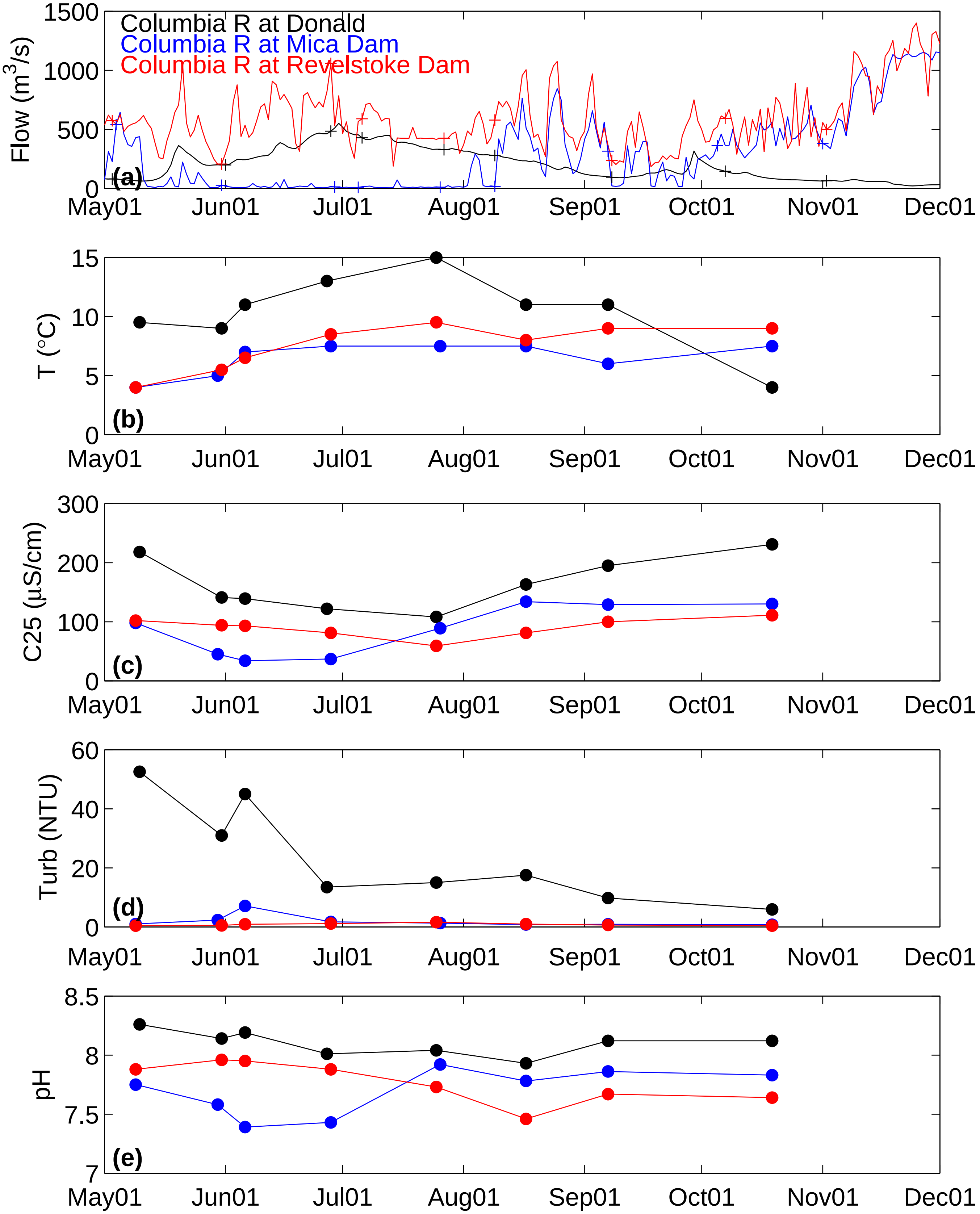

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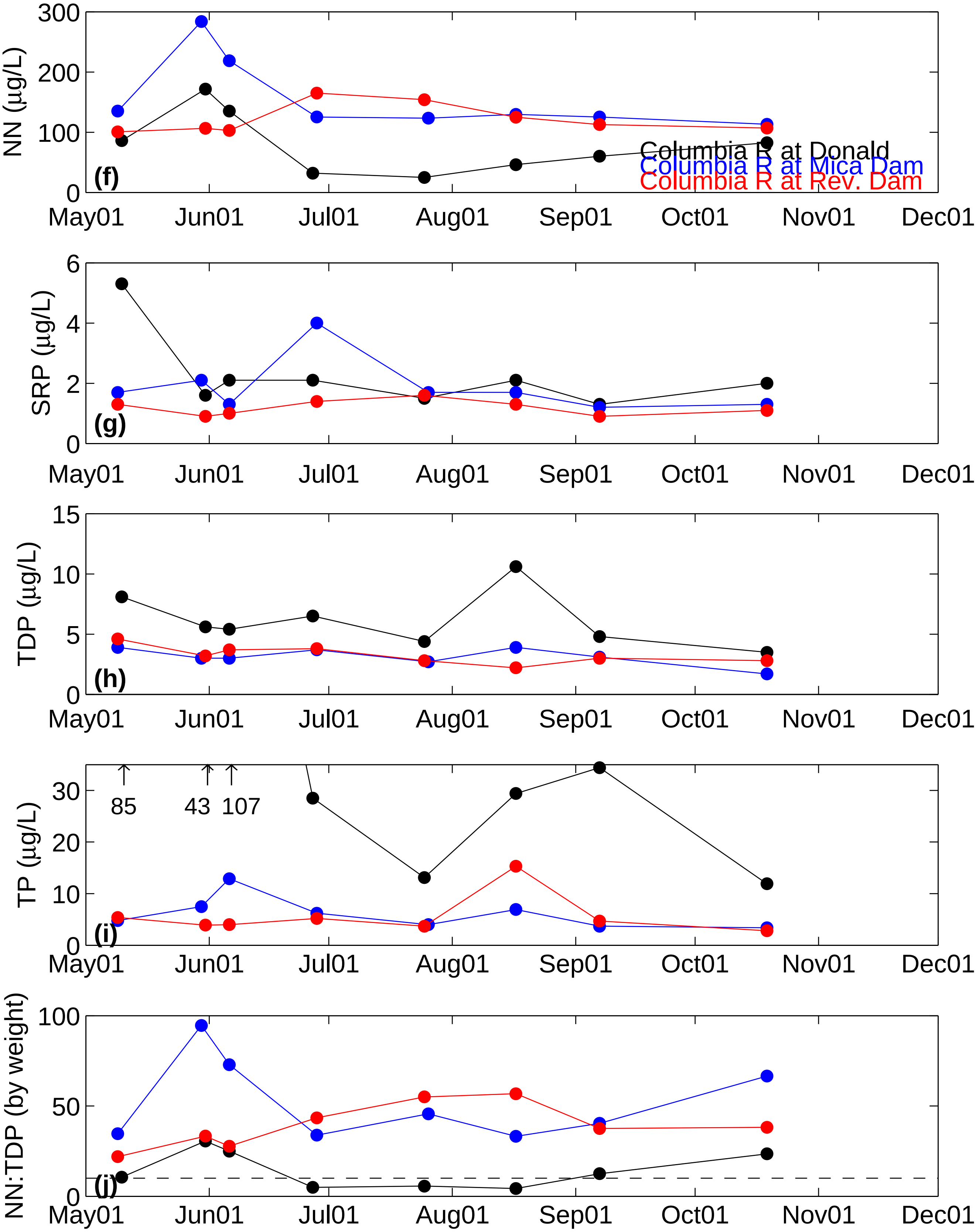

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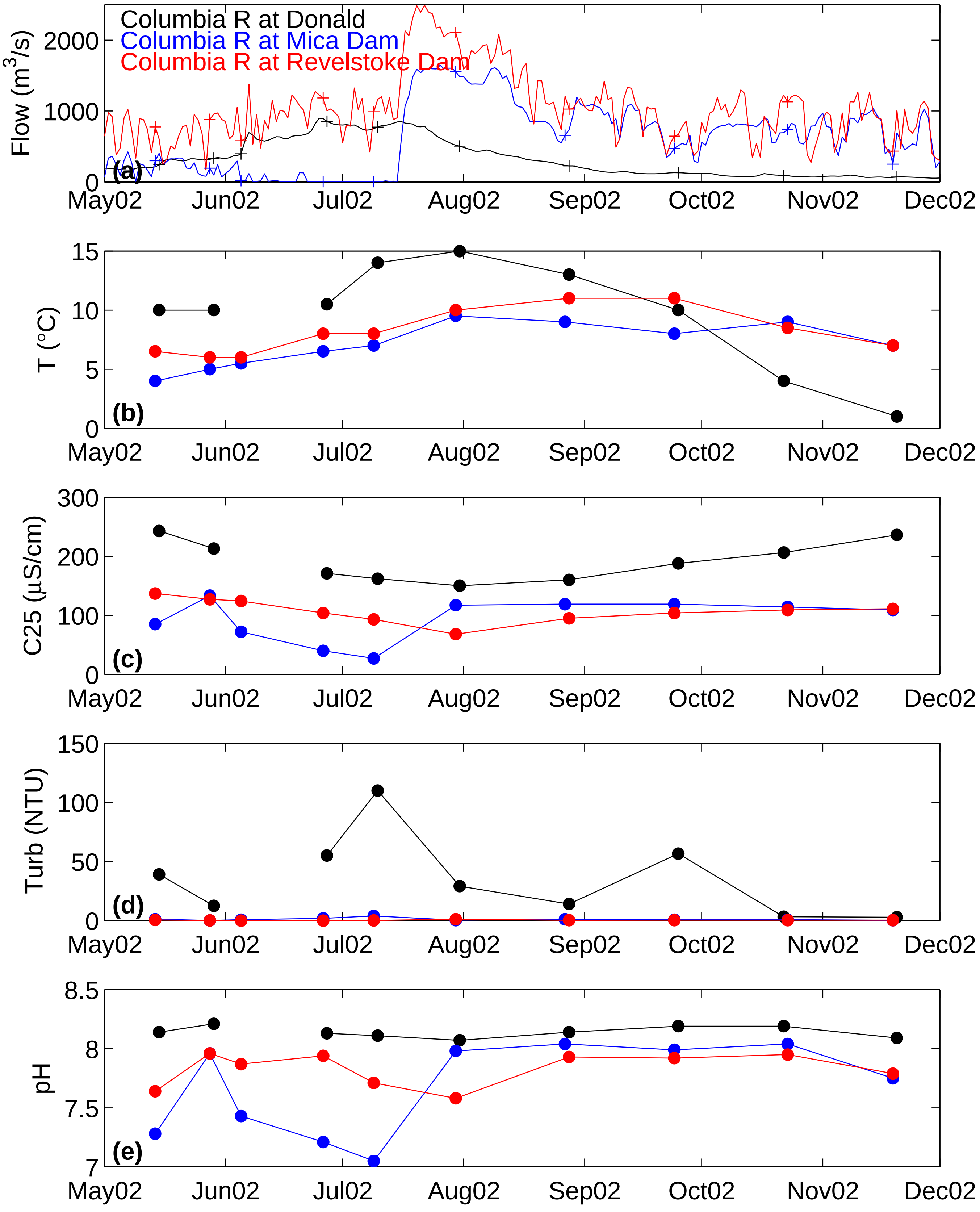

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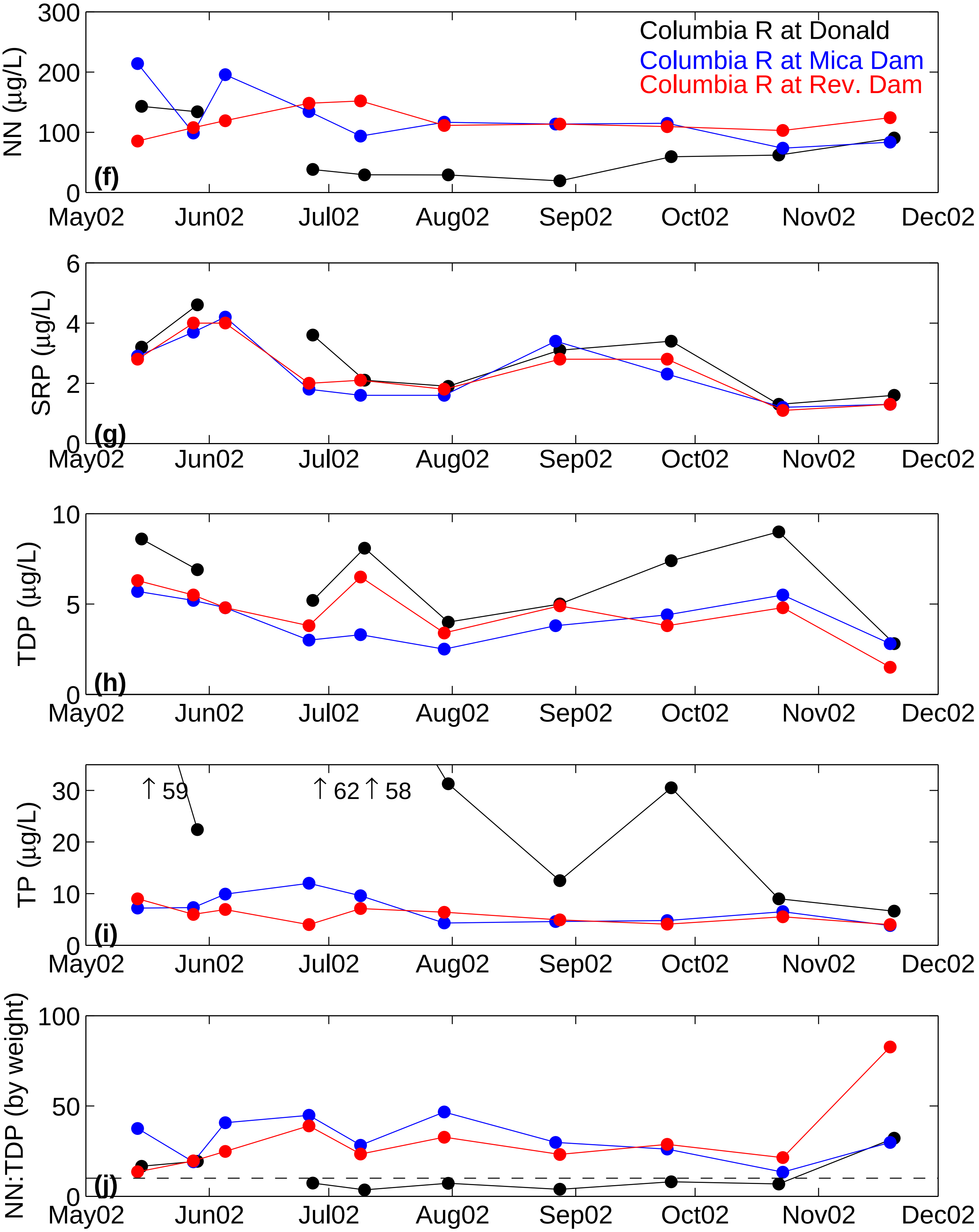

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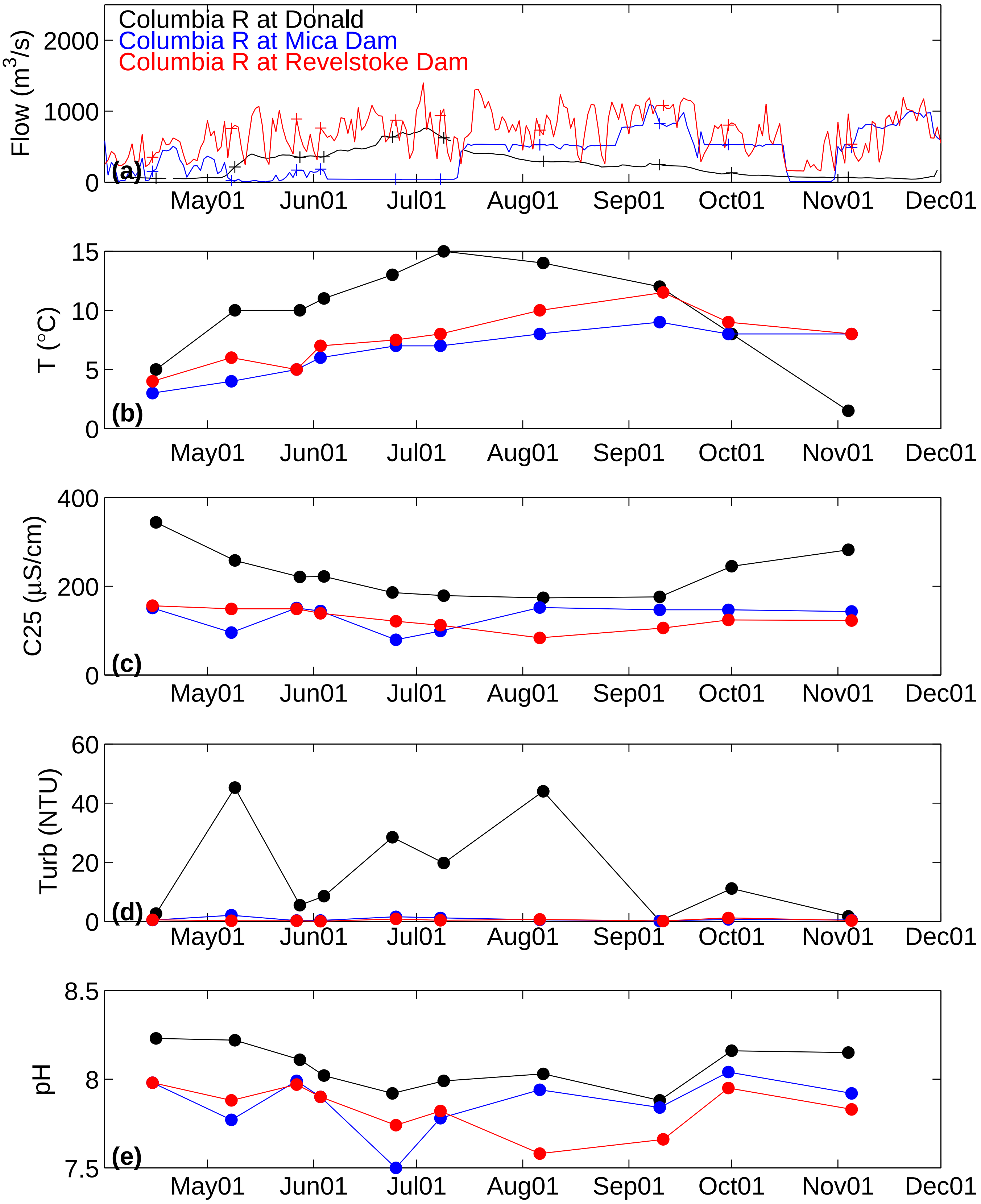

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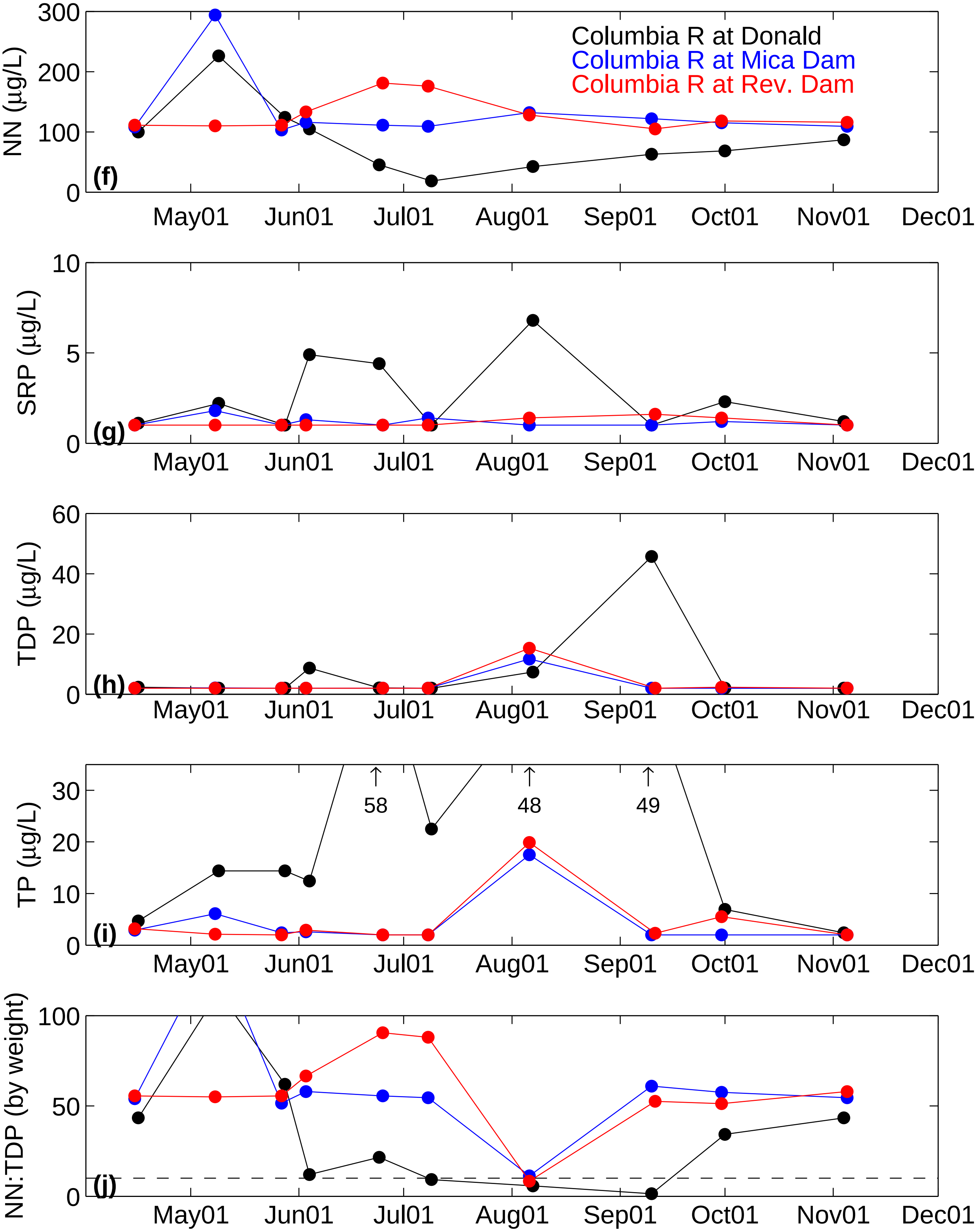

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Figure 3.3.1 Columbia R. at Donald, 2009, 2010, 2011, 2012 & 2013

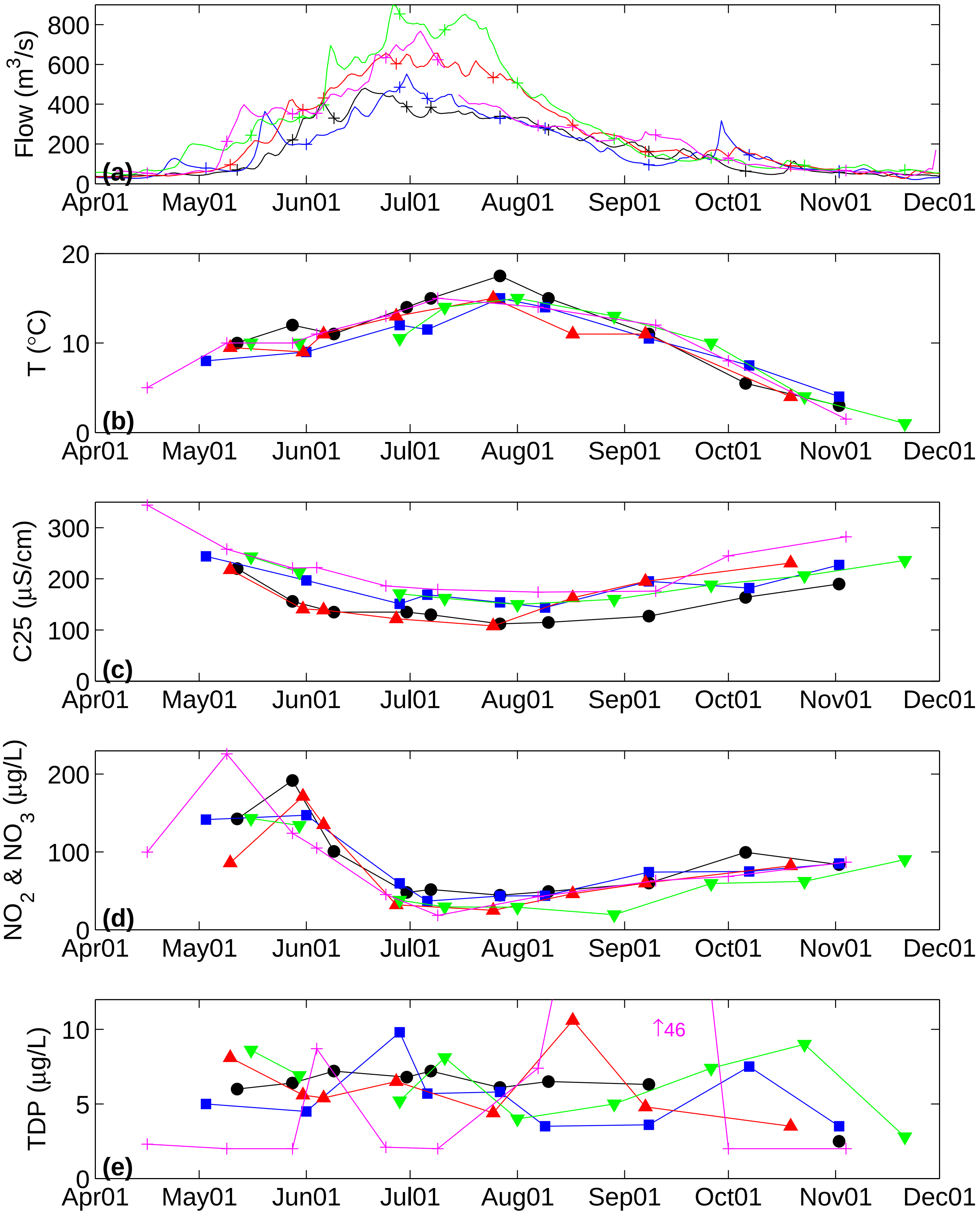

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Figure 3.3.2 Goldstream River, 2009, 2010, 2011, 2012 & 2013

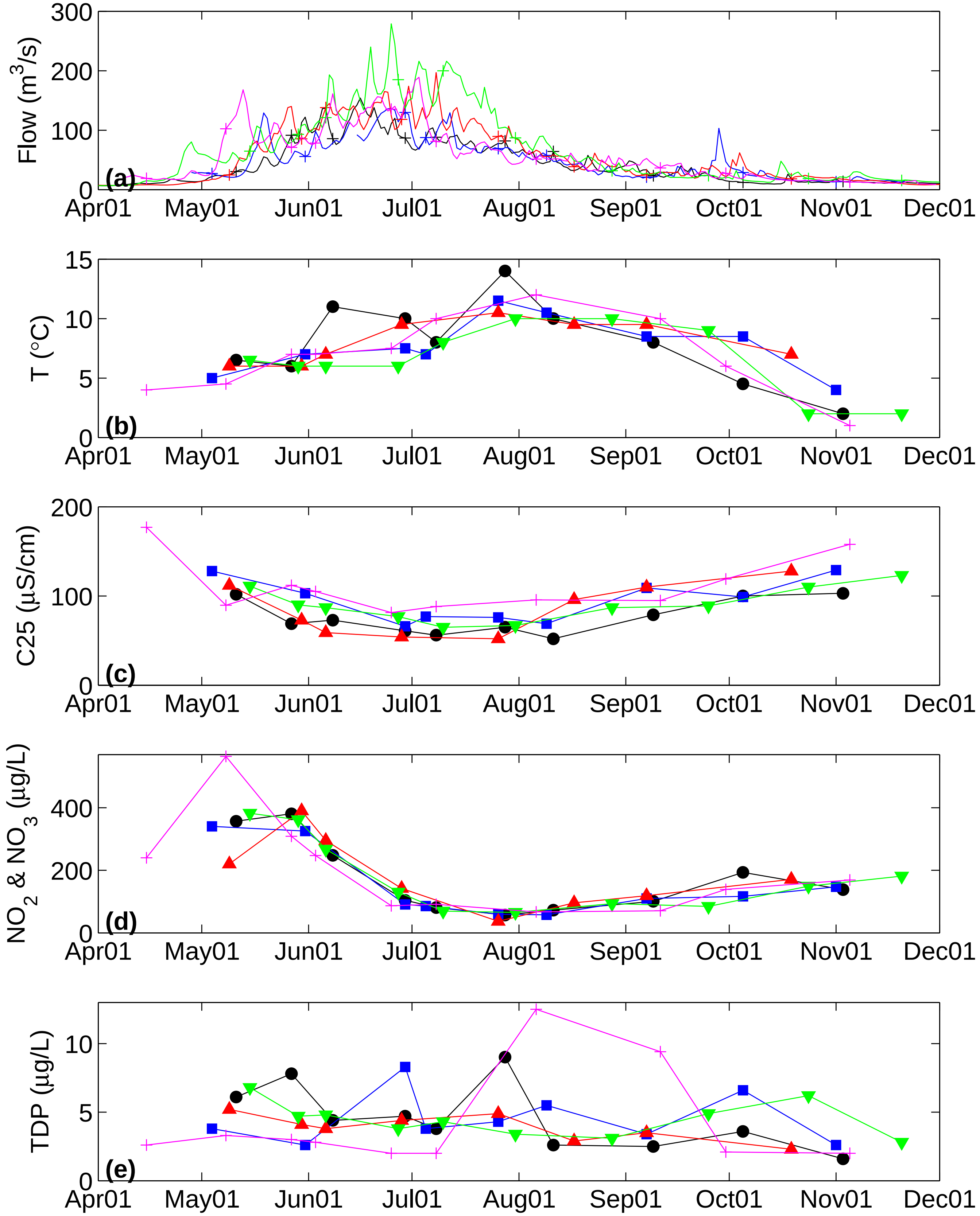

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Figure 3.3.3 Beaver River, 2009, 2010, 2011, 2012 & 2013,
all near East Park Gate except (+) above Cupola Creek

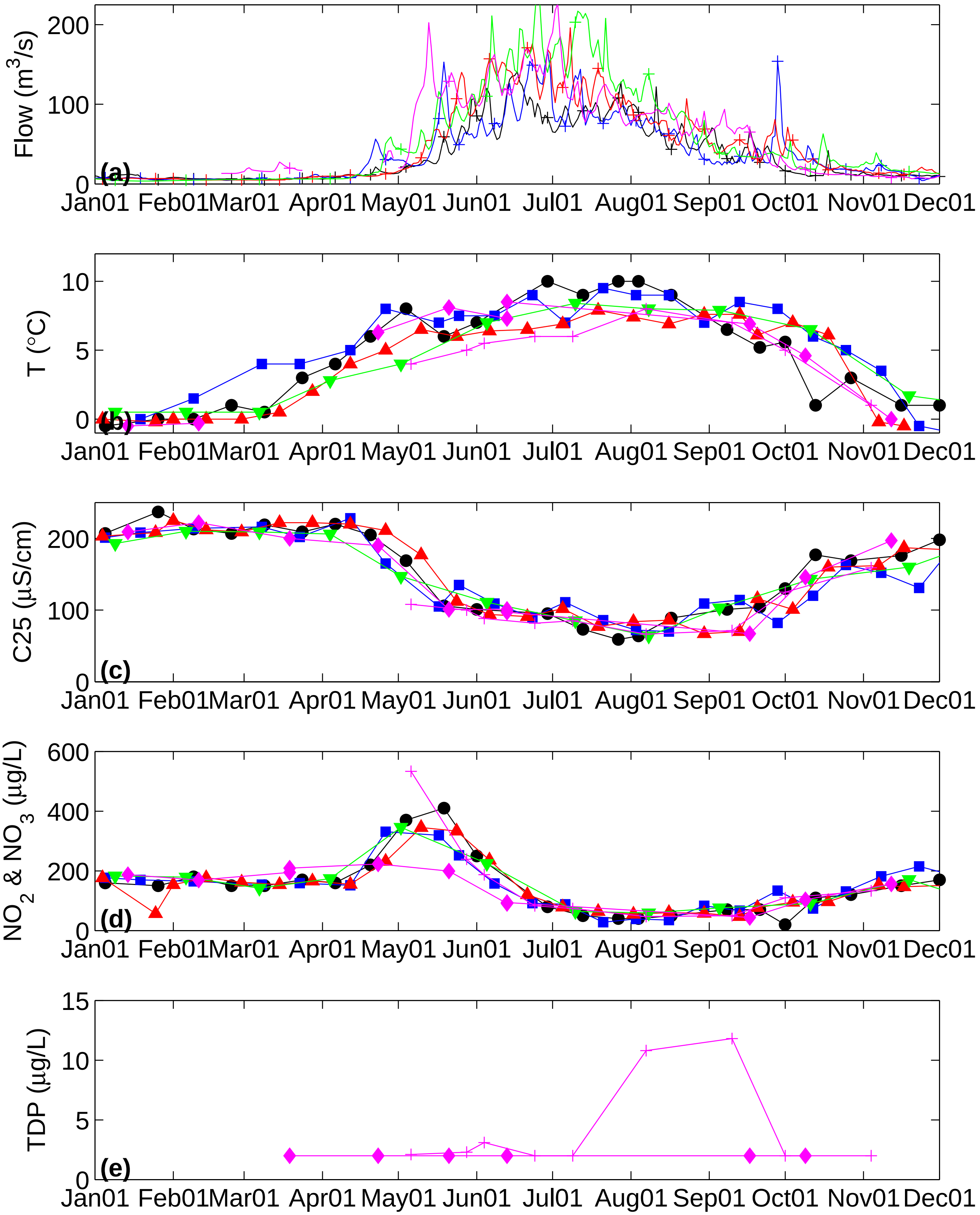

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Figure 3.3.4 Kinbasket Outflow, 2009, 2010, 2011, 2012 & 2013

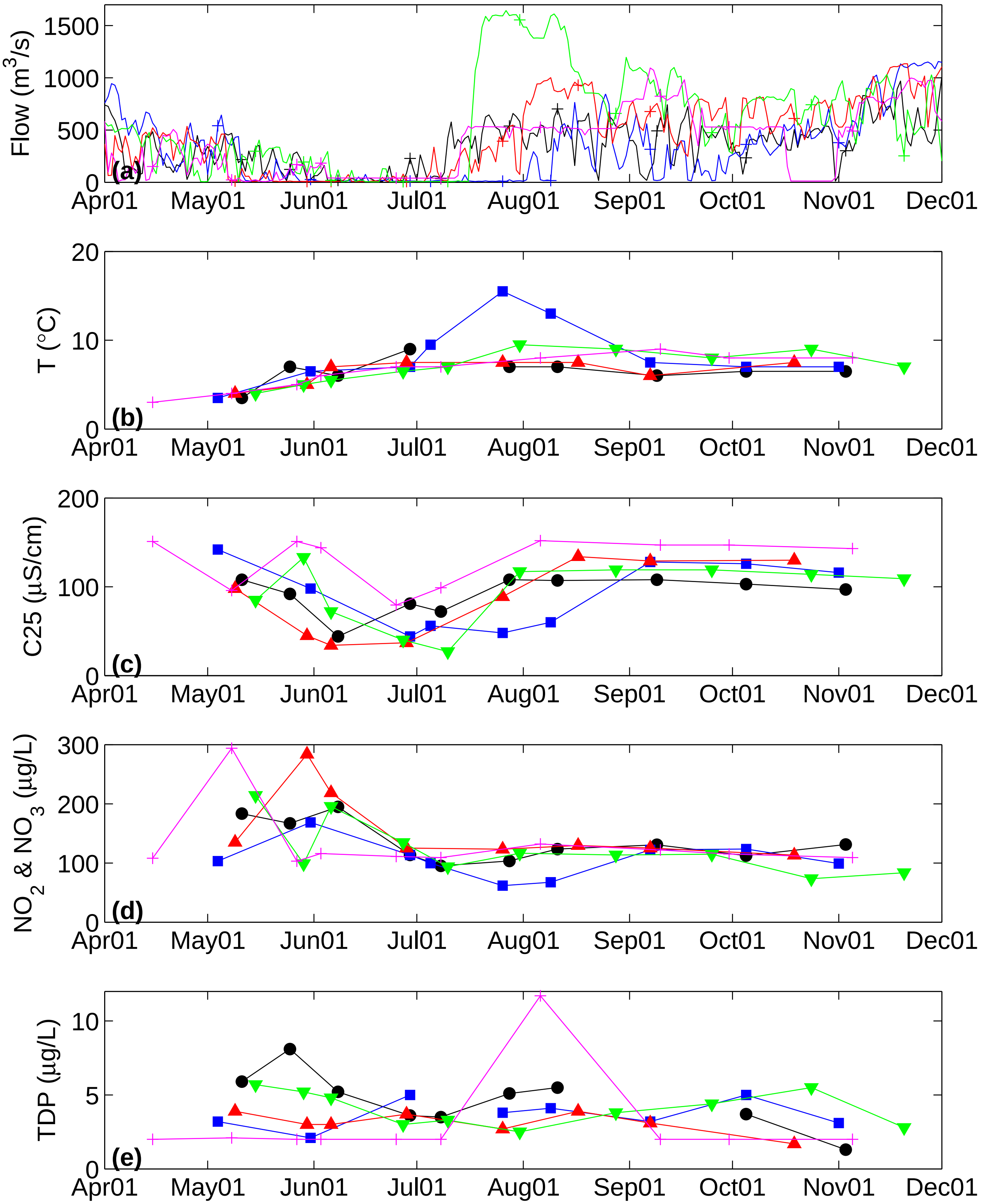

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Figure 3.3.5 Revelstoke Outflow, 2009, 2010, 2011, 2012 & 2013

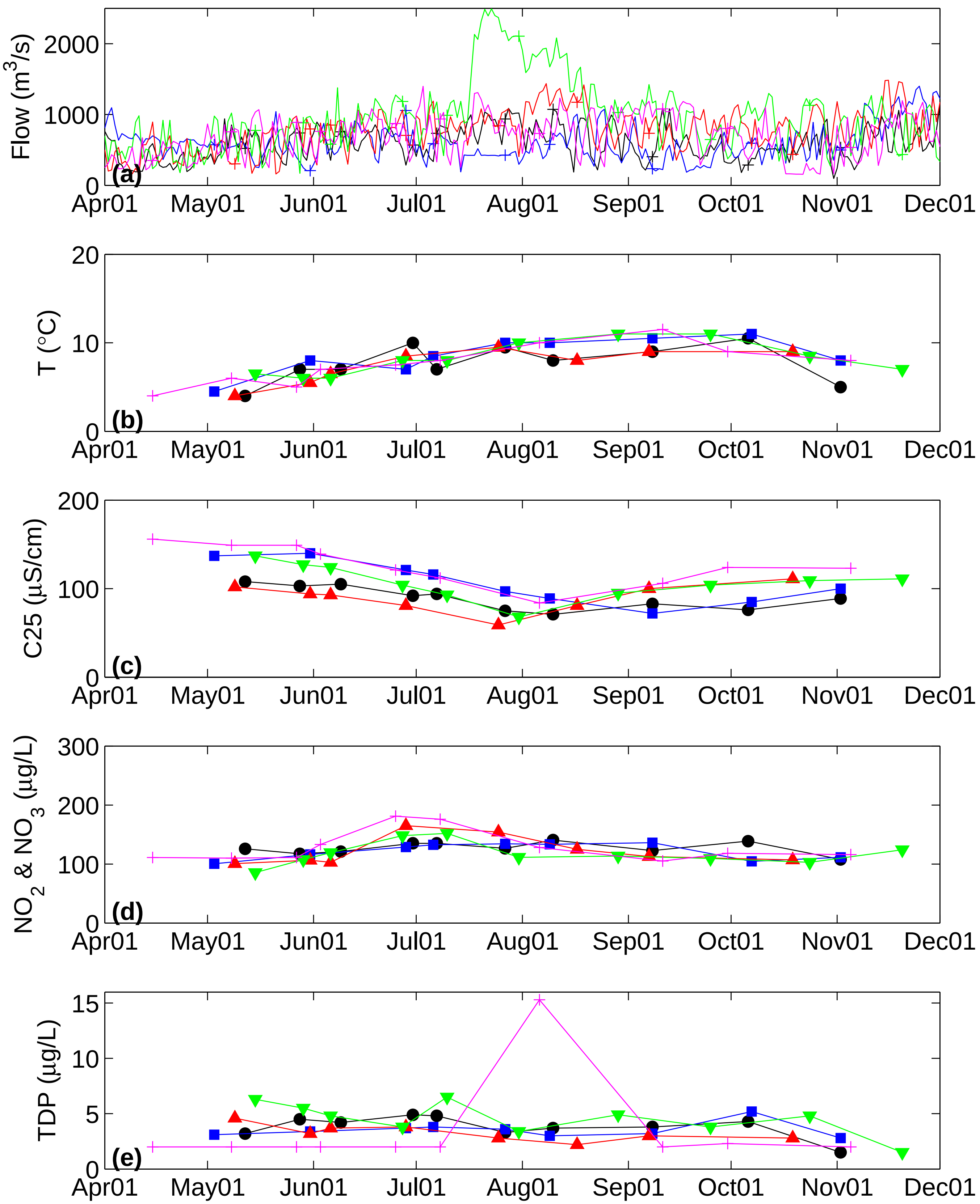

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Figure 3.4.1 Water quality of Illecillewaet River, 1997−2001

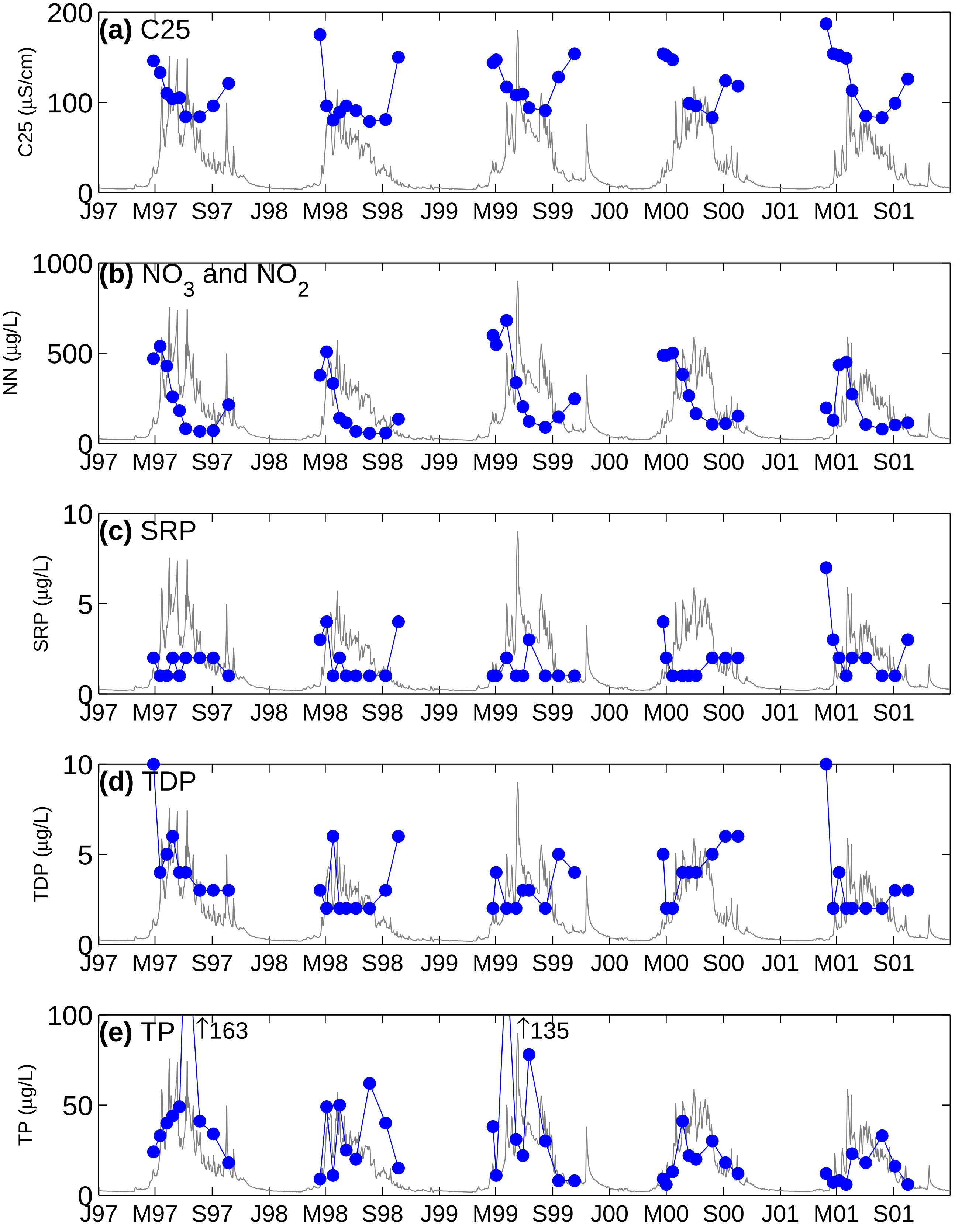

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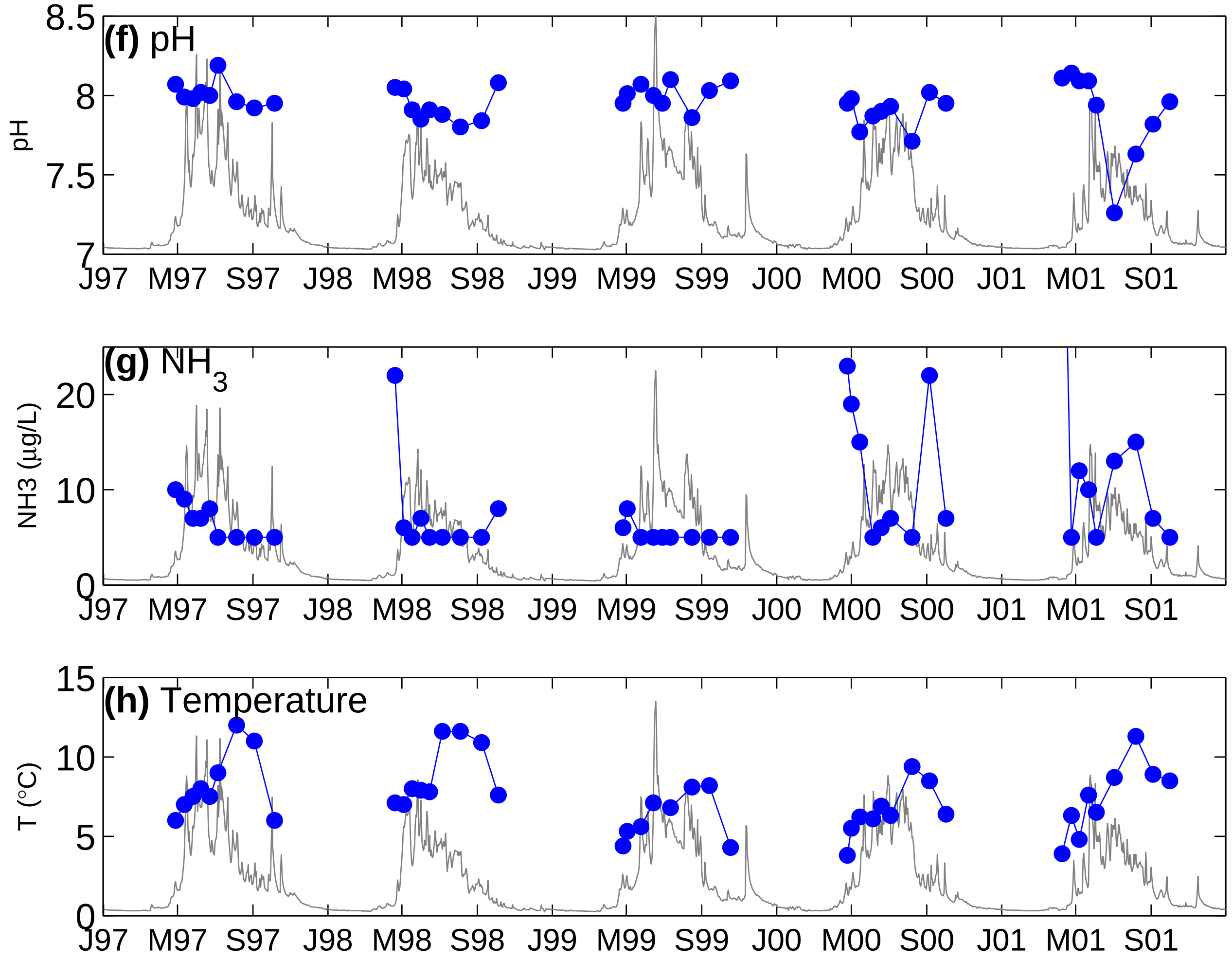
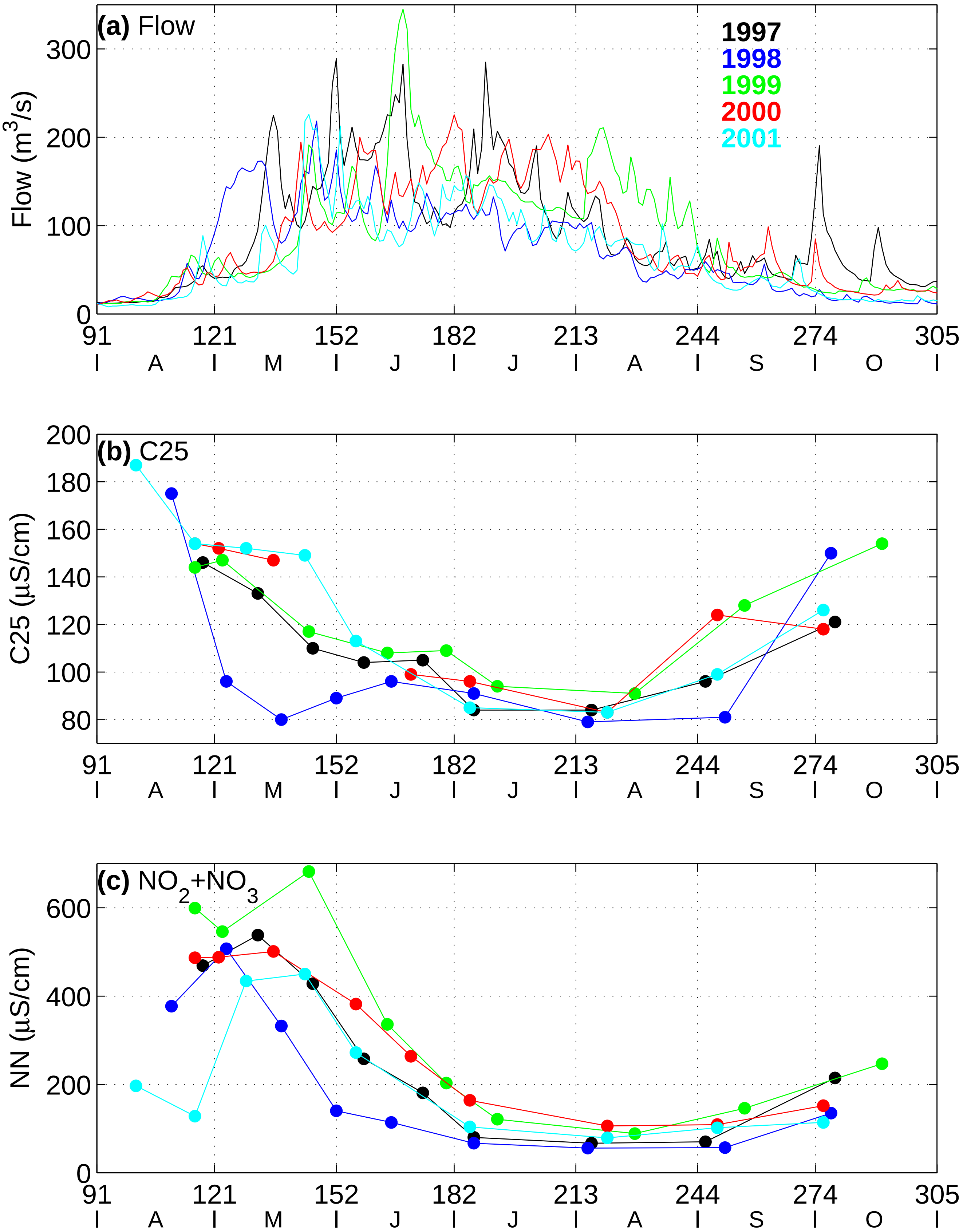
Figure 3.4.1 con’t Water quality of Illecillewaet River, 1997−2001



/ocean/rpieters/al97/chem/stream/plotillKINREV10p2.m fig= 1 2014−Jan−28

Figure 3.4.2 Flow, C25 and NN in the Illecillewaet River, 1997−2001



/ocean/rpieters/al97/chem/stream/plotillKINREV10p3.m fig= 1 2014−Jan−28

Fig 4.1.1 pH of Tributaries to Kinbasket R., 2008, 2009 2013

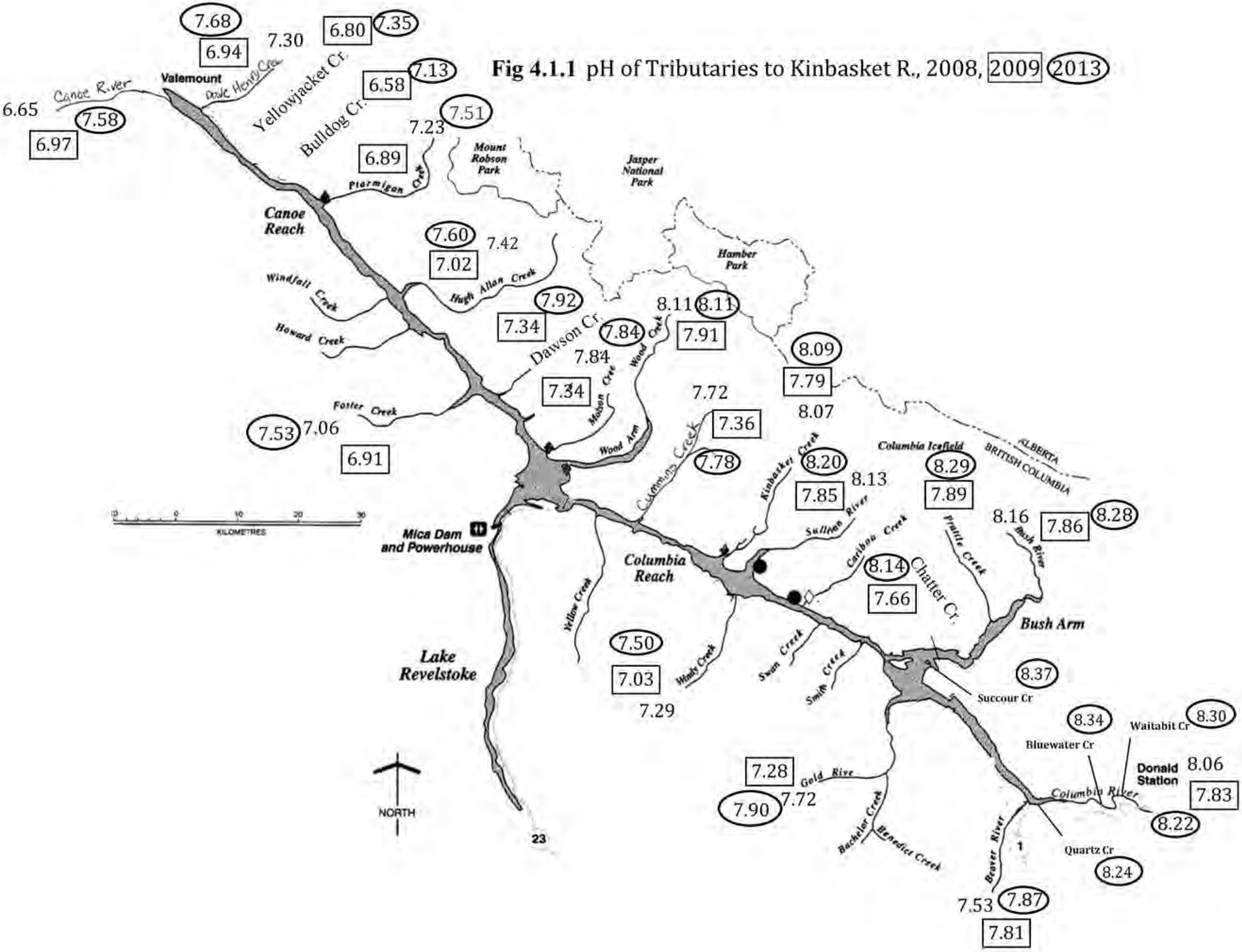
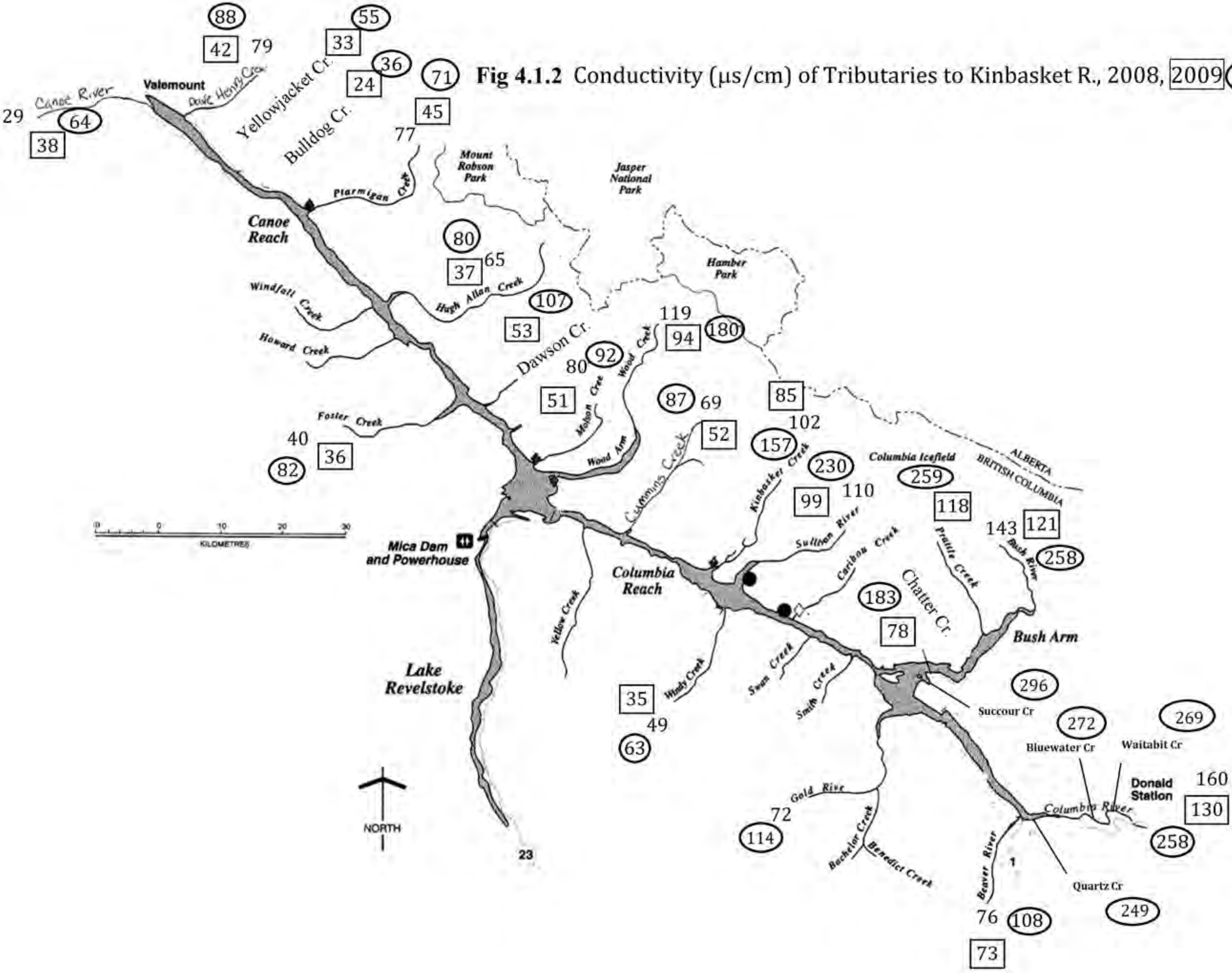


Fig 4.1.2 Conductivity (µs/cm) of Tributaries to Kinbasket R., 2008, 2009 2013



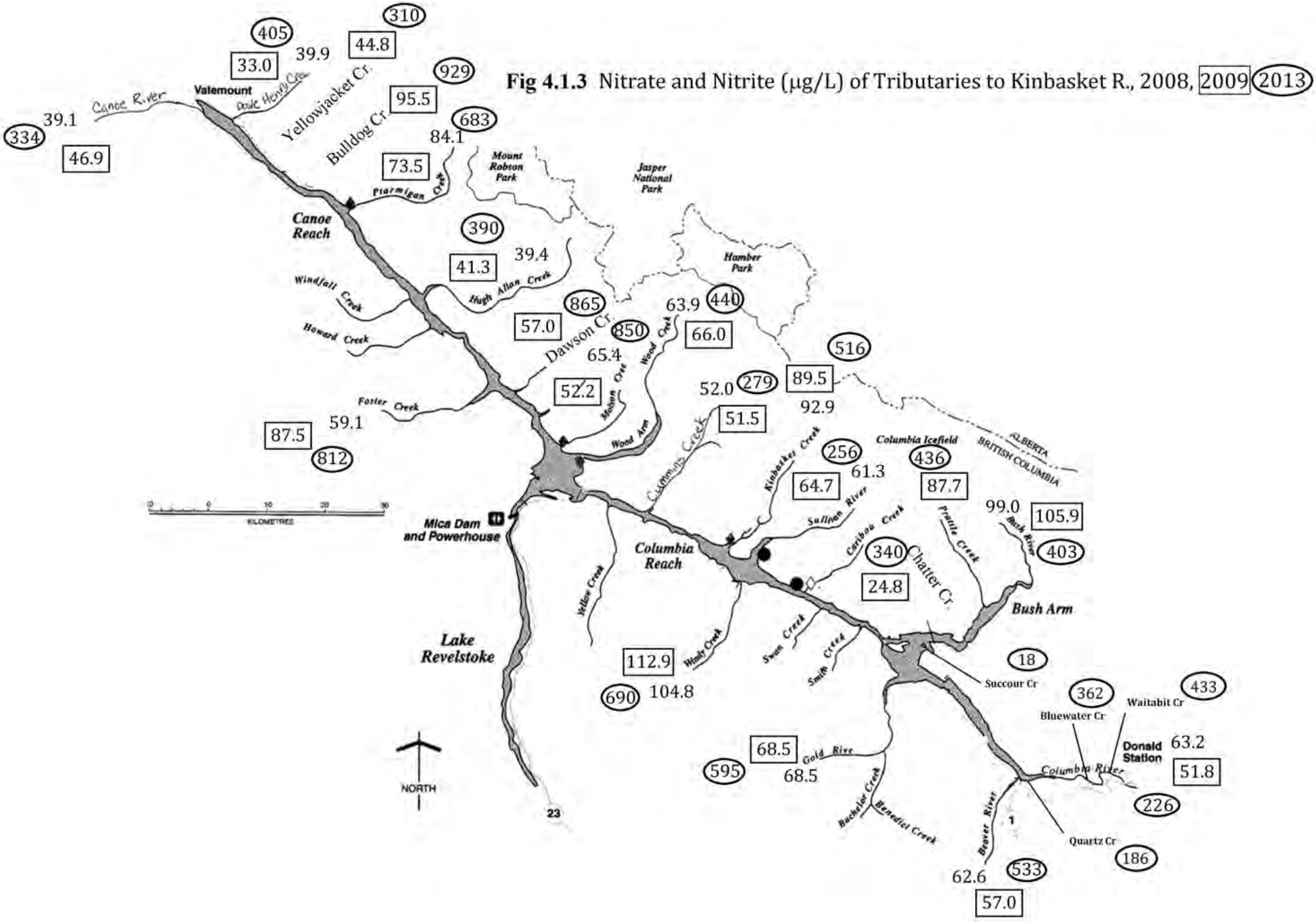


Fig 4.1.3 Nitrate and Nitrite (μg/L) of Tributaries to Kinbasket R., 2008, 2009 2013

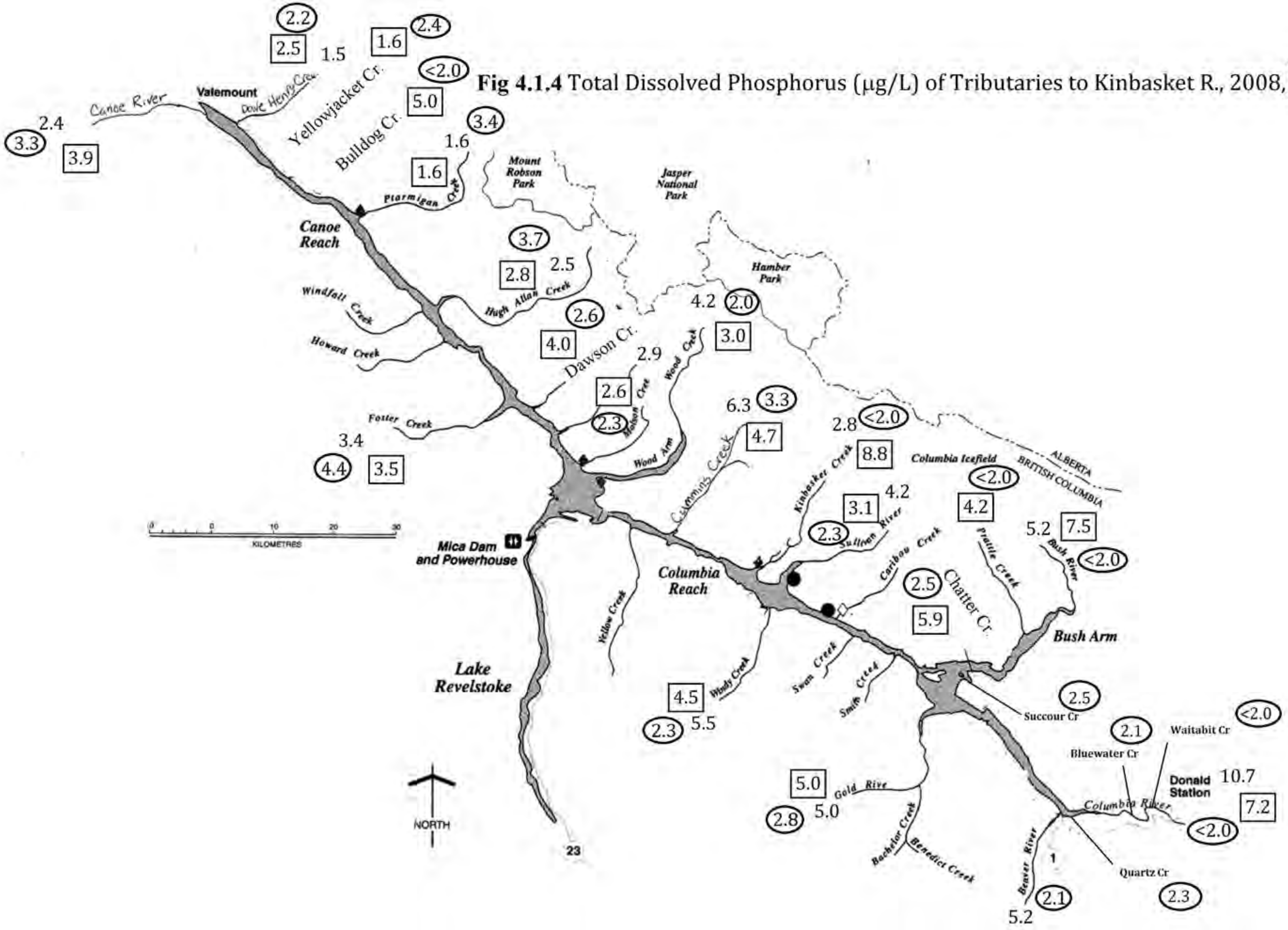


Fig 4.1.4 Total Dissolved Phosphorus (µg/L) of Tributaries to Kinbasket R., 2008, 2009 2013

Fig 4.1.5 Total Phosphorus (µg/L) of Tributaries to Kinbasket R., 2008, 2009 2013

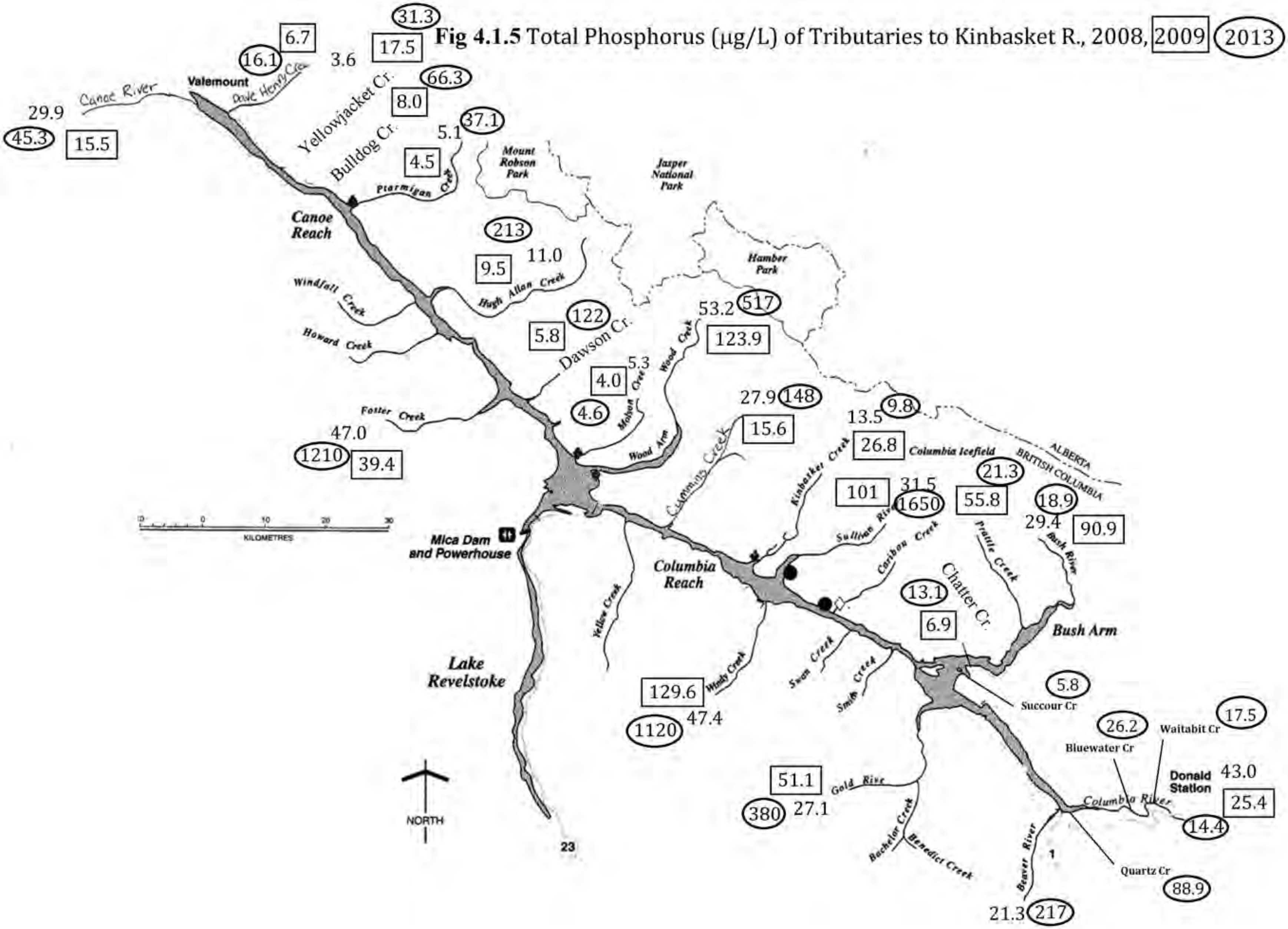


Fig 4.2.1 pH of Tributaries to Revelstoke R., 2008, 2009 2013

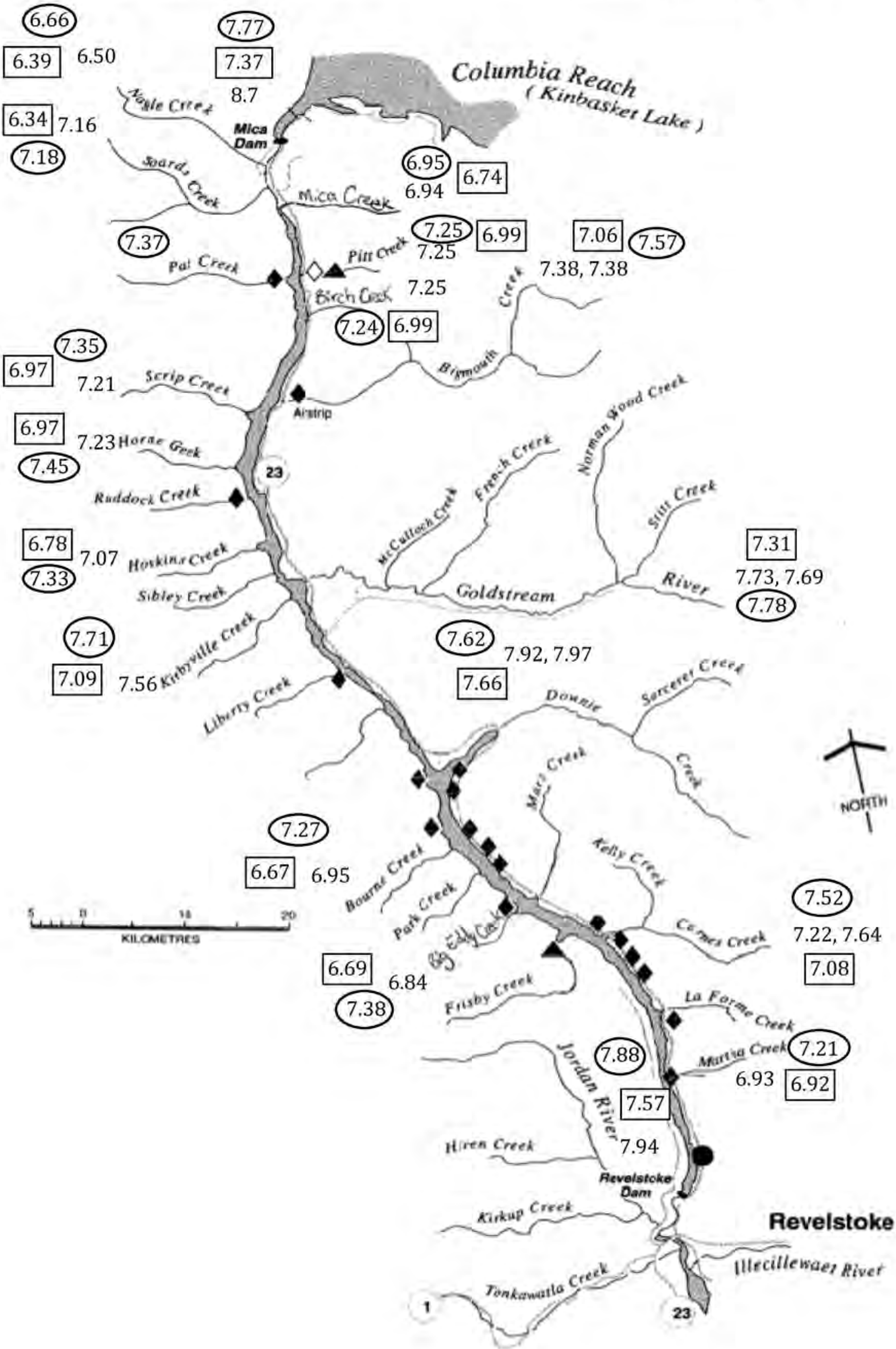


Fig 4.2.2 Conductivity (μS/cum) of Tributaries to Revelstoke R., 2008, 2009 2013

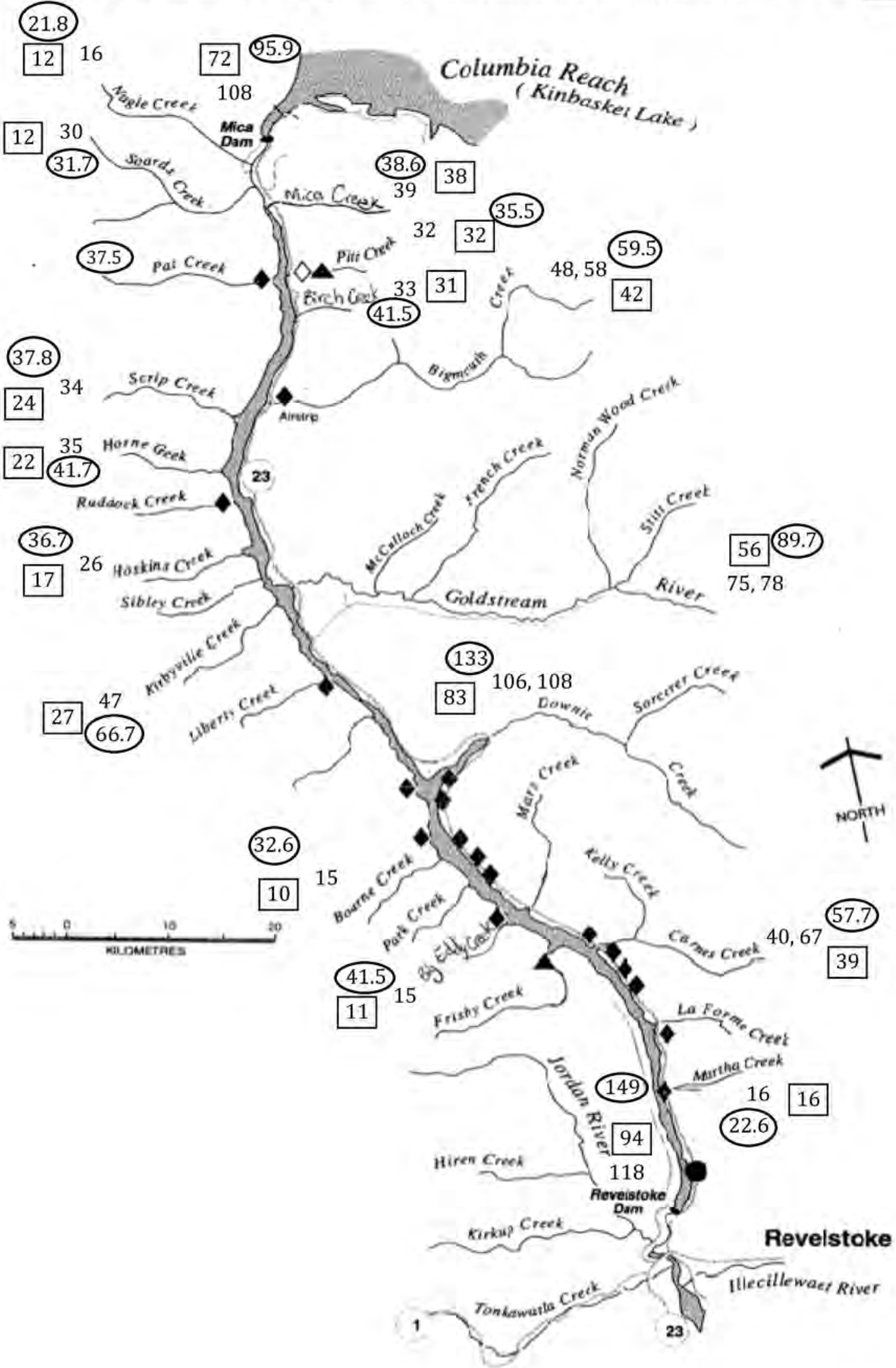


Fig 4.2.3 Nitrate and Nitrite (µg/L) of Tributaries to Revelstoke R., 2008, 2009 2013

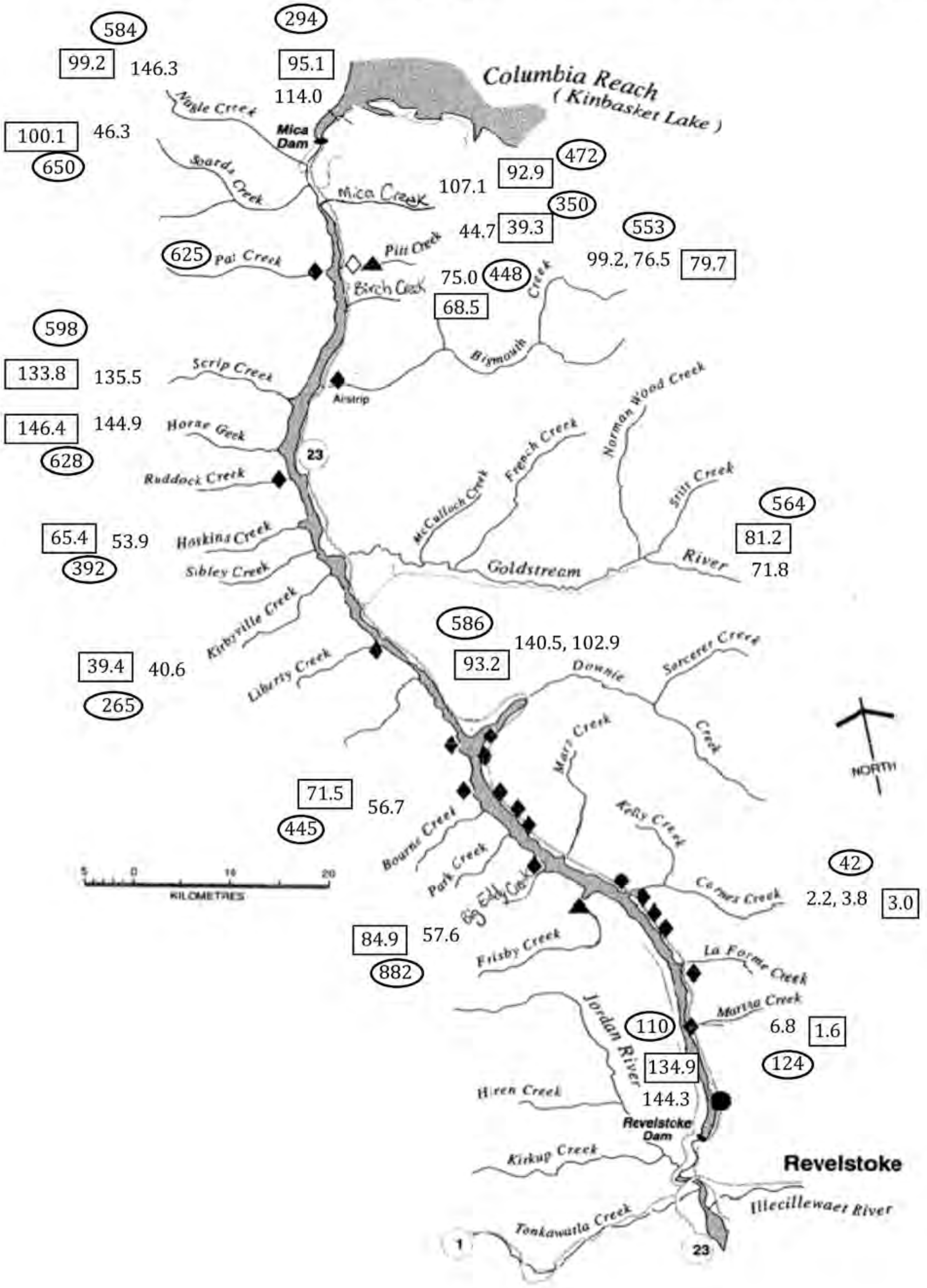


Fig 4.2.4 Total Dissolved Phosphorus (μg/L) of Tributaries to Revelstoke R., 2008, 2009

2013

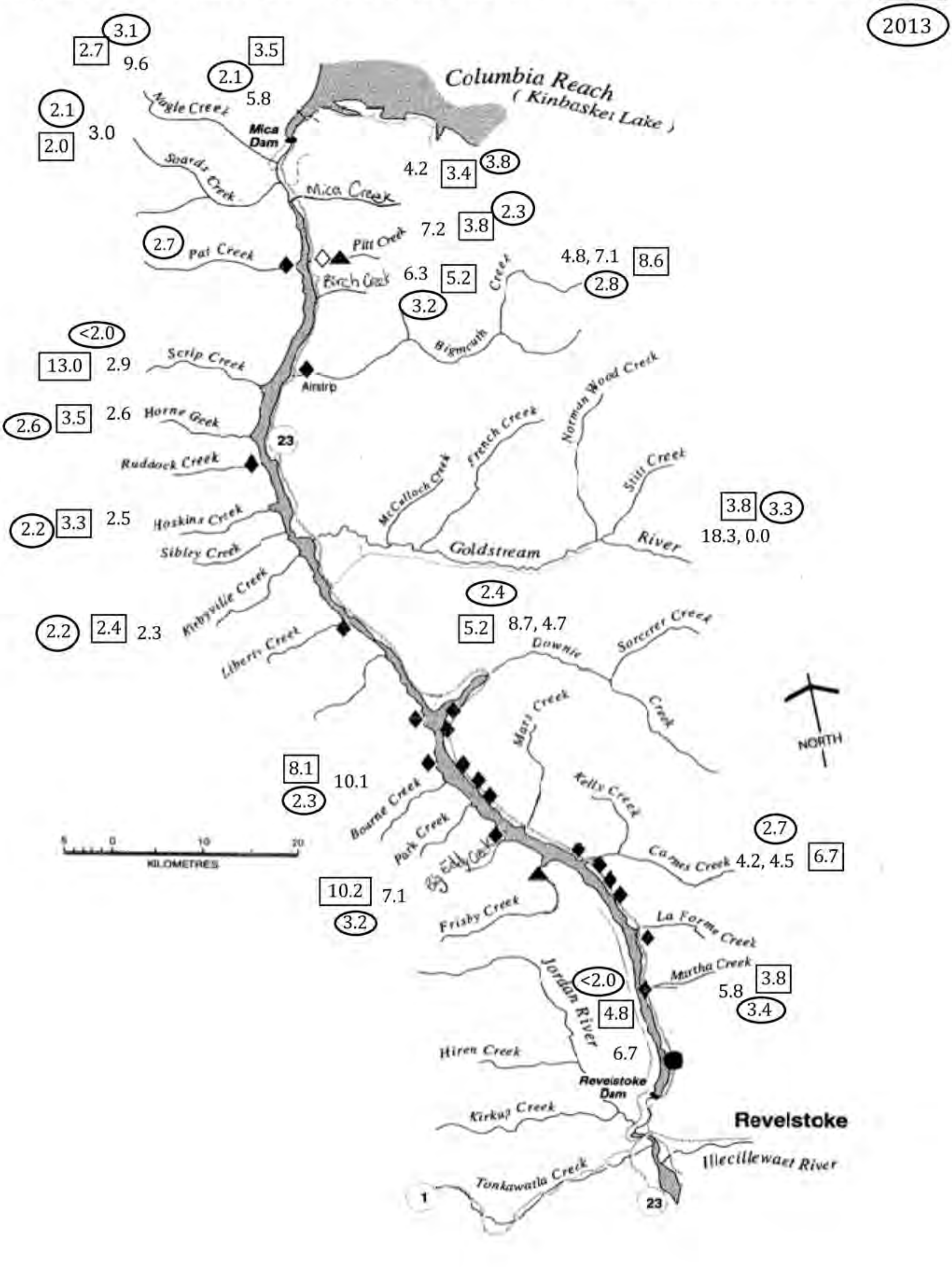
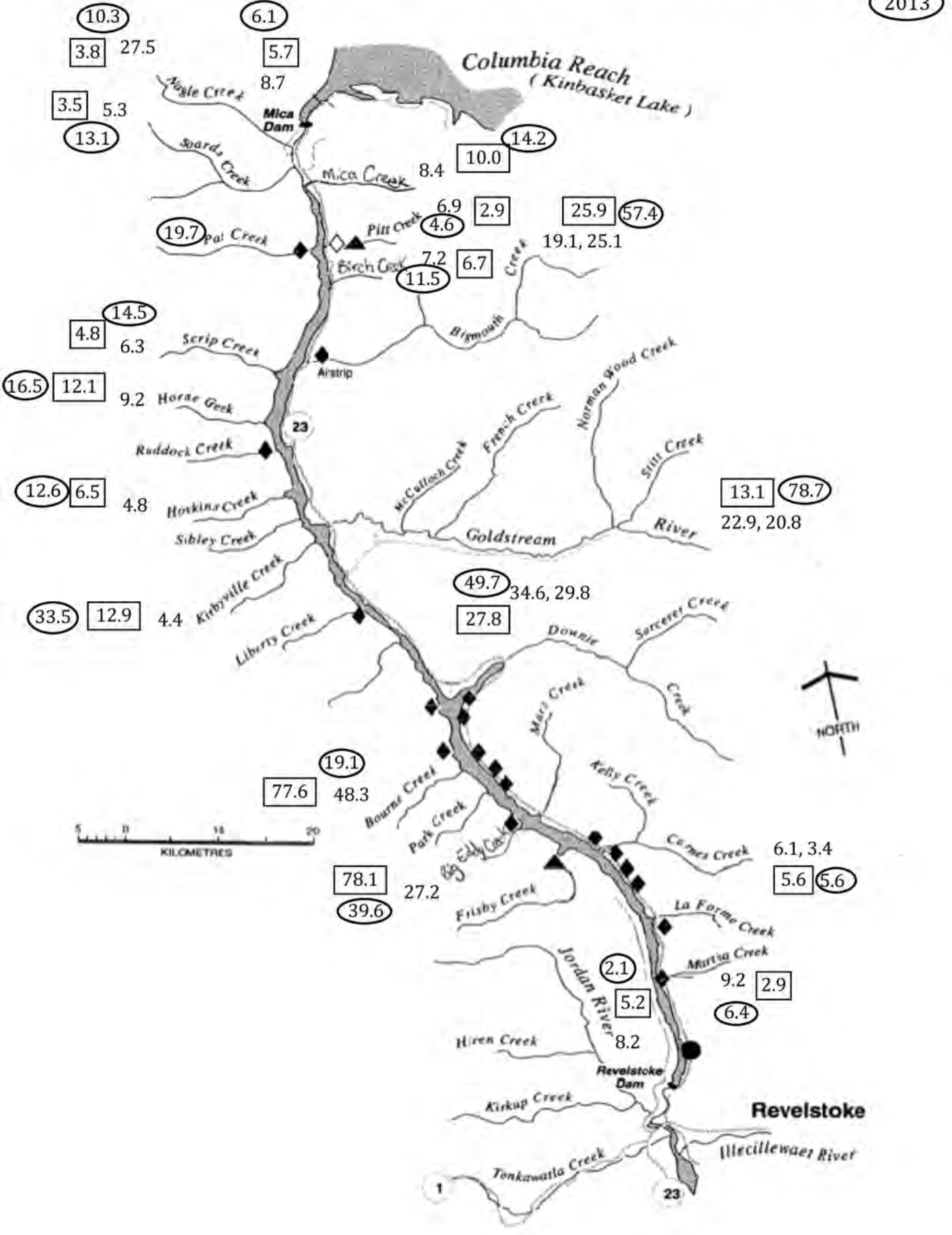


Fig 4.2.5 Total Phosphorus (µg/L) of Tributaries to Revelstoke R., 2008, 2009

2013



Appendix 1
Summary of Methods, Maxxam Analytics

Samples for NO_3+NO_2, 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 NO_3+NO_2 and SRP were frozen.

A summary of selected laboratory methods were abstracted from Maxxam method summaries as follows.

Phosphorus Standard Methods 22nd Edition, Method 2580 B

Total Phosphorus is the term used to describe the sum of all of the phosphorus present in a sample regardless of form, as measured by the persulphate digestion procedure.

Total orthophosphate is the phosphate that responds to colorimetric tests without preliminary hydrolysis or oxidative digestion of the sample; however a small fraction of condensed phosphates is usually hydrolyzed unavoidably. This form is termed 'reactive phosphorus'.

Phosphorus analysis involves two general steps: a) conversion of the phosphorus form of interest to dissolved orthophosphate, and b) colourimetric determination of dissolved orthophosphate. The sample is divided and the subsamples are prepared for determination of orthophosphate or total phosphate, which are determined sequentially in the Konelab. Ammonium molybdate and antimony potassium tartrate react in an acidic medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex. This complex is reduced to an intensely blue coloured complex by ascorbic acid. The colour is proportional to the phosphorus concentration and is measured colorimetrically at 880 nm.

Nitrate and Nitrite Plus Nitrate by Automated Colourimetric Method Standard Methods 22nd Edition, Method 4500-NO3 – I

This method incorporates a split manifold used to determine both nitrite singly and nitrite and nitrate combined. The nitrite (that was originally present, plus reduced nitrate) is determined by diazotizing with sulphanilamide and coupling with N-(1-naphthyl)-ethylenediamine to form an azo dye, measured colourimetrically at 520 nm. For nitrite and nitrate combined, the nitrate in a portion of the sample is quantitatively reduced to nitrite in a reductor column containing amalgamated copperized cadmium filings. The nitrite yielded by the reduction plus the nitrite already present in the sample is then determined as for nitrite. Nitrate is determined by subtraction of the nitrite result from the nitrate + nitrite value.

Conductivity, pH and Alkalinity Standard Methods 22nd Edition, Methods 2510B (Conductivity), 4500B (pH), 2320B (Alkalinity)

Conductivity, pH, and alkalinity are determined sequentially on a sample using a fully automated instrument. Electrometric methods are calibrated daily to account for probe drift and fluctuations in temperature.

A multipoint calibration using standards of known conductivity and the measured cell constant is used to verify system performance. EC is calibrated daily because the cell constant may change over time.

pH measurement is the determination of the activity of the hydrogen ions by potentiometric measurement between electrodes. Combination electrodes, where both electrodes are contained in a single body with a saturated KCl filling solution are most commonly employed. The reference electrode is usually Ag/AgCl or calomel.

Alkalinity is determined by pH end-point titration of a sample aliquot with a standard solution of strong acid. The amount of acid added to the aliquot to bring the pH to 8.3 is used to calculate the phenolphthalein alkalinity. The amount of acid added to the aliquot to bring the pH to 4.5 is used to calculate the total alkalinity. For samples less than 20 mg/L CaCO3, low-level alkalinity is determined by carefully measuring the volume of acid required to lower the total alkalinity end point by exactly 0.3 pH units (doubling the H+ concentration) to pH 4.2.

Turbidity Standard Methods 22nd Edition, Method 2130B
A light source from a tungsten filament lamp is passed through a sample in order to measure the light scattered by the particles suspended in the sample. The intensity of the scattered light is measured by a 90° detector, a forward scatter light detector and a transmitted light detector. The intensity of the scattered light and the transmitted light is mathematically calculated to determine the concentration of the turbidity in the sample.

Correction of Alkalinity data, 2008-2012
Samples analyzed by the Cultus Lake lab were assessed using the low alkalinity method, and these values were given in all previous reports. However, only a few of the samples had alkalinity < 20 mg CaCO3/L for which the low level method is suitable (APHA 1975). The laboratory provided the spreadsheet from which it was possible to re-calculate the appropriate alkalinity, examples of which are shown in Table A1-1. Note that the first end point was not exactly pH 4.5 but ranged from pH 4.3 to 4.7; unfortunately the specific pH end point for each sample was not recorded. The alkalinity was recalculated assuming the end point pH was 4.5. The resulting error was estimated by adding 2/3 of the second end point, which was 0.3 pH units below the first. The resulting errors are less than 10% (Table A1-1). In summary, for alkalinity > 20 mg CaCO3/L, the recalculated values are approximately half of the uncorrected values.

Table A1-1 Example of recalculation of alkalinity, August 5, 2008

Tributary	pH	A or B mls acid to first pH(1)	C mls acid to 0.3 pH lower	N Norm-ality of acid	Low Level Alk (2) mg CaCO3 /L	Regular Alk (3) mg CaCO3 /L	Revised Alk mg CaCO3 /L	Estimated Error %
Beaver R	7.51	3.20	0.170	0.02	62.3	32	32	3.5
Bush R	8.16	8.20	0.290	0.02	161.1	82	82	2.4
Canoe R	6.86	0.70	0.120	0.02	12.8	7	12.8	-
Cummins R	7.68	3.60	0.150	0.02	70.5	36	36	2.8
Dave Henry Cr	7.30	1.80	0.160	0.02	34.4	18	18	5.9
Foster Cr	7.05	1.10	0.150	0.02	20.5	11	11	9.1
Gold R	7.71	3.00	0.200	0.02	58.0	30	30	4.4
Hugh Allen Cr	7.44	2.50	0.170	0.02	48.3	25	25	4.5
Kinbasket R	8.03	5.90	0.220	0.02	115.8	59	59	2.5
Molson Cr	7.81	4.30	0.170	0.02	84.3	43	43	2.6
Ptarmigan Cr	7.28	1.70	0.160	0.02	32.4	17	17	6.3
Sullivan R	8.15	6.50	0.320	0.02	126.8	65	65	3.3
Windy Cr	7.31	1.60	0.150	0.02	30.5	16	16	6.3
Wood R	8.10	6.90	0.250	0.02	135.5	69	69	2.4

All sample volumes V = 100 mL.

(1) First pH = 4.5 (4.3 - 4.7)

(2) Low level alkalinity ((2*B-C)*N*50000)/V

(3) Regular alkalinity (A*N*50000)/V

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
Waitabit Creek (new in 2013)	51°30.201 117°11.796	*~400*
Bluewater Creek (new in 2013)	51°30.164 117°13.571	*~400*
Quartz Creek (new in 2013)	51°31.310 117°23.947	*~100*
Beaver River at confluence during low pool, ~800 m below confluence at full pool (accessed by helicopter during 2013 survey)	51°32.105 117°25.592	
Beaver River near confluence at full pool (Kinbasket Lake Resort)	51°31.668 117°26.012	
Beaver River at WSC gauge 08NB019 (just above railroad bridge and ~2.5 km above confluence at full pool)	51^{o} 30.58 117^{o} 27.70	1150
Beaver River above Cupola Cr (near Roger’s Road bridge and ~6 km above confluence at full pool)	51°29.264 117°29.503	
Beaver River near East Park Gate (at Highway 1 bridge and ~18 km above confluence at full pool)(2)	51°23 / 117°27	*~600*
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
Succour Creek (new in 2013)	51°45.014 117°35.631	*~50*
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 River	51^{o} 58.5 117^{o} 57.5	*160*
Cummins	52^{o} 03.1 118^{o} 09.5	268
Wood Arm		
Wood River	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 51º 30.58 N and 117º 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**	**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
Pat Creek (new in 2013)	51°57.0 118°34.7	*200*
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 3.1 Reference Tributaries

		Date	pH	Cond	NN	SRP	TDP	TP	TP Turb	TPc[1]	Turb	Alk [2]	T	Color [3]
				(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	83	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	132	10	TM
Columbia at Donald	1	05/28/2009	8.14	156	191.9	4.6	6.4	9.7	3.7	6	28	100	12	TB
Columbia at Donald	1	06/09/2009	8.05	135	100.6	2.6	7.2	46.5	NaN	NaN	15.8	83	11	TB
Columbia at Donald	1	06/30/2009	7.78	135	48	2.5	6.8	18	3.4	14.6	3.8	79.2	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	77	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	75.6	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	73	15	TM
Columbia at Donald	1	09/08/2009	7.83	127	60	1.7	6.3	28	17	11	29.6	78.4	11	MB
Columbia at Donald	1	10/06/2009	8	164	99.6	1.4	NaN	9.5	5.8	3.7	3.31	103.5	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	114.2	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	115	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	93.4	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	77.5	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	79.5	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	74	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	70.1	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	95.5	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	91.5	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	113	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	145	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	102	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	106	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	86	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	78.6	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	79.5	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	95.5	11.0	TB
Columbia at Donald	1	10/19/2011	8.12	231	82.3	2.0	3.5	11.9	**	NaN	5.90	108.5	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	125.5	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	112.5	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	112.2	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	114.9	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	87.9	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	90.7	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	108.5	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	109	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	124	1.0	C
Columbia at Donald	1	04/16/2013	8.23	344	99.8	1.10	2.30	4.70	NaN	NaN	2.6	145	5	GC
Columbia at Donald	1	05/09/2013	8.22	258	226	2.20	<2.00	14.40	NaN	NaN	45.2	114	10	B
Columbia at Donald	1	05/28/2013	8.11	221	124	1.00	<2.00	14.40	NaN	NaN	5.46	94	10	MG
Columbia at Donald	1	06/04/2013	8.02	222	105	4.90	8.70	12.40	NaN	NaN	8.49	95.8	11	GB
Columbia at Donald	1	06/24/2013	7.92	186	45.3	4.40	2.10	58.30	NaN	NaN	28.4	79.7	13	B
Columbia at Donald	1	07/09/2013	7.99	179	18.5	<1.00	<2.00	22.50	NaN	NaN	19.7	77.8	15	B
Columbia at Donald	1	08/07/2013	8.03	174	42.5	6.80	7.40	47.60	NaN	NaN	44	74.6	14	MB
Columbia at Donald	1	09/10/2013	7.88	176	62.9	<1.00	45.70	48.80	NaN	NaN	0.13	71.1	12	B
Columbia at Donald	1	10/01/2013	8.16	245	68.5	2.30	<2.00	6.90	NaN	NaN	11.1	97.8	8	B
Columbia at Donald	1	11/04/2013	8.15	282	86.8	1.20	<2.00	2.40	NaN	NaN	1.74	112	1.5	C

		Date	pH	Cond	NN	SRP	TDP	TP	TP Turb	TPc[1]	Turb	Alk [2]	T	Color [3]
Columbia at Donald	1	5/27/2014	8.08	201	206.0	4.90	<2.00	60.50	NaN	NaN	46.10	87.9	8	B
Columbia at Donald	1	6/10/2014	8.15	203	97.6	<1.00	3.50	2.60	NaN	NaN	29.80	87.3	10	B
Columbia at Donald	1	7/9/2014	7.96	172	29.9	2.60	<2.00	22.30	NaN	NaN	11.60	72.0	15	B
Columbia at Donald	1	8/5/2014	8.06	176	45.8	<1.00	3.60	16.70	NaN	NaN	9.33	72.0	14	B
Columbia at Donald	1	9/3/2014	8.04	202	62.9	6.20	<2.00	9.50	NaN	NaN	13.40	78.5	10	MG
Columbia at Donald	1	10/6/2014	8.04	242	78.2	2.80	<2.00	3.00	NaN	NaN	2.89	93.8	7	GC
Columbia at Mica Outflow	2	06/24/2008	7.80	108	114.0	2.9	5.8	8.7	0.9	7.8	0.74	52	7	n/a
Columbia at Mica Outflow	2	05/11/2009	7.83	108	183.2	4.8	6.1*	5.9	0.1	5.9	0.77	58	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	55	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	22	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	48.1	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	44	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	71	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	70	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	70	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	65.9	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	62	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	69	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	44.1	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	17.7	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	23	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	20	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	26.4	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	64.7	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	64	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	60	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	60.9	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	26	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	20	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	22.2	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	61.4	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	66	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	63.5	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	63	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	37.3	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	53.65	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	33.25	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	17.5	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	11.1	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	64.5	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	67.7	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	64.2	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	61.3	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	60.2	7.0	C
Columbia at Mica Outflow	2	04/15/2013	7.98	151	108	<1.00	2.00	2.90	NaN	NaN	0.4	66	3	C
Columbia at Mica Outflow	2	05/08/2013	7.77	95.9	294	1.80	2.10	6.10	NaN	NaN	2.03	40.2	4	LB
Columbia at Mica Outflow	2	05/27/2013	7.99	151	103	<1.00	2.40	<2.00	NaN	NaN	0.27	62.9	5	C
Columbia at Mica Outflow	2	06/03/2013	7.9	144	116	1.30	<2.00	2.60	NaN	NaN	0.3	59.6	6	C
Columbia at Mica Outflow	2	06/25/2013	7.5	79.4	111	<1.00	<2.00	<2.00	NaN	NaN	1.54	29	7	C

		Date	pH	Cond	NN	SRP	TDP	TP	TP Turb	TPc[1]	Turb	Alk [2]	T	Color [3]
Columbia at Mica Outflow	2	07/08/2013	7.78	99	109	1.40	<2.00	<2.00	NaN	NaN	1.17	39.4	7	C
Columbia at Mica Outflow	2	08/06/2013	7.94	152	132	1.00	11.70	17.50	NaN	NaN	0.51	66.4	8	C
Columbia at Mica Outflow	2	09/10/2013	7.84	147	122	<1.00	<2.00	<2.00	NaN	NaN	0.12	62.8	9	C
Columbia at Mica Outflow	2	09/30/2013	8.04	147	115	1.20	<2.00	<2.00	NaN	NaN	0.65	62.8	8	C
Columbia at Mica Outflow	2	11/05/2013	7.92	143	109	<1.00	<2.00	<2.00	NaN	NaN	0.44	58.9	8	C
Columbia at Mica Outflow	2	5/26/2014	7.51	58	319.0	4.90	<2.00	7.40	NaN	NaN	2.43	17.2	4	C
Columbia at Mica Outflow	2	6/9/2014	7.53	54	185.0	1.60	<2.00	<2.00	NaN	NaN	2.02	16.7	5	LB
Columbia at Mica Outflow	2	7/8/2014	7.61	65	107.0	1.50	<2.00	4.20	NaN	NaN	1.38	25.5	12	C
Columbia at Mica Outflow	2	8/6/2014	8.01	151	128.0	<1.00	3.80	4.20	NaN	NaN	0.42	63.8	6	C
Columbia at Mica Outflow	2	9/2/2014	7.94	158	128.0	<1.00	<2.00	2.60	NaN	NaN	0.38	64.0	6	C
Columbia at Mica Outflow	2	10/7/2014	7.93	150	212.0	<1.00	<2.00	<2.00	NaN	NaN	0.59	63.1	7	C
Goldstream River	3	06/24/2008	7.73	75	1172.5	2.0	18.3	22.9	2.2	20.7	1.01	38	9.5	n/a
Goldstream River	3	08/05/2008	7.69	78	71.8	2.1	0.0	20.8	7.5	13.3	2.71	41	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	63	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	45	6	TB
Goldstream River	3	06/08/2009	7.77	73	247.7	2.3	4.4	9.1	0.6	8.5	1.86	46	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	40	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	37.5	8	C
Goldstream River	3	07/28/2009	7.64	65	57.2	2.2	9	177.3	116	61.3	189	40.5	14	TB
Goldstream River	3	08/11/2009	7.23	52	72.5	1	2.6	91.9	33	58.9	45.6	35	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	51	8	C
Goldstream River	3	10/05/2009	7.76	100	193.4	1.4	4.9*	3.6	0.6	3	1.72	64.5	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	67	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	65	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	51	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	33.5	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	37	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	36.9	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	34.1	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	55.4	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	51	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	68	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	76	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	51	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	40	7.0	TB
Goldstream River	3	06/28/2011	7.80	54	142.1	1.2	4.4	146.9	**	NaN	4.50	38.5	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	37.5	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	47	9.5	C
Goldstream River	3	09/07/2011	7.88	110	118.7	1.1	3.5	17.6	**	NaN	7.10	55.5	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	64	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	55.4	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	47	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	46.5	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	42.1	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	37	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	37.2	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	50	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	48	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	65	2.0	C

		Date	**pH**	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TPc**[1]	**Turb**	**Alk** [2]	**T**	**Color** [3]
Goldstream River	3	11/19/2012	7.82	123	181.7	1.4	2.8	4.6	<0.1	4.5	0.47	69.6	2.0	C
Goldstream River	3	04/15/2013	8.05	177	240	<1.00	2.60	3.70	NaN	NaN	1.07	80.8	4	GC
Goldstream River	3	05/08/2013	7.78	89.7	564	1.70	3.30	78.70	NaN	NaN	35.3	37.5	4.5	B
Goldstream River	3	05/27/2013	7.81	112	309	<1.00	3.00	8.50	NaN	NaN	1.3	50.2	7	GC
Goldstream River	3	06/03/2013	7.81	105	247	1.50	2.80	3.60	NaN	NaN	1.85	46.7	7	GC
Goldstream River	3	06/25/2013	7.58	81.5	86.7	1.70	<2.00	5.90	NaN	NaN	6.4	33.9	7.5	BG
Goldstream River	3	07/08/2013	7.76	88.2	91.2	2.30	<2.00	10.90	NaN	NaN	4.57	37.8	10	MG
Goldstream River	3	08/06/2013	7.85	95.7	66.9	1.70	12.50	78.70	NaN	NaN	49.5	43.7	12	MB
Goldstream River	3	09/11/2013	7.76	94.9	70.5	<1.00	9.40	16.00	NaN	NaN	0.24	39.8	10	B
Goldstream River	3	09/30/2013	7.95	119	139	2.20	2.10	2.70	NaN	NaN	3.4	51.2	6	GC
Goldstream River	3	11/05/2013	7.95	158	169	<1.00	<2.00	<2.00	NaN	NaN	0.61	68.7	1	C
Goldstream River	3	5/26/2014	7.82	101	411.0	4.40	2.50	36.00	NaN	NaN	13.40	42.1	4	B
Goldstream River	3	6/9/2014	7.87	97	255.0	1.10	2.10	2.20	NaN	NaN	4.85	41.3	6	B
Goldstream River	3	7/8/2014	7.74	76	76.9	3.40	<2.00	14.90	NaN	NaN	7.48	33.3	8	MG
Goldstream River	3	8/6/2014	7.88	88	79.8	1.20	3.80	23.40	NaN	NaN	13.60	40.4	12	MG
Goldstream River	3	9/2/2014	7.75	108	99.7	2.60	<2.00	19.90	NaN	NaN	5.20	41.6	8	MG
Goldstream River	3	10/7/2014	7.79	107	112.0	5.90	2.00	6.70	NaN	NaN	6.22	41.6	8	MG
Columbia above Jordan [4]	4	06/24/2008	7.94	118	144.3	2.7	6.7	8.2	1.0	7.2	0.16	50	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	64	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	63	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	64	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	56	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	58.4	7	C
Columbia above Jordan	4	07/27/2009	7.49	75	126.7	3.1	3.3	4.7	0.1	4.7	0.63	49	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	45.4	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	52.6	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	50	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	55.2	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	63.7	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	66.6	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	59.5	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	56	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	46.7	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	44.2	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	34.7	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	42	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	51	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	64	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	61.7	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	60	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	55.5	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	41.9	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	38	8.0	C
Columbia above Jordan	4	09/07/2011	7.67	100	112.8	0.9	3.0	4.7	**	NaN	0.60	47	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	51.5	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	64.55	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	62.5	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	63.6	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	52.6	8.0	C

		Date	**pH**	**Cond**	**NN**	**SRP**	**TDP**	**TP**	**TP Turb**	**TPc**[1]	**Turb**	**Alk** [2]	**T**	**Color** [3]
Columbia above Jordan	4	07/09/2012	7.71	93	151.8	2.1	6.5	7.1	0.8	6.3	0.05	48.2	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	35.8	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	52.6	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	56.46	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	61	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	60.4	7.0	C
Columbia above Jordan	4	04/15/2013	7.98	156	111	<1.00	<2.00	3.20	NaN	NaN	0.53	67.7	4	C
Columbia above Jordan	4	05/08/2013	7.88	149	110	<1.00	<2.00	2.10	NaN	NaN	0.18	64.1	6	C
Columbia above Jordan	4	05/27/2013	7.97	149	111	<1.00	<2.00	<2.00	NaN	NaN	0.21	64.4	5	C
Columbia above Jordan	4	06/03/2013	7.9	139	133	<1.00	<2.00	2.90	NaN	NaN	0.024	59.3	7	C
Columbia above Jordan	4	06/25/2013	7.74	121	181	<1.00	<2.00	<2.00	NaN	NaN	0.79	48.7	7.5	C
Columbia above Jordan	4	07/08/2013	7.82	112	176	<1.00	<2.00	<2.00	NaN	NaN	0.37	48.2	8	C
Columbia above Jordan	4	08/06/2013	7.58	83.9	128	1.40	15.30	19.90	NaN	NaN	0.62	35.2	10	C
Columbia above Jordan	4	09/11/2013	7.66	106	105	1.60	2.00	2.30	NaN	NaN	0.11	42.6	11.5	C
Columbia above Jordan	4	09/30/2013	7.95	124	118	1.40	2.30	5.50	NaN	NaN	1.19	51.6	9	C
Columbia above Jordan	4	11/05/2013	7.83	123	116	<1.00	<2.00	<2.00	NaN	NaN	0.3	50.3	8	C
Columbia above Jordan	4	5/27/2014	7.78	142	117.0	2.70	<2.00	<2.00	NaN	NaN	0.27	56.2	4	C
Columbia above Jordan	4	6/9/2014	8.06	140	128.0	<1.00	<2.00	2.70	NaN	NaN	0.28	59.3	5	C
Columbia above Jordan	4	7/8/2014	7.86	118	170.0	<1.00	<2.00	2.20	NaN	NaN	0.45	50.0	8	C
Columbia above Jordan	4	8/5/2014	7.78	89	144.0	1.30	4.10	6.10	NaN	NaN	0.89	35.7	9	C
Columbia above Jordan	4	9/2/2014	7.83	111	122.0	1.00	<2.00	<2.00	NaN	NaN	0.61	45.6	8	C
Columbia above Jordan	4	10/6/2014	7.84	127	123.0	1.20	<2.00	<2.00	NaN	NaN	0.82	52.0	8	C
Beaver River	6	05/06/2013	7.87	108	533	1.90	2.10	217.00	NaN	NaN	62.6	44.9	4	B
Beaver River	6	05/28/2013	7.82	100	239	1.70	2.30	8.10	NaN	NaN	3.33	39.5	5	C
Beaver River	6	06/04/2013	7.71	88.2	187	1.90	3.10	6.40	NaN	NaN	3.16	36.2	5.5	C
Beaver River	6	06/24/2013	7.55	81.7	83.2	2.60	<2.00	5.80	NaN	NaN	9.14	30.7	6	GT
Beaver River	6	07/09/2013	7.77	85.1	74.1	3.60	<2.00	9.70	NaN	NaN	8.03	34.1	6	C
Beaver River	6	08/07/2013	7.57	66.4	47.2	6.20	10.80	37.10	NaN	NaN	20.8	28	8	M
Beaver River	6	09/10/2013	7.5	71.4	49.7	5.50	11.80	17.00	NaN	NaN	0.23	28.5	7	M
Beaver River	6	10/01/2013	7.93	125	110	2.10	<2.00	<2.00	NaN	NaN	2.33	50.9	5	C
Beaver River	6	11/04/2013	7.93	159	133	<1.00	<2.00	2.50	NaN	NaN	0.74	64	1	C
Beaver River	6	5/27/2014	7.61	83	327.0	3.30	<2.00	15.20	NaN	NaN	10.70	31.6	3.5	GB
Beaver River	6	6/10/2014	7.74	77	173.0	<1.00	<2.00	2.20	NaN	NaN	6.53	29.7	3	MG
Beaver River	6	7/9/2014	7.65	70	64.1	5.00	<2.00	17.40	NaN	NaN	6.25	28.7	6	MG
Beaver River	6	8/5/2014	7.71	73	53.9	<1.00	4.00	9.70	NaN	NaN	5.14	28.8	7	MG
Beaver River	6	9/3/2014	7.74	86	65.5	5.20	<2.00	6.90	NaN	NaN	8.12	34.2	6	MG
Beaver River	6	10/6/2014	7.73	101	82.2	2.70	<2.00	3.80	NaN	NaN	2.02	38.7	6	C

1 TP=TP-Tpturb Total phosphorus corrected for turbidity

2 Corrected Alkalinity 2008 - 2012

3 (C)lear, (T)urbid, (M)ilky, (G)reen, (B)rown, (S)lightly, (L)ight

4 Columbia above Jordan is located just below Revelstoke Dam

* TDP > TP, values swapped in figures and analysis

** TPTurb not measured

Appendix 3.2

Station: Beaver River near East Park Gate (BC08NB0002)

Raw data from Environment Canada

Date Time	ALK-T	Ca	Cl	K	Mg	Na	NH3	NO2	NO3	pH	OP	TP	SO4	Cond	T	Turb	TN	TND	TDP
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	mg/L
12/4/2012 19:15	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	NaN
1/14/2013 22:50	87.7	30.0	1.0	0.5	9.6	2.1	NaN	0.005	0.182	8.16	0.001	0.003	17.7	209	-0.5	1.24	0.17	0.17	NaN
2/11/2013 18:54	89.2	29.1	1.0	0.4	9.4	2.1	NaN	0.005	0.164	8.09	0.001	0.002	17.8	222	-0.3	0.88	0.17	0.17	NaN
3/19/2013 19:10	83.9	26.2	2.1	0.4	8.4	2.6	NaN	0.005	0.190	7.87	NaN	0.002	16.1	200	NaN	0.59	0.21	0.21	0.002
3/19/2013 19:20	83.9	26.7	2.1	0.4	8.4	2.6	NaN	0.005	0.204	7.91	NaN	0.002	16.3	200	NaN	0.65	0.24	0.24	0.002
4/23/2013 18:45	80.4	25.6	2.6	0.5	8.0	2.8	NaN	0.005	0.218	7.94	NaN	0.002	13.6	190	6.3	0.66	0.22	0.22	0.002
5/21/2013 19:20	38.9	13.6	0.5	0.3	3.9	0.8	NaN	0.005	0.194	7.91	NaN	0.015	6.5	101	8.1	8.53	0.41	0.19	0.002
6/13/2013 20:16	42.8	13.7	0.3	0.2	4.2	0.7	NaN	0.005	0.086	7.90	NaN	0.009	7.5	101	7.3	5.31	0.11	0.10	0.002
6/13/2013 20:27	42.6	13.8	0.3	0.3	4.2	0.7	NaN	0.005	0.089	7.90	NaN	0.007	7.6	97	8.5	5.35	0.11	0.10	0.002
9/17/2013 18:17	27.4	10.7	0.1	0.2	2.0	0.2	NaN	0.005	0.039	7.78	NaN	0.031	4.8	67	6.9	29.5	0.04	0.04	0.002
10/9/2013 18:30	62.9	19.3	0.4	0.4	6.0	1.1	NaN	0.005	0.098	7.93	NaN	0.002	14.4	146	4.6	0.69	0.12	0.11	0.002
11/12/2013 17:50	80.0	25.4	0.8	0.4	8.4	1.7	NaN	0.005	0.151	8.01	NaN	0.001	18.0	197	0	NaN	NaN	0.14	NaN
1/20/2014 19:35	88.6	28.2	0.8	0.4	9.1	1.9	NaN	NaN	NaN	7.93	NaN	0.005	18.4	208	-0.7	NaN	NaN	0.15	NaN
2/18/2014 18:40	86.7	25.8	0.9	0.5	9.0	2.0	NaN	0.005	0.180	7.93	NaN	0.002	19.2	207	-0.2	NaN	NaN	0.16	NaN

Appendix 3.3.1 Tributaries to Kinbasket Reservoir sampled in 2008

Name	Date Sampled	pH	Cond (uS/cm)	NN (ug/L)	SRP (ug/L)	TDP (ug/L)	TP (ug/L)	TP Turb[2] (ug/L)	TP_C[3] (ug/L)	Turb (NTU)	Alk[4] ($mgCaCO_3$/L)	T (^{o}C)	Water Clarity[1]
Columbia River at Donald Station	24-Jun-04	8.06	160	63.2	2.7	10.7	43.0	25.5	17.5	19.20	83.0	11.5	B
Beaver River	4-Aug-04	7.53	76	62.6	2.3	5.2	21.3	7.2	14.1	4.20	32.0	9	-
Gold River	4-Aug-04	7.72	72	68.5	1.5	5.0	27.1	10.1	17.0	10.78	30.0	8	-
Bush Arm													
Bush River	4-Aug-04	8.16	143	99.0	1.6	5.2	29.4	14.5	14.9	7.64	82.0	8	-
Columbia Reach													
Windy Creek	4-Aug-04	7.29	49	104.8	2.3	5.5	47.4	50.1	-2.7	11.50	16.0	9	-
Sullivan River	4-Aug-04	8.13	110	61.3	1.4	4.2	31.5	59.6	-28.1	21.00	65.0	7.5-8	-
Kinbasket Creek	4-Aug-04	8.07	102	92.9	1.3	2.8	13.5	8.5	4.9	6.71	59.0	10	-
Cummins	4-Aug-04	7.72	69	52.0	1.8	6.3	27.9	18.6	9.2	7.13	36.0	11	-
Wood Arm													
Wood Creek	4-Aug-04	8.11	119	63.9	1.7	4.2	53.2	26.6	26.6	7.63	69.0	11	-
Canoe Reach													
Canoe River	4-Aug-04	6.65	29	39.1	0.8	2.4	29.9	10.6	19.4	13.00	12.8	10	-
Dave Henry Creek	4-Aug-04	7.30	79	39.9	1.4	1.5	3.6	<0.1	3.5	0.60	18.0	10	-
Ptarmigan Creek	4-Aug-04	7.23	77	84.1	1.6	1.6	5.1	1.2	3.9	0.93	17.0	11	-
Hugh Allan Creek	4-Aug-04	7.42	65	39.4	2.6	2.5	11.0	3.1	7.9	1.87	25.0	10.5-11	-
Foster Creek	4-Aug-04	7.06	40	59.1	1.4	3.4	47.0	15.5	31.4	16.90	11.0	9	B
Molson Creek	4-Aug-04	7.84	80	65.4	1.6	2.9	5.3	0.5	4.8	0.37	43.0	11	-

[1] B(rown), G(lacial), C(lear)

2 The color/turbidity correction for TP

3 TP corrected for color/turbidity: $TP_C = TP - TP_{Turb}$

4 Corrected alkalinity

Appendix 3.3.2 Tributaries to Revelstoke Reservoir sampled in 2008

Name	**Date Sampled**	**pH**	**Cond** (uS/cm)	**NN** (ug/L)	**SRP** (ug/L)	**TDP** (ug/L)	**TP** (ug/L)	**TP Turb**[2] (ug/L)	**TP_C**[2] (ug/L)	**Turb** (NTU)	**Alk**[4] ($mgCaCO_3/L$)	**T** (°C)	**Water Clarity**[1]
Upper													
Columbia River at Mica Outflow	23-Jun-04	7.80	108	114.0	2.9	5.8	8.7	0.9	7.8	0.74	52.0	7	-
Nagle Creek	23-Jun-04	6.50	16	146.3	5.6	9.6	27.5	2.7	24.8	0.59	6.5	6.5	-
Soards Creek	4-Aug-04	7.16	30	46.3	2.8	3.0	5.3	2.7	2.7	2.14	11.0	12	G
Mica Creek	23-Jun-04	6.94	39	107.1	2.0	4.2	8.4	1.2	7.2	0.38	14.2	6.5	-
Pitt Creek	23-Jun-04	7.25	32	44.7	3.1	7.2	6.9	0.5	6.4	0.16	14.0	7	-
Birch Creek	23-Jun-04	7.25	33	75.0	3.7	6.3	7.2	1.1	6.1	0.15	14.0	8	-
Bigmouth Creek	23-Jun-04	7.38	48	99.2	2.4	4.8	19.1	5.2	13.9	2.19	19.0	9.5	B/G
Bigmouth Creek	5-Aug-04	7.38	58	76.5	2.9	7.1	25.1	14.9	10.2	12.2	25.0	9.5	-
Scrip Creek	4-Aug-04	7.21	34	135.5	2.7	2.9	6.3	0.6	5.7	0.46	15.0	10.5	C
Horne Creek	4-Aug-04	7.23	35	144.9	1.5	2.6	9.2	1.1	8.1	0.82	16.0	11.5	C
Hoskins Creek	4-Aug-04	7.07	26	53.9	1.4	2.5	4.8	1.8	3.0	2.33	11.0	13	G
Goldstream River	23-Jun-04	7.73	75	1172.5	2.0	18.3	22.9	2.2	20.7	1.01	38.0	9.5	-
Goldstream River	4-Aug-04	7.69	78	71.8	2.1	0.0	20.8	7.5	13.3	2.71	41.0	13	-
Kirbyville Creek	4-Aug-04	7.56	47	40.6	1.4	2.3	4.4	0.7	3.7	0.81	25.0	14	C
Lower													
Downie Creek	23-Jun-04	7.92	106	140.5	2.2	8.7	34.6	4.1	30.5	1.10	56.0	9	-
Downie Creek	5-Aug-04	7.97	108	102.9	2.2	4.7	29.8	5.2	24.5	4.86	58.0	11.5	-
Bourne Creek	4-Aug-04	6.95	15	56.7	2.8	10.1	48.3	20.8	27.5	42.1	14.1	13	B
Big Eddy Creek	4-Aug-04	6.84	15	57.6	1.5	7.1	27.2	15.3	11.9	17.1	14.5	10.5	G
Carnes Creek	24-Jun-04	7.22	40	2.2	2.0	4.2	6.1	1.1	5.0	0.18	20.0	8	C
Carnes Creek	5-Aug-04	7.64	67	3.8	2.4	4.5	3.4	<0.1	3.3	0.25	32.0	13.5	-
Martha Creek	24-Jun-04	6.93	16	6.8	2.4	5.8	9.2	0.4	8.8	0.17	17.7	8	-
Columbia River above Jordan	24-Jun-04	7.94	118	144.3	2.7	6.7	8.2	1.0	7.2	0.16	50.0	10	-

[1] B(rown), G(lacial), C(lear)

2 The color/turbidity correction for TP

3 TP corrected for color/turbidity: $TP_C=TP-TP_{Turb}$

4 Corrected Alkalinity

Appendix 3.3.3 Tributaries to Kinbasket Reservoir sampled in 2009

Site	Date	pH	Cond (uhoms)	NN (ug/L)	SRP (ug/L)	TDP (ug/L)	TP (ug/L)	TP Turb (ug/L)	TP_c[1] (ug/L)	Turb (NTU)	Alk [2] (mgCaCO$_3$/L)	T (°C)	Water Clarity[1]
Columbia River at Donald*	7-Jul-09	7.83	130	51.8	3.5	7.2	25.4	5.8	19.6	19.2	77	15	TB/W
Gold River	8-Jul-09	7.28	53	68.5	1.4	5	51.1	7.5	43.6	13.4	27.9	7	TG
Bush Arm													
Bush River	8-Jul-09	7.86	121	105.9	1.4	7.5	90.9	34.7	56.2	95.9	82	6.5	TG/W
Prattle Creek	8-Jul-09	7.89	118	87.7	1.7	4.2	55.8	26.4	29.4	60.3	92	6	TG
Chatter Creek	8-Jul-09	7.66	78	24.8	2.3	5.9	6.9	0.2	6.7	0.43	51.5	6.5	C
Columbia Reach													
Windy Creek	8-Jul-09	7.03	35	112.9	1.7	4.5	129.6	14.1	115.5	17.2	15	6	TG
Sullivan River	8-Jul-09	7.85	99	64.7	1	3.1	101.1	47	54.1	71.8	82.5	6.5	G/W/Gr
Kinbasket River	8-Jul-09	7.79	85	89.5	0.7	8.8	26.8	7	19.8	29.2	57.8	7	TGr / G
Cummins River	8-Jul-09	7.36	52	51.5	1.5	4.7	15.6	6.1	9.5	12.4	35.7	8	TG / Gr
Wood Arm													
Wood River	8-Jul-09	7.91	94	66	0.9	3	123.9	61.9	62	44.4	76.5	7.5-8	VTMG
Canoe Reach													
Canoe River	8-Jul-09	6.97	38	46.9	1	3.9	15.5	5	10.5	6.53	15.5	7	-
Dave Henry Creek	8-Jul-09	6.94	42	33	0.9	2.5	6.7	0.8	5.9	2.58	12.4	7	CLT
Yellowjacket Creek	8-Jul-09	6.8	33	44.8	0.9	1.6	17.5	2.4	15.1	1.38	15.2	7	C
Bulldog Creek	8-Jul-09	6.58	24	95.5	0.7	5	8	<0.1	8	1.12	9.5	6.5	C
Ptarmigan Creek	8-Jul-09	6.89	45	73.5	1.1	1.6	4.5	0.9	3.6	5.17	12	7	CLT
Hugh Allan Creek	8-Jul-09	7.02	37	41.3	1	2.8	9.5	0.5	9	0.82	15.7	7	CLT
Foster Creek	8-Jul-09	6.91	36	87.5	1.1	3.5	39.4	3.4	36	16.9	14	6.5	TG
Dawson Creek	8-Jul-09	7.34	53	57	0.9	4	5.8	0.1	5.7	1.17	35.4	6.5	C
Molson Creek	8-Jul-09	7.34	51	52.2	2.5	2.6	4	<0.1	4	0.8	33.2	6.5	C

*Reference tributary, additional data in Table A3-5

[1] (G)rey, (W)hite, (Gr)een, (C)lear, Turbid Brown (TB), Turbid Grey (TG), Turbid Milky (TM), Turbid Green (TGr), Clear Lightly Turbid (CLT), Very Turbid Milky Grey (VTMG)

[2] TP corrected for color and turbidity, $TP_c = TP – TP Turb$

[3] Corrected alkalinity

Appendix 3.3.4 Tributaries to Revelstoke Reservoir sampled in 2009

Site	Date	pH	Cond (uhoms)	NN (ug/L)	SRP (ug/L)	TDP (ug/L)	TP (ug/L)	TP Turb (ug/L)	TP$_c$[2] (ug/L)	Turb (NTU)	Alk[3] (mgCaCO$_3$/L)	T (°C)	Water Clarity[1]
Upper													
Columbia River at Mica Outflow*	8-Jul-09	7.37	72	95.1	1.5	3.5	5.7	<0.1	5.7	0.42	44	-	-
Nagle Creek	8-Jul-09	6.39	12	99.2	1	2.7	3.8	1.1	2.7	2.69	6.7	7	C
Soards Creek	8-Jul-09	6.34	12	100.1	1.3	2	3.5	1	2.5	1.68	6.1	6.5	C
Mica Creek	8-Jul-09	6.74	38	92.9	2.6	3.4	10	5.4	4.6	6.83	17.8	7.5	TM
Pitt Creek	8-Jul-09	6.99	32	39.3	1.9	3.8	2.9	<0.1	2.9	0.84	16.8	8	C
Birch Creek	8-Jul-09	6.99	31	68.5	2.3	5.2	6.7	<0.1	6.7	0.55	17	8	C
Bigmouth Creek	8-Jul-09	7.06	42	79.7	3.1	8.6	25.9	4.2	21.7	24.8	23	7.5	TM
Scrip Creek	8-Jul-09	6.97	24	133.8	5.7	13	4.8	0.7	4.1	0.56	14.4	6	C
Horne Creek	8-Jul-09	6.97	22	146.4	1.8	3.5	12.1	0.1	12	0.65	14.2	6	C
Hoskins Creek	8-Jul-09	6.78	17	65.4	1	3.3	6.5	0.2	6.3	2.86	17.2	6	C/A
Goldstream River*	8-Jul-09	7.31	56	81.2	0.9	3.8	13.1	1.6	11.5	4.11	37.5	8	C
Kirbyville Creek	8-Jul-09	7.09	27	39.4	1	2.4	12.9	<0.1	12.9	0.85	20	7.5-8	C
Lower													
Downie Creek	7-Jul-09	7.66	83	93.2	1.7	5.2	27.8	2	25.8	8.38	52	8	TM
Bourne Creek	8-Jul-09	6.67	10	71.5	1.8	8.1	77.6	60.9	16.7	49.6	12.5	6.5	TG
Big Eddy Creek	8-Jul-09	6.69	11	84.9	2.7	10.2	78.1	28.7	49.4	67.6	15.1	6.3	TG
Carnes Creek	7-Jul-09	7.08	39	3	1.7	6.7	5.6	<0.1	5.6	1.36	23.5	10.5	C
Martha Creek	7-Jul-09	6.92	16	1.6	2	3.8	2.9	<0.1	2.9	0.14	12	10	C
Columbia River above Jordan*	7-Jul-09	7.57	94	134.9	1.6	4.8	5.2	<0.1	5.2	0.63	58.4	7	C

* Reference tributary, additional data in Table A3-5

[1] Turbid Milky (TM), Turbid Grey (TG), Clear (C), Clear/Algae (C/A)

[2] TP corrected for color and turbidity, TP$_c$ = TP – TP Turb

[3] Corrected alkalinity

Appendix 3.3.5 Tributaries to Kinbasket Reservoir sampled in 2013

Name	Date Sampled	pH	Cond (uS/cm)	Nitrate/Nitrite (ug/L)	SRP (ug/L)	TDP (ug/L)	TP (ug/L)	Turb (NTU)	Alk (mgCaCO$_3$/L)	T (°C)	Water Clarity[1]
Columbia River at Donald Station	09-May-13	8.22	258	226	2.2	<2.0	14.4	45.2	114.0	10.0	B
Beaver River	06-May-13	7.87	108	533	1.9	2.1	217	62.6	44.9	4.0	B
Waitabit Creek	06-May-13	8.30	269	433	1.9	<2.0	17.5	47.3	130.0	4.5	GrG
Bluewater Creek	06-May-13	8.34	272	362	3.9	2.1	26.2	46.5	135.0	4.5	GrG
Quartz Creek	06-May-13	8.24	249	186	4.6	2.3	88.9	47.1	110.0	3.5	Gr
Gold River	06-May-13	7.90	114	595	1.9	2.8	380	73.2	44.5	4.5	Gr
Bush Arm											
Bush River	06-May-13	8.28	258	403	2.7	<2.0	18.9	29.2	117.0	6.0	GrGBl
Prattle Creek	06-May-13	8.29	259	436	2.2	<2.0	21.3	98.2	120.0	4.5	GGr
Chatter Creek	06-May-13	8.14	183	340	2.3	2.5	13.1	11.2	91.9	5.0	GBGr
Succour Creek	06-May-13	8.37	296	18	1.9	2.5	5.8	3.8	156.0	9.0	C/B
Columbia Reach											
Windy Creek	06-May-13	7.50	63.3	690	2.7	2.3	1120	31.2	16.9	5.0	BSa
Sullivan River	06-May-13	8.20	230	256	2.4	2.3	1650	1830.0	103.0	6.0	GrB
Kinbasket River	06-May-13	8.09	157	516	4.6	<2.0	9.8	15.2	68.3	5.0	GrB
Cummins Creek	06-May-13	7.78	86.5	279	4.0	3.3	148	29.5	38.2	6.5	B
Wood Arm											
Wood River	06-May-13	8.11	180	440	2.3	2.0	517	125.0	83.4	6.0	GrWB
Canoe Reach											
Canoe River	06-May-13	7.58	64.3	334	5.4	3.3	45.3	20.6	26.4	7.0	B
Dave Henry Creek	06-May-13	7.68	88.3	405	1.9	2.2	16.1	5.2	28.6	5.0	C
Yellowjacket Creek	06-May-13	7.35	54.5	310	2.3	2.4	31.3	5.5	12.7	7.0	CSa
Bulldog Creek	06-May-13	7.13	36.1	929	2.3	<2.0	66.3	4.4	7.5	6.0	C
Ptarmigan Creek	06-May-13	7.51	70.5	683	2.6	3.4	37.1	7.8	16.7	6.5	BSaSi
Hugh Allen Creek	06-May-13	7.60	80	390	3.6	3.7	213	90.5	26.8	8.5	DBSa
Foster Creek	06-May-13	7.53	82.1	812	3.8	4.4	1210	126.0	27.7	7.0	DBSa
Dawson Creek	06-May-13	7.92	107	865	1.8	2.6	122	6.8	46.3	5.0	B/C
Molson Creek	06-May-13	7.84	91.5	850	1.4	2.3	4.6	1.1	40.7	4.5	C

[1] (B)rown, (Bl)uish, (C)lear, (D)ark, (G)reen, (Gr)ey, (Sa)ndy, (Si)lty, (W)hite

Appendix 3.3.6 Tributaries of Revelstoke Reservoir sampled in 2013

Name	**Date Sampled**	**pH**	**Cond** (uS/cm)	**Nitrate/Nitrite** (ug/L)	**SRP** (ug/L)	**TDP** (ug/L)	**TP** (ug/L)	**Turb** (NTU)	**Alk** (mgCaCO$_3$/L)	**T** (°C)	**Water Clarity**[1]
Upper											
Columbia River at Mica Outflow	08-May-13	7.77	95.9	294	1.8	2.1	6.1	2.03	40.2	4	LB
Nagle Creek	8-May-13	6.66	21.8	584	2.1	3.1	10.3	3.32	4.01	3	LB
Soards Creek	7-May-13	7.18	31.7	650	3.3	2.1	13.1	5.15	8.38	3	C
Mica Creek	8-May-13	6.95	38.6	472	4	3.8	14.2	6.45	6.38	3.5	B
Pat Creek	7-May-13	7.37	37.5	625	2.7	2.7	19.7	4.93	13	3.5	C
Pitt Creek	8-May-13	7.25	35.5	350	1.5	2.3	4.6	1.45	12.5	3	C
Birch Creek	8-May-13	7.24	41.5	448	2.4	3.2	11.5	2.81	12.8	4	VLB
Big Mouth Creek	7-May-13	7.57	59.5	553	1.6	2.8	57.4	10.9	22	4	B
Scrip Creek	7-May-13	7.35	37.8	598	2.7	<2.0	14.5	2.81	13.7	3	C
Horne Creek	7-May-13	7.45	41.7	628	2.1	2.6	16.5	4.73	14.6	3	C
Hoskins Creek	7-May-13	7.33	36.7	392	1.9	2.2	12.6	3.59	11.9	4	C
Goldstream	08-May-13	7.78	89.7	564	1.7	3.3	78.7	35.3	37.5	4.5	B
Kirbyville Creek	7-May-13	7.71	66.7	265	4.1	2.2	33.5	9.23	30.4	3.5	C
Lower											
Downie Creek	8-May-13	7.62	133	586	4.9	2.4	49.7	11.3	60.7	5	LB
Bourne Creek	7-May-13	7.27	32.6	445	2	2.3	19.1	3.77	11.9	4	C/B
Big Eddy Creek	7-May-13	7.38	41.5	882	3.2	3.2	39.6	24.6	14.9	4	B
Carnes Creek	8-May-13	7.52	57.7	42	2	2.7	5.6	2.47	24.7	6	C
Martha Creek	8-May-13	7.21	22.6	124	1.8	3.4	6.4	1.39	8.92	4.5	LG
Columbia River Above Jordan	08-May-13	7.88	149	110	<1.0	<2.0	2.1	0.18	64.1	6	C

[1] (B)rown, (C)lear, (L)ight, (G)reen, (V)ery

Appendix 3

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2013

Roger Pieters and Greg Lawrence
University of British Columbia

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2013

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

[1] Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C. V6T 1Z4
[2] Civil Engineering, University of British Columbia, Vancouver, B.C. V6T 1Z4

Revelstoke Reservoir, 26 August 2013

Prepared for

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

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Contents

List of Figures

1. Introduction

We report on CTD (conductivity-temperature-depth) profiles collected from Kinbasket and Revelstoke Reservoirs in 2013. This is the sixth 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 2013, sampling was conducted in both reservoirs monthly from April to September. A list of the profiles collected in 2013 is given in Appendix 2, and a summary is given in Tables 2.1 and 2.2. The profiler was tested in the Revelstoke forebay on 17 April 2013. Intensive CTD surveys were collected on 1-2 May in Kinbasket Reservoir, and on 29-30 April, 10 July and 26 August in Revelstoke Reservoir.

Additional casts were collected during measurement of primary production, 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 From 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 3. 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.

In 2012 and 2013, the minimum conductivity frequency was correctly set to zero. In 2012 casts were collected to evaluate the effect of having the pump turned off. For casts with the pump on and off, the temperature and conductivity data were very similar. However, having the pump off did affect the dissolved oxygen readings, and as a result the oxygen data for 2009-2011, other than confirming generally oxygenated conditions, were not accurate. The data for light transmission and fluorescence (Chl a) are independent of the pump. For further detail see Pieters and Lawrence (2014a).

Early descent After the Seabird is turned on:

- it is hung in the air for 60 sec,
- it is lowered into the water to soak for 90 sec, and
- at 150 sec from the start, the Seabird was lowered, beginning the descent.

The pump comes on half way through the soak at 105 sec (420 scans). However, in 2013, the descent was erroneously begun at 90 sec from the start, earlier than in previous years. As a result, the pump did not turn on until the Seabird was at a depth of 4-6 m. The data before the pump turned on was removed from the plots, and as a result most plots begin at 4-6 m depth. As observed in past years, the top 5 m is often relatively uniform, not unexpected given wind mixing in these large reservoirs.

Table 2.1 Kinbasket surveys, 2013

Date	FB		MI	CO	CA	WO
	K1	K1.5	K2	K3	Kca1	Kwo1
22-23 April	✓		✓	✓	✓	✓
1-2 May	✓	✓	✓+3	✓+3	✓+1	✓+3
13-14 May	✓		✓	✓	✓	✓
10-11 June	✓		✓	✓	✓	✓
19 June		✓*				
15-16 July	✓		✓	✓	✓	✓
24 July		✓*				
12-13 August	✓		✓	✓	✓	✓
21 August		✓*				
19 September		✓*				

* Collected during measurement of primary production (see Appendix 4)

Table 2.2 Revelstoke surveys, 2013

Date	FB	MI	UP	Downie Arm	
				D0	D1
17 April	✓+1				
29-30 April	✓+5	✓+3	✓		
21-22 May	✓	✓	✓		
17-18 June	✓	✓	✓	✓	✓
20-21 June	✓*	✓*			
10 July	✓+5	✓+3	✓	✓	
22-23 July	✓*	✓	✓	✓	✓
25 July		✓*			
19-20 August	✓*	✓	✓	✓	✓
22 August		✓*			
26 August	✓+5	✓+3	✓		
17-18 September	✓*	✓*	✓	✓	✓

* Primary production (see Appendix 4)

3. Results

We first look at the water levels and flows during 2013, shown in Figure A2. In Kinbasket Reservoir the surveys began in April, right at the minimum water level, and end in September, after the maximum water level (Figure A2a). Note the water level rose very high in 2013, reaching slightly above normal full pool (754.4 m ASL) in mid-September (Figure A2a inset). The center of the outlet from Kinbasket Reservoir is located 64.6 m below normal full pool. In Revelstoke Reservoir there is normally little variation in water level (< 1.3 m), but in 2013 the water level experienced three 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. 2016b). This seasonal change in the conductivity of the inflow will assist in identifying water masses as discussed below.

3.1 Kinbasket Reservoir

April 2013 Line plots for the six surveys of Kinbasket Reservoir are shown in Figures B1-6. In April 2013, there was little temperature stratification with temperature ranging from 3 to 5 ºC (Figure B1b). During this time, the outlet from Kinbasket Reservoir was 33 m below the surface, as marked in Figure B1.

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 was the Columbia reach, K3co, which had a higher conductivity of 210-250 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 B1c to B6c) and relatively unchanged (Figure B9c) throughout the summer. In Canoe Reach, slightly reduced conductivity around 20 m suggests low-conductivity inflow (green, Figure B1c).

Throughout the reservoir, the water was quite clear in April, as indicated by high light transmission (Figure B1d). Dissolved oxygen was high (>10 mg/L) throughout the reservoir (Figure B1e). The nominal concentration of chlorophyll was very low (< 0.8 ug/L) and confined to the top 30 m (Figure B1g). The 1% light level determined from PAR is marked with dashed lines; the 1% light level varied from 18 to 25 m.

May 2013 During the intensive survey of May 2013, the reservoir remained relatively unstratified, with slightly increased temperatures (to 8 ºC) seen only in Wood Arm and far up the Columbia Reach (Figure B2c). By 13-14 May the reservoir had begun to stratify with surface temperature at some locations reaching 10 ºC (Figure B3c). In both cases, layers of turbid inflow are observed (Figures B2d and B3d)

.

June 2013 In June, surface temperature varied from 5 to 12 ºC (Figure B4b), showing the beginnings of a broad thermocline extending from the surface to 40 m depth. In conductivity, the most notable feature is the decline in the conductivity in the top 60 m (black, Figure B4c). In June, there were layers of very high turbidity (low light transmission) in Wood Arm (blue), Canoe Reach (green) and the Columbia Reach (black, Figure B4d).

July 2013 In July, surface temperature varied from 13 to 15 ºC (Figure B5b). As in June, there was a broad thermocline, now extending from the surface to 60 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, compare Figure B4c and Figure B5c).

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 B5d). Oxygen remained high (Figure B5e,f).

In July, the chlorophyll layer around 10 m was slightly reduced from that observed in June (compare Figures B4g and B5g). The high readings in Wood Arm should be ignored (cyan, Figure B5g); these readings occur at 30 to 50m depth, well below the photic zone (15 m), in a region of high turbidity and do not represent biological activity. A similar peak occurs in Wood Arm in August (Figure B6g).

August 2013 The temperature at the surface warmed to ~20 ºC at all stations, and the broad thermocline extended to about 60 m (Figure B6b). The overall conductivity of the surface layer continued to decline (Figure B6c). 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 B6d).

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 (e.g. Figure B6e). To remove the effect of temperature, dissolved oxygen is also plotted as percent saturation in Figure B6f. 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.

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 C1-6. 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.

After the reservoir stratified, the surface layer depth and temperature were relatively uniform along the reservoir during each survey (Figure C3a to C6a). As the summer progresses, a distinct layer of low conductivity appears in the top 60 m (Figures C1b to C6b). The conductivity is lowest in Canoe Reach (e.g. Figure C2b). Light transmission was generally high (turbidity low) in the deep water (Figures C1c to C6c), with the exception of the Canoe Reach in early May (Figure C2c). Lenses of turbidity can be observed in the thermocline at different times and locations along the reservoir. Oxygen is generally high (Figures C1-6d). Chlorophyll is generally low, with peaks well below 2 μg/L in the top 20 m, just above the 1% light level (marked by black bars).

3.2 Revelstoke Reservoir

April to June 2013 In April, Revelstoke Reservoir was unstratified with relatively uniform temperature between 4 and 6 °C (Figure D1a). The conductivity was also relatively uniform (150 µS/cm), light transmission and dissolved oxygen were both uniform and high, and chlorophyll levels were low (Figure D1).

Thermal stratification was observed in late May, with surface temperature reaching 10 °C (Figure D2b). The conductivity in the upper reaches of the reservoir had declined (Figure D2c). There were decreases in light transmission (increases in turbidity) consistent with freshet inflow (Figure D2d). In addition, there was a shallow peak in chlorophyll suggesting an increase in biological activity (Figure D2g).

In June, thermal stratification continued to develop with surface temperature reaching 12 °C (Figure D3b). The conductivity of the top 50 m of the reservoir continued to decline due to freshet inflow (Figure D3c) with corresponding layers of turbidity (Figure D3d). Chlorophyll fluorescence had small peaks just over 1 µg/L above the depth of the one percent light level (Figure D3g).

July to October 2013 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 (e.g. Figure D9c).

From mid-July to October, changes in the reservoir are then dominated by the inflow from Mica, which increased from < 50 m^3/s in June and early July to > 500 m^3/s from mid-July to mid-October; this inflow is both cool and higher in conductivity that the surface of Revelstoke Reservoir. In the 22-25 July profiles, the effect of the Kinbasket inflow can be seen at the bottom of upper station, R3up, which is 9 °C and 120 µS/cm (black, Figure D5b,c). This cool water plunges and forms an interflow which can be seen clearly in the high conductivity layer centered at 40 m in August, strongest at the upper station but reaching right along the reservoir to Revelstoke forebay (Figures E6b and E7b). The interflow continued around the level of the outlet, 30 m, into September (Figure E8b). From data in previous years, this interflow persisted until October, when surface cooling began to mix the surface layer down into the interflow.

Comparison of casts in the forebay (Figure D9) 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 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 2001), including the problem of decomposing allochthonous debris. The declines in hypolimnetic oxygen over the summer in Kinbasket and Revelstoke Reservoirs are consistent with oligotrophy, and are comparable to those observed in oligotrophic 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 to 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 (Figure A2c). 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, in Revelstoke Reservoir, this water forms an interflow directly to the outlet at Revelstoke Dam (e.g. Figure E7b). This interflow appears to be below the photic zone (Figure E7e). If this occurs, nutrients from Mica will short circuit below the photic zone until fall cooling mixes the interflow into the surface layer later in October. However, profiler data from mid-September to mid-October 2012 showed that internal wave motions can bring the interflow into the photic zone for significant periods of time (Pieters and Lawrence 2014c).

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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, 2013

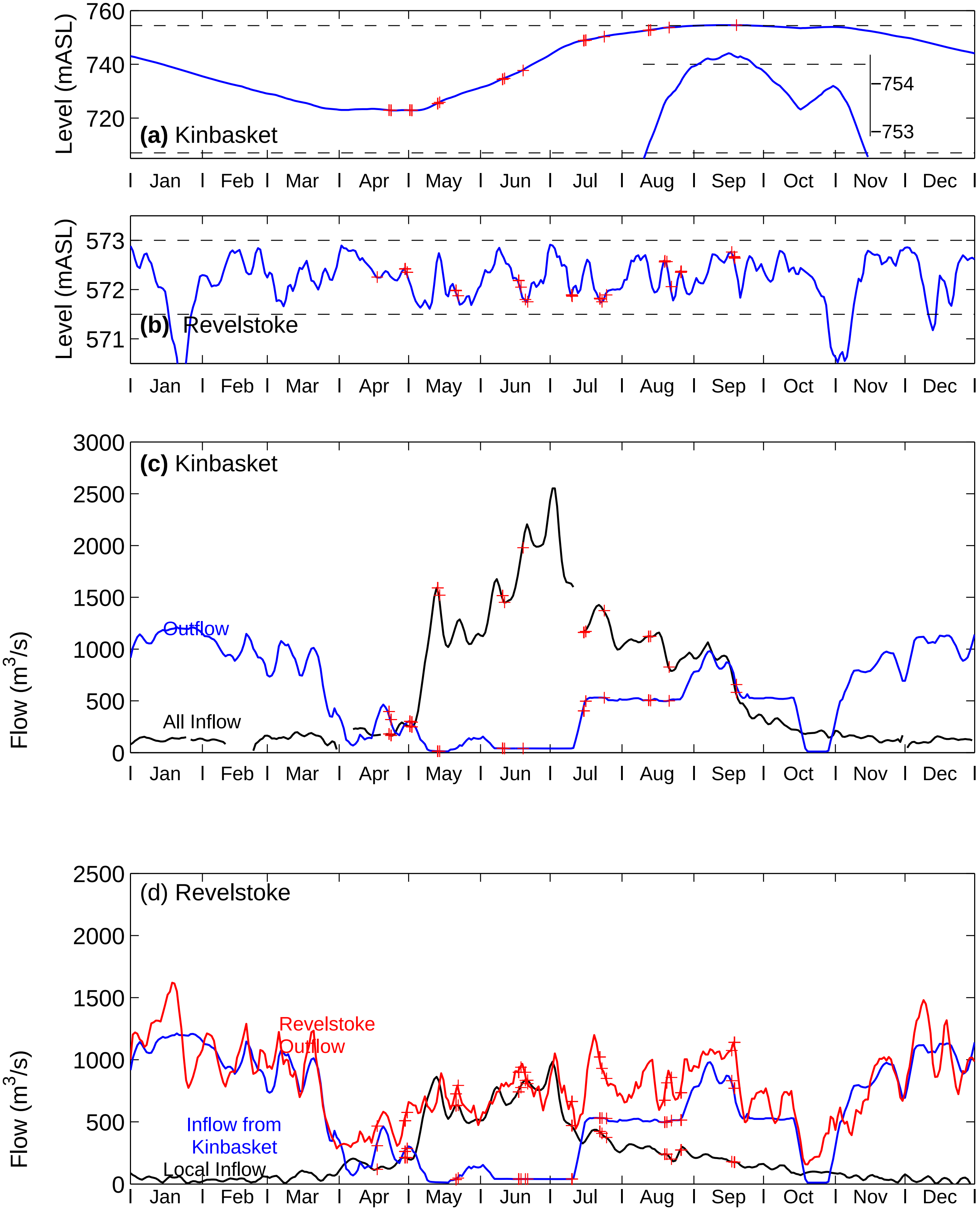
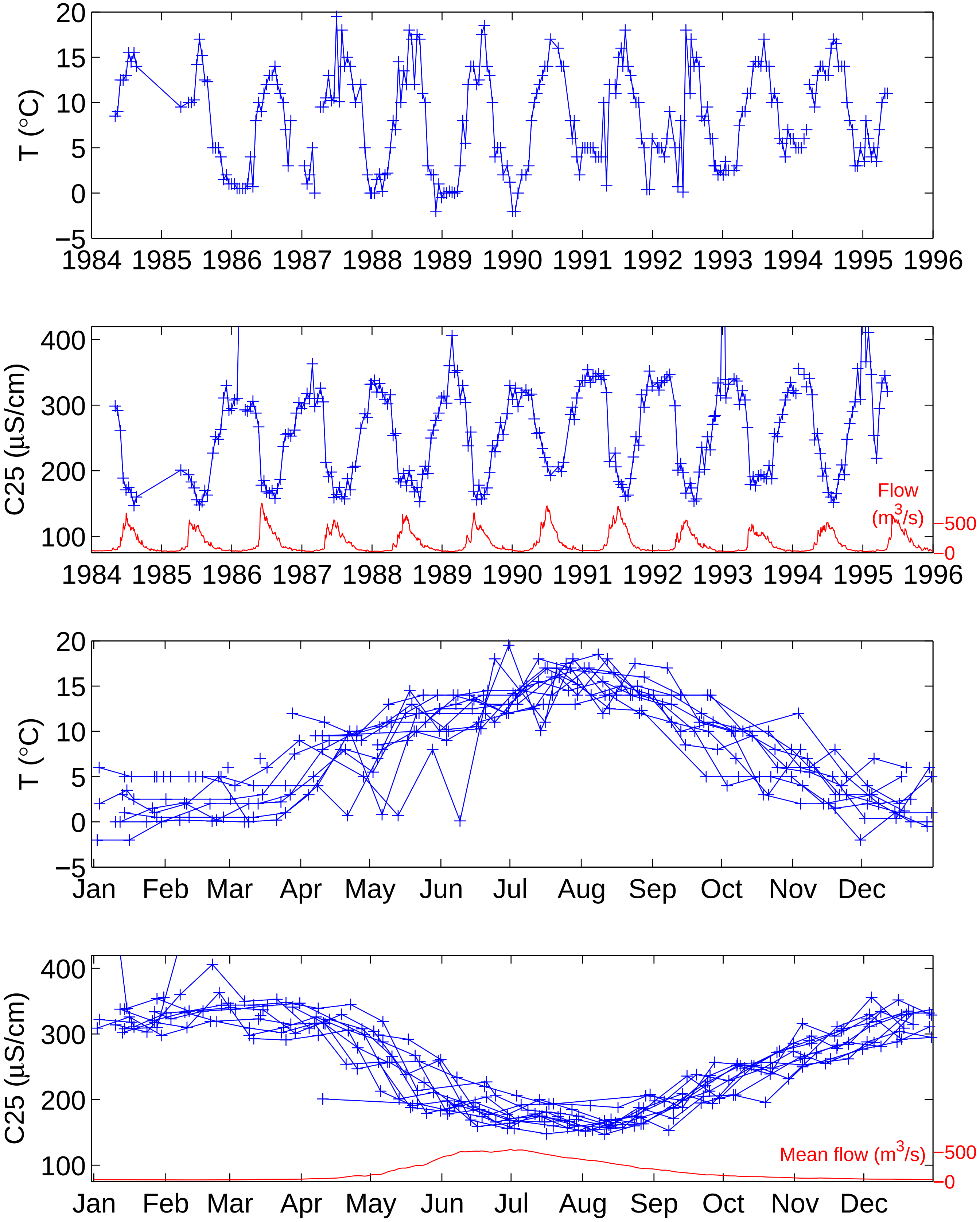


Figure A3 Columbia River at Donald, T and C25, 1984−1995



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

Figure A4 1% Light Level = 2.5 X Secchi Depth

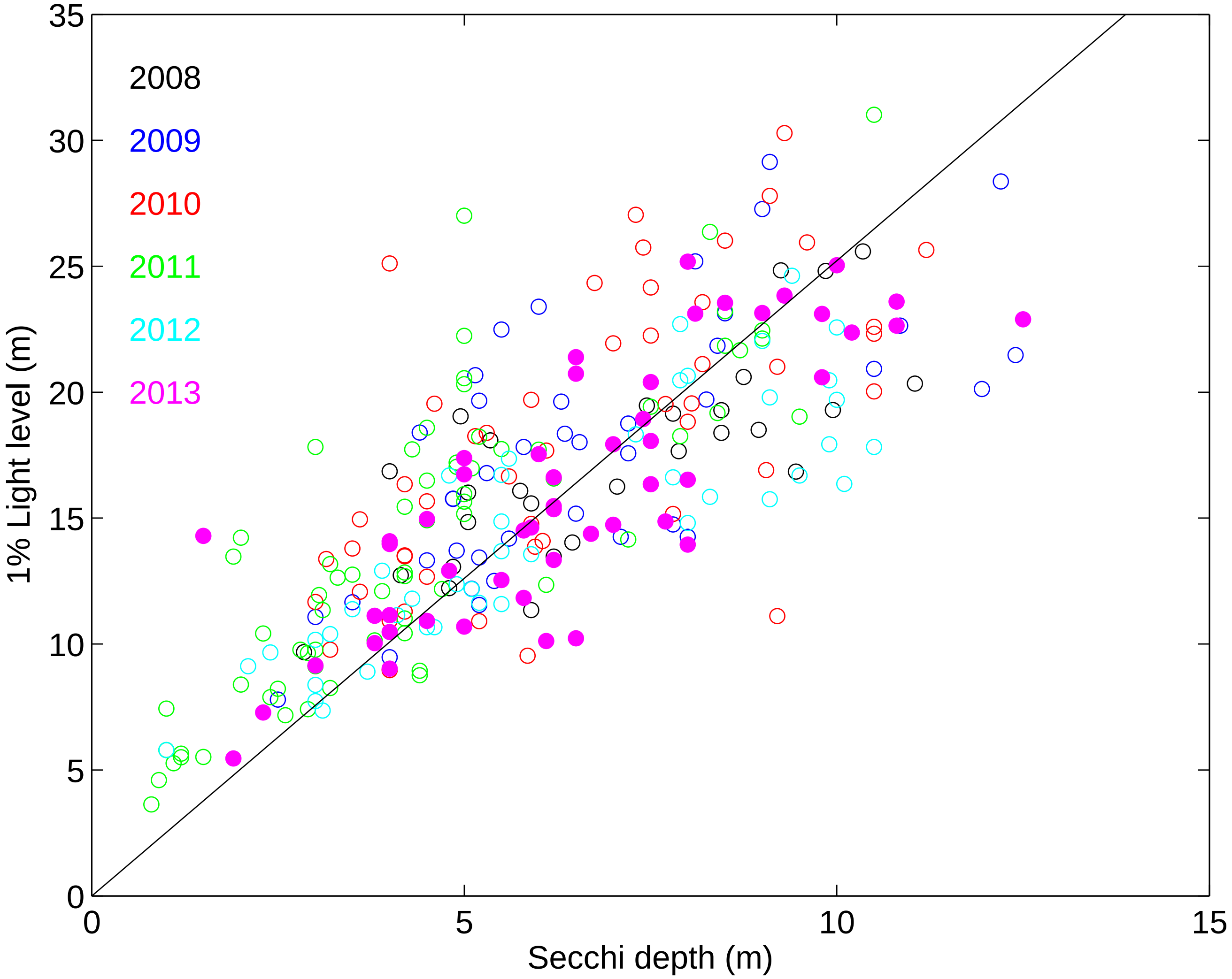


Figure B1 Kinbasket Reservoir, 22−23 Apr 2013

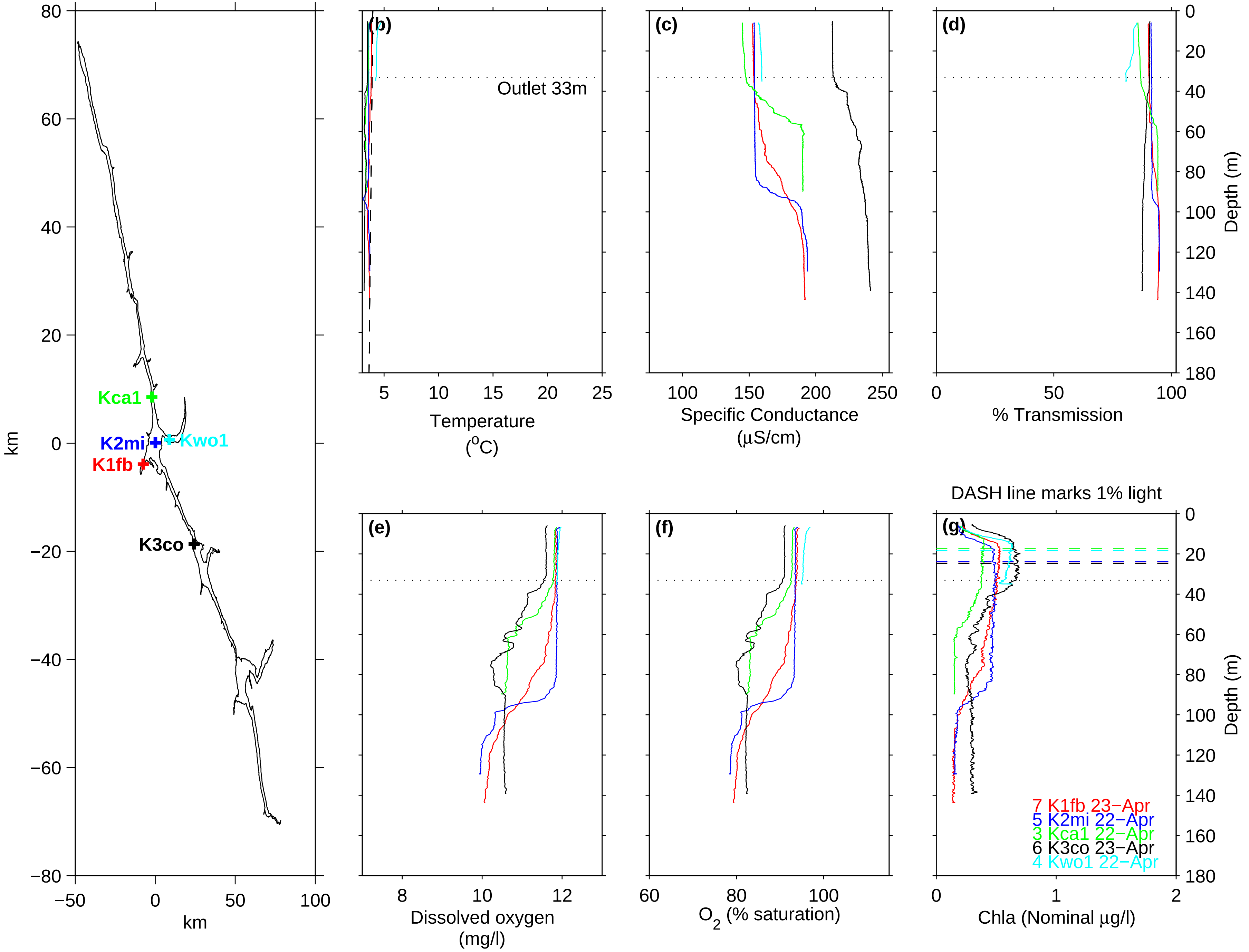


Figure B2 Kinbasket Reservoir, 1−2 May 2013

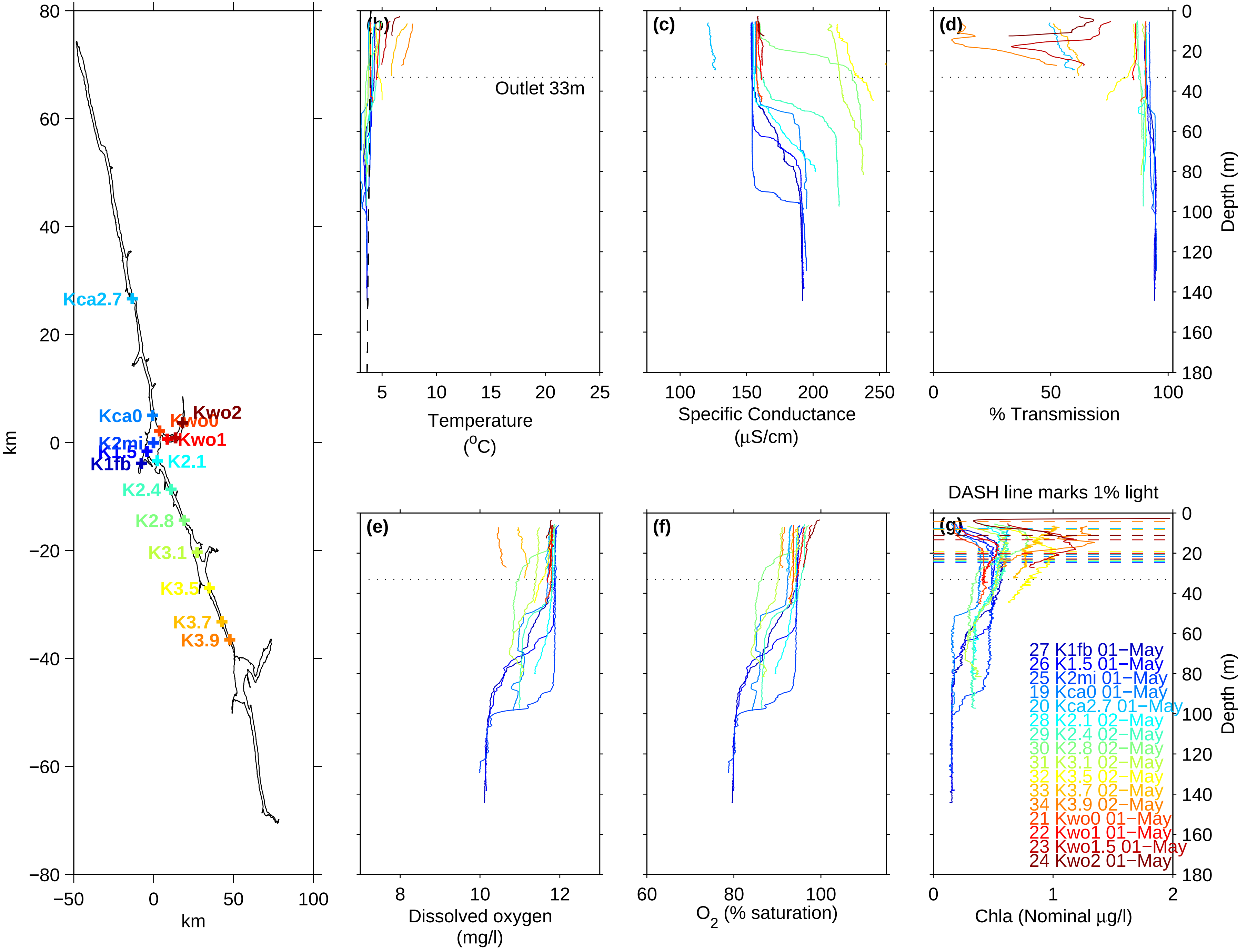


Figure B3 Kinbasket Reservoir, 13−14 May 2013

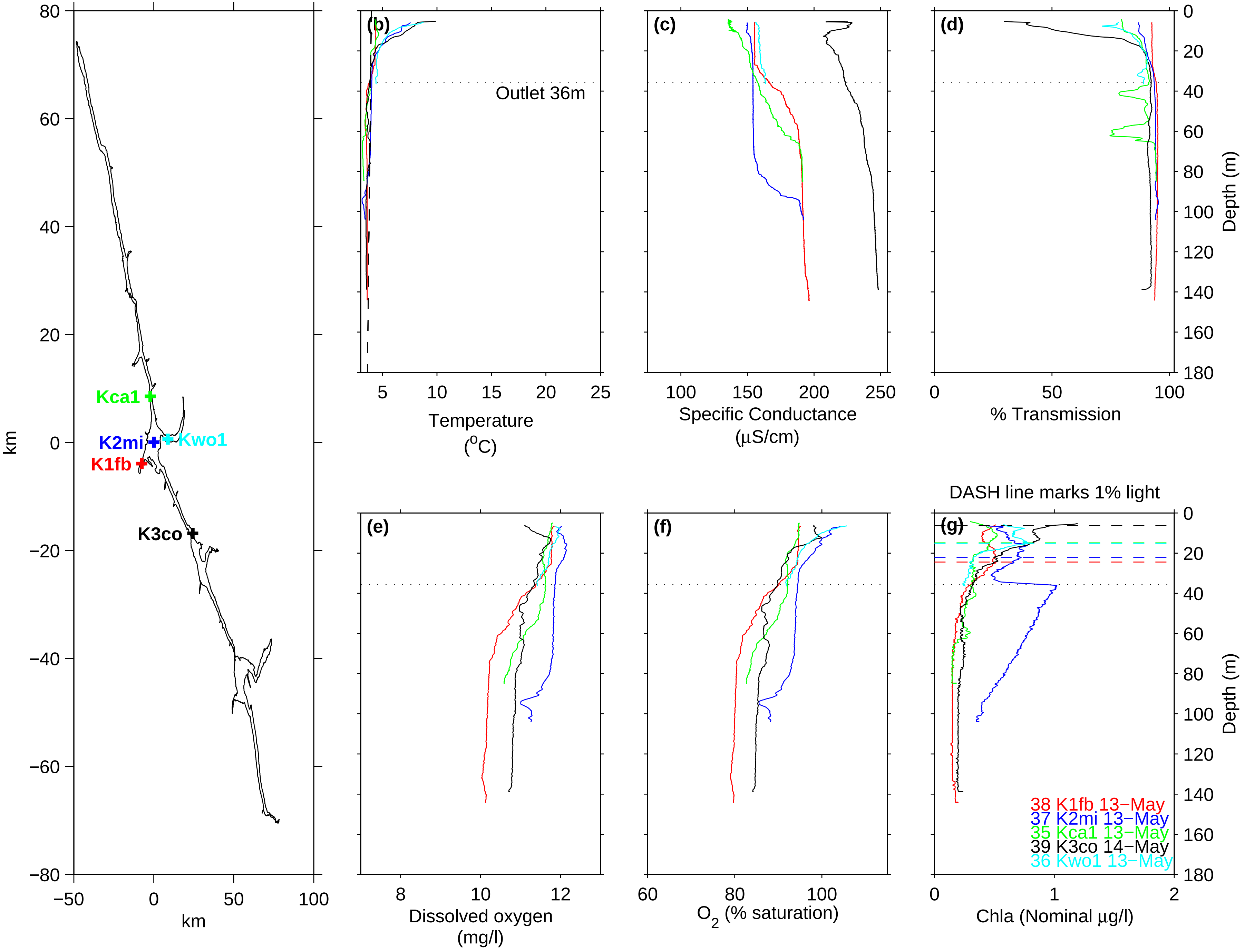


Figure B4 Kinbasket Reservoir, 10−11 Jun 2013

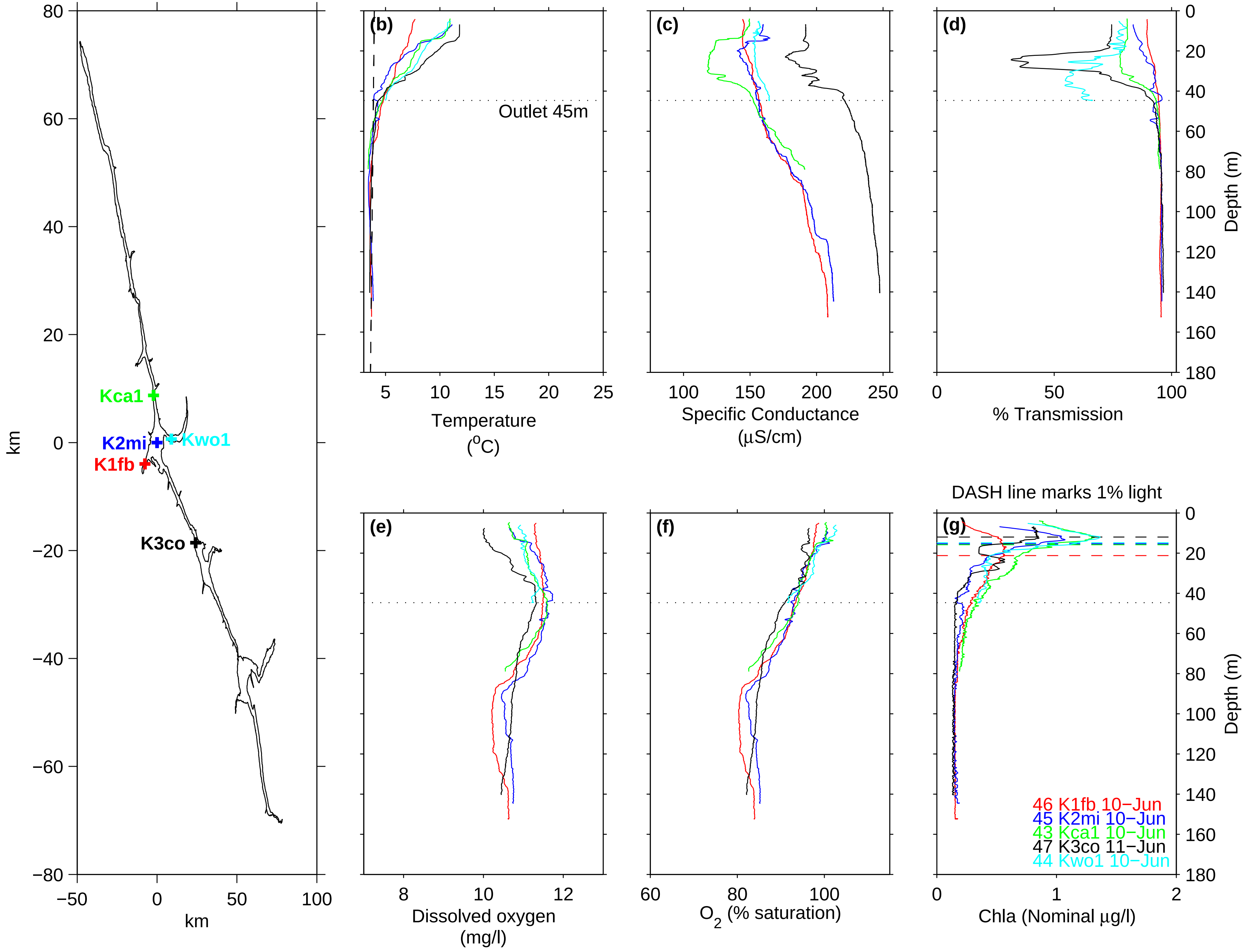


Figure B5 Kinbasket Reservoir, 15−16 Jul 2013

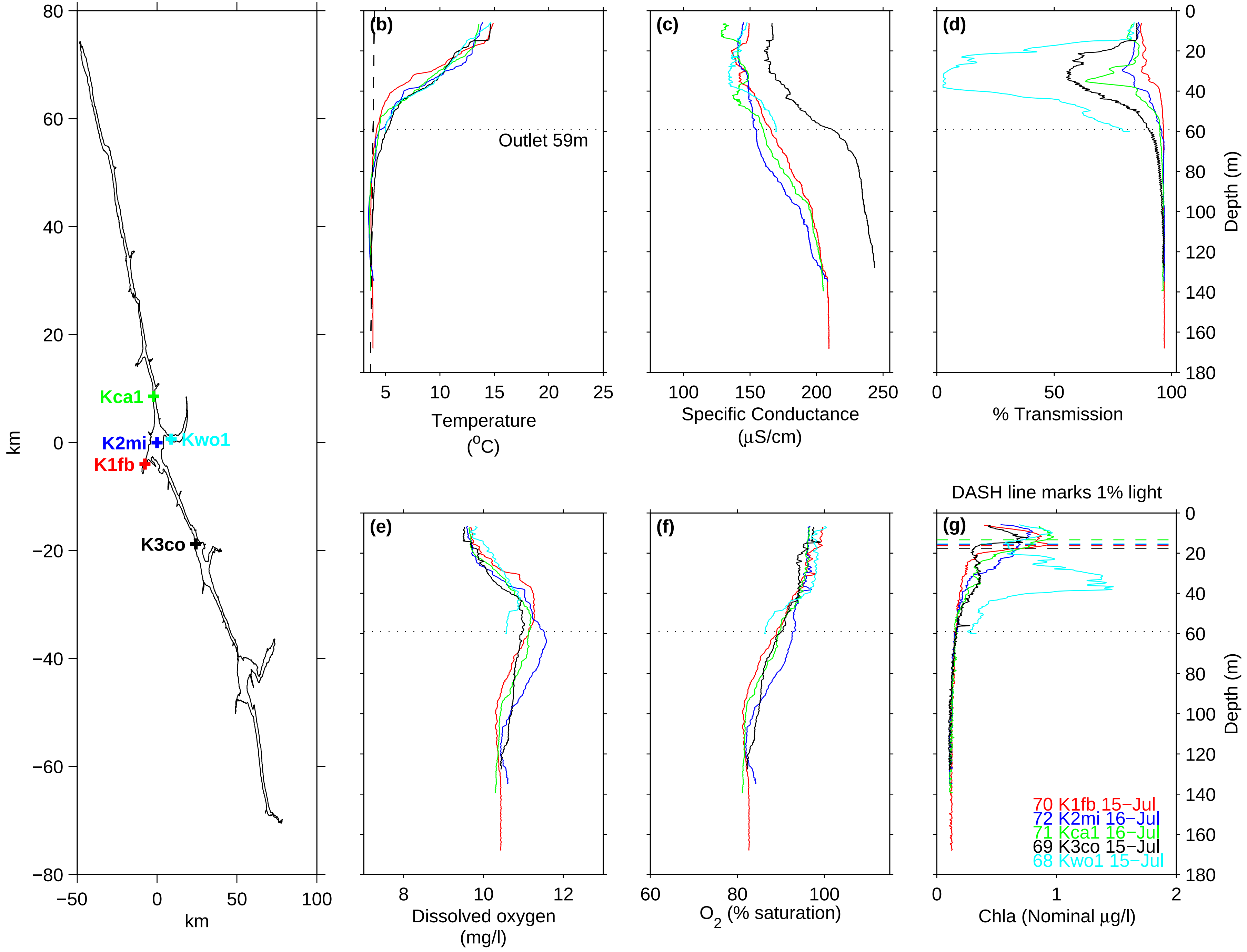


Figure B6 Kinbasket Reservoir, 12−13 Aug 2013

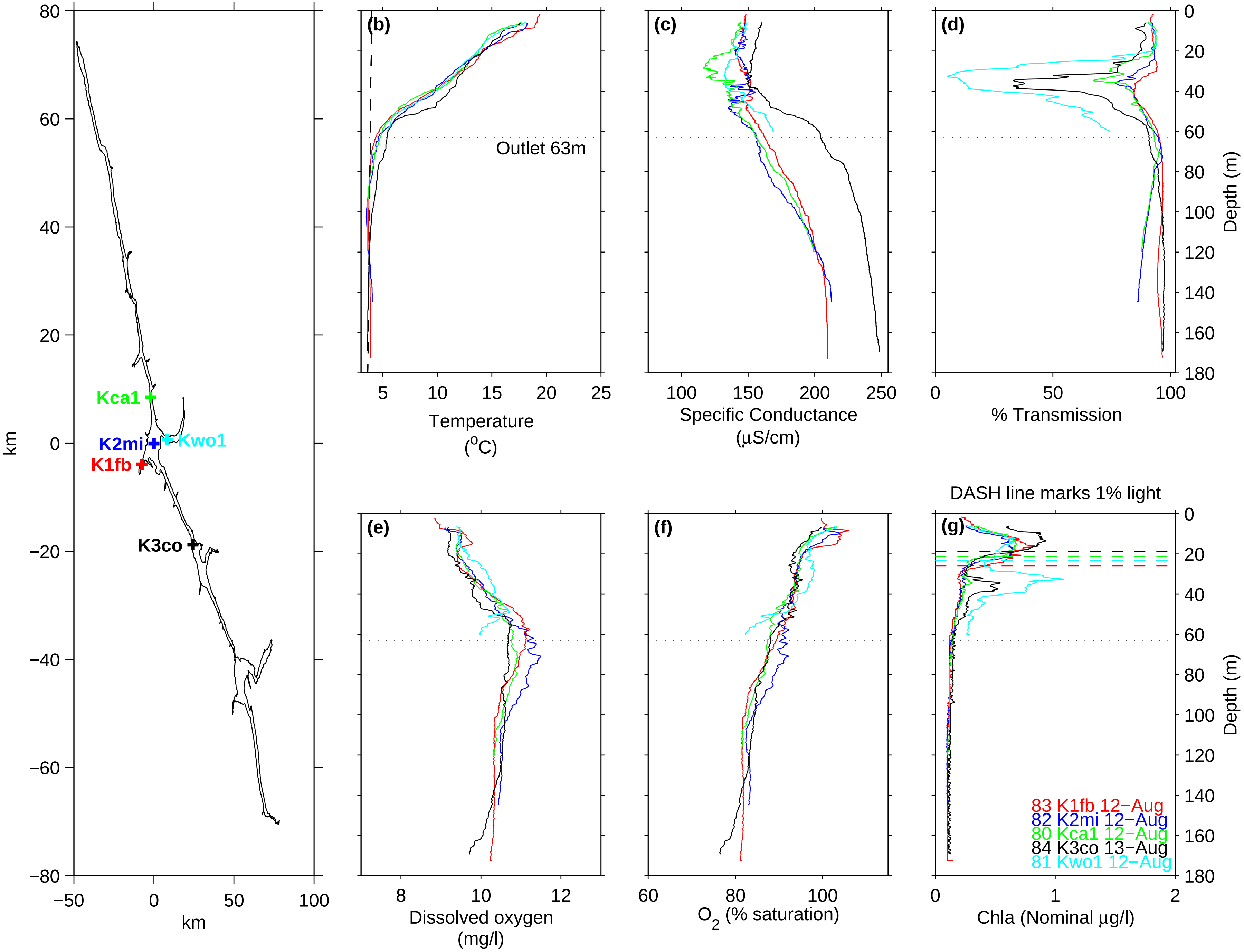


Figure B7 Kinbasket Reservoir, Forebay, K1fb, 2013

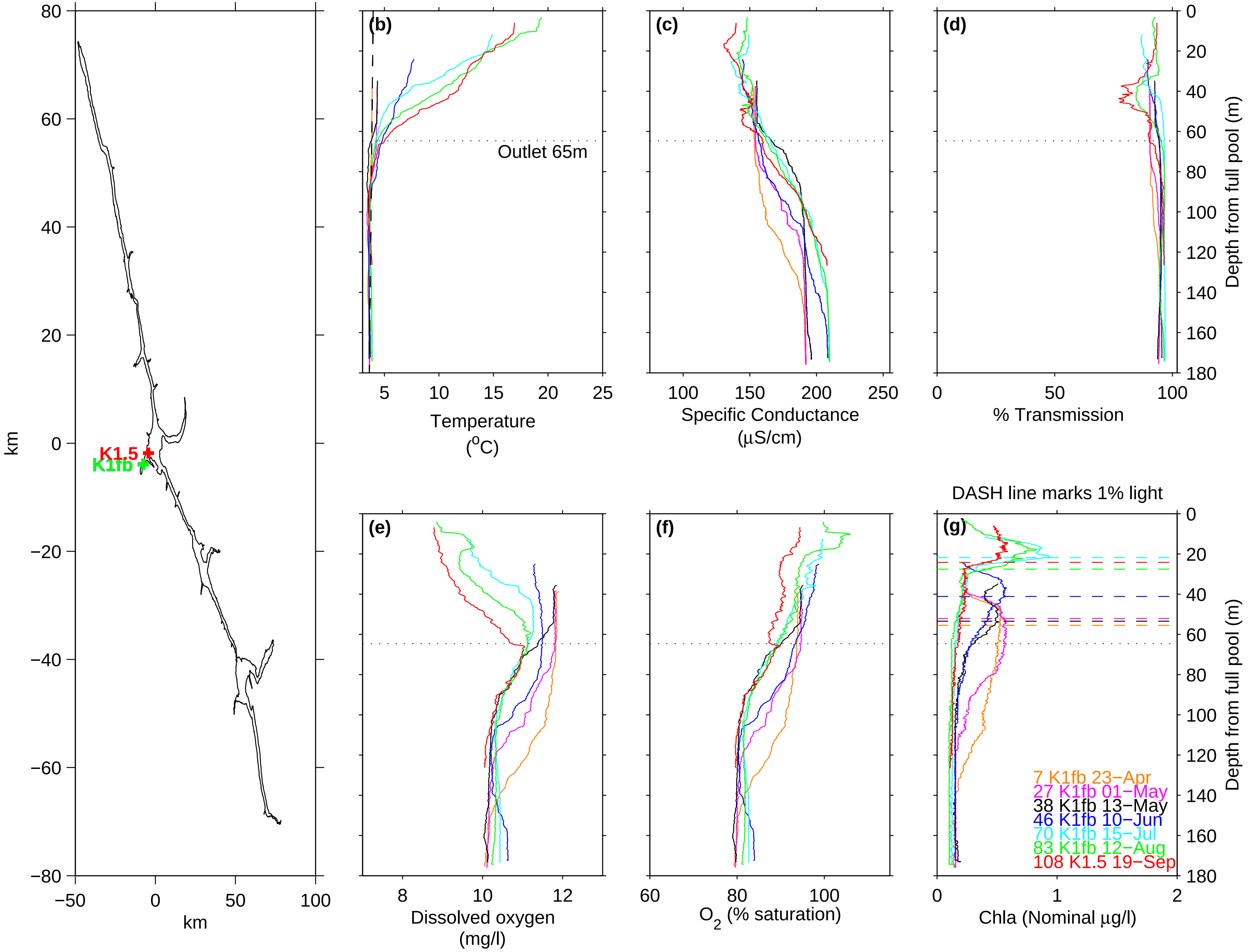


Figure B8 Kinbasket Reservoir, Middle, K2mi, 2013

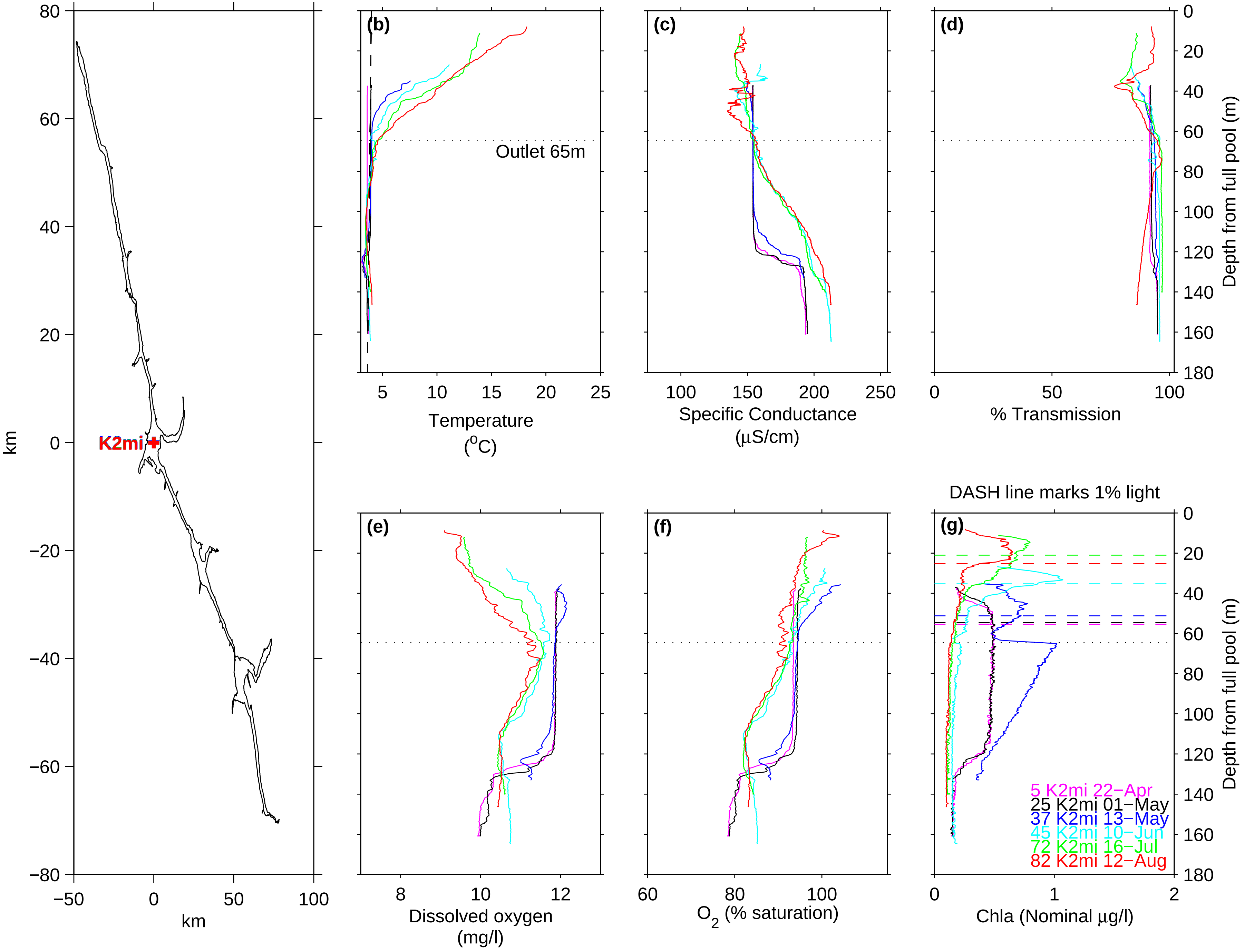


Figure B9 Kinbasket Reservoir, Columbia, K3co, 2013

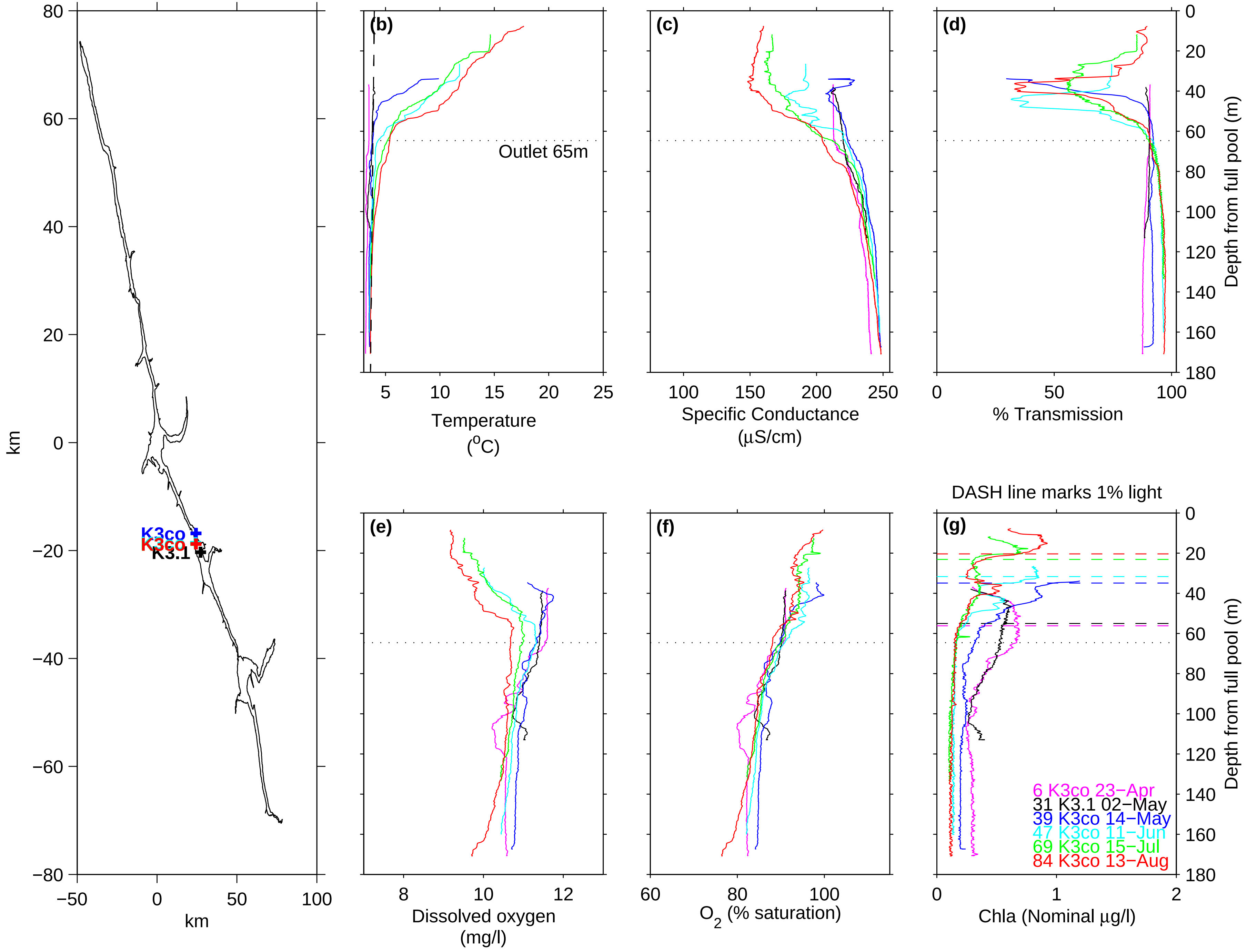


Figure B10 Kinbasket Reservoir, Canoe, Kca1, 2013

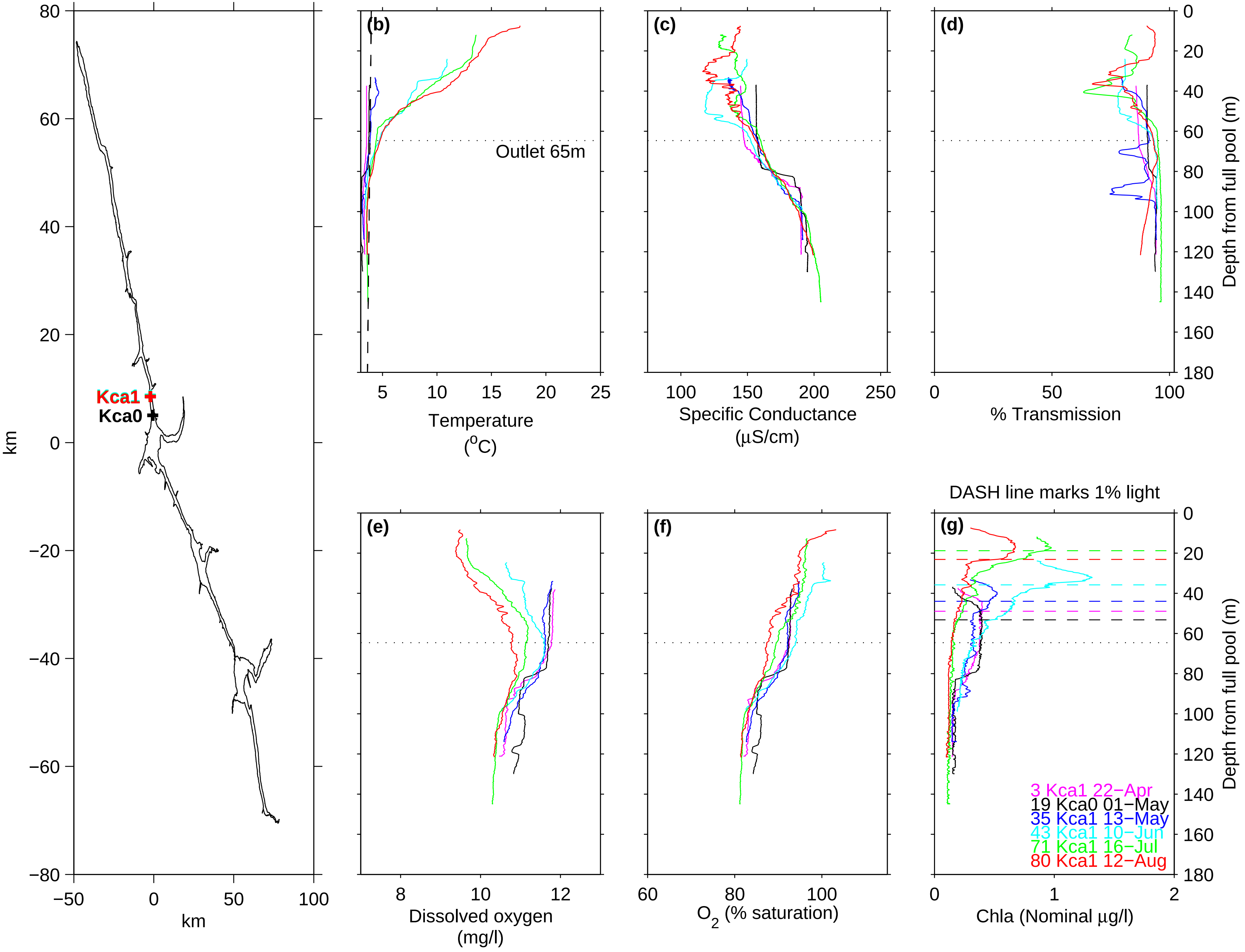


Figure B11 Kinbasket Reservoir, Wood, Kwo1, 2013

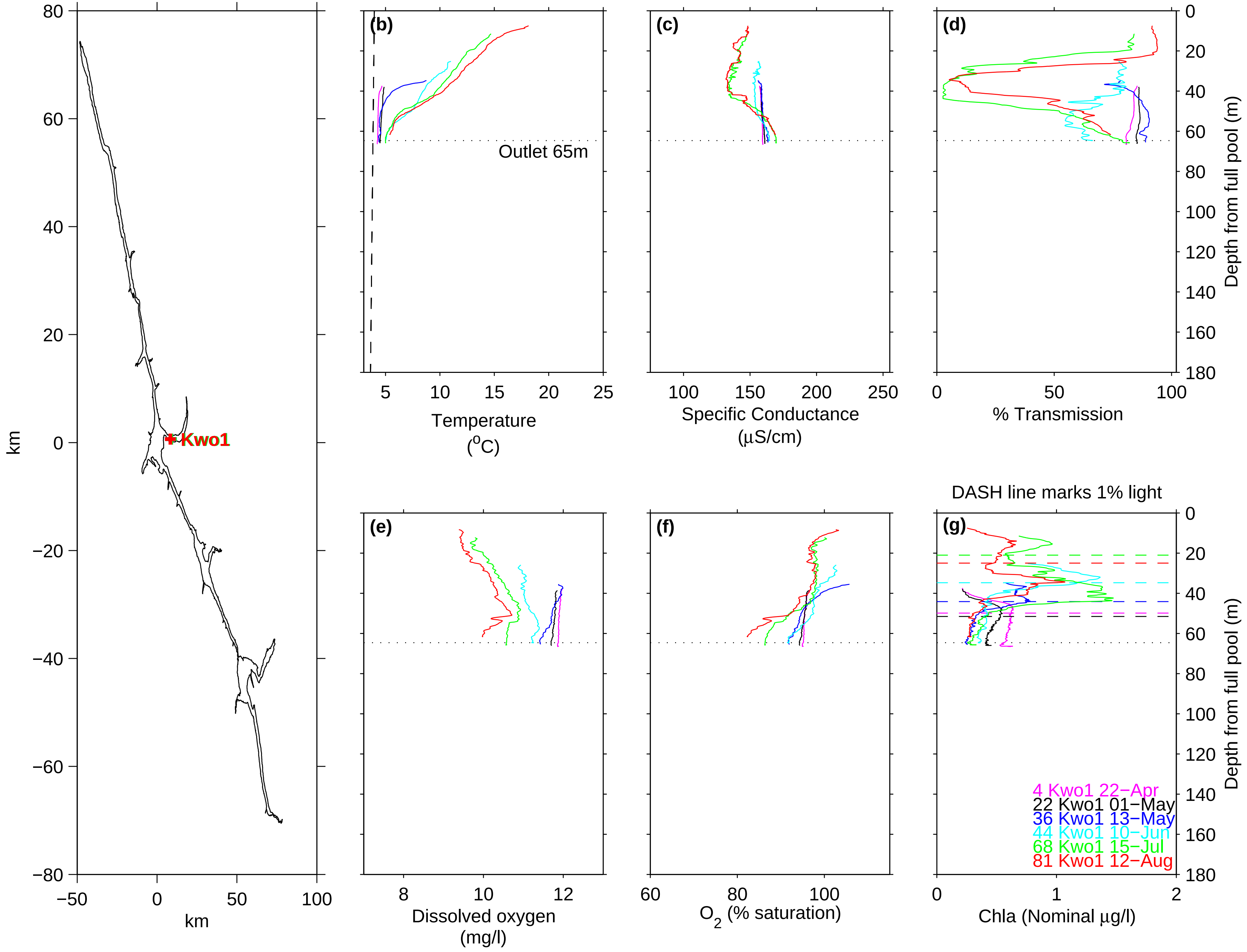


Figure C1 Kinbasket Reservoir 22−23 Apr, 2013

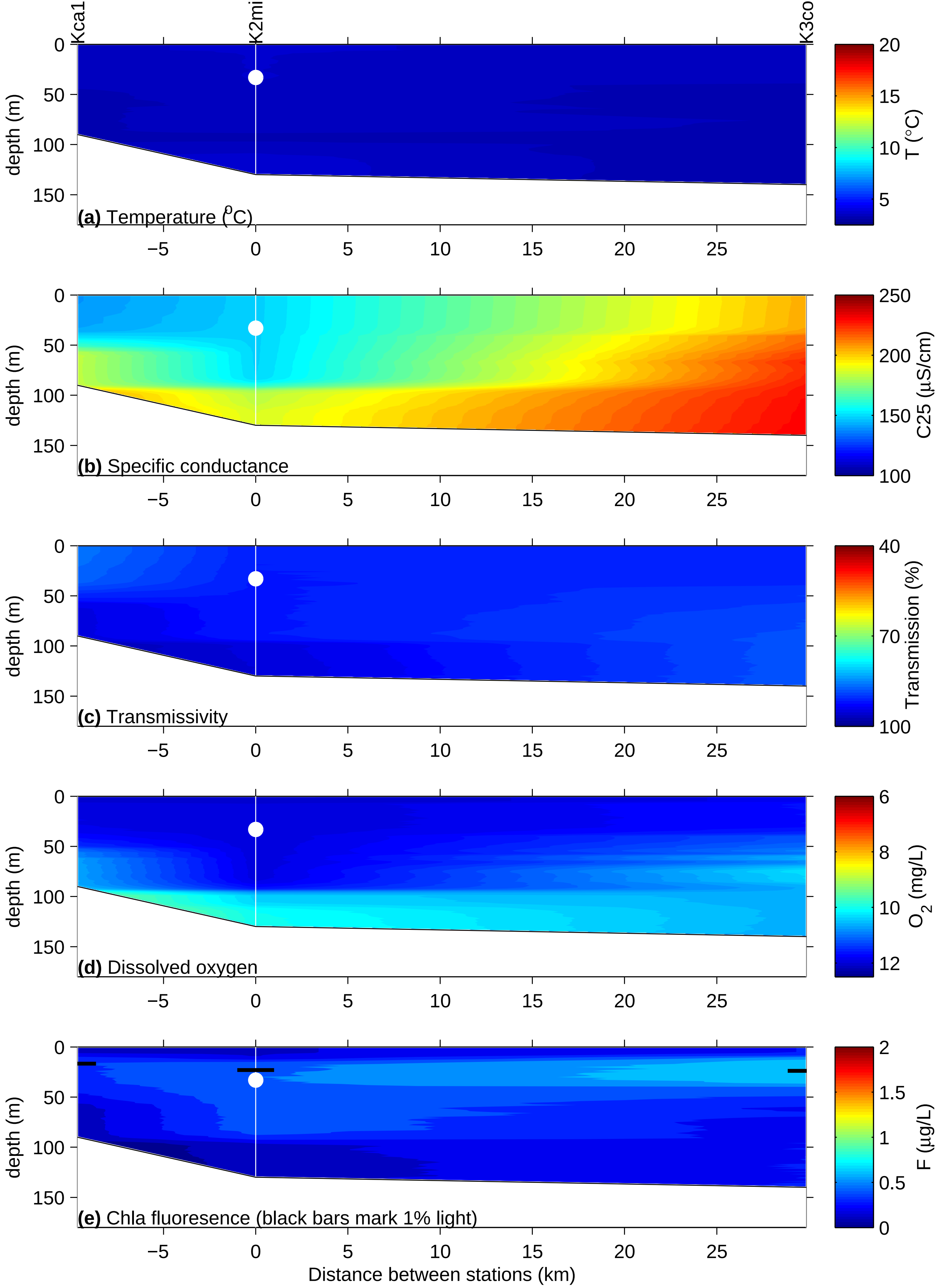


Figure C2 Kinbasket Reservoir 1−2 May, 2013

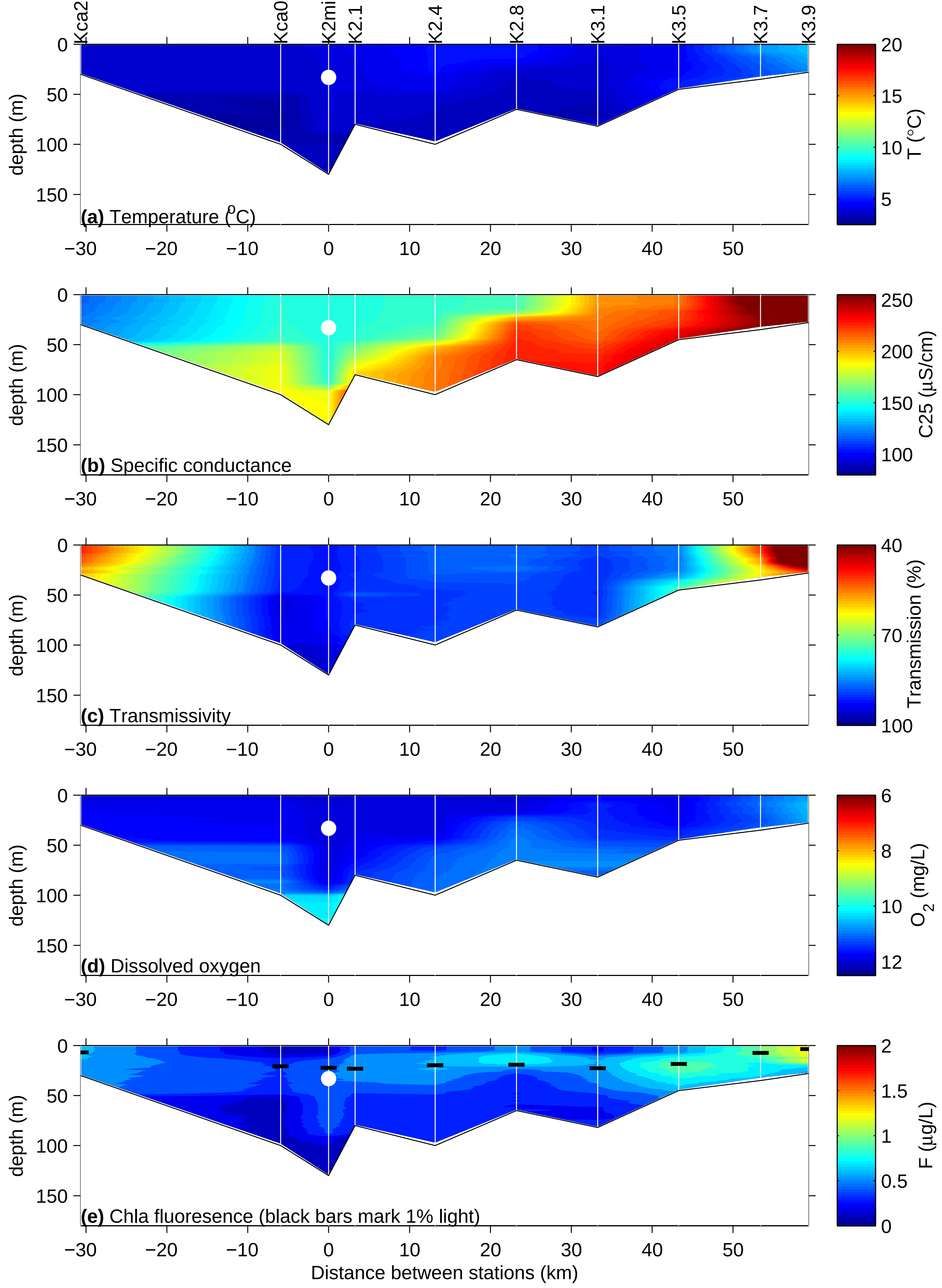


Figure C3 Kinbasket Reservoir 13−14 May, 2013

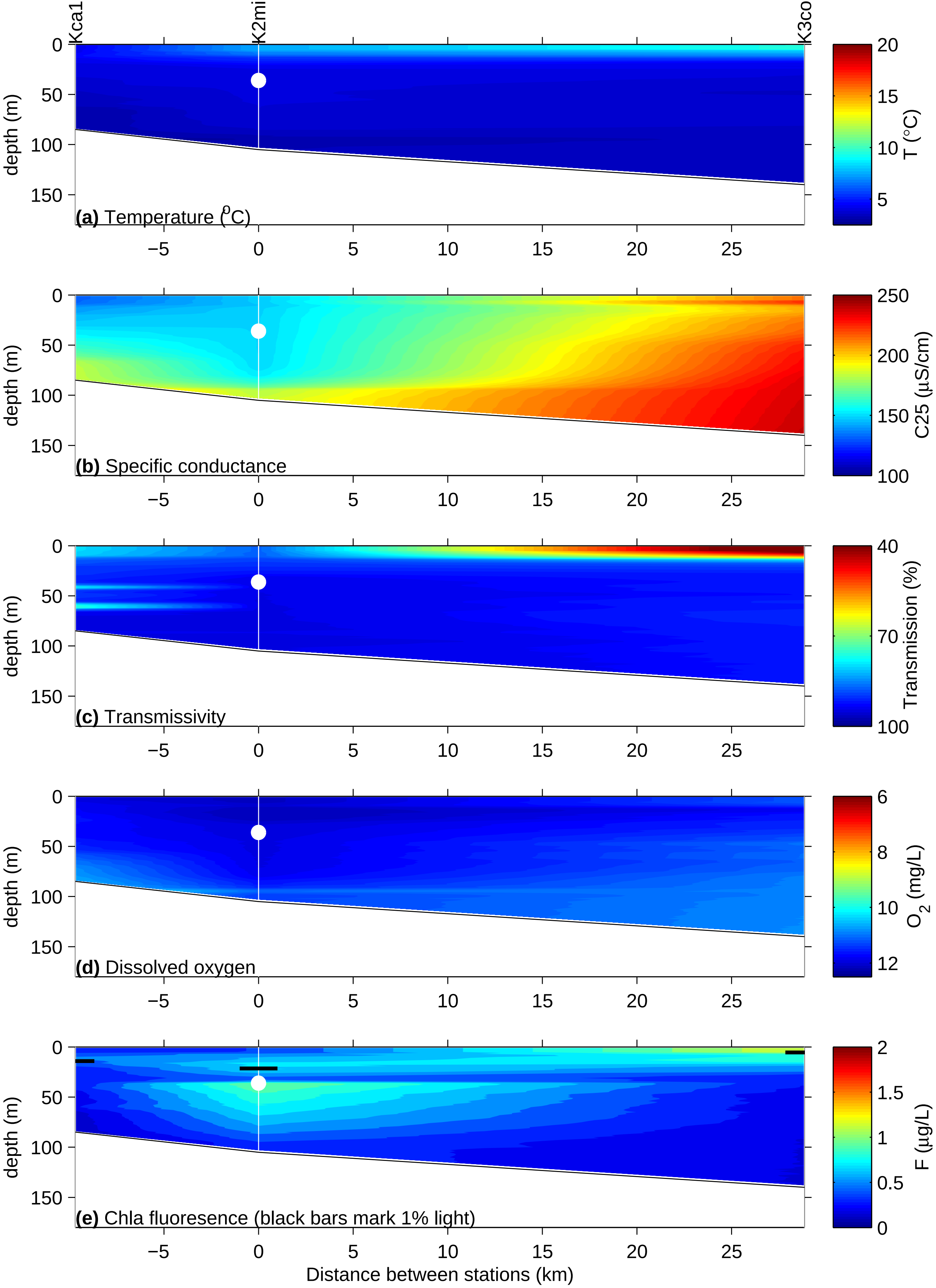


Figure C4 Kinbasket Reservoir 10−11 Jun, 2013

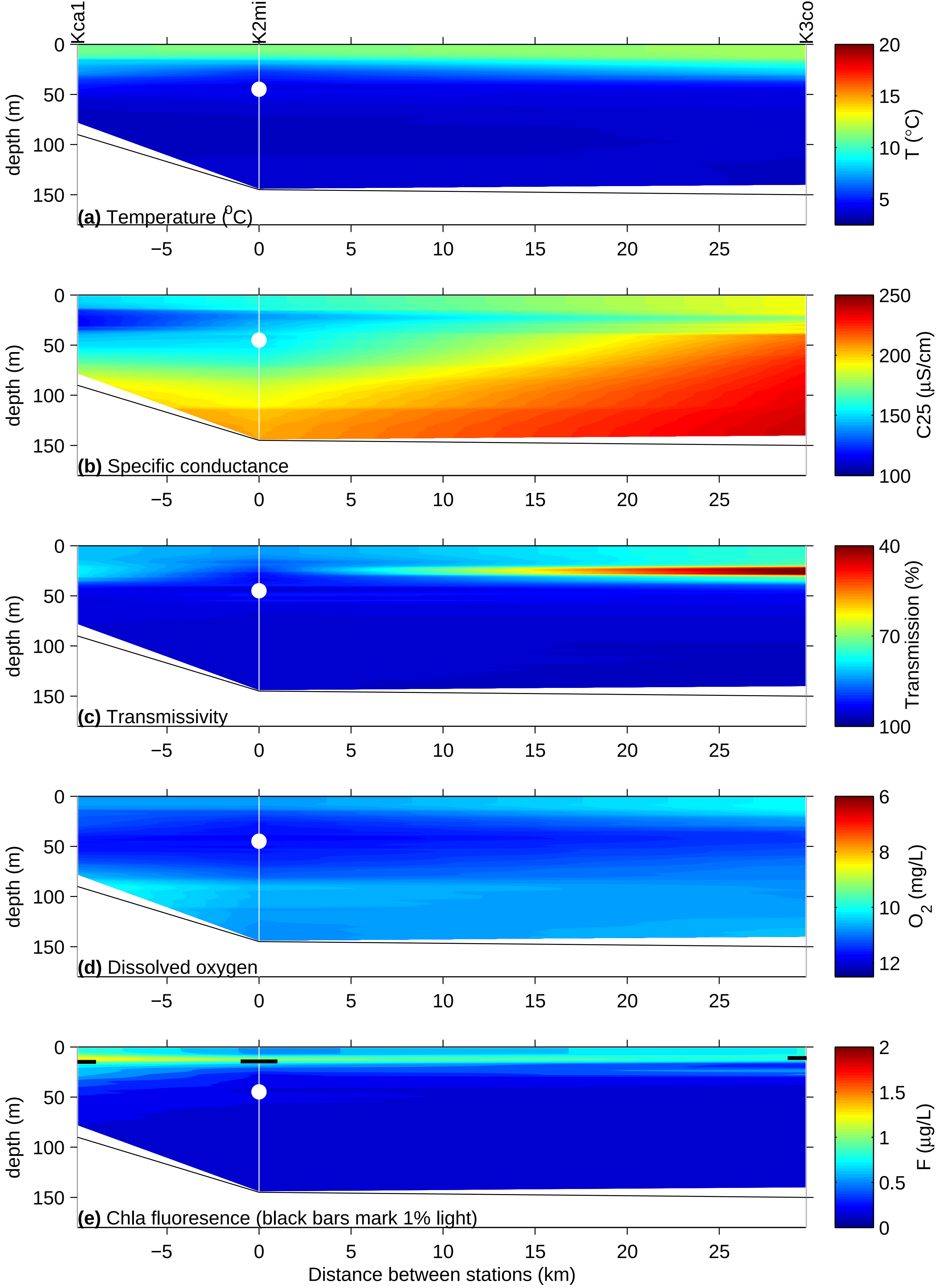


Figure C5 Kinbasket Reservoir 15−16 Jul, 2013

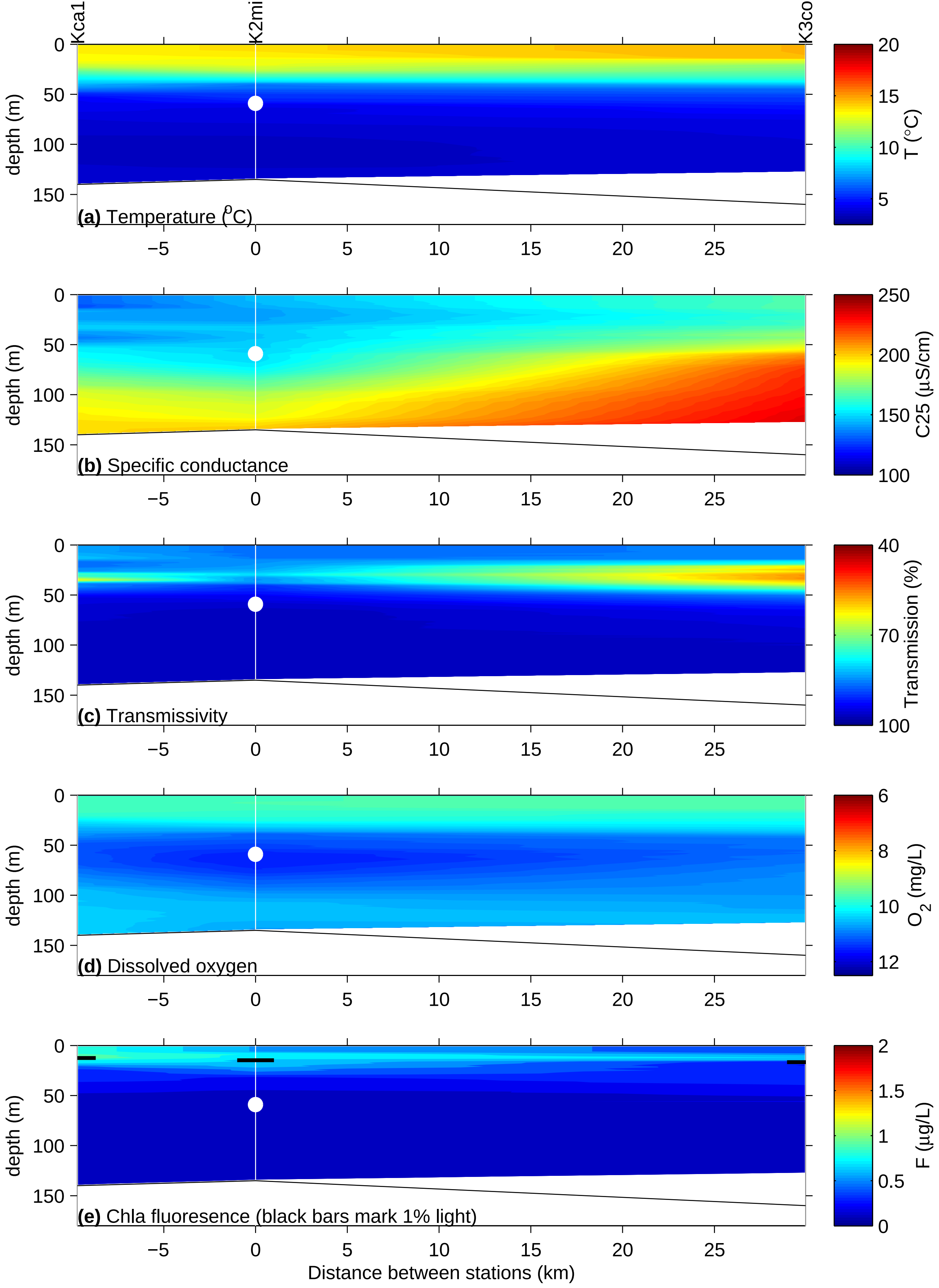


Figure C6 Kinbasket Reservoir 12−13 Aug, 2013

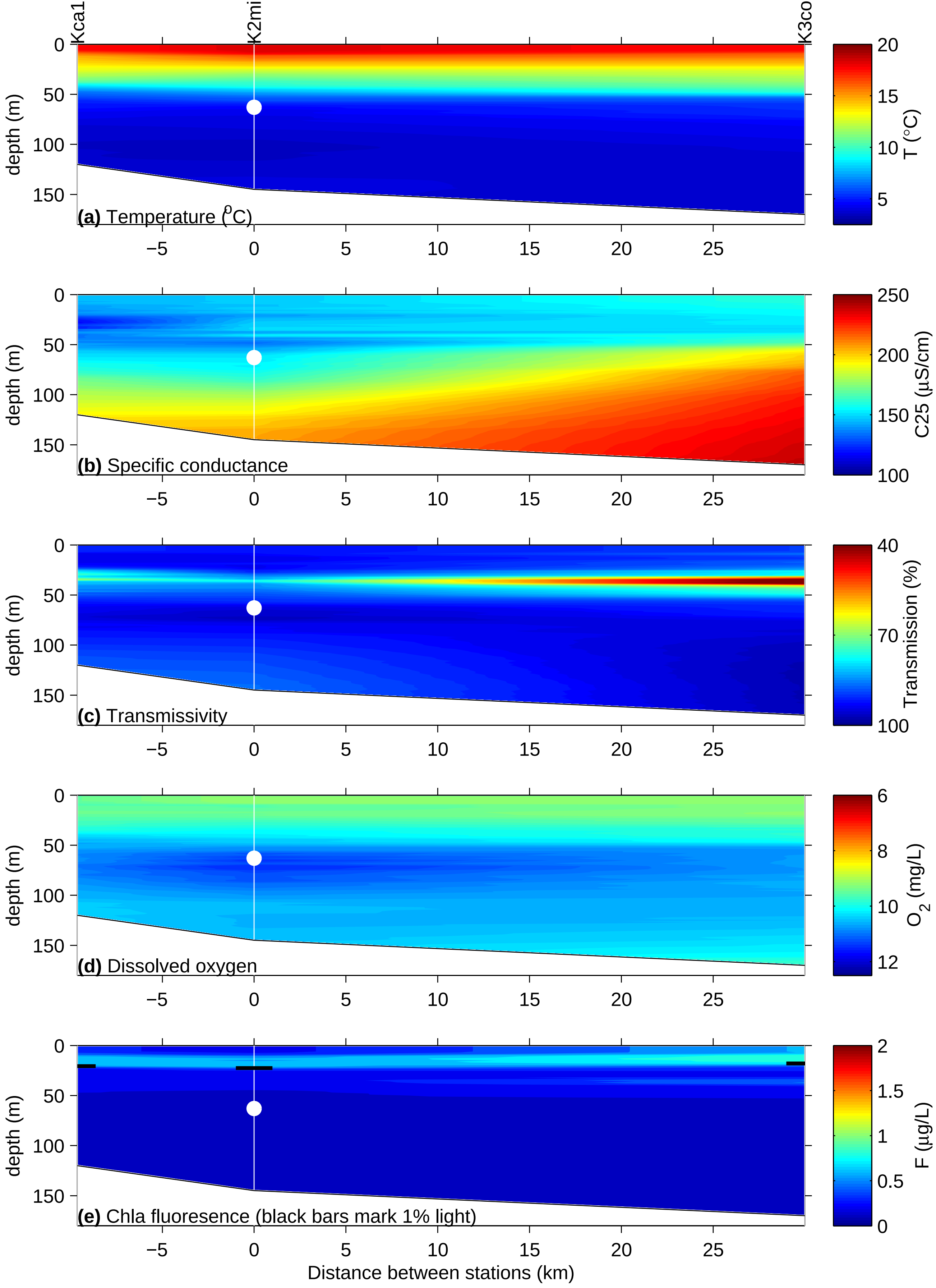


Figure D1 Revelstoke Reservoir, 17, 29−30 Apr 2013

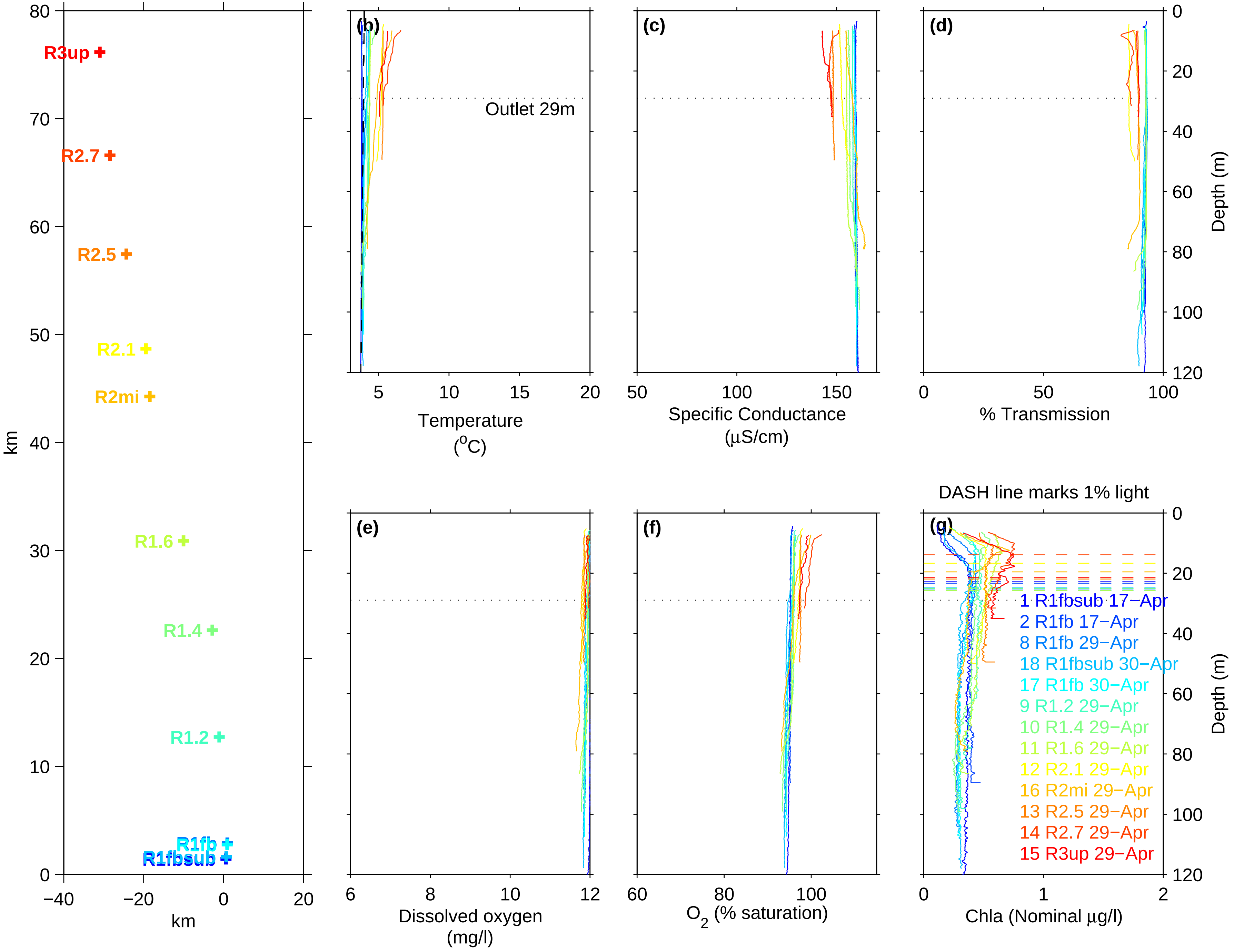


Figure D2 Revelstoke Reservoir, 21−22 May 2013

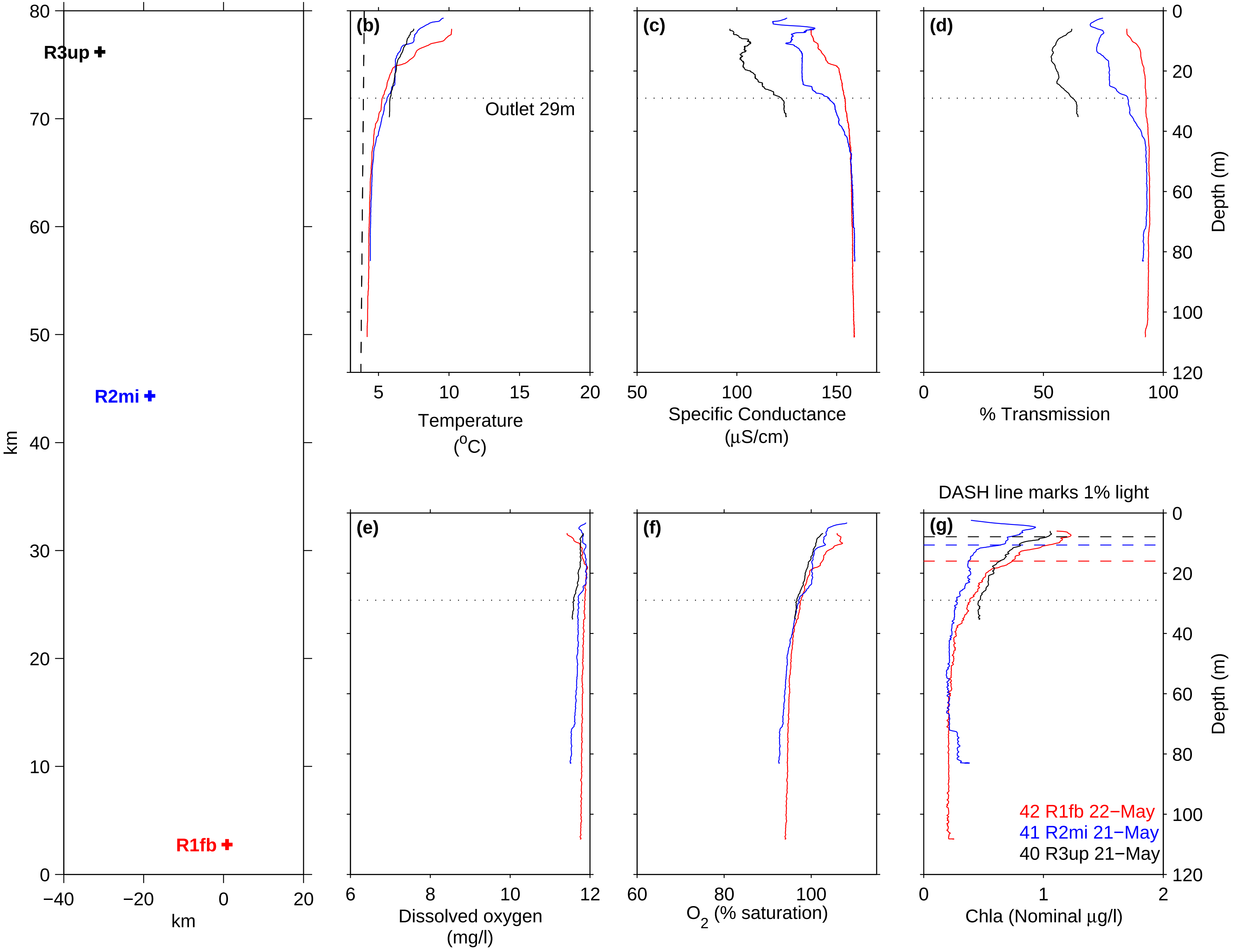


Figure D3 Revelstoke Reservoir, 17−21 Jun 2013

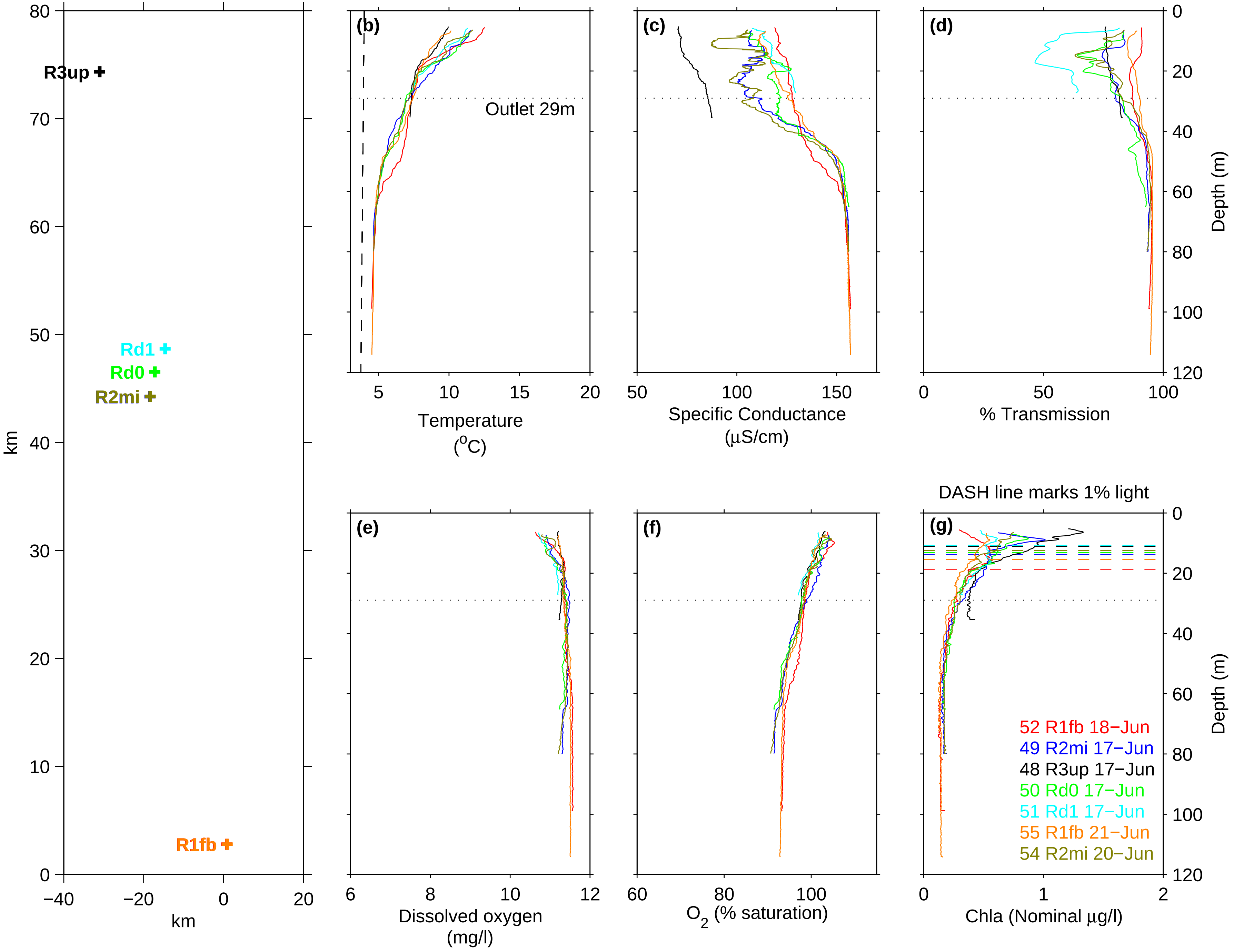


Figure D4 Revelstoke Reservoir, 10 Jul 2013

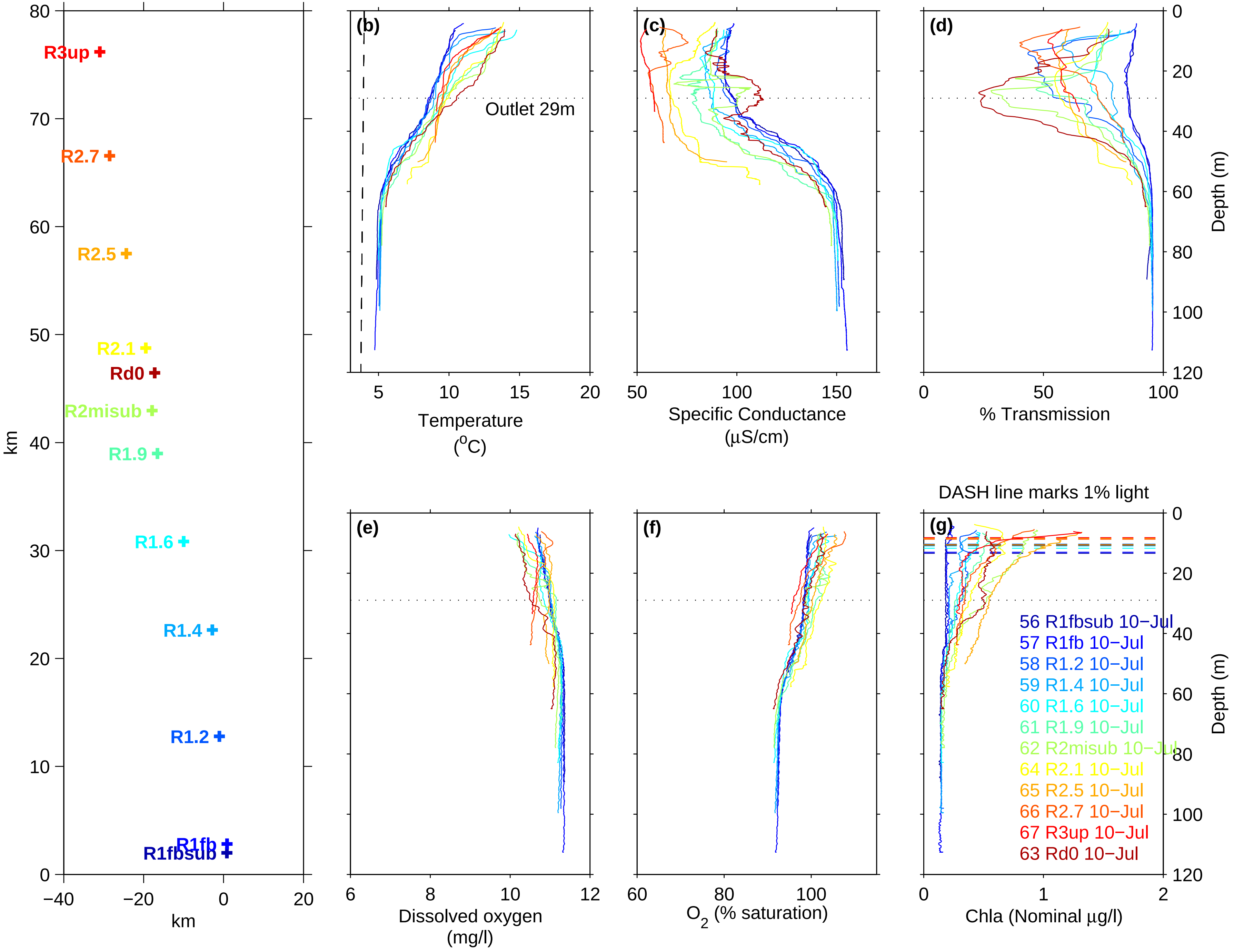


Figure D5 Revelstoke Reservoir, 22−25 Jul 2013

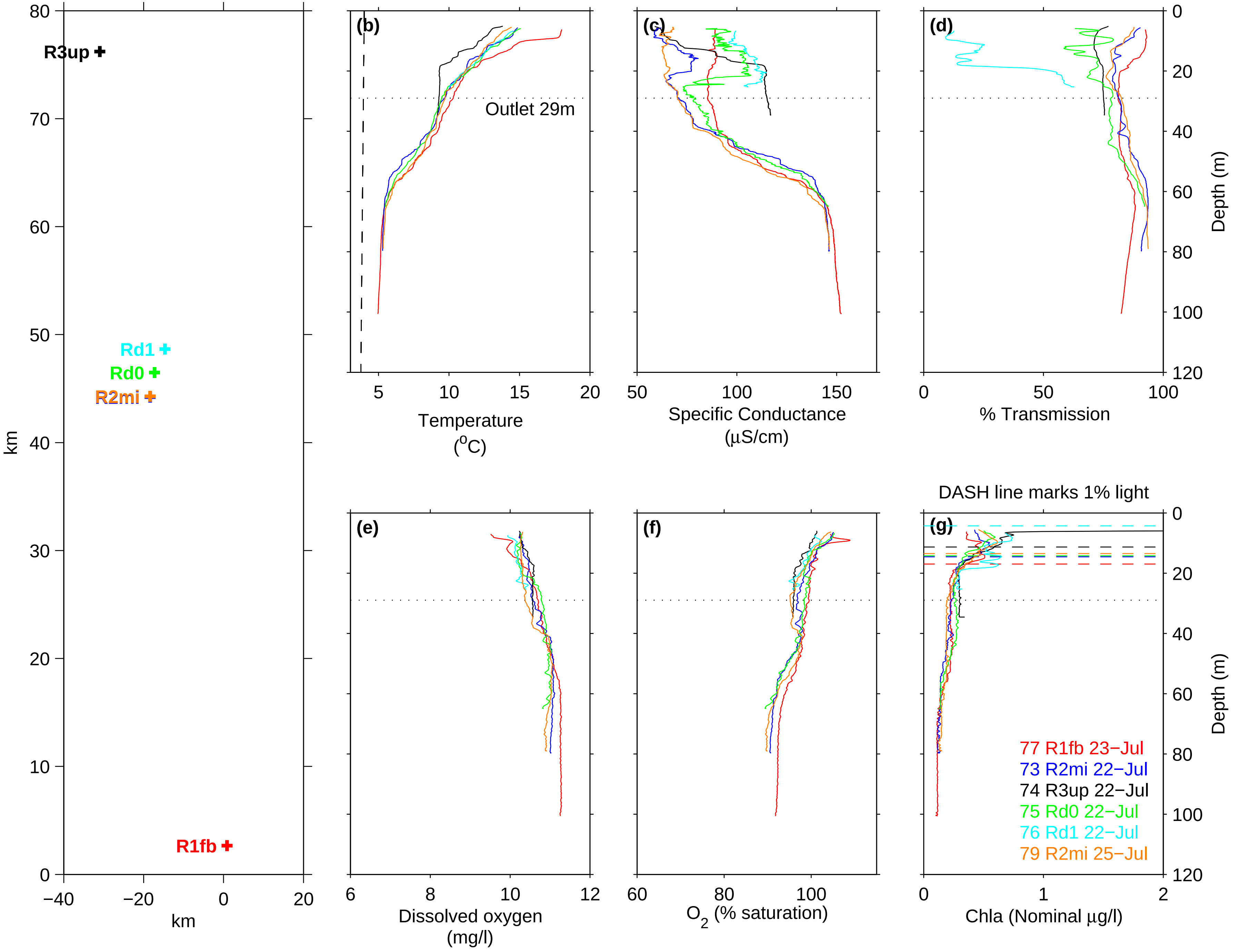


Figure D6 Revelstoke Reservoir, 19−22 Aug 2013

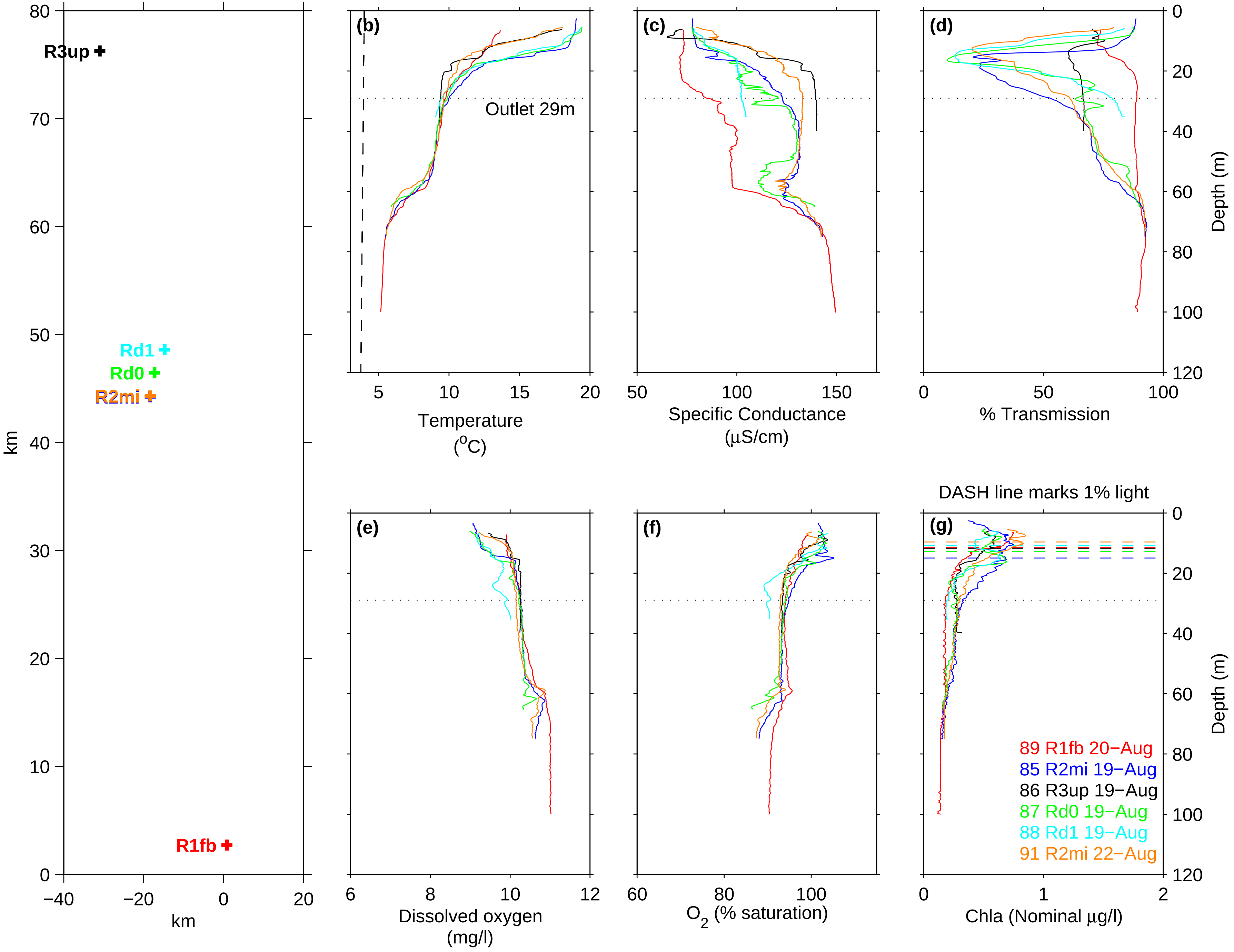


Figure D7 Revelstoke Reservoir, 26 Aug 2013

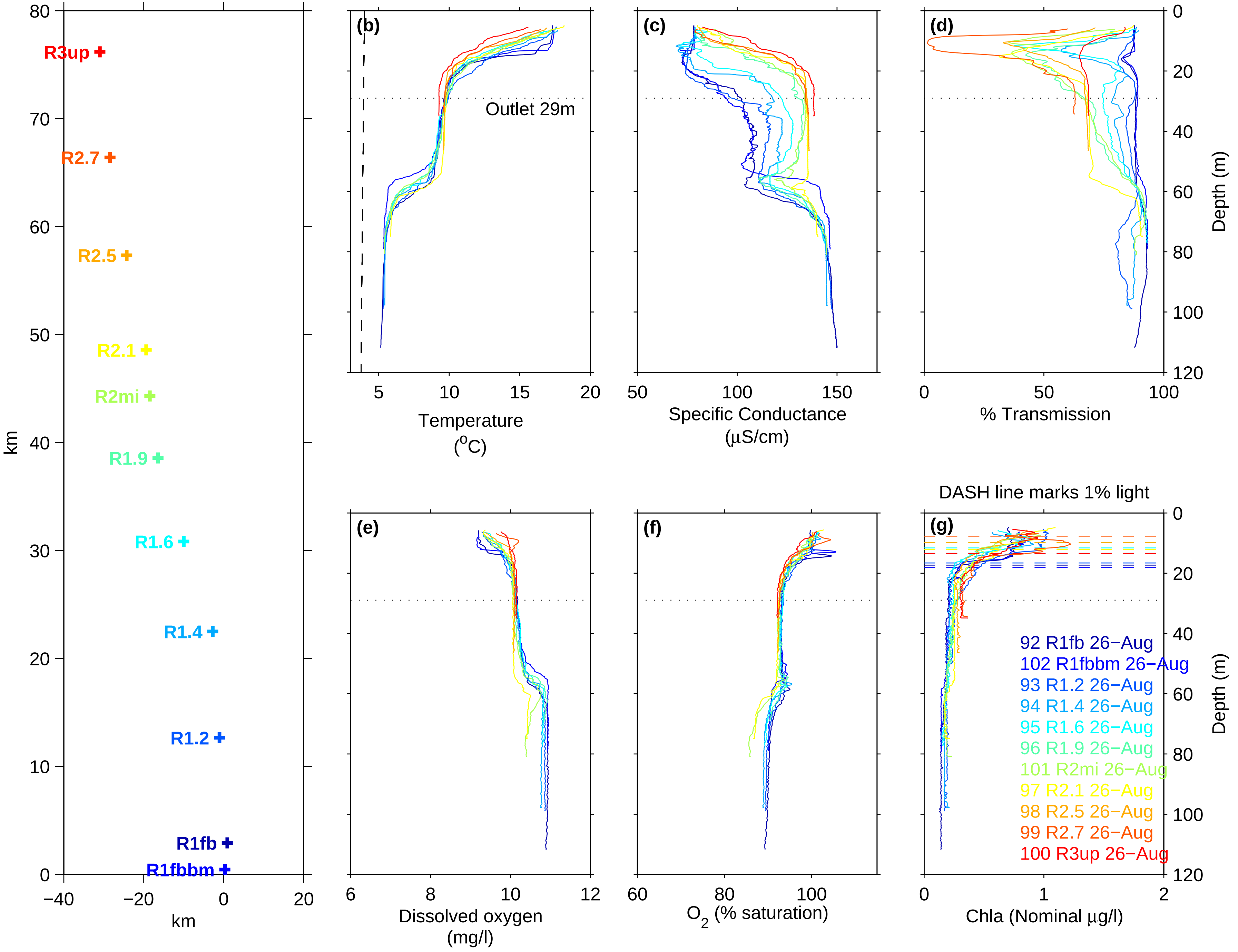


Figure D8 Revelstoke Reservoir, 17−18 Sep 2013

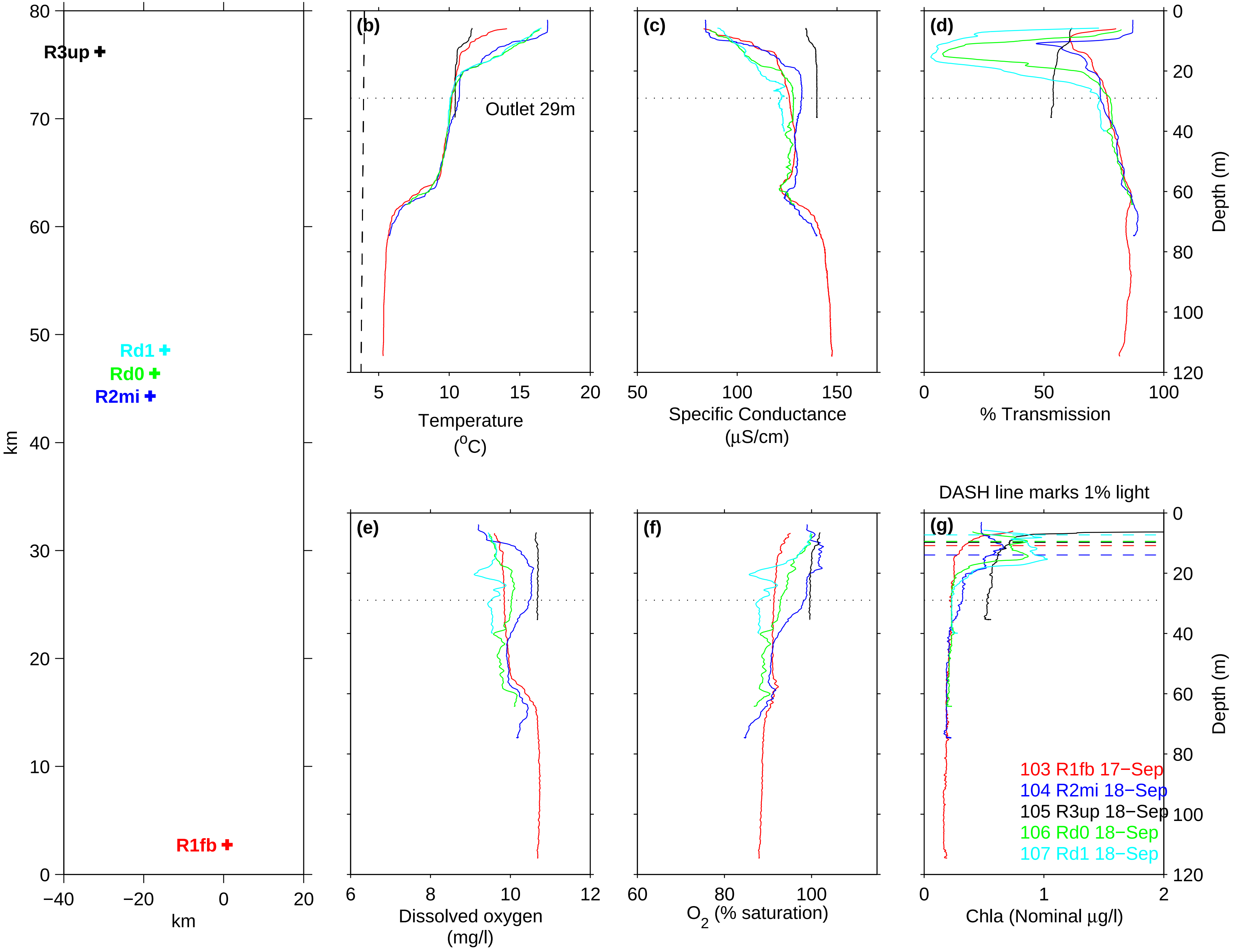


Figure D9 Revelstoke Reservoir, Forebay 2013

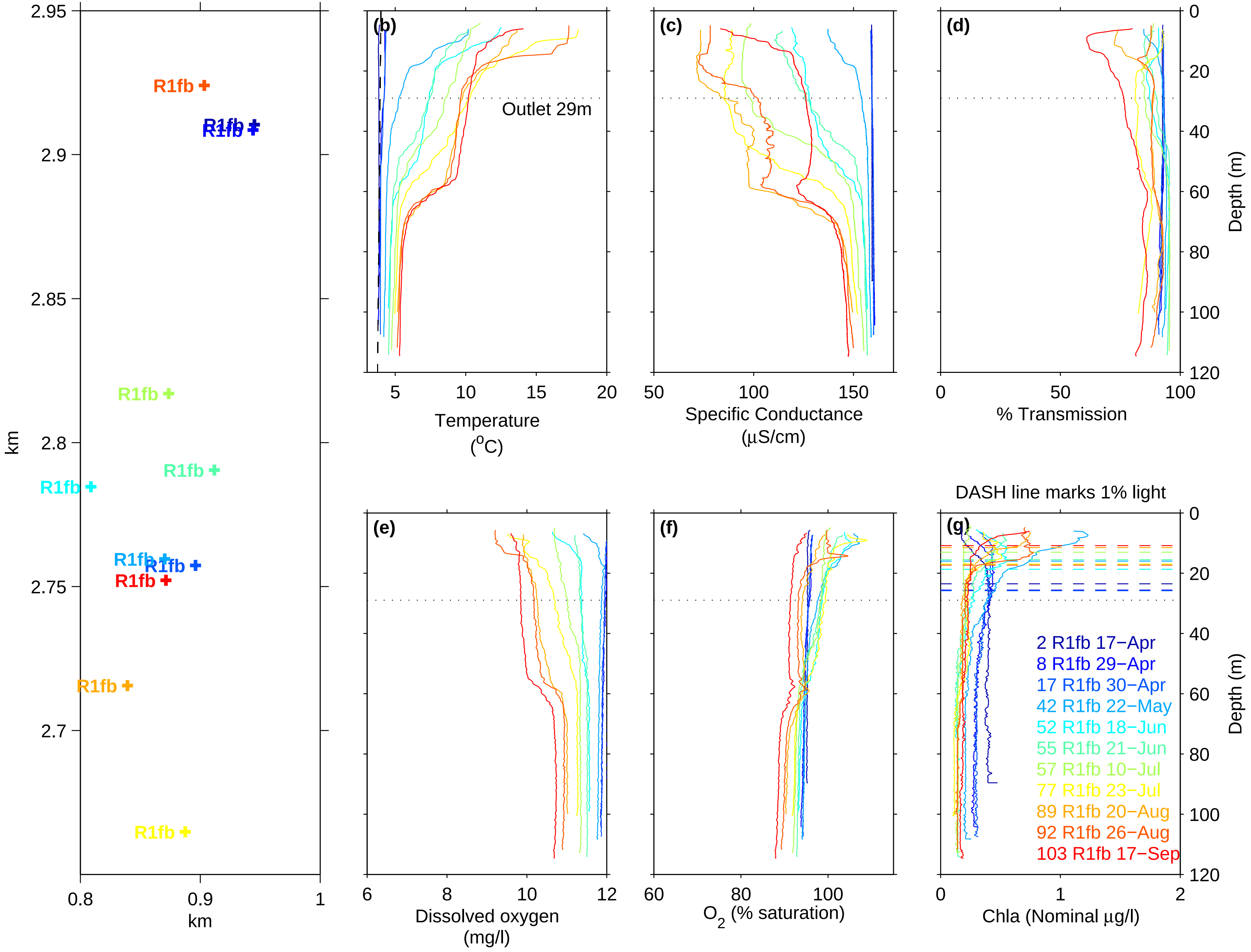


Figure D10 Revelstoke Reservoir, Middle 2013

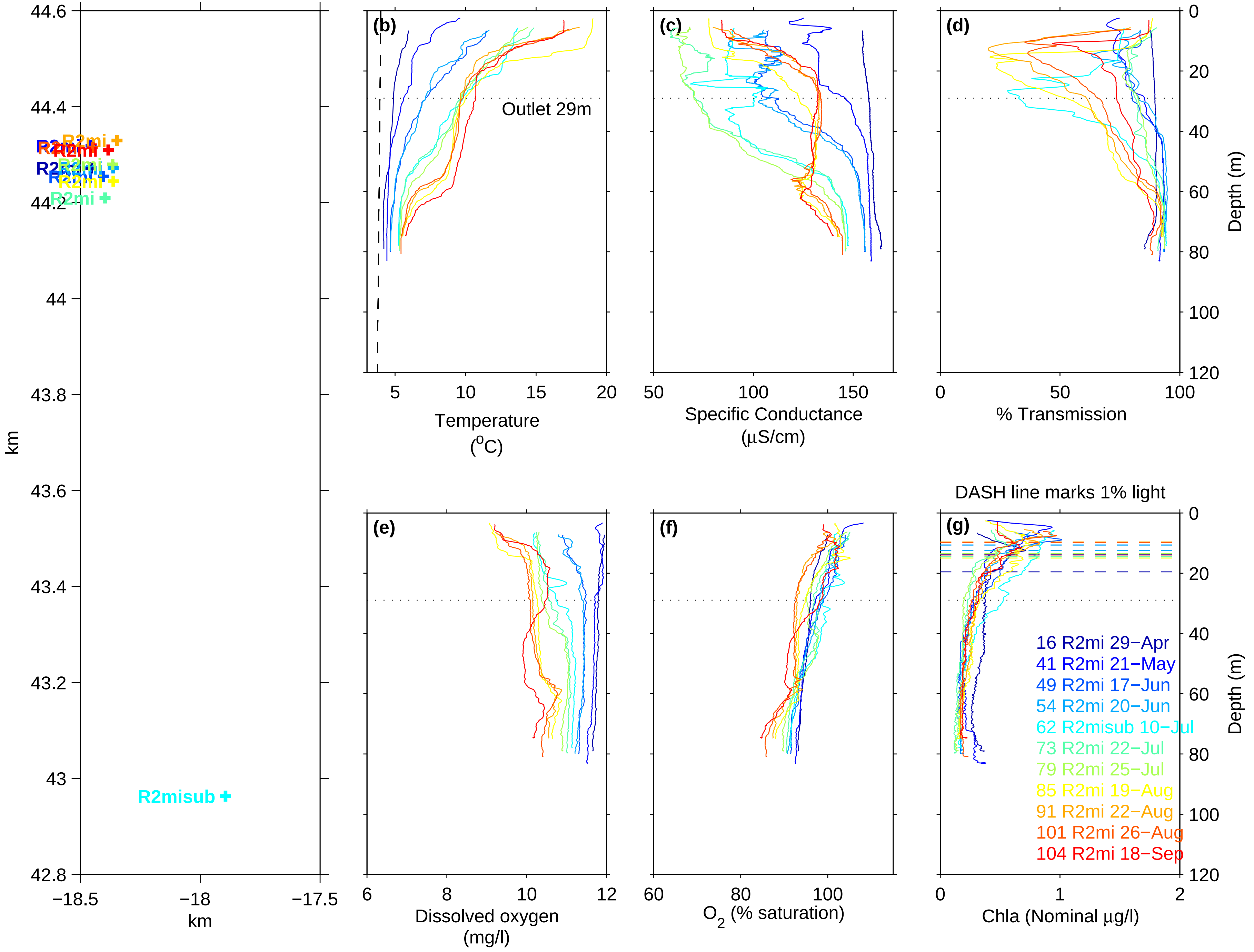


Figure D11 Revelstoke Reservoir, Upper 2013

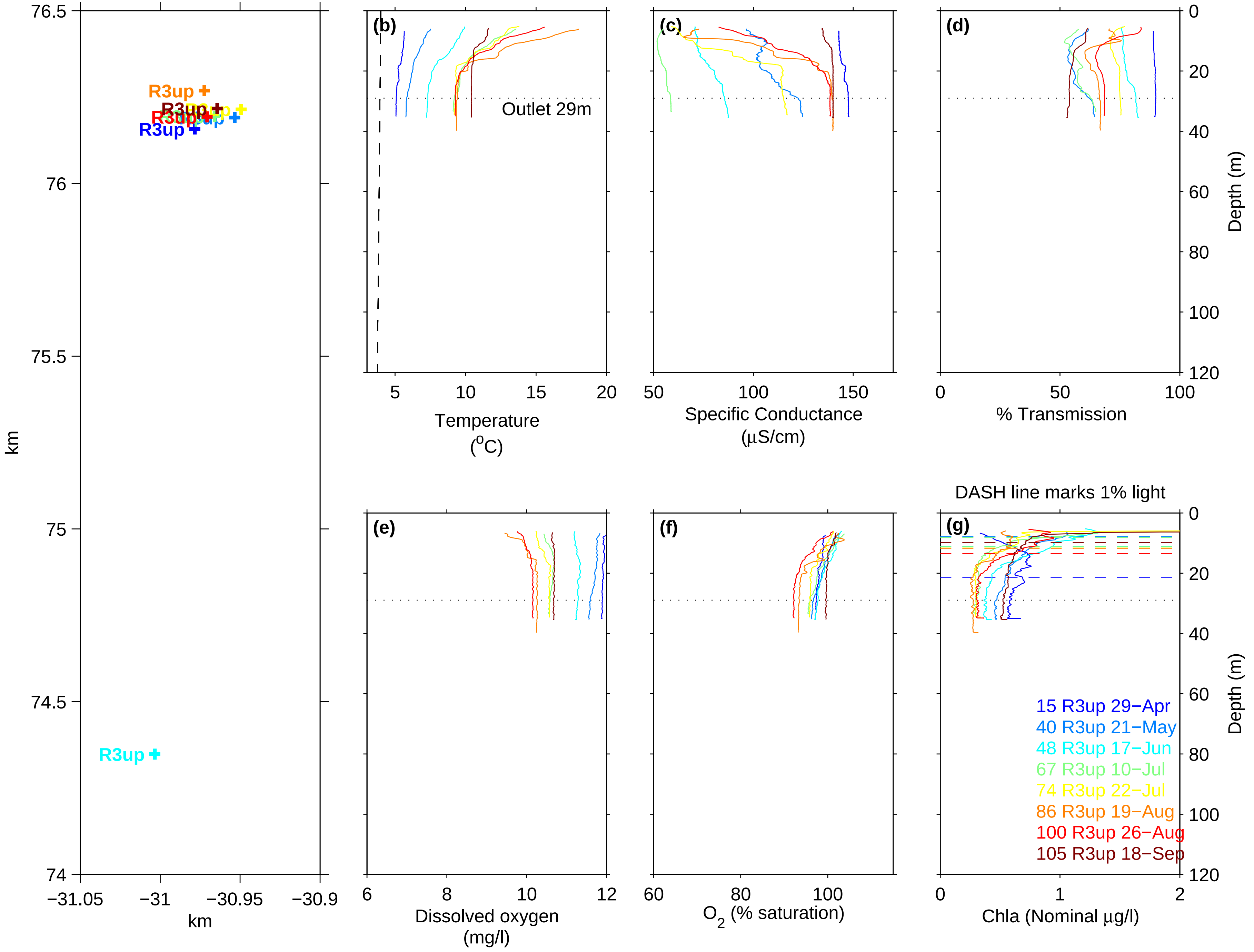


Figure D12 Revelstoke Reservoir, Downie Arm 2013

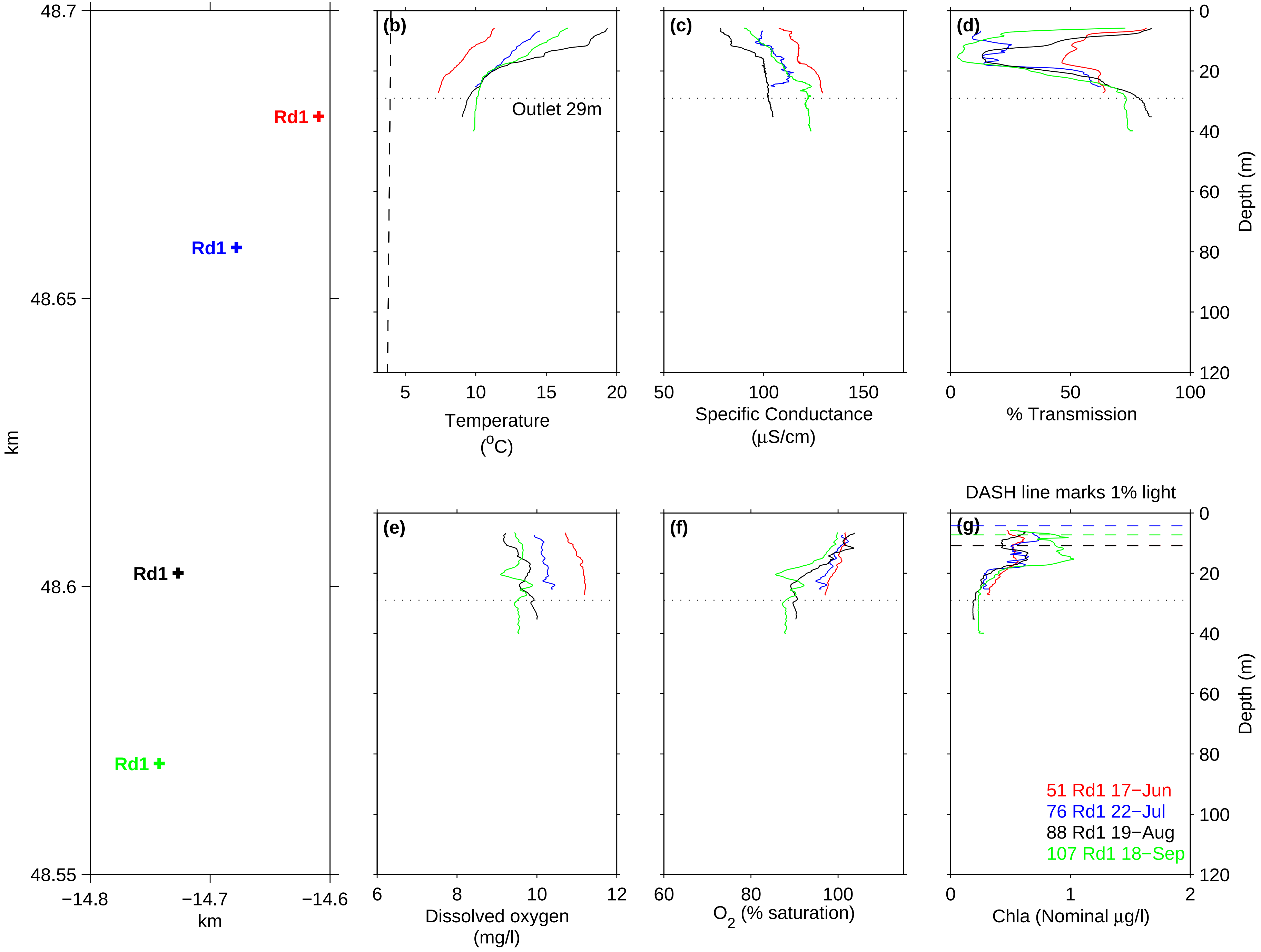


Figure E1 Revelstoke Reservoir 29−30 Apr, 2013

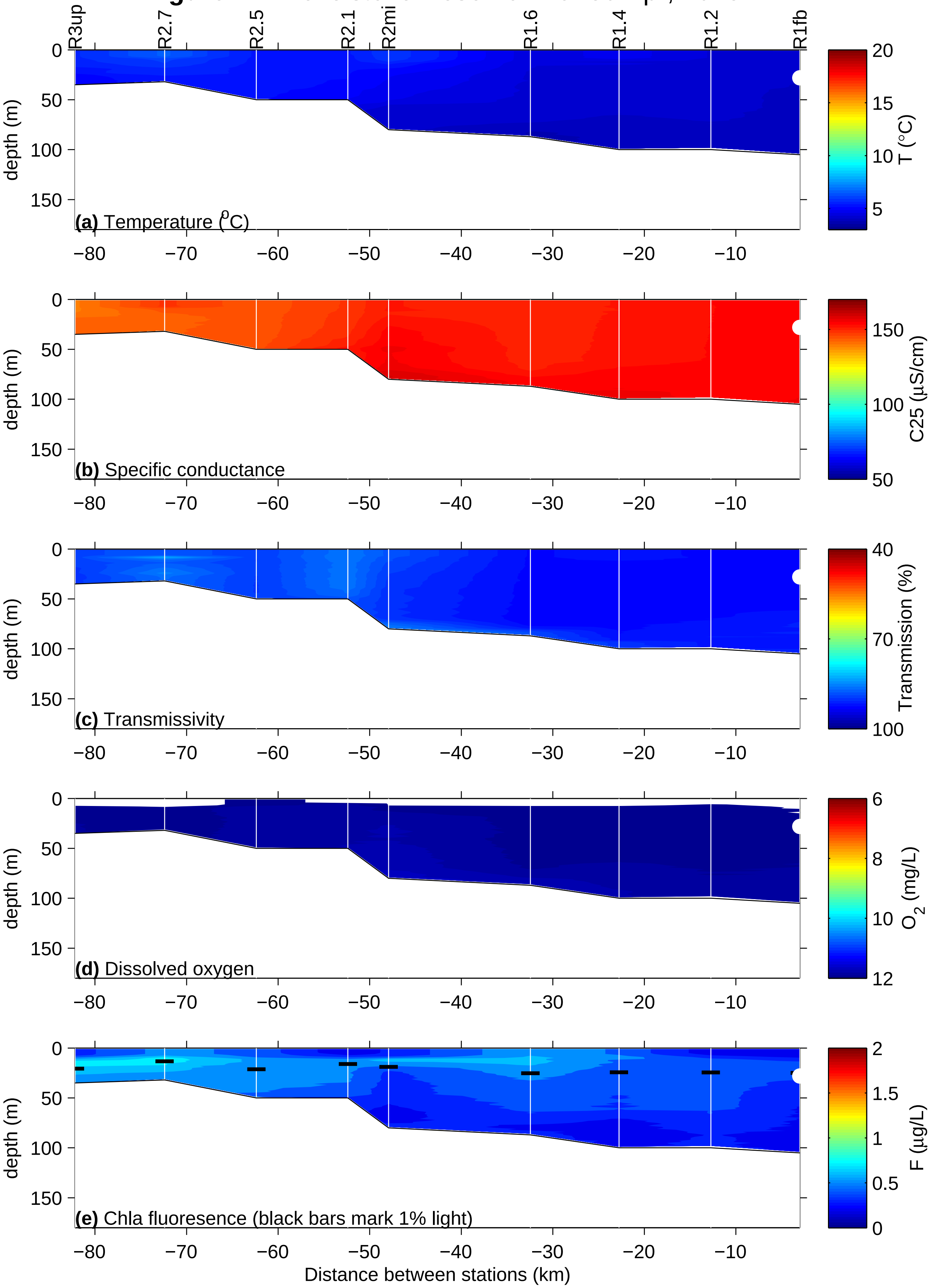


Figure E2 Revelstoke Reservoir 21−22 May, 2013

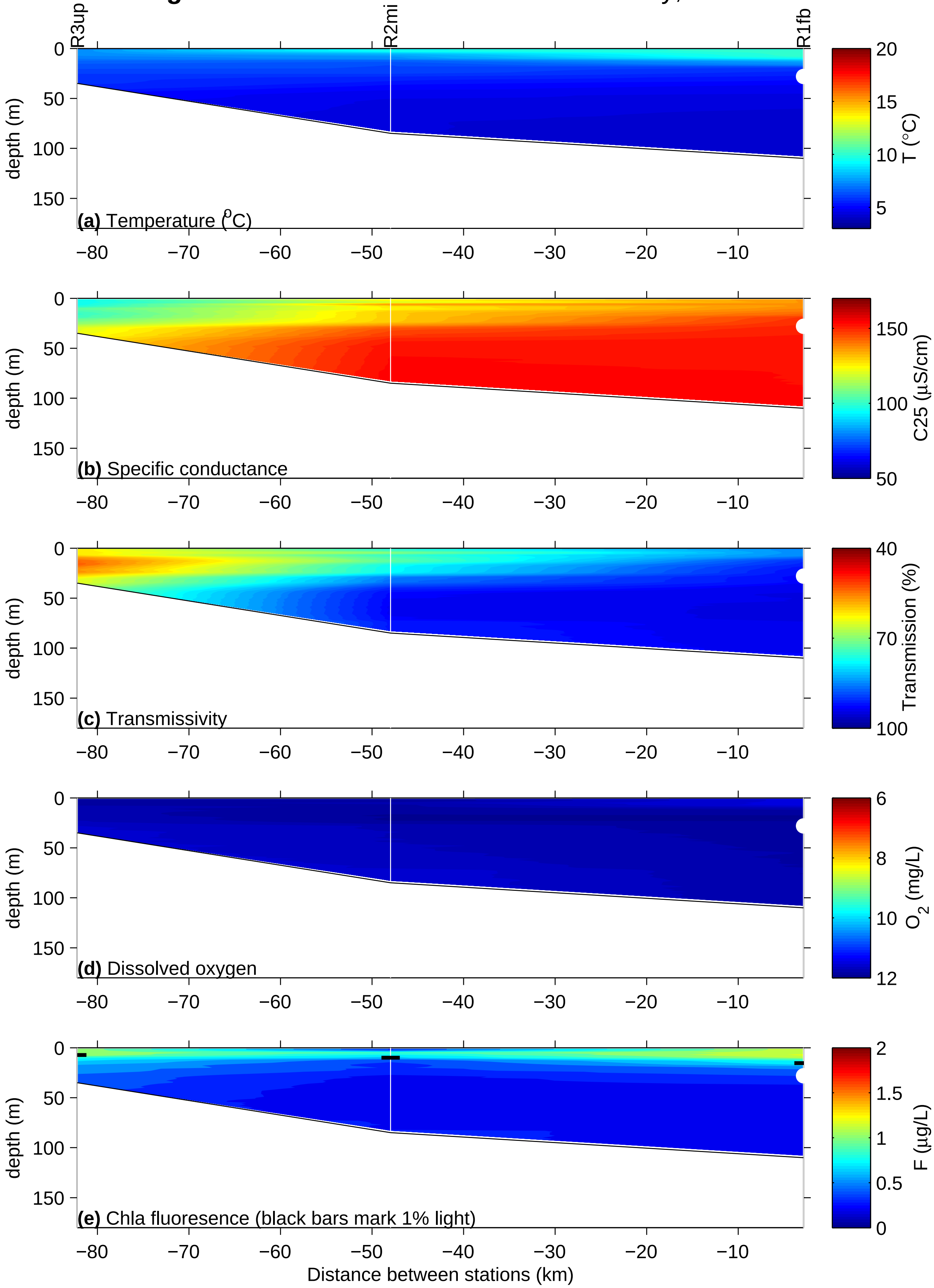


Figure E3 Revelstoke Reservoir 17−18 Jun, 2013

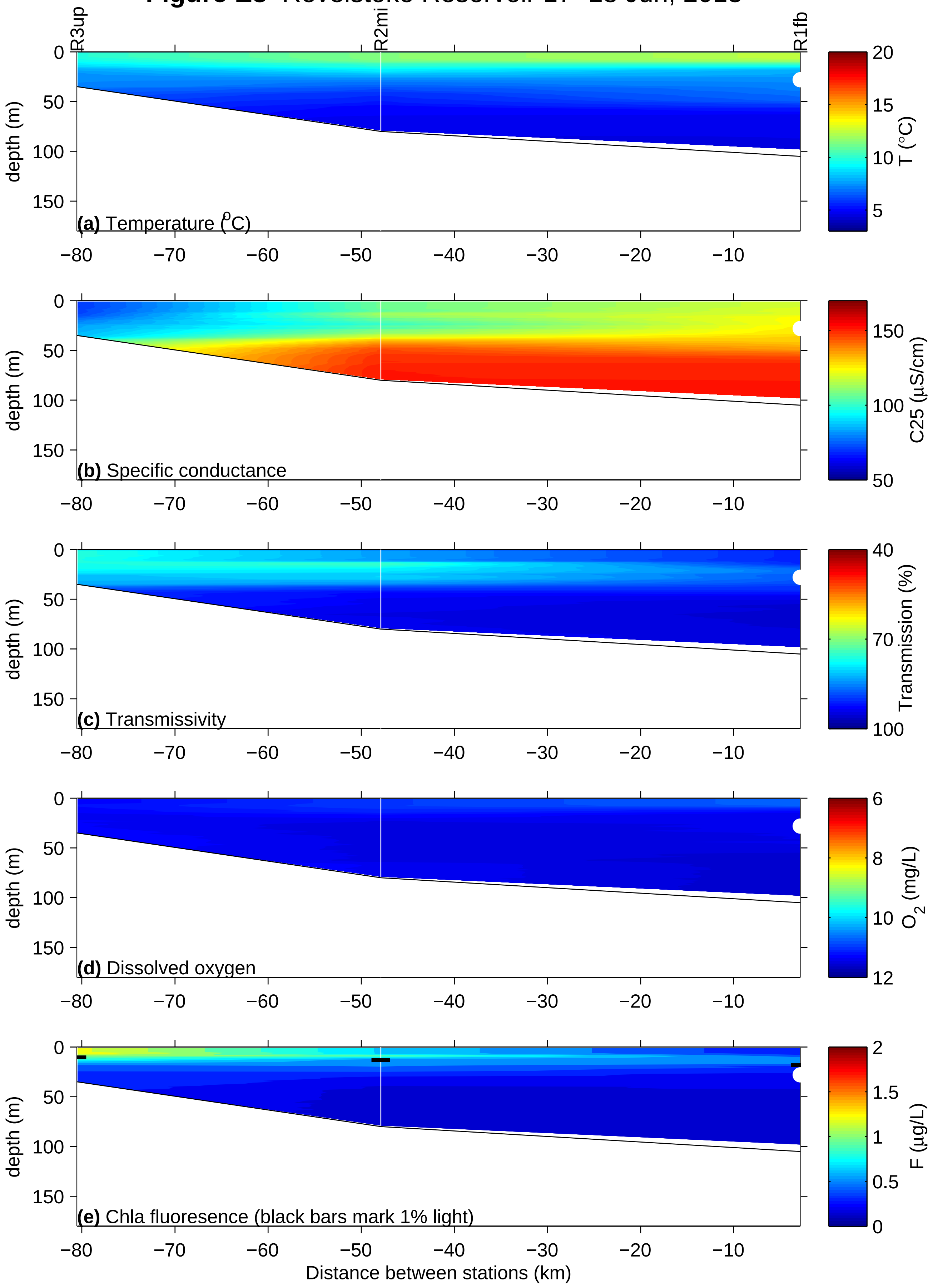


Figure E4 Revelstoke Reservoir 10 Jul, 2013

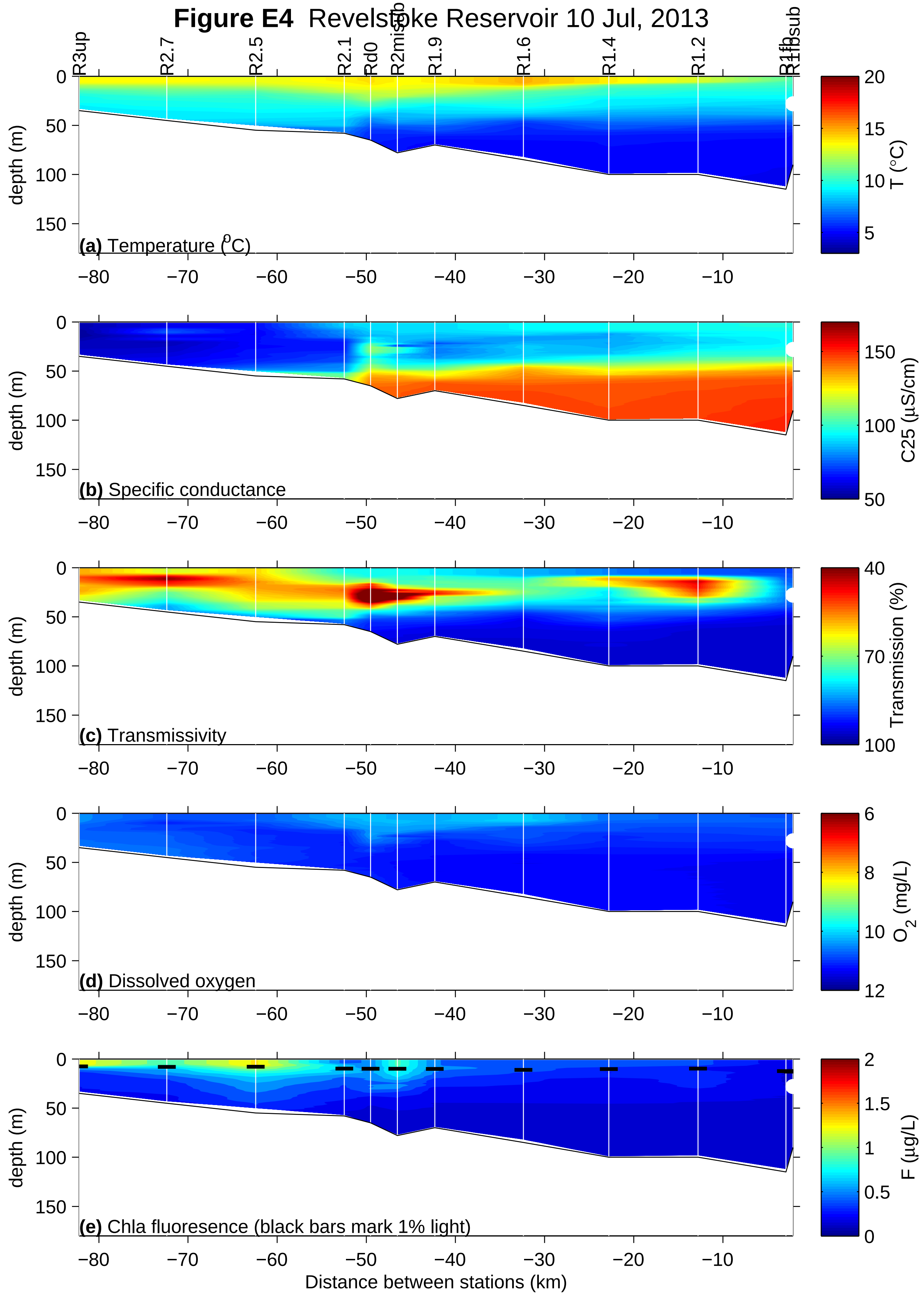


Figure E5 Revelstoke Reservoir 22−23 Jul, 2013

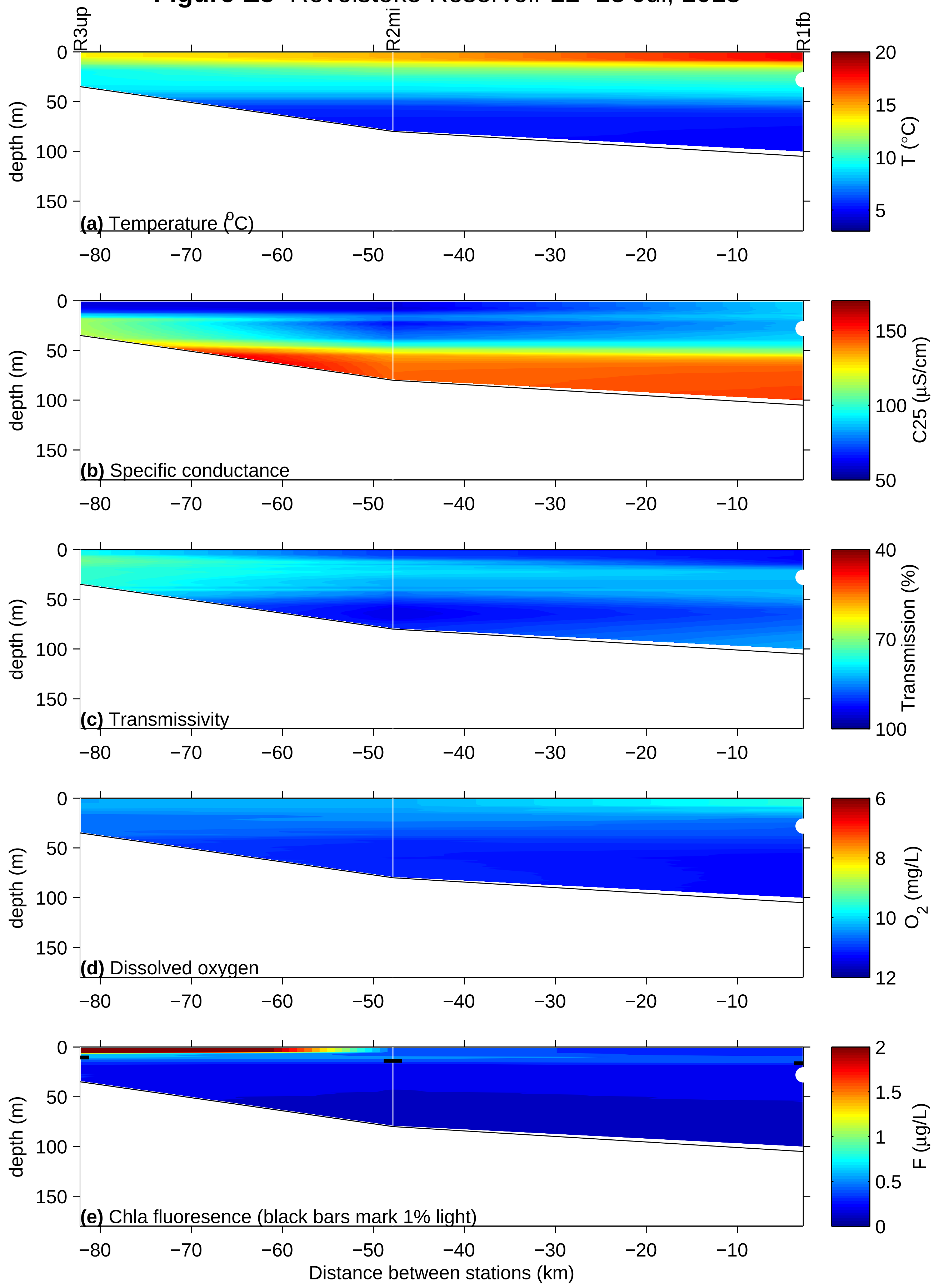


Figure E6 Revelstoke Reservoir 19−20 Aug, 2013

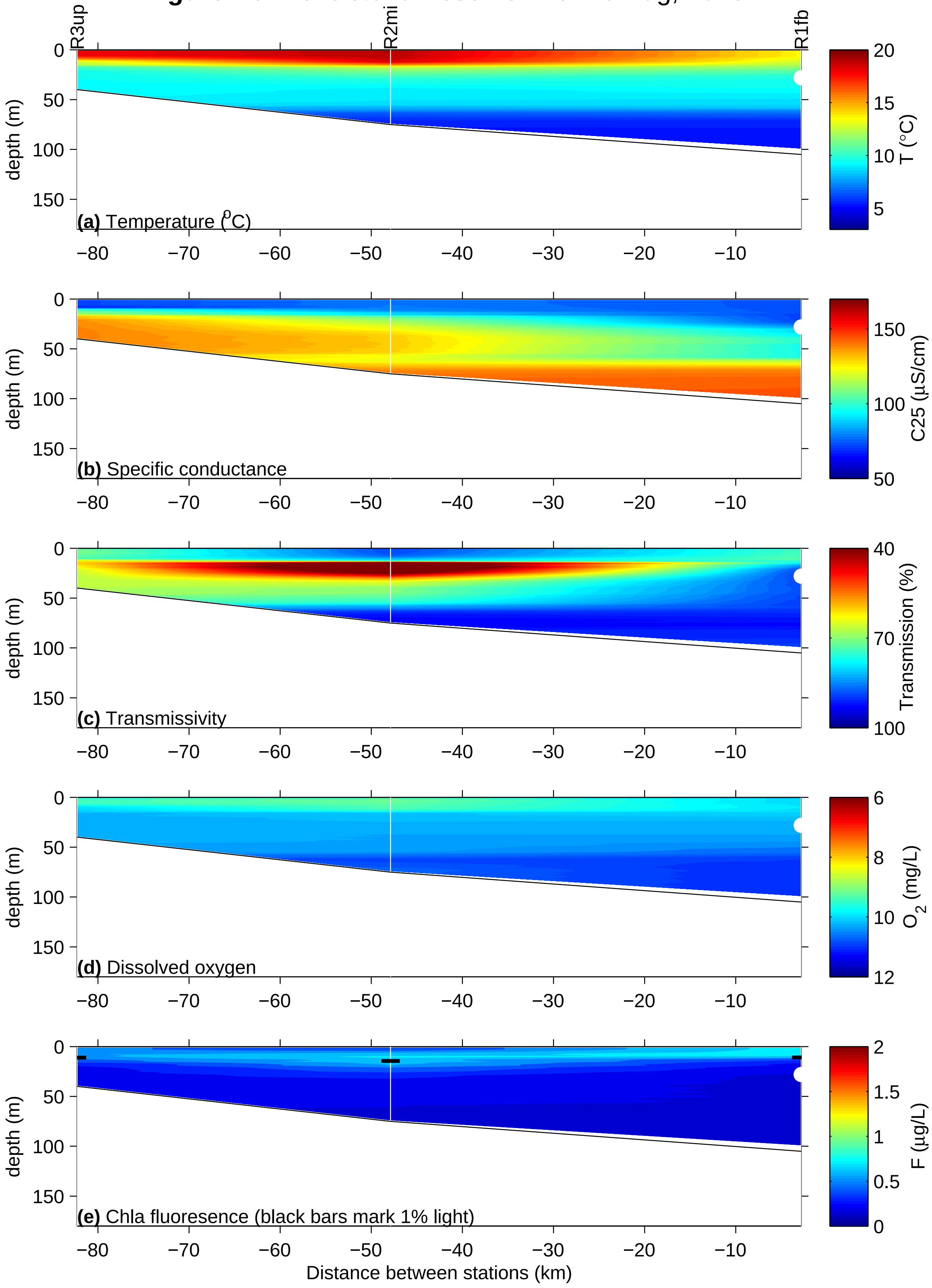


Figure E7 Revelstoke Reservoir 26 Aug, 2013

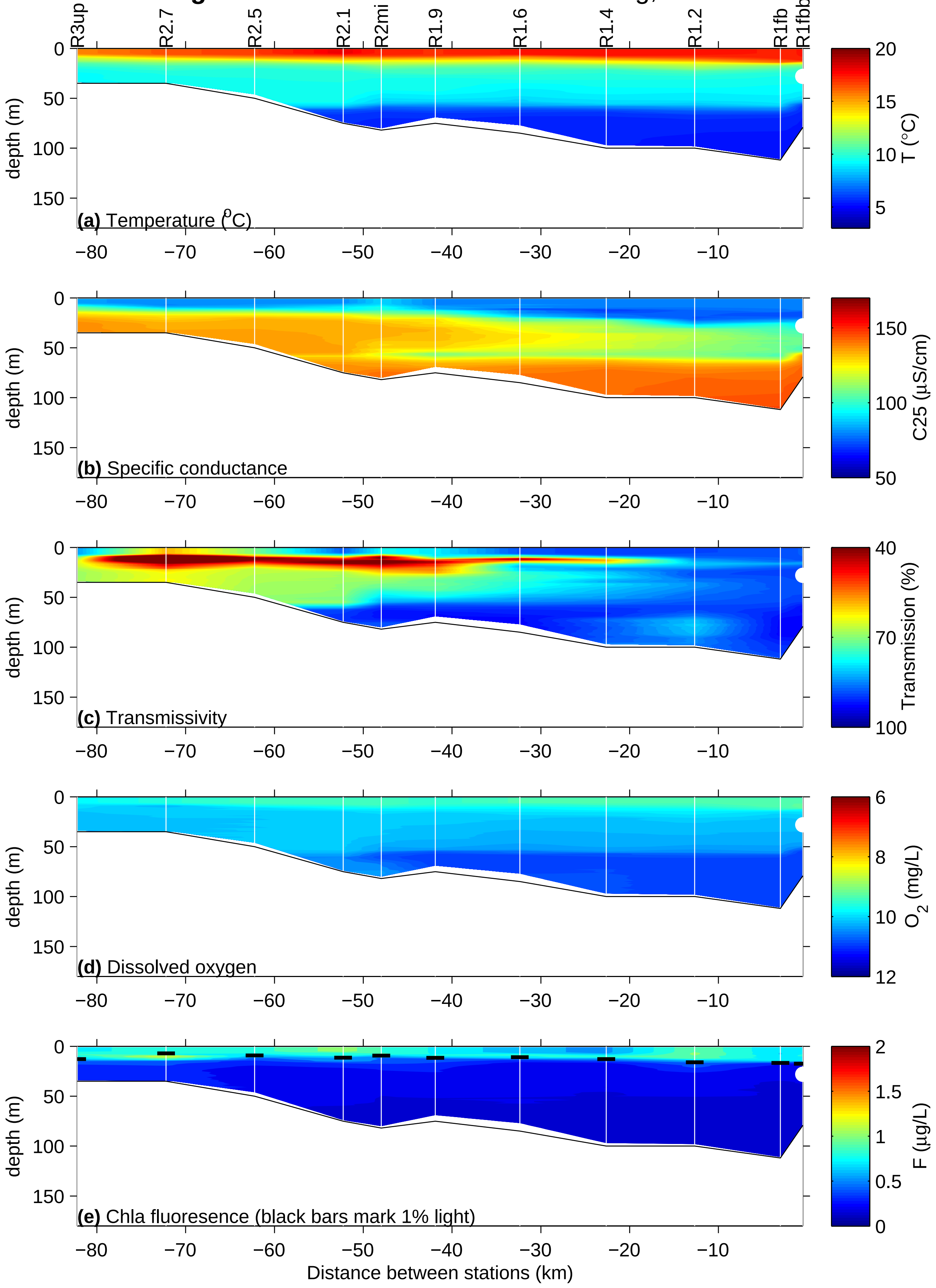


Figure E8 Revelstoke Reservoir 17−18 Sep, 2013

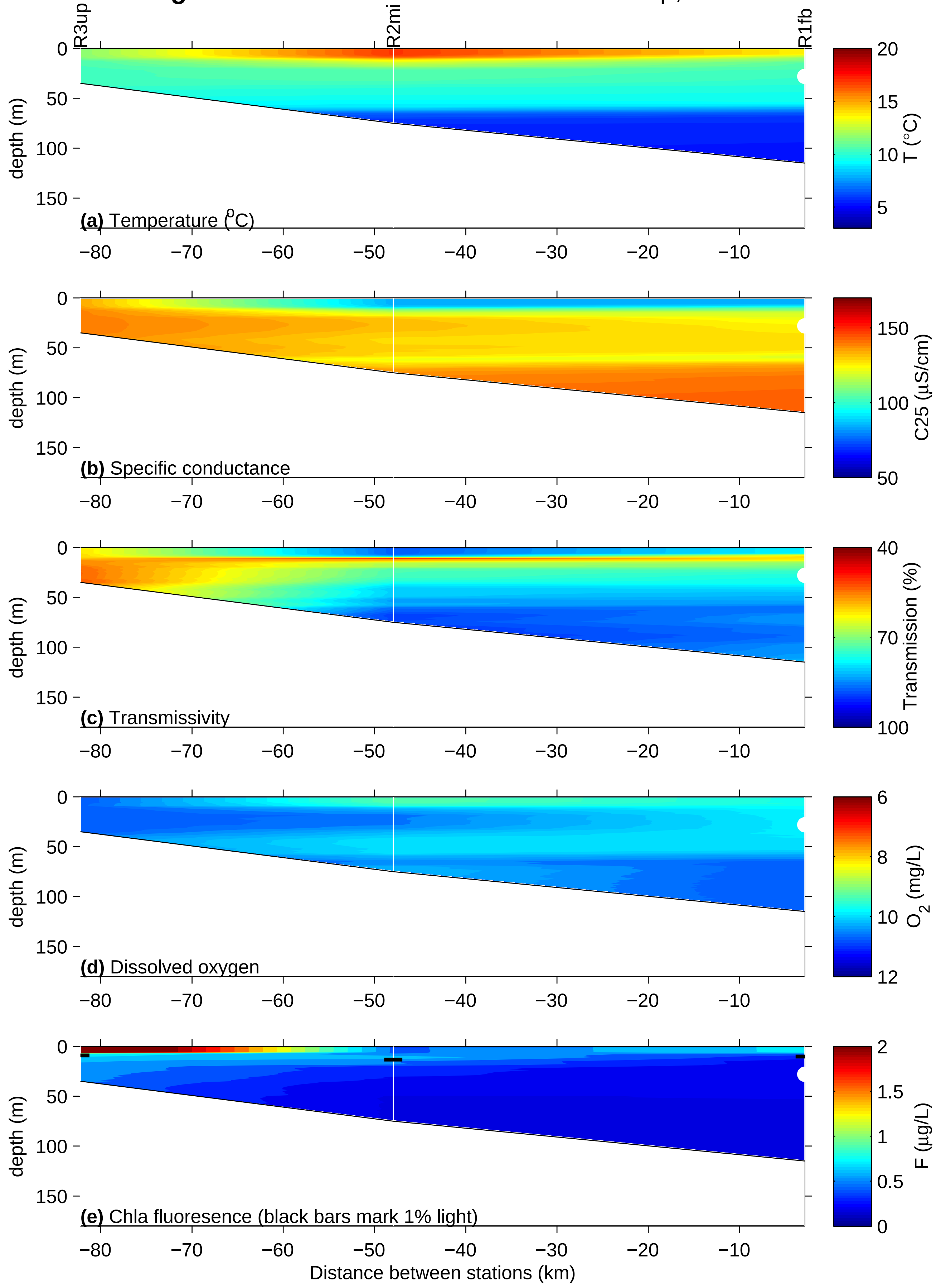
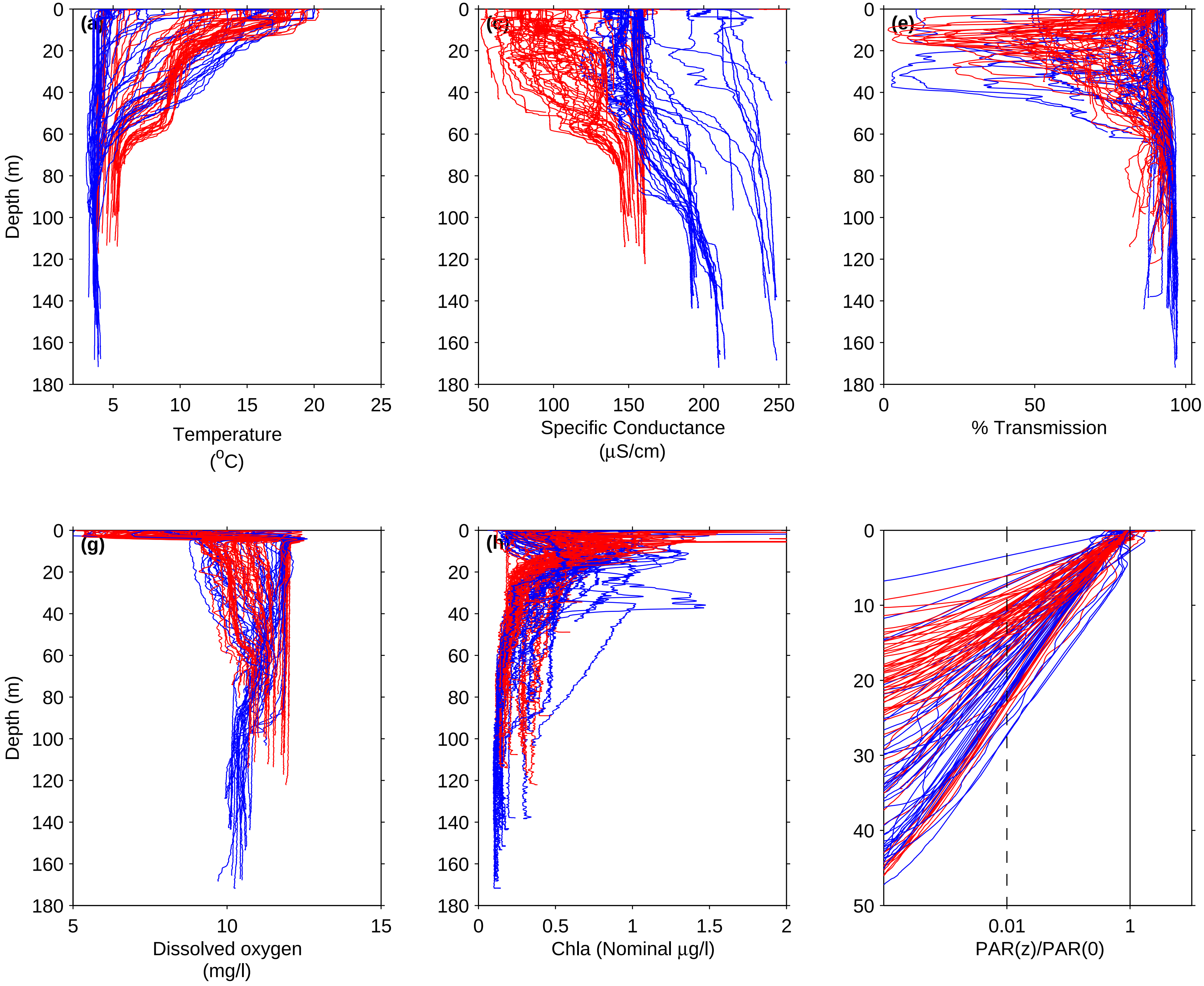


Figure F1 All Kinbasket (BLU) and Revesltoke (RED) Data, 2013



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

Appendix 2 List of Profiles

Cast No	Date	Site Name	Time On	Time Off	GPS	Depth (m)	Stn
1	17/Apr/2013	Rev - Forebay Boat test run	10:46	10:58	51°03.759 118°11.140	123	R1fbsub
2	17/Apr/2013	Rev - Forebay Boat test run	11:07	11:16	51°04.560 118°10.862	90	R1fb
3	22/Apr/2013	Kin - Canoe	10:42	10:51	52°12.427 118°28.457	90	Kca1
4	22/Apr/2013	Kin - Wood	12:58	1:03	52°08.292 118°18.726	35	Kwo1
5	22/Apr/2013	Kin - Middle	13:42	13:55	52°07.884 118°26.374	130	K2mi
6	23/Apr/2013	Kin - Columbia	8:25	8:38	51°58.028 118°04.902	140	K3co
7	23/Apr/2013	Kin - Forebay	10:33	10:47	52°05.674 118°32.859	145	K1fb
8	29/Apr/2013	Rev - Forebay	8:35	8:45	51°04.559 118°10.863	105	R1fb
9	29/Apr/2013	Rev - 10km from Forebay	9:00	9:10	51°09.838 118°12.742	100	R1.2
10	29/Apr/2013	Rev - 20km from Forebay	9:23	9:33	51°15.164 118°14.347	100	R1.4
11	29/Apr/2013	Rev - 30km from Forebay	9:47	9:56	51°19.550 118°20.700	87	R1.6
12	29/Apr/2013	Rev - 50km from Forebay	10:28	10:33	51°29.047 118°29.090	50	R2.1
13	29/Apr/2013	Rev - 60km from Forebay	10:48	10:53	51°33.727 118°33.506	50	R2.5
14	29/Apr/2013	Rev - 70km from Forebay	11:09	11:13	51°38.612 118°37.231	32	R2.7
15	29/Apr/2013	Rev - Upper	11:29	11:34	51°43.732 118°39.614	35	R3up
16	29/Apr/2013	Rev - Middle	13:06	13:14	51°26.681 118°28.182	80	R2mi
17	30/Apr/2013	Rev - Forebay	8:18	8:28	51°04.477 118°10.902	110	R1fb
18	30/Apr/2013	Rev - Submerged Temperature Array	9:21	9:32	51°03.864 118°11.073	120	R1fbsub
19	01/May/2013	Kin - Mouth of Canoe Reach	10:18	10:28	52°10.567 118°27.096	100	Kca0
20	01/May/2013	Kin - 25km from mouth of Canoe	10:59	11:03	52°22.067 118°38.626	30	Kca2.7
21	01/May/2013	Kin - Mouth of Wood Arm	11:59	12:04	52°09.045 118°23.142	45	Kwo0
22	01/May/2013	Kin - 5km from mouth of Wood	12:12	12:17	52°08.289 118°18.882	35	Kwo1
23	01/May/2013	Kin - 10km from mouth of Wood	12:25	12:29	52°08.449 118°14.424	27	Kwo1.5
24	01/May/2013	Kin - 14.3km from mouth of Wood	12:40	12:43	52°09.990 118°10.576	12	Kwo2
25	01/May/2013	Kin - Middle	13:27	13:39	52°07.831 118°26.460	130	K2mi
26	01/May/2013	Kin - Forebay PP Site	13:50	14:03	52°06.920 118°29.974	140	K1.5
27	01/May/2013	Kin - Forebay Submerged Temp Array	14:15	14:28	52°05.669 118°33.027	145	K1fb
28	02/May/2013	Kin - Mouth of Columbia Reach	7:37	7:45	52°06.044 118°24.326	80	K2.1
29	02/May/2013	Kin - 10km from mouth of Columbia	7:59	8:08	52°03.287 118°16.732	100	K2.4
30	02/May/2013	Kin - 20km from mouth of Columbia	8:23	8:30	52°00.256 118°09.443	65	K2.8
31	02/May/2013	Kin - 30km from mouth of Columbia	8:46	8:54	51°57.143 118°02.260	82	K3.1
32	02/May/2013	Kin - 40km from mouth of Columbia	9:09	9:14	51°53.625 117°55.581	45	K3.5
33	02/May/2013	Kin - 50km from mouth of Columbia	9:30	9:34	51°50.309 117°48.579	35	K3.7
34	02/May/2013	Kin - 56km from mouth of Columbia	9:53	9:57	51°48.532 117°44.300	28	K3.9
35	13/May/2013	Kin - Canoe	10:46	10:55	52°12.440 118°28.463	85	Kca1
36	13/May/2013	Kin - Wood	12:16	12:21	52°08.282 118°18.691	38	Kwo1
37	13/May/2013	Kin - Middle	13:03	13:13	52°07.896 118°26.340	105	K2mi
38	13/May/2013	Kin - Forebay	13:47	14:00	52°05.667 118°32.905	145	K1fb
39	14/May/2013	Kin - Columbia	8:18	8:26	51°58.998 118°04.885	140	K3co
40	21/May/2013	Rev - Upper	9:47	9:51	51°43.750 118°39.593	35	R3up
41	21/May/2013	Rev - Middle	11:18	11:27	51°26.706 118°28.182	85	R2mi
42	22/May/2013	Rev - Forebay	8:17	8:28	51°04.478 118°10.924	110	R1fb
43	10/Jun/2013	Kin - Canoe	10:26	10:35	52°12.534 118°28.487	90	Kca1
44	10/Jun/2013	Kin - Wood	12:03	12:08	52°08.281 118°18.622	45	Kwo1
45	10/Jun/2013	Kin - Middle	13:11	13:25	52°07.840 118°26.407	145	K2mi
46	10/Jun/2013	Kin - Forebay	13:41	13:55	52°05.630 118°32.946	155	K1fb
47	11/Jun/2013	Kin - Columbia	8:16	8:30	51°58.064 118°04.992	150	K3co
48	17/Jun/2013	Rev - Upper	9:18	9:23	51°42.756 118°39.600	35	R3up
49	17/Jun/2013	Rev - Middle	10:56	11:04	51°26.672 118°28.137	80	R2mi
50	17/Jun/2013	Rev - Downie Loop Across from Boat Launch	12:05	12:12	51°27.915 118°27.125	65	Rd0
51	17/Jun/2913	Rev - Downie Loop 3.35km from BL Site	12:23	12:27	51°29.100 118°24.936	27	Rd1
52	18/Jun/2013	Rev - Forebay	9:28	9:38	51°04.491 118°10.977	105	R1fb
53	19/Jun/2013	Kin - PP Site	7:32	7:47	52°06.919 118°30.030	155	K1.5
54	20/Jun/2013	Rev - Middle PP	7:46	7:54	51°26.682 118°28.102	80	R2mi
55	21/Jun/2013	Rev - Forebay PP	7:30	7:41	51°04.495 118°10.889	115	R1fb
56	10/Jul/2013	Rev - Temp Array FB Site	8:05	8:14	51°04.067 118°10.936	90	R1fbsub
57	10/Jul/2013	Rev - Forebay	8:18	8:29	51°04.509 118°10.922	115	R1fb
58	10/Jul/2013	Rev - 10km from Forebay	8:45	8:54	51°09.867 118°12.697	100	R1.2

59	10/Jul/2013	Rev - 20km from Forebay	9:08	9:17	51°15.173 118°14.353	100	R1.4
60	10/Jul/2013	Rev - 30km from Forebay	9:32	9:41	51°19.518 118°20.669	85	R1.6
61	10/Jul/2013	Rev - 40km from Forebay	9:55	10:02	51°23.849 118°26.438	70	R1.9
62	10/Jul/2013	Rev - Temp Array Middle Site	10:13	10:21	51°25.981 118°27.675	78	R2misub
63	10/Jul/2013	Rev - Downie Loop Across from Boat Launch	10:29	10:36	51°27.873 118°27.152	65	Rd0
64	10/Jul/2013	Rev - 50km from Forebay	10:44	10:51	51°29.091 118°29.116	58	R2.1
65	10/Jul/2013	Rev - 60km from Forebay	11:05	11:11	51°33.749 118°33.503	55	R2.5
66	10/Jul/2013	Rev - 70km from Forebay	11:24	11:30	51°38.587 118°37.274	45	R2.7
67	10/Jul/2013	Rev - Upper Site	11:44	11:48	51°43.752 118°39.604	35	R3up
68	15/Jul/2013	Kin - Wood	10:14	10:21	52°08.280 118°18.716	60	Kwo1
69	15/Jul/2013	Kin - Columbia	12:01	12:17	51°57.948 118°04.880	160	K3co
70	15/Jul/2013	Kin - Forebay	14:37	14:52	52°05.620 118°32.978	170	K1fb
71	16/Jul/2013	Kin - Canoe	7:37	7:51	52°12.446 118°28.489	140	Kca1
72	16/Jul/2013	Kin - Middle	9:18	9:30	52°07.846 118°26.419	135	K2mi
73	22/Jul/2013	Rev - Middle	8:24	8:32	51°26.648 118°28.130	80	R2mi
74	22/Jul/2013	Rev - Upper	10:08	10:13	51°43.763 118°39.590	35	R3up
75	22/Jul/2013	Rev - Downie Loop Across from Boat Launch	11:36	11:43	51°27.882 118°27.184	65	Rd0
76	22/Jul/2013	Rev - Downie Loop 3.35km from BL Site	11:50	11:53	51°29.087 118°24.995	25	Rd1
77	23/Jul/2013	Rev - Forebay and PP	7:59	8:09	51°04.427 118°10.908	105	R1fb
78	24/Jul/2013	Kin - PP Site	7:34	7:49	52°06.934 118°29.983	170	K1.5
79	25/Jul/2013	Rev - Middle PP	7:19	7:27	51°26.686 118°28.104	80	R2mi
80	12/Aug/2013	Kin - Canoe	9:50	10:01	52°12.410 118°28.454	120	Kca1
81	12/Aug/2013	Kin - Wood	11:43	11:50	52°08.274 118°19.089	60	Kwo1
82	12/Aug/2013	Kin - Middle	12:52	1:06	52°07.817 118°26.422	145	K2mi
83	12/Aug/2013	Kin - Forebay	13:19	13:35	52°05.663 118°32.864	175	K1fb
84	13/Aug/2013	Kin - Columbia	7:49	8:05	51°57.943 118°04.856	170	K3co
85	19/Aug/2013	Rev - Middle	9:01	9:09	51°26.667 118°28.101	75	R2mi
86	19/Aug/2013	Rev - Upper	10:39	10:44	51°43.792 118°39.611	40	R3up
87	19/Aug/2013	Rev - Downie loops Across from Boat Launch	12:10	12:17	51°27.875 118°27.203	65	Rd0
88	19/Aug/2013	Rev - Downie Loops 3.35km from BL Site	12:24	12:28	51°29.056 118°25.036	35	Rd1
89	20/Aug/2013	Rev - Forebay And PP	7:49	7:59	51°04.454 118°10.950	105	R1fb
90	21/Aug/2013	Kin - PP Site	7:30	7:46	52°06.845 118°30.114	170	K1.5
91	22/Aug/2013	Rev - Middle PP	7:20	7:27	51°26.713 118°28.089	75	R2mi
92	26/Aug/2013	Rev - Forebay	8:26	8:37	51°04.567 118°10.898	112	R1fb
93	26/Aug/2013	Rev - 10km from Forebay	8:55	9:04	51°09.803 118°12.702	100	R1.2
94	26/Aug/2013	Rev - 20km from Forebay	9:21	9:31	51°15.096 118°14.305	100	R1.4
95	26/Aug/2013	Rev - 30km from Forebay	9:47	9:55	51°19.518 118°20.642	85	R1.6
96	26/Aug/2013	Rev - 40km from Forebay	10:14	10:21	51°23.629 118°26.323	75	R1.9
97	26/Aug/2013	Rev - 50km from Forebay	10:37	10:45	51°28.993 118°29.050	75	R2.1
98	26/Aug/2013	Rev - 60km from Forebay	11:00	11:05	51°33.668 118°33.425	50	R2.5
99	26/Aug/2013	Rev - 70km from Forebay	11:20	11:24	51°38.501 118°37.230	35	R2.7
100	26/Aug/2013	Rev - Upper	11:39	11:43	51°43.751 118°39.608	35	R3up
101	26/Aug/2013	Rev - Middle	12:38	12:47	51°26.704 118°28.176	82	R2mi
102	26/Aug/2013	Rev - Forebay by log boom	14:36	14:45	51°03.222 118°11.383	79.3	R1fbbm
103	17/Sep/2013	Rev - Forebay and PP	7:54	8:05	51°04.474 118°10.923	115	R1fb
104	18/Sep/2013	Rev - Middle and PP	8:38	8:47	51°26.702 118°28.120	75	R2mi
105	18/Sep/2013	Rev - Upper	11:06	11:11	51°43.764 118°39.603	35	R3up
106	18/Sep/2013	Rev - Downie Loop Across from Boat Launch	13:33	13:40	51°27.847 118°27.187	65	Rd0
107	18/Sep/2013	Rev - Downie Loop 3.35km from BL Site	13:46	13:51	51°29.038 118°25.049	40	Rd1
108	19/Sep/2013	Kin - PP Site	8:38	na	52°06.812 118°30.206	165	K1.5

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 A4−1 Kinbasket Reservoir, K1.5, 2013

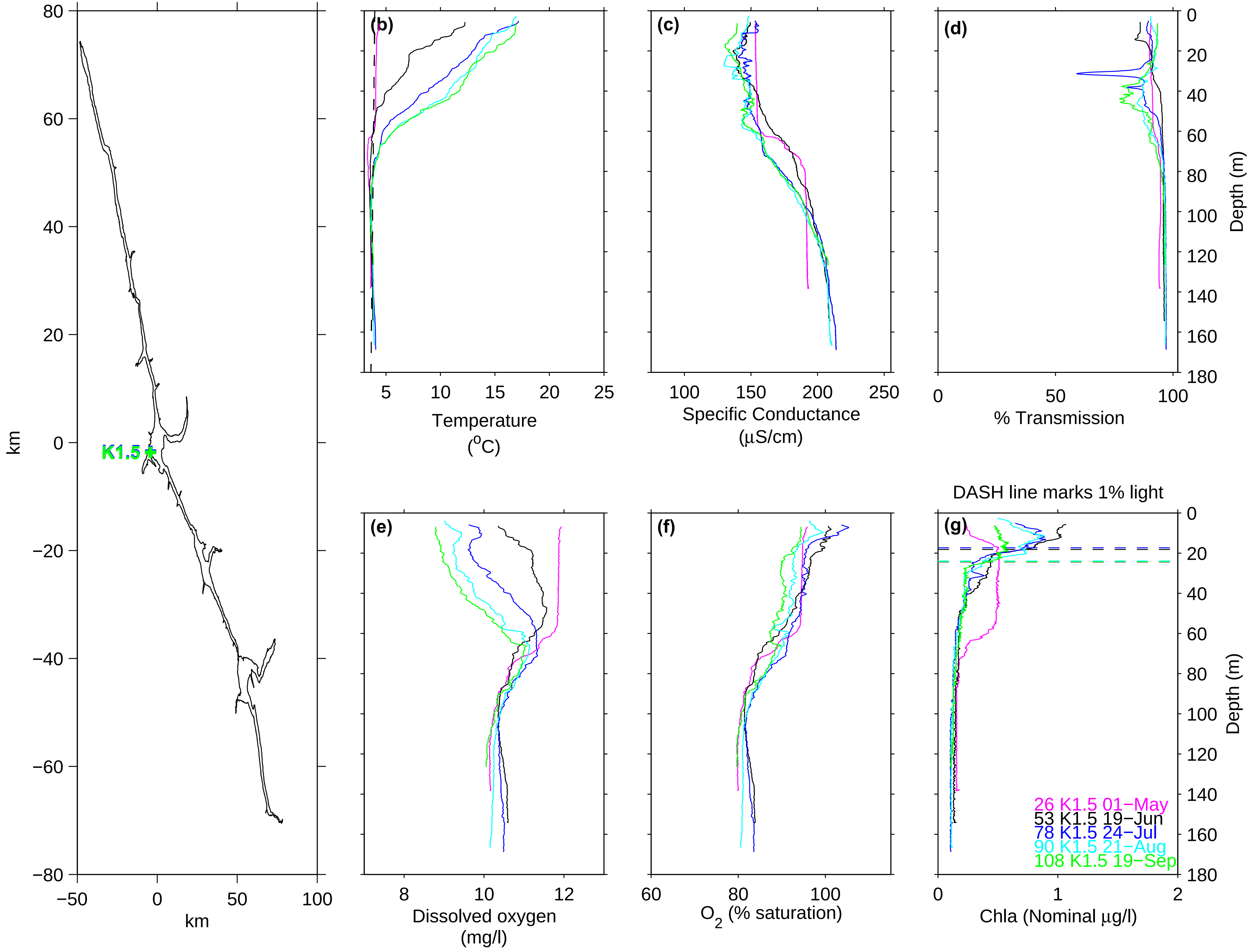


Figure A4−2 Revelstoke Reservoir, Forebay PP 2013

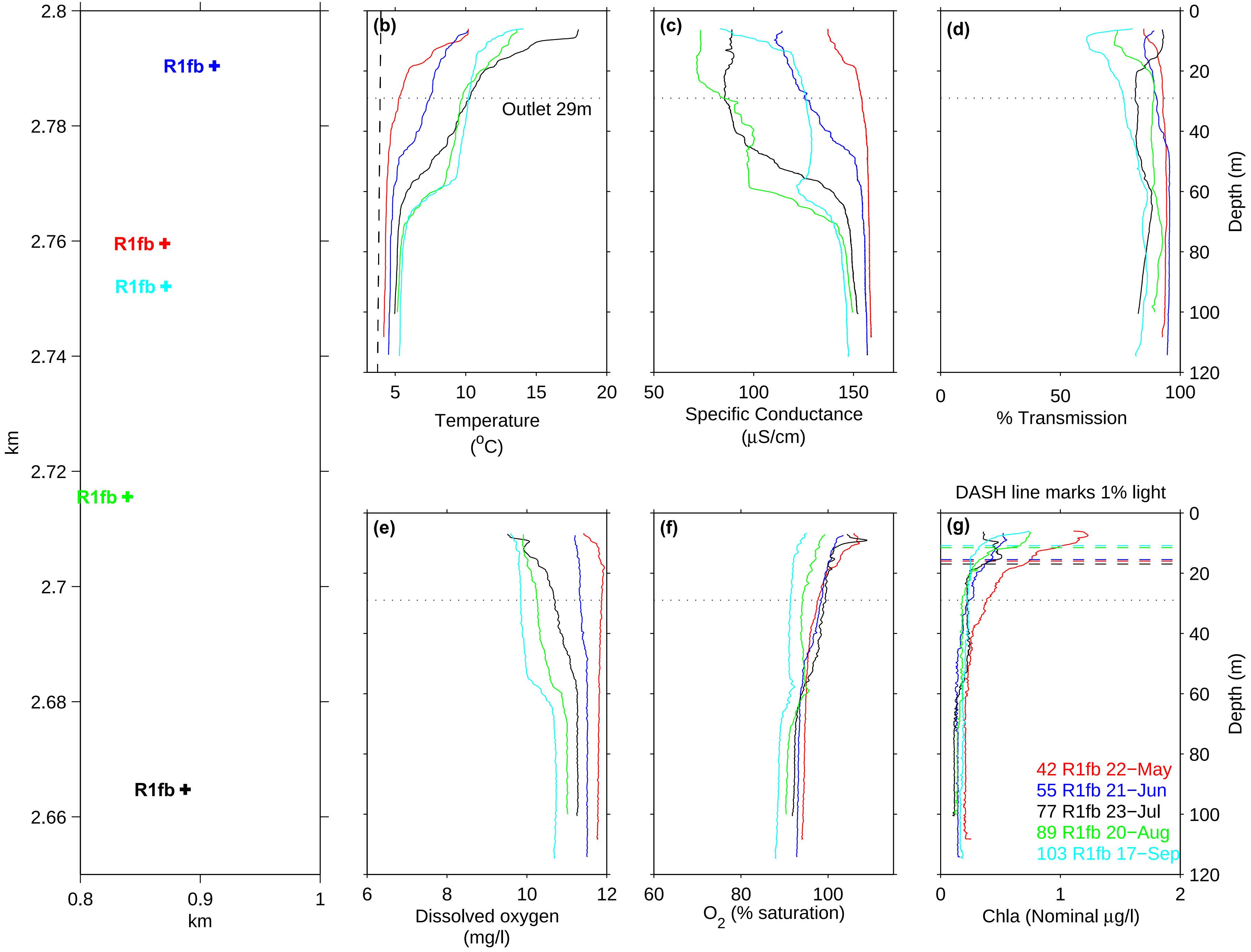
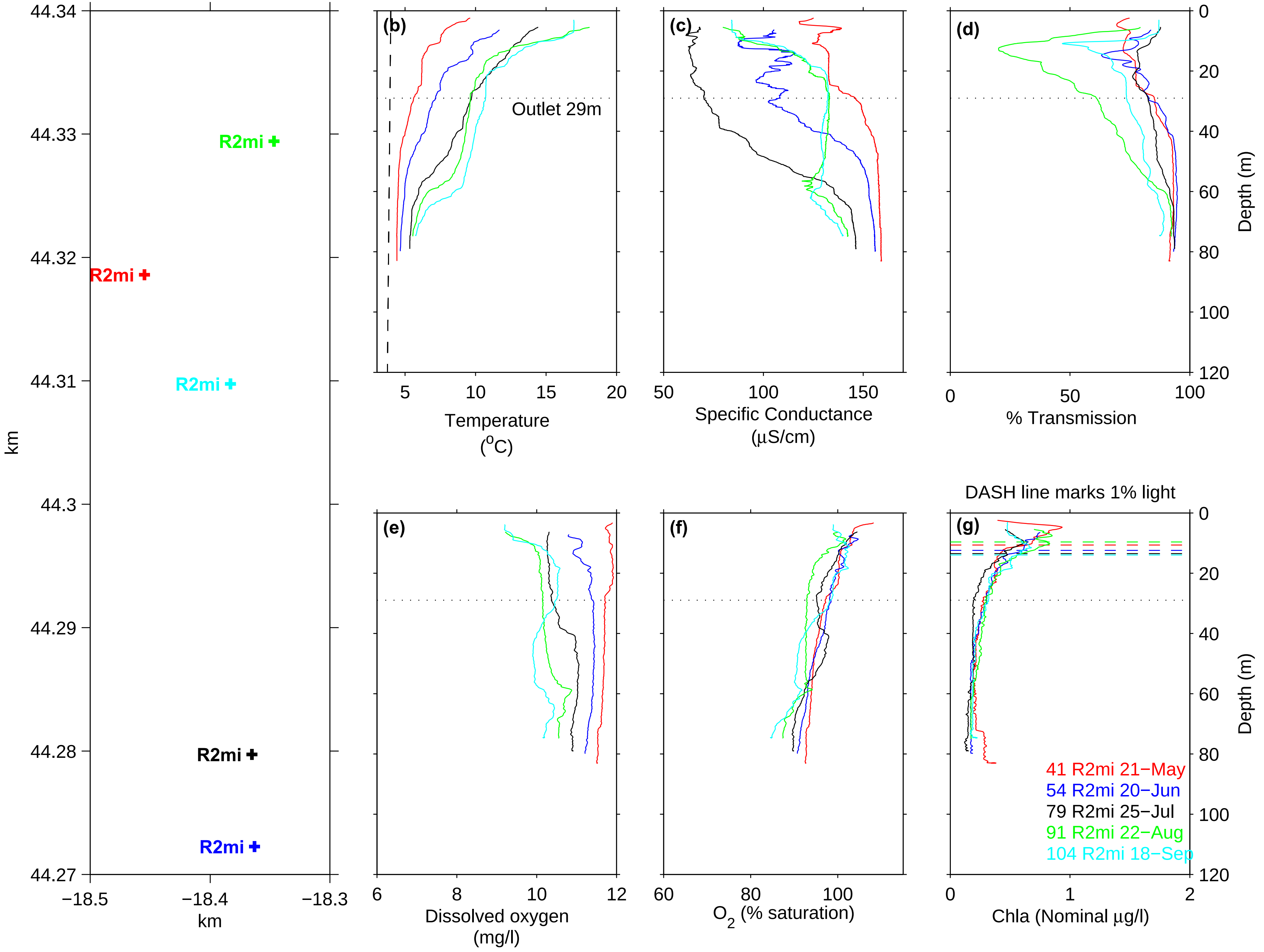


Figure A4−3 Revelstoke Reservoir, Middle PP 2013



Appendix 4

Reservoir Water Chemistry Kinbasket and Revelstoke Reservoirs, 2013

Karen Bray
BC Hydro

Reservoir Water Chemistry
Kinbasket and Revelstoke Reservoirs, 2013

Columbia Reach view toward main pool, May 2013

Prepared By:
Karen Bray
Revelstoke, B.C.

February 2015

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1. Introduction

This report summarises Year 6 (2013) 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, Figure 1). Regular sampling sessions are scheduled once a month from May to October; however, in 2013 an April session was added as per recommendations from previous years. September (Kinbasket) and October (both) sampling sessions were curtailed due to logistical issues.

Five litre Niskin bottles were lowered by cable in series to collect discrete depth samples at 2, 5, 10, 15, 20, 40, 60 and 80 m. A sample at 5 m above bottom was collected at all stations except for REV Upper and for some months in Kinbasket Wood when the site is <65 m depth. A 20 m tube with inside diameter of 2.54 cm was used to obtain a 0-20 m integrated depth sample for analysis of silica (Si) and chlorophyll *a* at each station. Only samples for TDP and SRP were field filtered and all samples were kept cold and packed on ice for shipping to the Maxxam Analytics Laboratory (Burnaby) for analyses. In previous project years samples were analysed at the Cultus Lake laboratory; however, in 2013 a change was made to Maxxam Analytics as Cultus Lake was no longer able to process samples.

Discrete depth 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. Integrated tube samples were analysed for soluble reactive silica. A summary of sample preparation, analytical methods, and laboratory detection limits can be found in Appendix 2 (Tributary Water Chemistry; Pieters et al. 2016).

Note that all alkalinity samples done previously by Cultus Lake were treated as from low alkalinity sources and therefore titrated with additional acid to a pH 4.2 endpoint. This method returned roughly double mg$CaCO_3$/L values as , and therefore, results from 2008-2012 have been adjusted to reflect a standard titration to 4.5 pH as per standard analytical methods (APHA 2012). Results for TP, TDP, and other parameters may be adjusted in future reports if analytical method differences are found between labs. The ratio of NO_2+NO_3 to TDP is no longer calculated as TDP values were almost uniformly near the detection limit of 2 μg/L. All results reported at less than detection limits are transformed to the detection limit for analysis and display purposes.

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 survey dates, 2013.

Station	Coordinates	Max Depth Sampled (m)	Dates Sampled in 2013
KIN Forebay	52°05.611 118°32.932	175	Apr 23, May 13, June 10, July 15, Aug 12
KIN Canoe Reach	52°12.400 118°28.417	140	Apr 22, May 13, June 10, July 16, Aug 12
KIN Wood Arm	52°08.314 118°18.637	60	Apr 22, May 13, June 10, July 15, Aug 12
KIN Columbia Reach	51°58.448 118°05.061	170	Apr 23, May 14, June 11, July 15, Aug 13
REV Forebay	51°04.504 118°10.981	115	Apr 30, May 22, June 18, July 23, Aug 20, Sep 17
REV Middle	51°26.495 118°28.116	85	Apr 29, May 21, June 17, July 22, Aug 19, Sep 18
REV Upper	51°43.797 118°39.579	35	Apr 29, May 21, June 17, July 22, Aug 19, Sep 18

3. Results

Stations were sampled at Kinbasket reservoir forebay elevations between 722.9 m and 752.8 m; full pool is 754.4m and minimum level is 707.1 m (cf. Figure 2 of main report). The reservoir reached its minimum level (722.8 m) for the year on April 24, 2013, and its maximum level (754.6 m) on September 16, 2013. Kinbasket reservoir was surcharged in September 2013, due to construction related outages at Mica Dam. The total range of elevation in 2013 was 31.8 m whereas the maximum licenced range is 47 m without surcharge. The average reservoir elevation range between 1977 and 2013 has been 25.6 m.

In 2013, Revelstoke reservoir daily average elevations ranged by 3m between 569.9 m and 572.9 m. Full pool is 573 m and the normal operating range is within 1.5m (to 571.5 m or Nmin), although the water licence allowable minimum level is much lower. Daily average elevation dipped below the Nmin for 9 days in winter due to cold snaps and for 15 days in fall as a result of a construction outage at Mica Dam. This operation is permitted under the water licence.

Nitrite and Nitrate (**NO_2+NO_3** ***or NN)*** – Average NN was similar across stations in Kinbasket reservoir (115–130 µg/L), with the greatest seasonal variation at KIN Columbia (Table 2, Figures 2 and 6). Average NN was also similar across stations in Revelstoke reservoir (125–147 µg/L), with the greatest seasonal variation at REV Upper station (Table 2, Figures 3 and 6). Overall NN tends to peak in June and decline steadily into the fall, a trend that is consistent across reservoirs and years (Figures 2 and 3). Epilimnetic NN was noticeably higher in June at Kinbasket Columbia and Wood stations and while REV Upper and Mid stations had highest NN in May. The NN monthly profiles tend to remain distinct through the water column until about 60 m where values begin to converge (Figure 6).

Phosphorus (TP/TDP/SRP) – Average Total Phosphorus (TP) in Kinbasket ranged from 2.2–2.8 µg/L with the greatest range at KIN Wood and KIN Forebay stations (Table 2). At Revelstoke stations average TP ranged from 2.3–3.2 µg/L with the highest seasonal average at REV Middle station (Table 2). This high average is a result of two unusually high TP results at 5 m in June and August at REV Middle (10.9 and 15.9 µg/L respectively). Other than a minor spike in alkalinity in August at 5 m, no other parameter from those samples is unusual and both TDP and SRP are low. With those removed from the dataset the average TP becomes 2.6 µg/L at REV Middle. A similar spike occurred in June at KIN Forebay (60 m) with TP at 10.6 µg/L, however, no other parameters were unusual. In May 2013, at REV Upper, three depths returned higher TDP than TP values explaining the range in Table 2. This can occur in systems with very low TP/TDP. Both TP and TDP results are often below the detection limit of 2 µg/L since the laboratory change and will be investigated further.

Average Total Dissolved Phosphorus (TDP) in Kinbasket and Revelstoke reservoirs was at or close to the detection limit (2.0–2.1 µg/L and 2.0–2.3 µg/L, respectively) (Table 2) with a maximum of 4.1 µg/L at KIN Columbia in July (20 m) and 8.6 µg/L at REV Middle in May (2 m) (Table 2), the latter possibly an error.

Soluble Reactive Phosphorus (SRP) across Kinbasket reservoir stations was on average 1.0 to 1.3 µg/L and 1.3 to 1.7 µg/L at all Revelstoke stations with many values below the detection limit of 1.0 µg/L. Highest values in Kinbasket occurred in Canoe Reach (2.8 µg/L) and at REV Forebay (3.9 µg/L) (Table 2). These is little seasonal or depth trend evident in SRP values (Figures 2, 3,and 7). The detection limit for SRP is now 1.0 µg/L as opposed to 0.5 µg/L with the previous laboratory.

Alkalinity and Conductivity – Alkalinity was higher in Kinbasket reservoir, average seasonal values ranging from 65 to 86 mgCaCO$_3$/L in Kinbasket and from 45 to 51 mgCaCO$_3$/L in Revelstoke reservoir (Table 2). Average seasonal conductivity is also higher in Kinbasket (151-198 µS/cm) than in Revelstoke (106-119 µS/cm) (Table 2; Figures 4, 5). Highest conductivity water in Kinbasket comes from the Columbia Reach while the Wood Arm station had lowest seasonal average conductivity. These stations also exhibited the greatest and least seasonal variability in both alkalinity and conductivity, respectively. In Revelstoke reservoir, alkalinities decline along the north-south axis of the reservoir from Rev Upper to REV Forebay stations while conductivities increased.

pH and Turbidity - pH varies little and is always slightly alkaline. Average turbidity was similar across most stations (0.3 – 1.2 NTUs) (Table 2) although KIN Wood and REV Middle had the highest point sample turbidity levels (10 and 3.5 NTUs, respectively).

Silica (Si) – Silica concentrations were similar across stations in each reservoir with a small decline through the sampling season (Figure 8). Reservoir silica averages ranged from 3.1 to 4.3 mg/L. Unusually high values were recorded in Revelstoke reservoir in September; the reason for this is unknown (Table 2; Figure 8).

Secchi – Secchi depths averaged from 5.4 – 8.7 m across the four Kinbasket reservoir stations in 2013 and from 4.1 – 6.8 m in Revelstoke with lowest values at the two most shallow stations: Wood Arm and REV Upper (Table 2; Figure 9). Secchi values were lowest in May at all stations in both reservoirs except KIN Forebay where May Secchi depth was the highest across the year (i.e., greatest clarity) (Figure 9).

Table 2. Average water chemistry values for all depths combined at Kinbasket (Apr-Aug) and Revelstoke (Apr-Sep) reservoir stations, sampled monthly, 2013. Range of values 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	115 (89.7-143)	121 (90.5-143)	116 (71.8-177)	130 (61.0-240)	125 (59.7-180)	134 (58.4-250)	147 (55.1-266)
TP*	µg/L	2.5 (2.0-10.6)	2.2 (2.0 – 4.0)	2.8 (2.0 – 6.2)	2.4 (2.0 – 3.9)	2.3 (2.0 – 4.2)	3.2 (2.0 – 15.9)	2.8 (2.0 – 3.9)
TDP*	µg/L	2.1 (2.0 – 3.1)	2.1 (2.0 – 3.3)	2.0 (2.0 – 2.7)	2.1 (2.0 – 4.1)	2.0 (2.0 – 2.5)	2.2 (2.0 – 8.6)	2.3 (2.0 – 4.3)
SRP*	µg/L	1.0 (1.0 – 1.6)	1.3 (1.0 – 2.8)	1.1 (1.0 – 3.5)	1.2 (1.0 – 2.6)	1.3 (1.0 – 3.9)	1.4 (1.0 – 3.6)	1.7 (1.0 – 3.6)
Alkalinity	mg $CaCO_3$/L	67 (53–87)	65 (40-85)	66 (59-71)	86 (66-105)	51 (29-67)	49 (23–70)	45 (21–64)
pH		8.0 (7.7 – 8.2)	8.0 (7.8 – 8.2)	8.0 (7.9 – 8.1)	8.1 (7.9 – 8.2)	7.8 (7.5 – 8.1)	7.8 (7.5 – 8.0)	7.8 (7.6 – 8.0)
Conductivity	µS/cm	156 (107-203)	153 (124 - 199)	151 (135 - 165)	198 (109 - 243)	119 (72.4 - 155)	113 (61.3 - 158)	106 (55.2-143)
Turbidity†	NTU	0.3 (0.1 – 1.6)	0.4 (0.1 – 1.4)	1.2 (0.3 – 10)	0.7 (0.1 – 3.4)	0.5 (0.1 – 1.6)	0.7 (0.2 - 3.5)	1.2 (0.2 – 1.9)
Silica**	mg/L	3.1 (2.8 – 3.4)	3.2 (2.9 – 3.5)	3.1 (2.9 – 3.4)	3.3 (2.6 – 4.2)	3.8 (2.9 – 6.2)	4.0 (2.8 – 6.9)	4.3 (3.0 – 6.1)
Secchi	m	8.7 (6.2-10.8)	6.0 (4.0 – 9.8)	5.5 (1.5 -10)	5.4 (1.9 – 9.3)	6.8 (4.5 – 8.0)	5.9 (3.8 – 8.0)	4.1 (2.3 – 6.5)

*Laboratory detection limit for SRP=1.0 ug/L, for TP/TDP=2.0 ug/L

**Silica values are from a single 0-20 integrated sample per month.

4. Discussion

The 2013 results represent the sixth 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. With this increasing dataset, seasonal and spatial comparisons and trends are beginning to emerge and will be the subject of analysis in the next synthesis report following the 2015 monitoring year.

Similar seasonal patterns for reservoir average nitrite-nitrate, alkalinity, and conductivity are present among years. The change in laboratory in 2013 has resulted in much lower reported total and total dissolved phosphorus fractions that would classify both reservoirs as ultra-oligotrophic according to Wetzel's (2001) classification of productivity. 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 continue to begin in April to add early season data and 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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Wetzel, R. 2001. Limnology. Third Edition. Academic Press, San Diego, USA.

Acknowledgements

Thanks are extended to Beth Manson and Pierre Bourget who collected, field processed, and shipped water samples.

Figure 1. Location of sampling stations on Kinbasket and Revelstoke reservoirs, 2013.

Figure 2. Seasonal average NN, TP, TDP, and SRP (µg/L) at Kinbasket Reservoir stations, 2009-2013. Note change in laboratory in 2013.

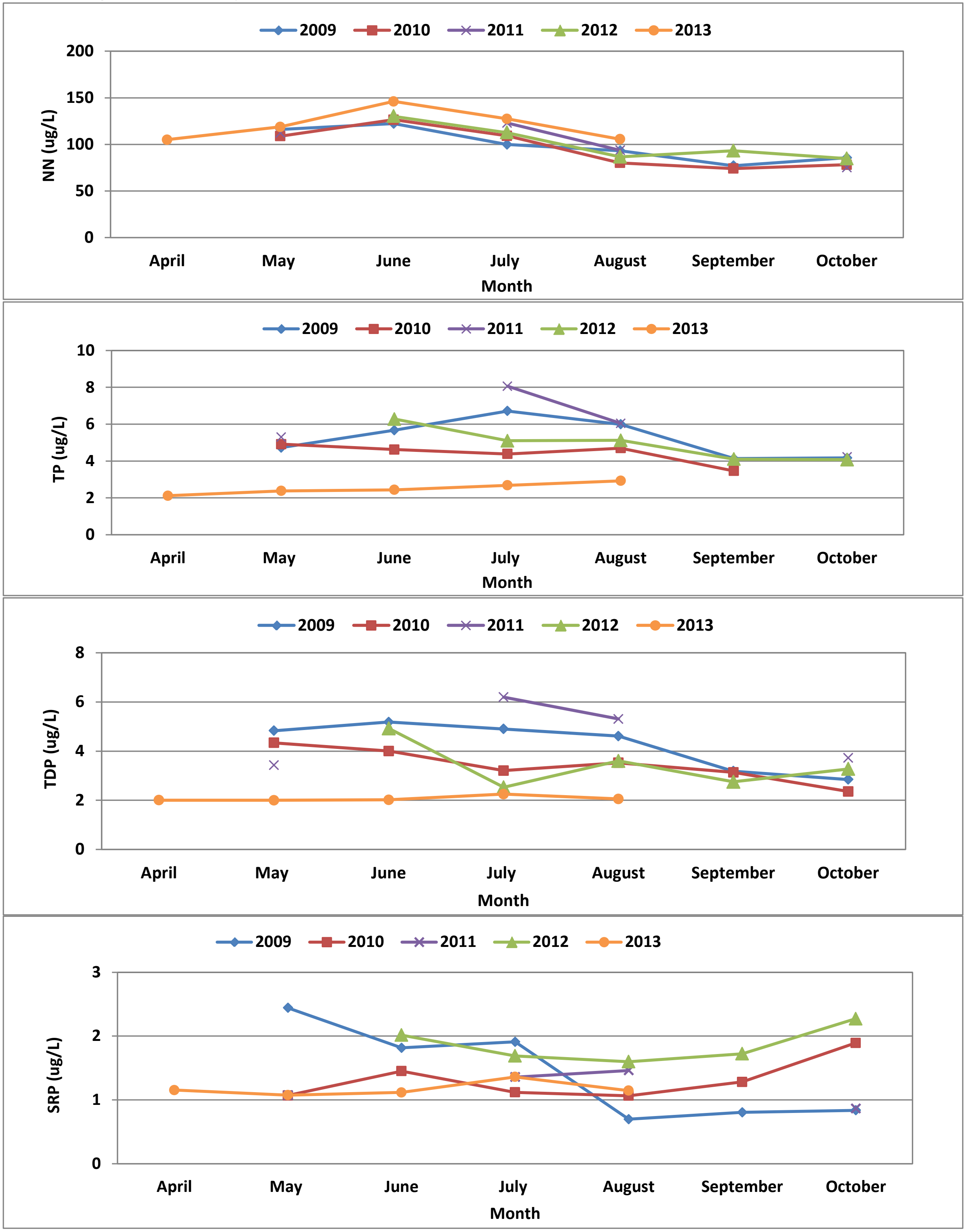


Figure 3. Seasonal average NN, TP, TDP, and SRP (µg/L) at Revelstoke Reservoir stations, 2009-2013. Note change in laboratory in 2013.

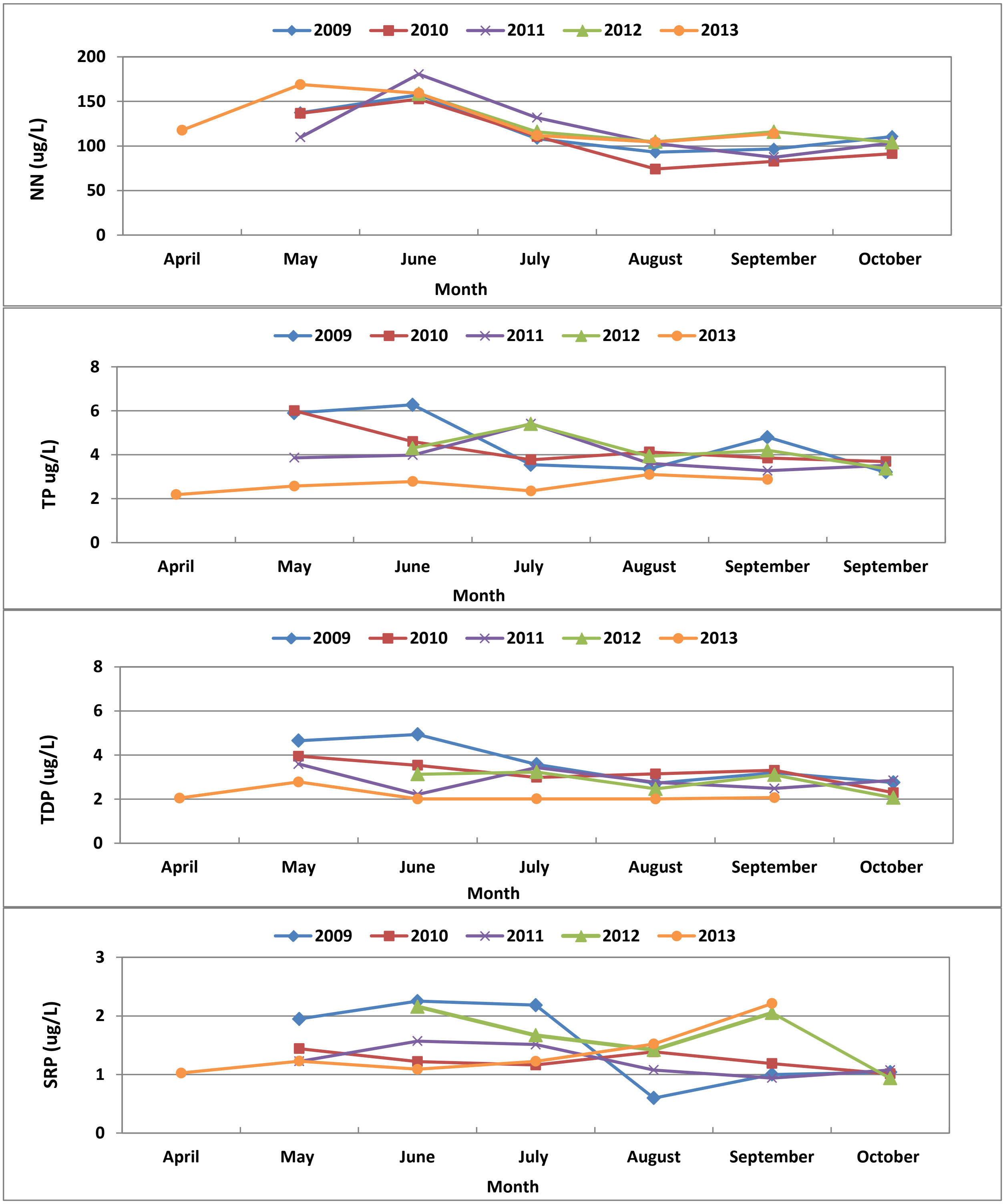
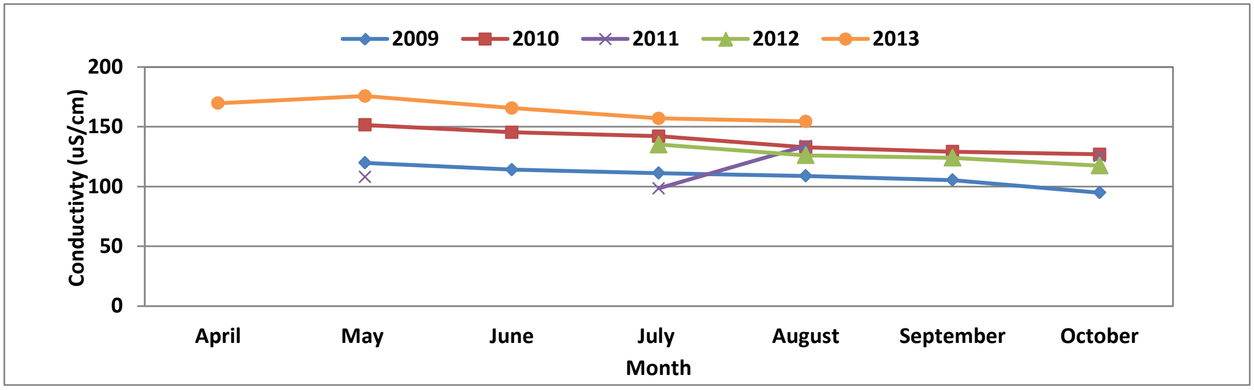


Figure 4. Seasonal average (a) conductivity (µS/cm) and (b) alkalinity (mgCaCO$_3$/L) at Kinbasket Reservoir stations, 2009-2013. Note change in laboratory in 2013.

(a)



(b)

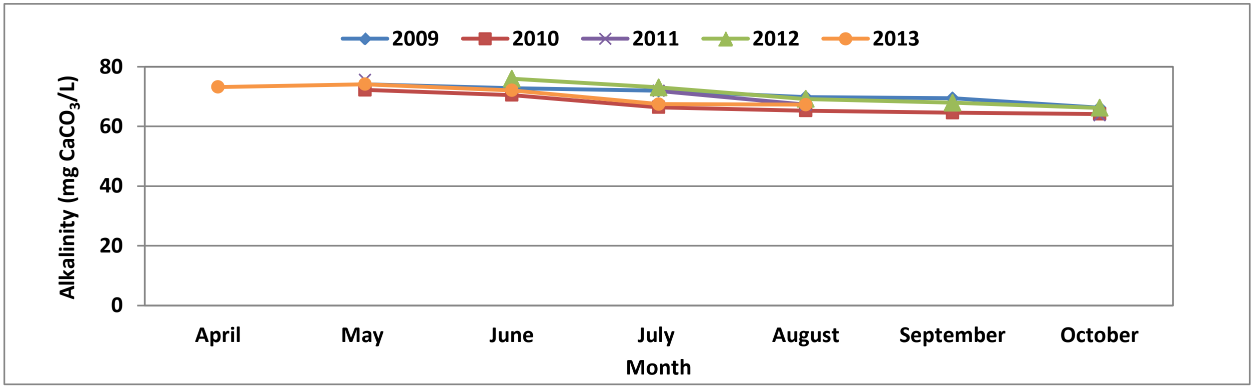


Figure 5. Seasonal average (a) conductivity (µS/cm) and (b) alkalinity (mg$CaCO_3$/L) at Revelstoke Reservoir stations, 2009-2013. Note change in laboratory in 2013.

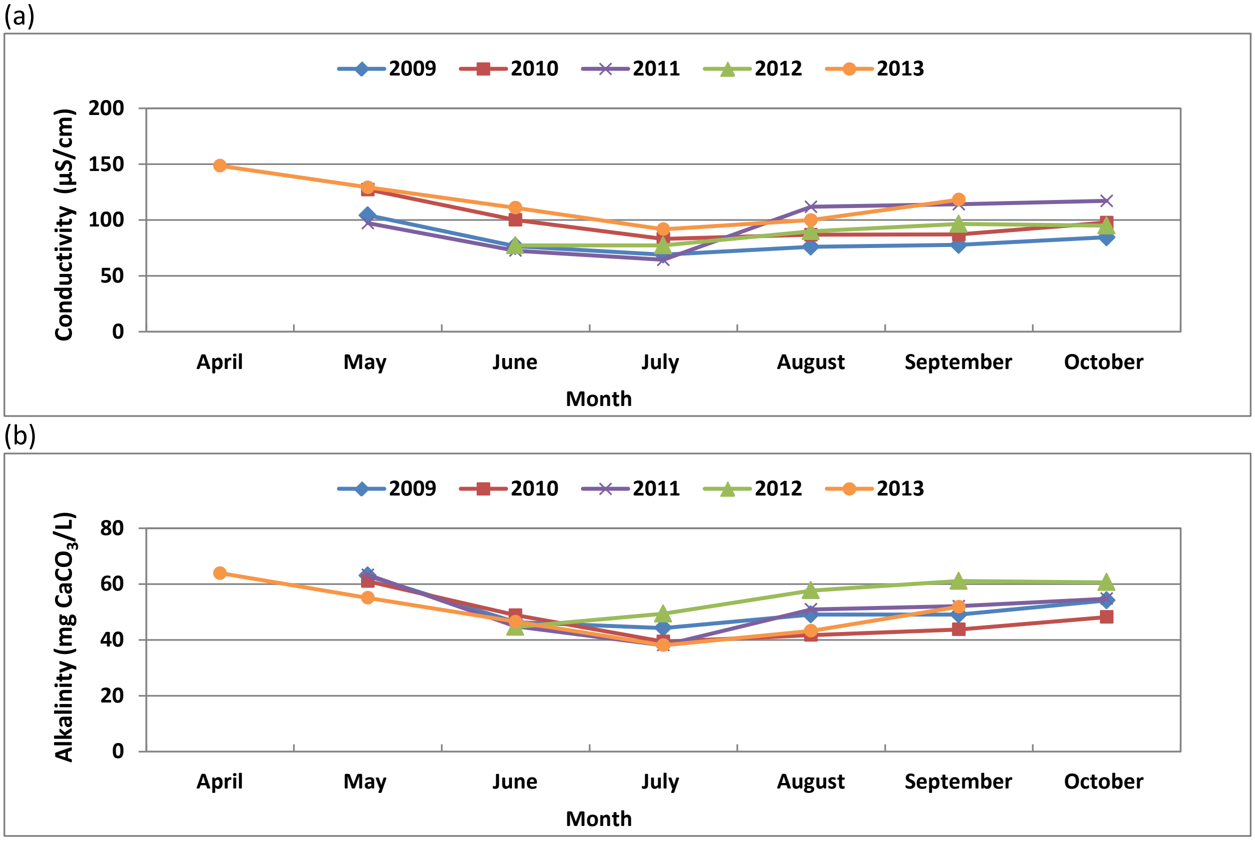
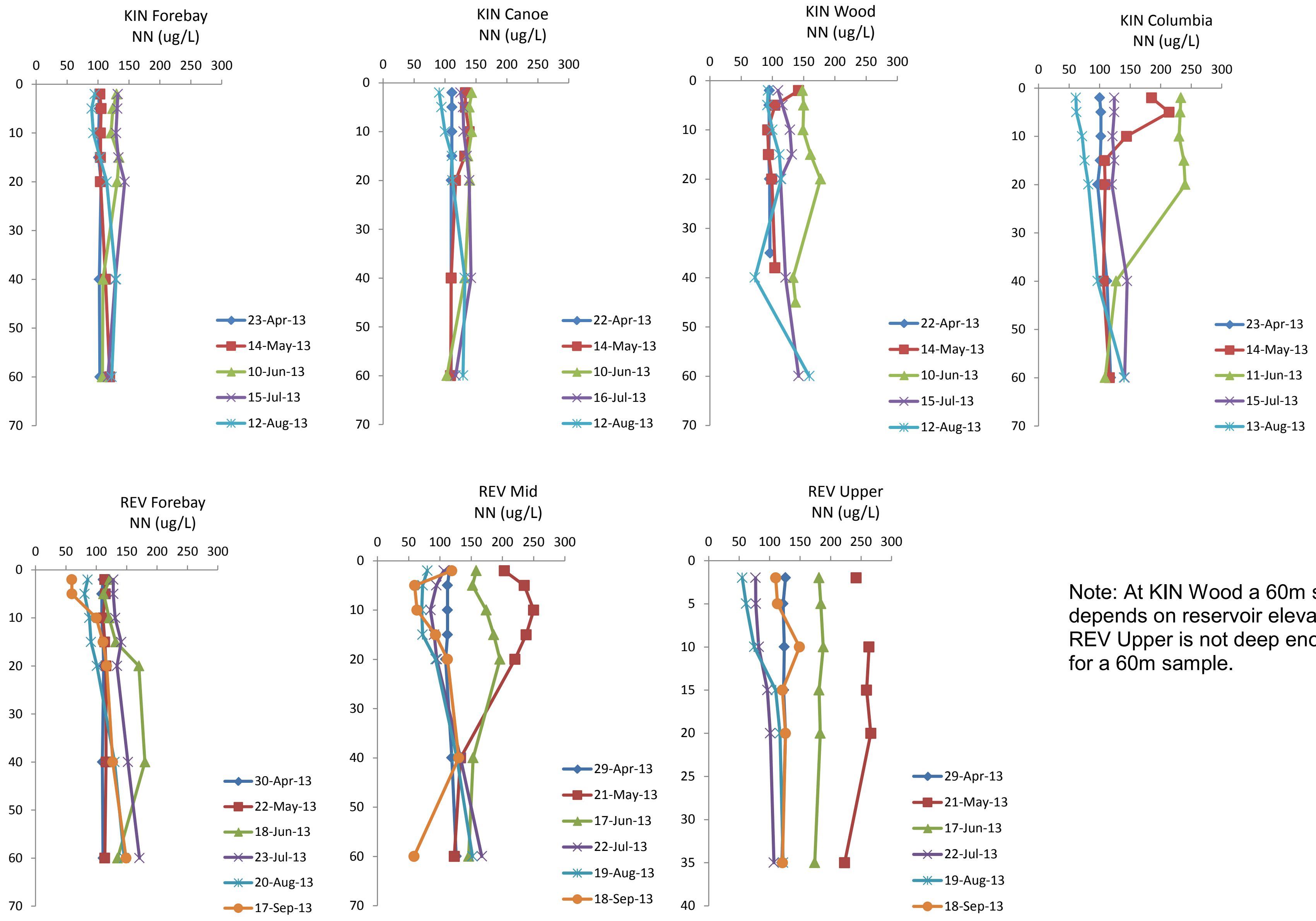


Figure 6. NN (µg/L) depth profiles (0-60m) for Kinbasket and Revelstoke Reservoir stations, 2013.



Note: At KIN Wood a 60m sample depends on reservoir elevation. REV Upper is not deep enough for a 60m sample.

Figure 7. SRP (µg/L) depth profiles (0-60m) for Kinbasket and Revelstoke Reservoir stations, 2013.

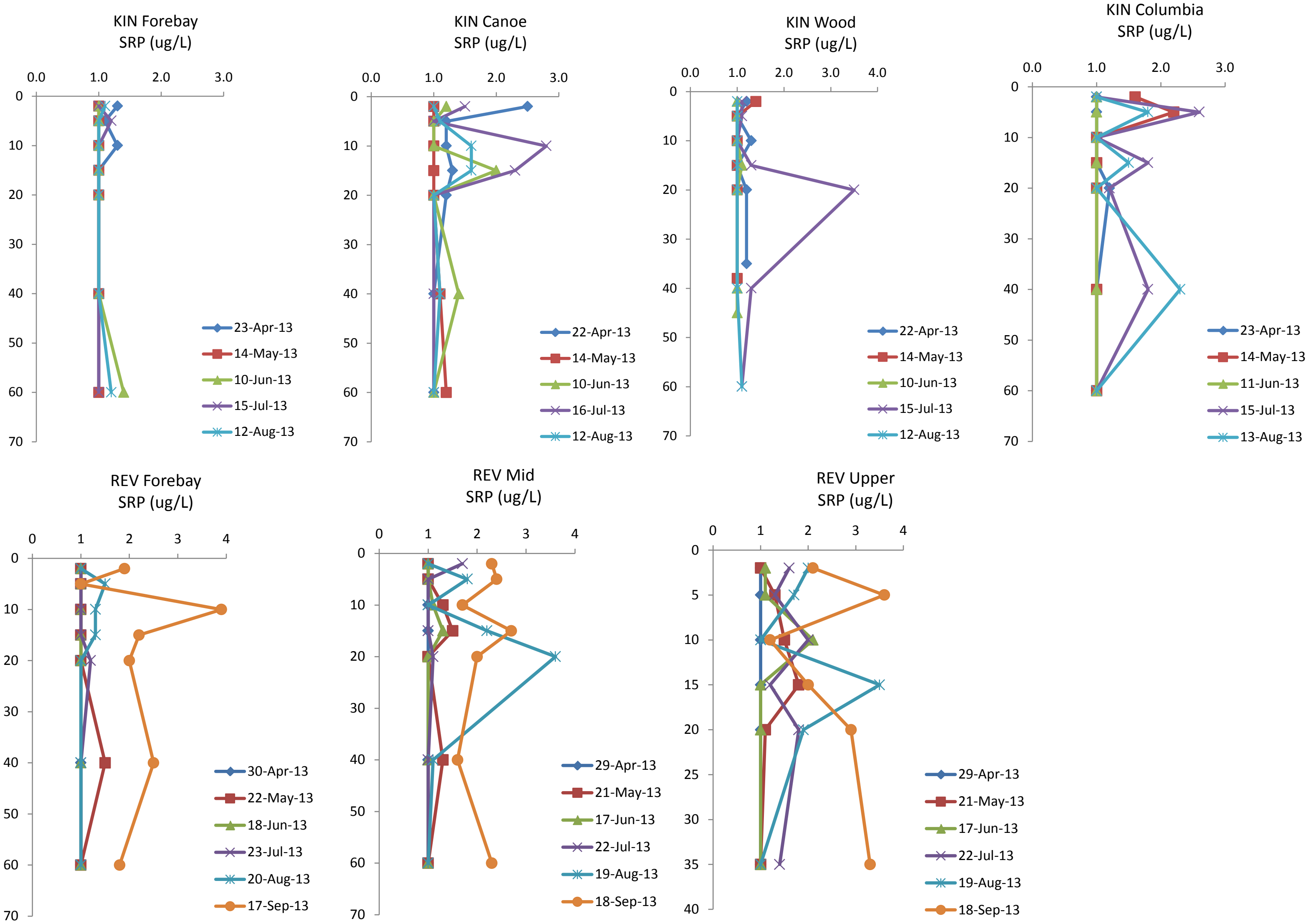


Figure 8. Seasonal silica (mg/L) from a 0-20m integrated tube sample at (a) Kinbasket and (b) Revelstoke stations, 2013.

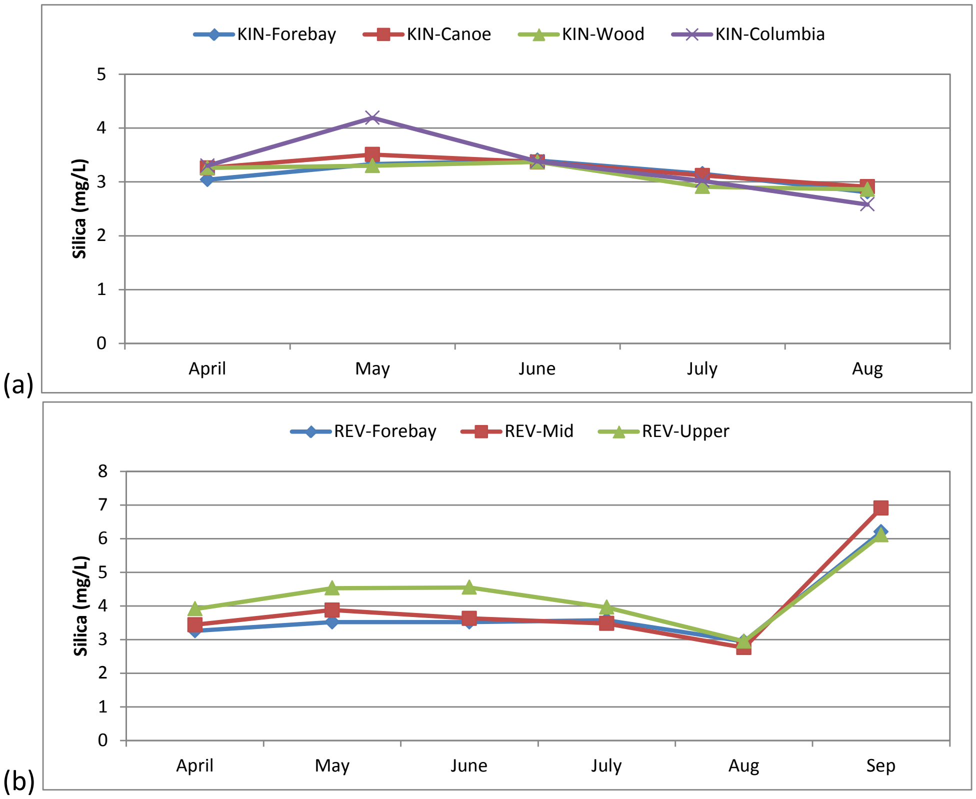
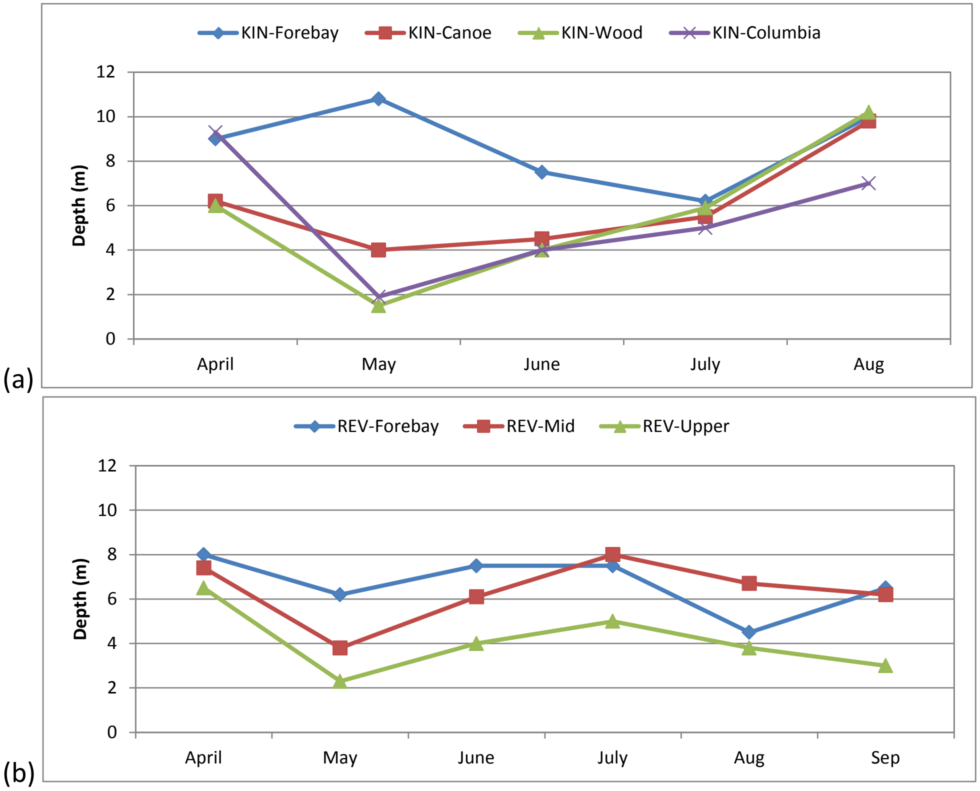


Figure 9. Seasonal Secchi depth (m) at (a) Kinbasket and (b) Revelstoke stations, 2013.



Appendix 1 – Data

Station	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uS/cms
KIN FB	2	23-Apr-13	101.0	1.30	2.00	2.00		63.3	8.05	0.31	146.0
	5	23-Apr-13	102.0	1.10	2.00	2.00		63.7		0.29	148.0
	10	23-Apr-13	101.0	1.30	2.00	2.00		64.0		0.27	148.0
	15	23-Apr-13	101.0	1.00	2.10	2.00		62.8	8.08	0.28	149.0
	20	23-Apr-13	105.0	1.00	2.00	2.00		61.8	8.09	0.27	148.0
	40	23-Apr-13	102.0	1.00	2.00	2.00		64.4	8.09	0.26	149.0
	60	23-Apr-13	103.0	1.00	2.00	2.00		65.6	8.09	0.25	154.0
	80	23-Apr-13	107.0	1.00	2.00	2.00		72.0	8.13	0.24	167.0
	145	23-Apr-13	123.0	1.00	2.00	2.00		79.5	8.12	0.17	184.0
	2	14-May-13	103.0	1.00	2.00	2.00		63.0	8.08	0.19	151.0
	5	14-May-13	105.0	1.00	2.00	2.00		63.7	8.03	0.18	150.0
	10	14-May-13	104.0	1.00	2.00	2.00		63.4	8.06	0.18	151.0
	15	14-May-13	104.0	1.00	2.60	2.00		63.5	8.07	0.19	152.0
	20	14-May-13	104.0	1.00	5.20	2.00		63.7	8.07	0.23	153.0
	40	14-May-13	112.0	1.00	2.30	2.00		68.9	8.11	0.18	165.0
	60	14-May-13	119.0	1.00	2.00	2.00		77.2	8.14	0.15	185.0
	80	14-May-13	126.0	1.00	2.10	2.00		80.2	8.16	0.15	188.0
	145	14-May-13	124.0	1.00	2.00	2.00		81.6	8.16	0.19	193.0
	2	10-Jun-13	130.0	1.00	2.00	2.00		61.1	7.99	0.29	142.0
	5	10-Jun-13	124.0	1.00	2.00	2.00		60.0	7.99	0.28	145.0
	10	10-Jun-13	121.0	1.00	2.00	2.00		61.5	7.99	0.25	146.0
	15	10-Jun-13	134.0	1.00	2.00	2.00		60.7	7.98	0.30	144.0
	20	10-Jun-13	131.0	1.00	2.00	2.00		61.8	7.98	0.26	145.0
	40	10-Jun-13	108.0	1.00	2.00	2.00		63.9	8.02	0.18	152.0
	60	10-Jun-13	107.0	1.40	10.60	2.00		67.3	8.01	0.13	158.0
	80	10-Jun-13	113.0	1.00	2.00	2.70		74.3	8.04	0.14	173.0
	155	10-Jun-13	118.0	1.00	2.00	2.00		86.5	8.07	0.16	201.0
	2	15-Jul-13	132.0	1.00	2.40	2.00		61.9	7.89	0.10	147.0
	5	15-Jul-13	131.0	1.20	2.40	2.00		63.4	7.91	0.48	147.0
	10	15-Jul-13	129.0	1.00	2.40	2.00		63.1	7.87	0.54	147.0
	15	15-Jul-13	133.0	1.00	2.40	3.10		62.0	7.78	0.54	143.0
	20	15-Jul-13	143.0	1.00	2.10	2.00		53.3	7.65	0.42	137.0
	40	15-Jul-13	128.0	1.00	2.00	2.00		59.2	7.87	0.13	143.0
	60	15-Jul-13	116.0	1.00	2.00	2.00		67.8	7.90	0.10	158.0
	80	15-Jul-13	121.0	1.00	2.10	2.00		73.9	7.92	<0.1	172.0
	170	15-Jul-13	125.0	1.60	2.00	2.00		86.0	7.97	<0.1	203.0
	2	12-Aug-13	94.7	1.10	5.20	2.00		59.5	7.88	0.32	143.0
	5	12-Aug-13	89.7	1.00	2.00	2.00		61.4	7.91	0.34	145.0
	10	12-Aug-13	92.5	1.00	5.80	2.00		62.7	7.93	0.34	145.0
	15	12-Aug-13	103.0	1.00	4.20	2.00		60.7	7.90	0.33	144.0
	20	12-Aug-13	114.0	1.00	2.10	2.60		59.9	7.91	0.30	141.0
	40	12-Aug-13	129.0	1.00	2.00	2.00		63.5	7.94	1.01	149.0
	60	12-Aug-13	122.0	1.20	2.10	2.00		64.5	7.93	0.30	153.0
	80	12-Aug-13	114.0	1.00	2.00	2.00		70.1	7.97	0.18	107.0
	175	12-Aug-13	128.0	1.00	2.50	2.00		84.0	7.85	1.58	200.0
	0 - 20	23-Apr-13					3.04				
	0 - 20	14-May-13					3.33				
	0 - 20	10-Jun-13					3.4				
	0 - 20	15-Jul-13					3.15				
	0 - 20	12-Aug-13					2.81				
KIN Canoe	2	22-Apr-13	111.0	2.50	2.00	2.00		60.5	8.03	0.53	143.0
	5	22-Apr-13	111.0	1.20	2.90	2.00		60.4	7.98	0.45	141.0
	10	22-Apr-13	111.0	1.20	2.00	2.00		60.2	8.03	0.81	142.0
	15	22-Apr-13	111.0	1.30	2.00	2.00		61.8	8.04	0.47	142.0
	20	22-Apr-13	110.0	1.20	2.20	2.00		71.0	7.97	0.48	142.0
	40	22-Apr-13	110.0	1.00	2.00	2.00		64.5	8.07	0.43	152.0
	60	22-Apr-13	110.0	1.00	2.00	2.00		78.3	8.12	0.16	181.0
	80	22-Apr-13	113.0	1.00	2.00	2.00		79.0	8.00	0.17	188.0
	90	22-Apr-13	116.0	1.90	4.00	2.00		85.0	8.12	0.18	183.0
	2	14-May-13	133.0	1.00	2.00	2.00		60.7	8.04	0.49	144.0
	5	14-May-13	133.0	1.00	2.00	2.00		58.9	8.05	1.04	144.0
	10	14-May-13	139.0	1.00	2.70	2.00		57.0	8.03	0.47	138.0
	15	14-May-13	132.0	1.00	2.00	2.00		57.0	8.02	0.49	139.0

Station	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uS/cms
	20	14-May-13	117.0	1.00	2.00	2.00		59.2	8.04	0.44	145.0
	40	14-May-13	110.0	1.10	2.00	2.00		65.9	8.07	0.23	155.0
	60	14-May-13	109.0	1.20	2.00	2.00		70.3	8.13	0.48	169.0
	80	14-May-13	116.0	1.00	2.00	2.00		79.4	8.16	0.14	188.0
	85	14-May-13	117.0	1.00	2.10	2.00		79.4	8.14	0.20	186.0
	2	10-Jun-13	143.0	1.20	3.00	2.00		62.2	8.02	0.61	151.0
	5	10-Jun-13	139.0	1.00	2.00	2.00		62.2	7.91	0.54	148.0
	10	10-Jun-13	143.0	1.00	2.00	2.00		63.7	8.03	0.62	150.0
	15	10-Jun-13	137.0	2.00	2.00	2.00		61.3	8.00	0.48	146.0
	20	10-Jun-13	140.0	1.00	2.00	2.00		49.6	7.91	0.73	124.0
	40	10-Jun-13	132.0	1.40	2.00	2.00		56.0	7.95	0.63	137.0
	60	10-Jun-13	103.0	1.00	2.00	2.00		65.8	8.00	0.13	155.0
	80	10-Jun-13	112.0	1.00	2.00	2.00		76.6	8.07	0.17	179.0
	90	10-Jun-13	120.0	1.60	2.00	2.00		79.9	8.08	0.17	186.0
	2	16-Jul-13	125.0	1.50	2.20	2.50		59.8	7.88	0.53	141.0
	5	16-Jul-13	129.0	1.00	2.00	3.30		56.9	7.85	0.65	139.0
	10	16-Jul-13	130.0	2.80	2.60	2.00		54.1	7.80	0.75	128.0
	15	16-Jul-13	135.0	2.30	2.50	2.00		56.6	7.83	0.70	133.0
	20	16-Jul-13	139.0	1.00	2.00	2.00		58.9	7.85	0.53	139.0
	40	16-Jul-13	142.0	1.00	2.40	3.30		58.7	7.85	0.52	138.0
	60	16-Jul-13	117.0	1.00	2.00	2.00		65.9	7.88	0.18	153.0
	80	16-Jul-13	119.0	1.50	2.00	2.30		71.2	7.92	0.14	166.0
	140	16-Jul-13	124.0	1.10	3.20	2.50		84.0	7.98	0.12	199.0
	2	12-Aug-13	90.5	1.00	2.00	2.20		59.9	7.91	0.34	144.0
	5	12-Aug-13	94.1	1.10	2.20	2.00		60.6	7.90	0.57	143.0
	10	12-Aug-13	100.0	1.60	2.30	2.00		59.0	7.91	0.26	143.0
	15	12-Aug-13	111.0	1.60	2.00	2.00		58.5	7.89	0.27	138.0
	20	12-Aug-13	112.0	1.00	2.00	2.00		59.2	7.89	0.38	137.0
	40	12-Aug-13	132.0	1.10	3.30	2.00		57.9	7.88	1.42	137.0
	60	12-Aug-13	129.0	1.00	2.30	2.00		63.0	7.91	0.34	148.0
	80	12-Aug-13	118.0	1.70	2.50	2.00		67.5	7.90	0.25	162.0
	120	12-Aug-13	118.0	1.00	2.00	2.00		81.9	8.01	0.16	191.0
	0 - 20	22-Apr-13					3.26				
	0 - 20	14-May-13					3.51				
	0 - 20	10-Jun-13					3.37				
	0 - 20	16-Jul-13					3.12				
	0 - 20	12-Aug-13					2.91				
KIN Wood	2	22-Apr-13	95.0	1.20	2.00	2.00		65.4	8.08	0.32	151.0
	5	22-Apr-13	94.4	1.00	2.20	2.10		64.2	8.08	0.40	152.0
	10	22-Apr-13	94.9	1.30	2.00	2.00		64.3	8.08	0.33	152.0
	15	22-Apr-13	94.2	1.00	2.00	2.00		66.0	8.10	0.34	154.0
	20	22-Apr-13	95.4	1.20	2.10	2.00		65.0	8.09	0.38	153.0
	35	22-Apr-13	96.1	1.20	2.30	2.00		66.7	8.11	0.47	156.0
	2	14-May-13	142.0	1.40	3.20	2.00		66.7	8.09	1.60	157.0
	5	14-May-13	104.0	1.00	3.40	2.00		63.9	8.08	1.06	149.0
	10	14-May-13	92.5	1.00	2.20	2.00		66.0	8.10	0.41	156.0
	15	14-May-13	93.7	1.00	2.00	2.00		68.5	8.10	0.26	157.0
	20	14-May-13	99.0	1.00	2.10	2.00		67.0	8.10	0.33	158.0
	38	14-May-13	104.0	1.00	2.00	2.00		68.3	8.11	0.34	160.0
	2	10-Jun-13	148.0	1.00	2.00	2.00		68.0	8.03	0.71	157.0
	5	10-Jun-13	150.0	1.00	2.40	2.00		67.9	8.05	0.71	157.0
	10	10-Jun-13	149.0	1.00	2.90	2.00		66.9	8.06	0.67	158.0
	15	10-Jun-13	161.0	1.10	2.00	2.00		66.9	8.04	0.79	153.0
	20	10-Jun-13	177.0	1.00	2.50	2.00		67.4	8.01	1.39	151.0
	40	10-Jun-13	133.0	1.00	2.00	2.00		68.6	8.03	2.20	162.0
	45	10-Jun-13	137.0	1.00	2.10	2.00		69.2	8.03	2.11	163.0
	2	15-Jul-13	109.0	1.10	2.90	2.00		63.8	7.91	0.68	150.0
	5	15-Jul-13	116.0	1.10	2.90	2.00		63.0	7.91	0.60	148.0
	10	15-Jul-13	128.0	1.00	4.80	2.00		61.6	7.88	0.65	143.0
	15	15-Jul-13	131.0	1.30	2.60	2.20		59.7	7.86	0.80	139.0
	20	15-Jul-13	113.0	3.50	3.50	2.00		62.0	7.87	2.16	139.0
	40	15-Jul-13	121.0	1.30	5.60	2.00		64.4	7.91	10.00	139.0
	60	15-Jul-13	142.0	1.10	3.60	2.00		71.4	7.92	0.90	165.0

Station	**Depth** m	**Date**	**Nitrate/ Nitrite** ug/L	**SRP** ug/L	**TP** ug/L	**TDP** ug/L	**SRS** mgSi/L	**Alkalinity** mgCaCO3/L	**pH**	**Turbidity** (NTU)	**Cond.** uS/cms
	2	12-Aug-13	93.1	1.00	2.00	2.00		70.7	7.89	0.34	144.0
	5	12-Aug-13	91.9	1.00	3.30	2.00		60.9	7.93	0.38	144.0
	10	12-Aug-13	99.8	1.00	2.30	2.00		63.0	7.94	0.49	145.0
	15	12-Aug-13	111.0	1.00	6.20	2.00		58.6	7.86	0.38	138.0
	20	12-Aug-13	114.0	1.00	3.20	2.70		70.4	7.86	0.34	140.0
	40	12-Aug-13	71.8	1.00	5.60	2.00		60.6	7.91	7.52	135.0
	60	12-Aug-13	159.0	1.10	2.50	2.00		69.9	7.97	2.02	164.0
	0 - 20	22-Apr-13					3.26				
	0 - 20	14-May-13					3.3				
	0 - 20	10-Jun-13					3.37				
	0 - 20	15-Jul-13					2.91				
	0 - 20	12-Aug-13					2.86				
KIN Col	2	23-Apr-13	100.0	1.00	2.00	2.00		88.6	8.19	0.25	205.0
	5	23-Apr-13	102.0	1.00	2.00	2.00		88.3	8.19	0.21	206.0
	10	23-Apr-13	102.0	1.00	2.00	2.00		88.9	8.20	0.20	207.0
	15	23-Apr-13	101.0	1.00	2.00	2.00		88.6	8.18	0.21	207.0
	20	23-Apr-13	96.6	1.20	2.00	2.00		88.4	8.19	0.28	205.0
	40	23-Apr-13	112.0	1.00	2.00	2.00		91.8	8.20	0.29	214.0
	60	23-Apr-13	118.0	1.00	2.10	2.00		98.2	8.19	0.32	221.0
	80	23-Apr-13	127.0	1.00	2.00	2.00		97.2	8.20	0.37	224.0
	140	23-Apr-13	119.0	1.00	2.00	2.00		100.0	8.21	0.33	235.0
	2	14-May-13	185.0	1.60	3.80	2.00		95.8	8.22	1.98	229.0
	5	14-May-13	214.0	2.20	3.70	2.00		96.3	8.19	3.40	228.0
	10	14-May-13	144.0	1.00	2.10	2.00		87.1	8.19	1.22	205.0
	15	14-May-13	108.0	1.00	2.50	2.00		90.3	8.19	0.29	212.0
	20	14-May-13	109.0	1.00	2.00	2.00		89.4	8.21	0.22	211.0
	40	14-May-13	106.0	1.00	2.00	2.00		94.0	8.22	0.25	224.0
	60	14-May-13	116.0	1.00	2.00	2.00		99.5	8.24	0.32	233.0
	80	14-May-13	118.0	1.00	2.00	2.00		99.3	8.23	0.23	237.0
	140	14-May-13	117.0	1.00	2.20	2.00		103.0	8.24	0.22	243.0
	2	11-Jun-13	233.0	1.00	2.90	2.00		85.3	8.13	0.89	193.0
	5	11-Jun-13	232.0	1.00	2.50	2.00		84.4	8.11	1.02	190.0
	10	11-Jun-13	230.0	1.00	2.40	2.00		85.8	8.13	1.05	193.0
	15	11-Jun-13	238.0	1.00	3.90	2.00		83.6	8.10	0.85	189.0
	20	11-Jun-13	240.0	1.00	2.00	2.00		84.2	8.02	1.50	190.0
	40	11-Jun-13	127.0	1.00	2.00	2.00		83.5	8.08	0.34	194.0
	60	11-Jun-13	109.0	1.00	2.00	2.00		98.9	8.16	0.14	225.0
	80	11-Jun-13	117.0	2.50	2.00	2.00		98.6	8.13	0.15	228.0
	150	11-Jun-13	122.0	1.00	2.00	2.00		105.0	8.16	0.17	242.0
	2	15-Jul-13	124.0	1.00	2.10	2.00		69.2	7.93	0.54	162.0
	5	15-Jul-13	124.0	2.60	2.00	2.00		72.3	7.92	0.49	163.0
	10	15-Jul-13	121.0	1.00	2.60	2.00		70.6	7.92	0.61	161.0
	15	15-Jul-13	124.0	1.80	3.90	2.00		71.9	7.94	0.61	163.0
	20	15-Jul-13	120.0	1.20	2.10	4.10		71.8	7.93	0.68	161.0
	40	15-Jul-13	145.0	1.80	3.70	2.00		74.9	7.94	1.70	166.0
	60	15-Jul-13	141.0	1.00	2.00	3.60		79.3	7.96	0.33	185.0
	80	15-Jul-13	130.0	1.00	2.00	2.00		89.3	7.90	0.28	208.0
	160	15-Jul-13	136.0	1.20	2.00	2.00		100.0	8.06	0.15	236.0
	2	13-Aug-13	61.0	1.00	2.30	2.00		69.5	7.95	0.55	159.0
	5	13-Aug-13	61.9	1.80	2.00	2.00		68.3	7.94	0.41	159.0
	10	13-Aug-13	71.3	1.00	3.60	2.00		67.7	7.94	0.71	157.0
	15	13-Aug-13	75.3	1.50	3.50	2.00		66.4	7.96	0.48	156.0
	20	13-Aug-13	81.5	1.00	2.00	2.00		67.8	7.98	0.56	155.0
	40	13-Aug-13	96.7	2.30	3.80	2.00		68.4	7.95	3.27	155.0
	60	13-Aug-13	140.0	1.00	2.00	2.00		82.9	8.02	0.59	195.0
	80	13-Aug-13	131.0	1.00	2.00	2.00		91.3	8.05	0.42	214.0
	170	13-Aug-13	139.0	1.10	3.40	2.20		102.0	8.08	0.31	239.0
	0 - 20	23-Apr-13					3.3				
	0 - 20	14-May-13					4.19				
	0 - 20	11-Jun-13					3.38				
	0 - 20	15-Jul-13					3.02				
	0 - 20	13-Aug-13					2.58				
REV FB	2	30-Apr-13	111.0	1.00	2.30	2.00		65.1	8.04	0.15	154.0

Station	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uS/cms
	5	30-Apr-13	109.0	1.00	2.00	2.00		64.6	8.00	0.20	153.0
	10	30-Apr-13	109.0	1.00	2.00	2.00		65.6	8.02	0.17	153.0
	15	30-Apr-13	111.0	1.00	2.30	2.50		67.1	8.05	0.16	155.0
	20	30-Apr-13	112.0	1.00	2.10	2.00		65.8	8.03	0.16	154.0
	40	30-Apr-13	110.0	1.00	2.40	2.00		65.9	8.00	0.15	153.0
	60	30-Apr-13	111.0	1.00	2.00	2.00		65.5	8.05	0.15	155.0
	80	30-Apr-13	113.0	1.30	2.00	2.00		66.9	8.02	0.16	155.0
	110	30-Apr-13	113.0	1.00	2.00	2.20		67.0	8.03	0.22	154.0
	2	22-May-13	114.0	1.00	2.00	2.00		56.7	7.89	0.42	135.0
	5	22-May-13	115.0	1.00	2.00	2.00		58.4	7.90	0.35	136.0
	10	22-May-13	111.0	1.00	2.00	2.30		59.4	7.91	0.26	136.0
	15	22-May-13	114.0	1.00	2.00	2.00		61.9	7.95	0.17	142.0
	20	22-May-13	116.0	1.00	2.10	2.00		63.6	7.97	0.20	148.0
	40	22-May-13	116.0	1.50	2.00	2.00		65.0	7.98	0.15	153.0
	60	22-May-13	114.0	1.00	2.00	2.00		66.6	7.97	0.17	155.0
	80	22-May-13	114.0	2.80	2.00	2.00		64.9	7.98	0.18	155.0
	110	22-May-13	112.0	1.00	2.00	2.00		66.9	7.98	0.20	154.0
	2	18-Jun-13	122.0	1.00	2.10	2.00		51.5	7.85	0.32	121.0
	5	18-Jun-13	112.0	1.00	2.00	2.00		52.1	7.83	0.27	120.0
	10	18-Jun-13	121.0	1.00	2.60	2.00		50.6	7.86	0.25	121.0
	15	18-Jun-13	132.0	1.00	2.00	2.00		52.1	7.85	0.26	121.0
	20	18-Jun-13	170.0	1.00	2.00	2.00		52.4	7.85	0.27	125.0
	40	18-Jun-13	180.0	1.00	3.00	2.00		54.4	7.83	0.13	131.0
	60	18-Jun-13	135.0	1.00	2.00	2.00		61.6	7.89	0.14	147.0
	80	18-Jun-13	122.0	1.00	2.00	2.00		64.8	7.93	0.15	153.0
	105	18-Jun-13	118.0	1.00	2.00	2.00		63.8	7.94	0.18	155.0
	2	23-Jul-13	128.0	1.00	2.40	2.00		38.3	7.83	0.44	89.3
	5	23-Jul-13	128.0	1.00	2.00	2.00		37.6	7.84	0.38	89.4
	10	23-Jul-13	131.0	1.00	2.00	2.00		38.0	7.72	0.38	88.6
	15	23-Jul-13	141.0	1.00	2.80	2.00		39.7	7.82	0.45	90.2
	20	23-Jul-13	134.0	1.20	2.00	2.00		37.7	7.79	1.20	86.7
	40	23-Jul-13	152.0	1.00	2.00	2.00		38.3	7.79	1.38	89.7
	60	23-Jul-13	171.0	1.00	2.00	2.00		54.6	7.99	0.28	129.0
	80	23-Jul-13	145.0	1.00	2.00	2.00		63.0	7.96	0.15	146.0
	105	23-Jul-13	137.0	1.00	2.10	2.00		62.8	7.92	0.16	148.0
	2	20-Aug-13	85.7	1.00	2.20	2.00		32.4	7.68	0.87	76.6
	5	20-Aug-13	80.6	1.50	4.20	2.00		33.2	7.67	1.14	75.1
	10	20-Aug-13	88.5	1.30	2.70	2.10		29.2	7.59	1.36	74.3
	15	20-Aug-13	91.3	1.30	2.40	2.00		31.6	7.49	1.16	73.3
	20	20-Aug-13	101.0	1.00	2.00	2.00		29.9	7.62	0.48	72.4
	40	20-Aug-13	130.0	1.00	2.00	2.00		37.8	7.74	0.60	94.6
	60	20-Aug-13	146.0	1.00	2.00	2.00		41.2	7.71	0.39	96.7
	80	20-Aug-13	171.0	1.00	2.50	2.00		59.9	7.92	0.77	141.0
	110	20-Aug-13	158.0	1.00	2.00	2.00		64.1	7.93	0.70	149.0
	2	17-Sep-13	59.7	1.90	2.00	2.00		61.2	7.74	0.48	80.6
	5	17-Sep-13	59.8	1.00	2.40	2.00		33.0	7.59	0.48	78.7
	10	17-Sep-13	100.0	3.90	2.70	2.00		39.6	7.82	1.55	95.9
	15	17-Sep-13	111.0	2.20	3.20	2.00		48.9	7.85	1.22	112.0
	20	17-Sep-13	117.0	2.00	2.30	2.00		49.4	7.84	0.83	121.0
	40	17-Sep-13	127.0	2.50	2.90	2.00		53.9	8.01	0.60	127.0
	60	17-Sep-13	149.0	1.80	2.40	2.00		51.8	7.91	0.10	121.0
	80	17-Sep-13	163.0	1.20	2.20	2.00		62.5	7.99	0.43	141.0
	115	17-Sep-13	161.0	2.00	2.10	2.00		61.9	7.88	0.38	144.0
	0 - 20	30-Apr-13					3.26				
	0 - 20	22-May-13					3.52				
	0 - 20	18-Jun-13					3.52				
	0 - 20	23-Jul-13					3.58				
	0 - 20	20-Aug-13					2.94				
	0 - 20	17-Sep-13					6.2				
REV Mid	2	29-Apr-13	115.0	1.00	2.60	2.00		65.0	8.03	0.25	150.0
	5	29-Apr-13	112.0	1.00	2.10	2.00		63.4	8.03	0.23	149.0
	10	29-Apr-13	112.0	1.00	2.00	2.30		65.5	8.04	0.29	151.0
	15	29-Apr-13	112.0	1.00	2.00	2.00		63.3	8.03	0.28	151.0

Station	Depth m	Date	Nitrate/ Nitrite ug/L	SRP ug/L	TP ug/L	TDP ug/L	SRS mgSi/L	Alkalinity mgCaCO3/L	pH	Turbidity (NTU)	Cond. uS/cms
	20	29-Apr-13	109.0	1.00	2.60	2.30		65.3	8.04	0.23	151.0
	40	29-Apr-13	119.0	1.00	2.00	2.00		65.9	8.00	0.23	153.0
	60	29-Apr-13	126.0	1.00	2.00	2.00		66.4	8.03	0.25	154.0
	80	29-Apr-13	144.0	1.30	2.00	2.00		69.5	8.03	0.29	158.0
	2	21-May-13	203.0	1.00	2.60	8.60		56.9	7.88	0.64	133.0
	5	21-May-13	235.0	1.00	3.00	2.50		50.8	7.85	0.81	120.0
	10	21-May-13	250.0	1.30	2.50	2.00		59.2	7.93	1.02	135.0
	15	21-May-13	238.0	1.50	2.20	2.00		55.6	7.88	1.23	128.0
	20	21-May-13	220.0	1.00	2.00	2.00		56.2	7.92	1.21	131.0
	40	21-May-13	133.0	1.30	2.00	2.00		64.1	7.93	0.24	148.0
	60	21-May-13	123.0	1.00	2.00	2.00		66.8	7.97	0.15	154.0
	80	21-May-13	126.0	1.00	2.00	2.00		68.0	7.96	0.24	154.0
	85	21-May-13	127.0	1.20	2.00	2.00		68.0	7.97	0.20	155.0
	2	17-Jun-13	158.0	1.00	2.70	2.00		44.9	7.73	0.55	109.0
	5	17-Jun-13	152.0	1.00	10.80	2.00		48.1	7.79	0.48	113.0
	10	17-Jun-13	174.0	1.10	3.10	2.00		44.4	7.79	0.66	109.0
	15	17-Jun-13	186.0	1.30	2.00	2.10		47.6	7.79	0.73	109.0
	20	17-Jun-13	196.0	1.00	2.70	2.20		43.2	7.76	0.76	97.9
	40	17-Jun-13	153.0	1.00	2.00	2.00		64.2	7.92	0.19	151.0
	60	17-Jun-13	146.0	1.00	2.00	2.00		64.5	7.94	0.17	151.0
	80	17-Jun-13	125.0	1.00	2.00	2.00		65.7	7.93	0.16	154.0
	2	22-Jul-13	106.0	1.70	2.10	2.00		34.9	7.79	0.54	82.9
	5	22-Jul-13	94.3	1.00	2.70	2.30		32.2	7.75	0.56	76.5
	10	22-Jul-13	84.7	1.00	4.20	2.00		25.7	7.53	0.77	62.4
	15	22-Jul-13	90.7	1.00	2.60	2.00		24.1	7.62	1.26	62.8
	20	22-Jul-13	95.0	1.10	2.60	2.10		23.4	7.58	1.40	61.3
	40	22-Jul-13	133.0	1.00	2.00	2.00		34.6	7.74	0.77	81.6
	60	22-Jul-13	167.0	1.00	2.00	2.00		58.6	7.94	0.20	138.0
	80	22-Jul-13	157.0	1.00	2.00	2.00		62.4	7.94	0.18	143.0
	2	19-Aug-13	79.8	1.00	2.40	2.00		33.6	7.70	0.53	78.0
	5	19-Aug-13	72.3	1.80	15.90	2.00		57.0	7.61	0.62	77.9
	10	19-Aug-13	70.9	1.00	2.00	2.00		34.6	7.69	0.42	78.7
	15	19-Aug-13	72.1	2.20	5.00	2.00		38.4	7.74	3.51	88.4
	20	19-Aug-13	93.1	3.60	3.90	2.20		45.3	7.78	1.13	107.0
	40	19-Aug-13	127.0	1.10	2.00	2.00		53.0	7.80	0.68	129.0
	60	19-Aug-13	152.0	1.00	2.00	2.00		53.0	7.81	0.36	123.0
	75	19-Aug-13	181.0	1.00	2.00	2.00		59.8	7.90	0.40	141.0
	2	18-Sep-13	119.0	2.30	2.90	2.00		49.5	7.83	0.71	120.0
	5	18-Sep-13	59.5	2.40	2.20	2.00		37.3	7.77	0.70	83.3
	10	18-Sep-13	63.2	1.70	3.30	2.00		38.1	7.80	1.14	86.3
	15	18-Sep-13	92.7	2.70	3.50	2.00		47.9	7.88	1.68	111.0
	20	18-Sep-13	112.0	2.00	2.50	2.00		54.4	7.90	1.17	122.0
	40	18-Sep-13	130.0	1.60	2.90	2.00		54.6	7.77	0.69	126.0
	60	18-Sep-13	58.4	2.30	2.00	2.00		35.8	7.71	0.43	84.3
	75	18-Sep-13	178.0	1.50	7.20	2.40		58.6	7.91	0.37	136.0
	0 - 20	29-Apr-13					3.44				
	0 - 20	21-May-13					3.88				
	0 - 20	17-Jun-13					3.63				
	0 - 20	22-Jul-13					3.48				
	0 - 20	19-Aug-13					2.76				
	0 - 20	18-Sep-13					6.91				
REV Upper	2	29-Apr-13	126.0	1.00	2.80	2.00		59.3	8.01	0.24	140.0
	5	29-Apr-13	122.0	1.00	2.00	2.00		64.4	7.99	0.26	139.0
	10	29-Apr-13	124.0	1.00	2.00	2.00		57.6	8.00	0.25	139.0
	15	29-Apr-13	123.0	1.00	2.30	2.00		59.5	7.97	0.23	137.0
	20	29-Apr-13	126.0	1.00	2.30	2.00		59.6	7.99	0.23	140.0
	35	29-Apr-13	120.0	1.00	2.20	2.00		61.7	8.01	0.24	143.0
	2	21-May-13	242.0	1.00	3.10	2.80		46.0	7.80	1.27	106.0
	5	21-May-13		1.30	3.70	4.30					
	10	21-May-13	263.0	1.50	3.90	4.00		39.8	7.75	1.88	99.4
	15	21-May-13	259.0	1.80	3.90	3.40		41.2	7.77	1.88	101.0
	20	21-May-13	266.0	1.10	3.30	2.70		41.1	7.77	1.90	102.0
	35	21-May-13	223.0	1.00	2.80	3.90		51.4	7.86	1.40	121.0

Station	**Depth** m	**Date**	**Nitrate/ Nitrite** ug/L	**SRP** ug/L	**TP** ug/L	**TDP** ug/L	**SRS** mgSi/L	**Alkalinity** mgCaCO3/L	**pH**	**Turbidity** (NTU)	**Cond.** uS/cms
	2	17-Jun-13	181.0	1.10	3.20	2.00		29.6	7.61	1.11	73.0
	5	17-Jun-13	184.0	1.10	3.00	2.00		30.9	7.64	1.02	72.1
	10	17-Jun-13	188.0	2.10	2.80	2.00		30.0	7.63	0.87	72.3
	15	17-Jun-13	181.0	1.00	3.30	2.00		29.8	7.59	1.22	72.9
	20	17-Jun-13	183.0	1.00	2.00	2.00		32.1	7.60	1.24	78.6
	35	17-Jun-13	174.0	1.00	2.20	2.00		32.9	7.59	0.87	87.0
	2	22-Jul-13	76.9	1.60	2.10	2.00		21.3	7.55	1.11	55.2
	5	22-Jul-13	77.3	1.30	3.20	2.00		21.8	7.56	1.44	57.8
	10	22-Jul-13	82.2	2.00	2.40	2.00		25.8	7.59	1.31	65.8
	15	22-Jul-13	96.4	1.20	2.30	2.00		33.7	7.72	1.73	84.3
	20	22-Jul-13	101.0	1.80	2.00	2.00		41.8	7.72	1.16	105.0
	35	22-Jul-13	107.0	1.40	2.30	2.00		46.8	7.84	1.82	114.0
	2	19-Aug-13	55.1	2.00	2.80	2.00		31.5	7.62	0.93	72.9
	5	19-Aug-13	61.5	1.70	2.10	2.00		31.2	7.63	1.14	73.3
	10	19-Aug-13	74.8	1.00	2.00	2.00		33.3	7.69	1.29	82.9
	15	19-Aug-13	110.0	3.50	2.30	2.00		48.0	7.85	1.92	114.0
	20	19-Aug-13	117.0	1.90	2.60	2.00		56.2	7.86	1.22	132.0
	35	19-Aug-13	122.0	1.00	2.90	2.00		58.4	7.83	1.46	139.0
	2	18-Sep-13	110.0	2.10	2.30	2.10		54.4	7.93	1.22	128.0
	5	18-Sep-13	113.0	3.60	3.70	2.00		56.1	7.95	1.46	132.0
	10	18-Sep-13	149.0	1.20	2.00	2.00		53.0	7.86	1.53	124.0
	15	18-Sep-13	121.0	2.00	3.00	2.00		60.5	7.95	1.70	137.0
	20	18-Sep-13	126.0	2.90	3.10	2.90		59.9	7.98	1.84	138.0
	35	18-Sep-13	121.0	3.30	3.00	2.00		60.0	7.97	1.76	138.0
	0 - 20	29-Apr-13					3.91				
	0 - 20	21-May-13					4.53				
	0 - 20	17-Jun-13					4.55				
	0 - 20	22-Jul-13					3.96				
	0 - 20	19-Aug-13					2.95				
	0 - 20	18-Sep-13					6.11				

Appendix 5

Primary Productivity Kinbasket and Revelstoke Reservoirs, 2013

Shannon Harris
Ministry of Environment

PRIMARY PRODUCTIVITY IN KINBASKET AND REVELSTOKE RESERVOIRS, 2013

Shannon Harris
Ministry of Environment

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Introduction

Phytoplankton is the foundation of all aquatic food web systems and is an important source of food for higher trophic level. In aquatic ecosystems, a vast diversity of phytoplankton species are concurrently observed in a waterbody ranging from small coccoidal cyanobacteria such as *Synechococcus* sp to large chain forming diatoms such as *Tabularia* sp. Aquatic ecosystems dominated by small cells generally support longer food chains compared to the shorter chains supports by larger sized phytoplankton. The relative contribution of each species will directly impact the functioning of the food web and the study of the phytoplankton community provides insight into the ecosystem dynamics of the reservoir. Our studies examined the size structure of the phytoplankton community in terms of chlorophyll and primary productivity, particularly the relative contribution of three commonly studied fractions-the picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm). This report summarizes the primary productivity studies carried out on Kinbasket and Revelstoke Reservoirs in 2013.

Methods

Field & Laboratory

The field sampling strategy and laboratory methodology were consistent with previous study years and can be found in Harris, 2012. Table 1 provides field and incubation information for the 2013 study.

Table 1 Field observations and incubation information for the 2013 primary productivity study. KB=Kinbasket-Forebay, RM=Revelstoke-Middle (also called Downie), RF=Revelstoke-Forebay and AC=attenuation coefficient calculated from vertical profiles of photosynthetically active radiation.

Date	Stn	Weather	AC (cm^{-1})	Inc. start	Inc. end	Total Inc Time (hr.min)	Incubation depths (m)
19-Jun-13	KB	10°C; cloudy; 4-12" waves	0.29	8:54	13:05	4.11	0,1,2,5,10,15,17
24-Jul-13	KB	19°C; sunny w/ few clouds	0.27	8:42	12:42	4.0	0,1,2,5,10,15,17
21-Aug-13	KB	13°C; sunny	0.24	8:40	12:40	4.0	0,1,2,5,10,15,18
19-Sep-13	KB	10°C; sunny w/ clouds	0.23	9:26	13:26	4.0	0,1,2,5,10,15,20
20-Jun-13	RM	14°C ; overcast w/ breaks	0.40	8:40	12:42	4.2	0,1,2,5,10,13
25-Jul-13	RM	18°C; sunny and clear	0.34	8:12	12:12	4.0	0,1,2,5,10,13
22-Aug-13	RM	12°C; sunny; light breeze	0.44	8:07	12:10	4.3	0,1,2,5,10,12
18-Sep-13	RM	12°C; cloudy; small waves	0.37	10:02	14:00	3.58	0,1,2,5,10,13
21-Jun-13	RF	12°C ; overcast; light breeze	0.24	8:30	12:30	4.0	0,1,2,5,10,15
23-Jul-13	RF	21°C; sunny and clear; windy	0.29	9:10	13:10	4.0	0,1,2,5,10,15,17
20-Aug-13	RF	13°C; sunny w/ clouds	0.40	8:42	12:45	4.3	0,1,2,5,10,12
20-Sep-13	RF		0.34	8:48	12:38	4.0	0,1,2,5,10,12

Results

The growing season started with low availability of photosynthetically active radiation (PAR), defined as the radiation in the 400-700 nm waveband, averaging ~400 µmol/m^2/s at all three stations. As shown in Table 1, the weather conditions were recorded as cloudy/overcast which supports the low PAR measurements. Light availability generally improved in July, August and September where surface PAR was ~1000 µmol/m^2/s (Figure 1) with the exception of low light availability at Revelstoke Forebay in August. As shown in Figure 1 the 1% depth was generally lower in Kinbasket Forebay than in Revelstoke Forebay and Revelstoke Middle. 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).

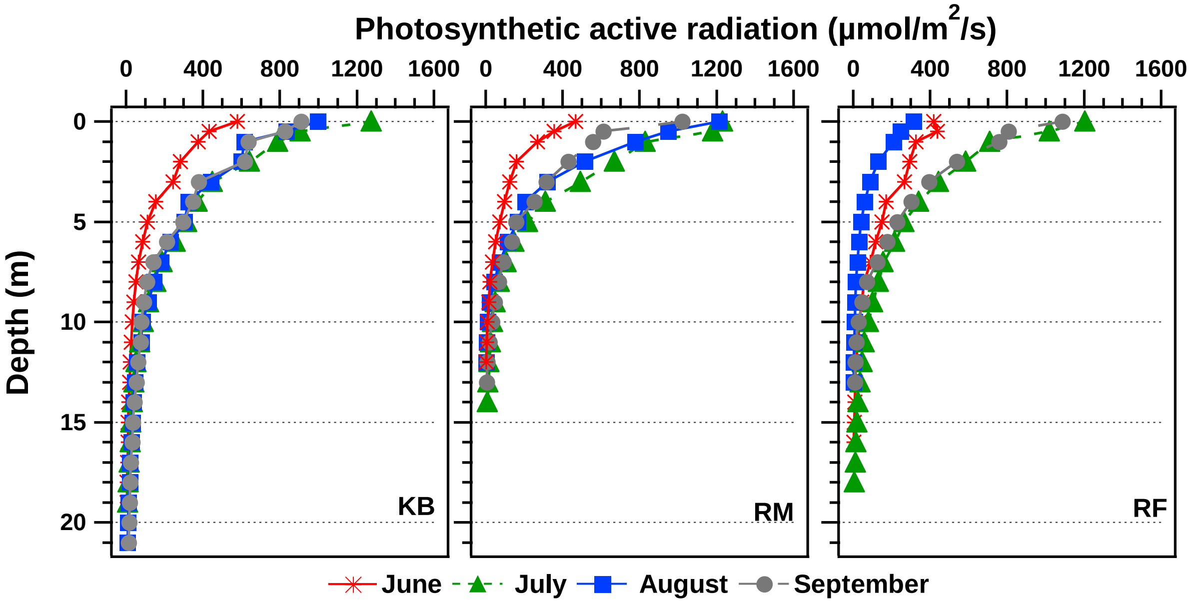

Figure 1 Photosynthetic active radiation (µmol/m^2/s) at Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2013. PAR measurements recorded to the depth of 1% of surface light.

The trends in the attenuation coefficient, a measure of the transparency, have been consistent since 2009 (the first year attenuation coefficient was monitored) where the lowest attenuation coefficient was measured at Kinbasket Forebay at 0.23 cm^{-1}, (about 77% transmission m^{-1}) and the highest attenuation coefficient was measured at Revelstoke Middle at 0.44 cm^{-1} (about 56% transmission m^{-1}) (Figure 2). On average, the seasonal mean attenuation coefficient was 0.26 cm^{-1} at Kinbasket Forebay, followed by 0.32 cm^{-1} at Revelstoke Forebay and highest at Revelstoke Middle at 0.39 cm^{-1} (Table 1). In Kinbasket Reservoir, light transmission improved as the season progressed, increasing from 71% transmission in June to 77% transmission in September. Both stations in Revelstoke Reservoir showed differing seasonal cycles of light transmission. In Revelstoke Middle, light transmission was dynamic, showing no consistent trend seasonally whereas in Revelstoke Forebay, the light transmission gradually decreased as the season progressed with the exception in September where a slightly improvement in transmission was observed (Figure 2).

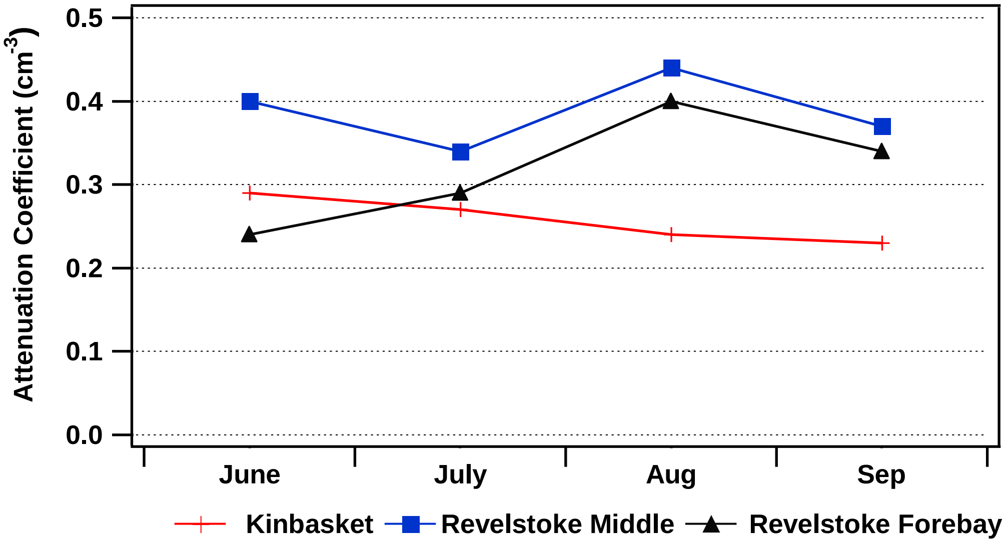

Figure 2 Attenuation coefficients Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2013.

Biomass in Kinbasket and Revelstoke Reservoirs was low ranging from 1-3 mg/m^3 (Figure 3), which is indicative of oligotrophic trophic conditions (Wetzel, 2001). In most months very little heterogeneity throughout the water column was observed with one notable exception in August in Kinbasket where a subsurface minimum was observed at 5-10 m. In 2013, the discrete seasonal averages were 1.52 mg/m^3 in Kinbasket, and 1.1 mg/m^3 in Revelstoke Middle and 1.2 mg/m^3 in Revelstoke Forebay. As seen in previous study years (Harris, 2010, 2011, 2012), the depth integrated biomass was higher in Kinbasket Forebay than in Revelstoke Middle or Revelstoke Forebay for all months (Figure 4). While this was evident during the entire season the differences between Kinbasket and Revelstoke varied from month to month but on average biomass was 41% lower at Revelstoke Middle and Revelstoke Forebay than at Kinbasket. Extreme differences between stations were most evident in August where the biomass in Revelstoke Middle was 63% of the biomass measured in Kinbasket. On average, biomass is slightly higher in Revelstoke Forebay than in Revelstoke Middle, however the differences between station were minimal, they varied seasonally and the concentrations measured in both basins was extremely low. The seasonal cycle of biomass was as seen in previous years where the highest biomass was observed in August in Kinbasket and Revelstoke Forebay whereas in contrast in Revelstoke Middle the seasonal low was seen in August. The depth integrated seasonal averages were 26.2 mg/m^2 in Kinbasket, 15.5 mg/m^2 in Revelstoke Middle, and 14.7 mg/m^2 in Revelstoke Forebay (Table 2). These means are similar to the concentrations measured in 2012, which had means of 22.0, 13.0, and 16.5 mg/m^2 for Kinbasket, Revelstoke Middle and Forebay, respectively (Harris, 2012).

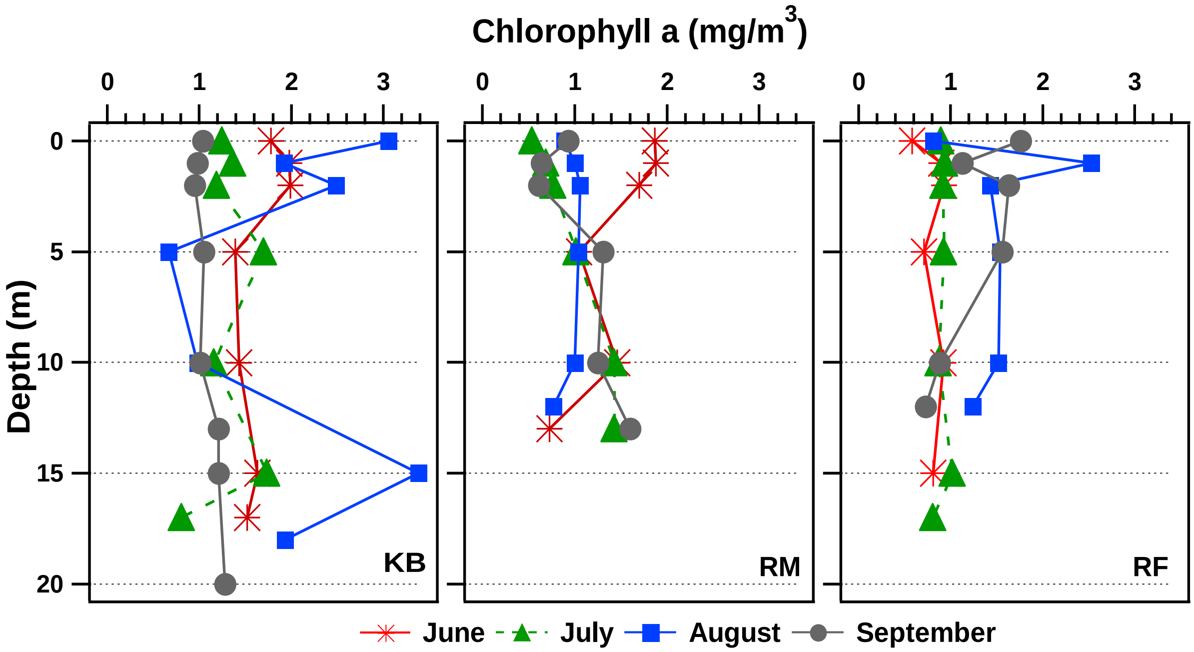

Figure 3 Vertical profiles of chlorophyll *a* (mg/m^3) for Kinbasket Forebay and Revelstoke Middle and Revelstoke Forebay in 2013.

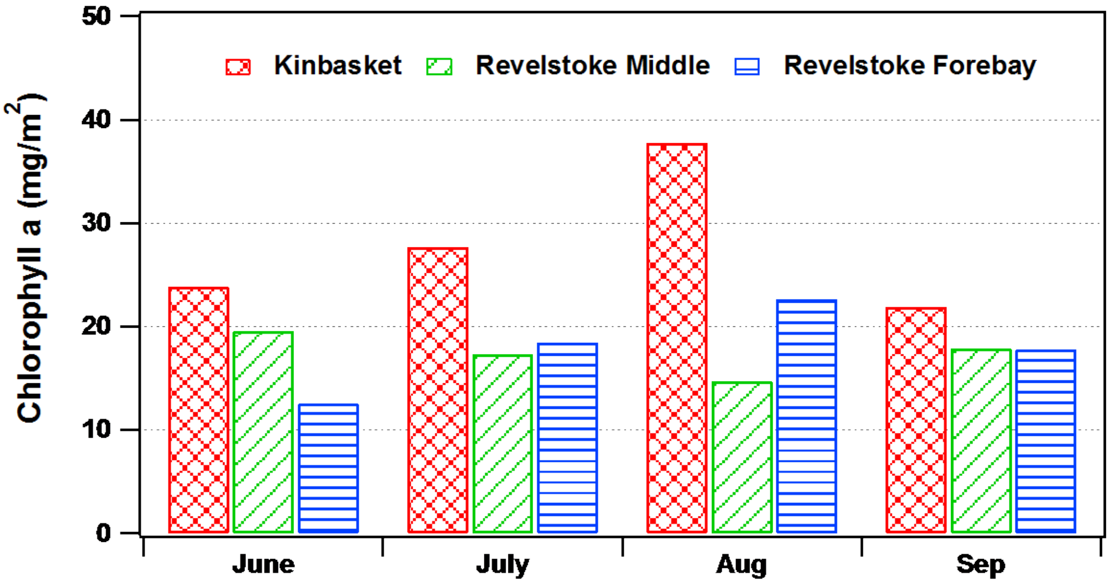

Figure 4 Integrated chlorophyll *a* (mg Chl *a*/m^2) in Kinbasket and Revelstoke in 2013.

While total chlorophyll measurements do provide some insight into reservoir productivity, a further mechanistic understanding about ecosystem dynamics can be realized by examining the size composition of the phytoplankton biomass. On average picoplankton sized cells (0.2-2 µm) accounted for 52% of the total phytoplankton biomass, followed closely by nanoplankton (2.0-20 µm) at 44% and microplankton (>20 µm) accounted for only 11% (Figure 5). Together in 2013, picoplankton and nanoplankton sized cells accounted for 89% of the biomass in Kinbasket and Revelstoke; this is slightly higher than was observed in 2012 where these two size structures accounted for only 86% (Harris, 2012). It appears that the relative contribution of these two size classes is progressively increasing as the study progresses as Bray et al. (2013) reported that 82 and 85% of the biomass was composed of picoplankton and nanoplankton sized phytoplankton in 2010 and 2011 respectively. It is also noteworthy that, in 2012 microplankton accounted for 18% of the biomass whereas in 2013, this value was only 11%.

The relative contribution of picoplankton and microplankton at Kinbasket Forebay were more dynamic than the relatively static seasonal contribution of nanoplankton (Figure 5). For instance picoplankton and microplankton each varied by 20%, whereas nanoplankton varied by just 10%. Picoplankton and microplankton were highly dynamic in Revelstoke Middle while the nanoplankton component of the phytoplankton community was relatively stable throughout the season. In Revelstoke Forebay the relative contribution of picoplankton and nanoplankton varied both by ~15% while the microplankton varied by just 5%. Nanoplankton, the size class preferred by *Daphnia* sp. (Thompson, 1999) were a large component of the community accounting for between 36-49% of the biomass in Kinbasket, 31-39% of the biomass in Revelstoke Middle and 28-49% at Revelstoke Forebay. Microplankton generally accounted for less than 20% of the community, suggesting nutrient limitation, specifically limitation of nitrate (Dugdale and Wilkerson, 1998).

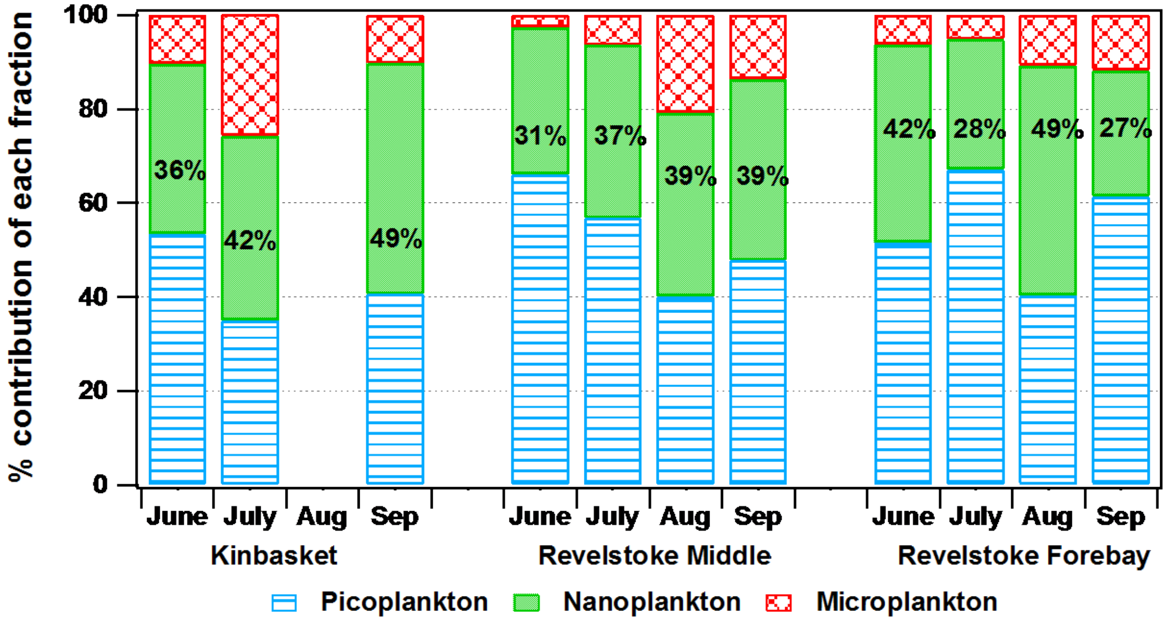

Figure 5 Relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to chlorophyll in Kinbasket and Revelstoke in 2013.

Primary Productivity

Total primary production of all algal size fractions, measured as the radioactive carbon retained on the 0.2 µm filter, has remained extremely low and has never exceeded 100 mg C/m^2/d on any occasion (Figure 6). The seasonal average primary productivity was on average 44% higher at Kinbasket than in Revelstoke Reservoir where Kinbasket primary productivity was 62.9 mg C/m^2/d and 37.8 mg C/m^2/d at Revelstoke Forebay followed closely by Revelstoke Middle at 36.8 mg C/m^2/d (Table 2). The highest primary productivity rate measured in 2013 was 87.5 mg C/m^2/d in June at Kinbasket (Figure 6) whereas in Revelstoke the highest rates were measured in September at each of Revelstoke Middle and Revelstoke Forebay at 50.7 and 45.9 mg C/m^2/d, respectively. For the first time since the start of the primary productivity study in 2008, mean production rates of 62.9 mg C/m^2/d in Kinbasket Reservoir have exceeded 50 mg C/m^2/d, which is the upper limit for Wetzel's classification matrix for ultraoligotrophic conditions (Wetzel, 2001). Production rates in Kinbasket Reservoir are at the lower range of the scale for Wetzel's oligotrophic trophic type (50-300 mg C/m^2/d) whereas production rates in Revelstoke remain below 50 mg C/m^2/d, which is indicative of ultraoligotrophic state conditions (Wetzel, 2001).

This pattern of the highest production at Kinbasket Forebay and the lowest production at Revelstoke Middle was also observed in earlier years (Harris, 2012, 2011). Throughout the study period, Kinbasket Forebay has consistently had the highest water transparency as reflected by low attenuation factors whereas Revelstoke had the least transparent water suggesting physical factors likely play an important role in the regulation of primary productivity in Kinbasket and Revelstoke Reservoirs.

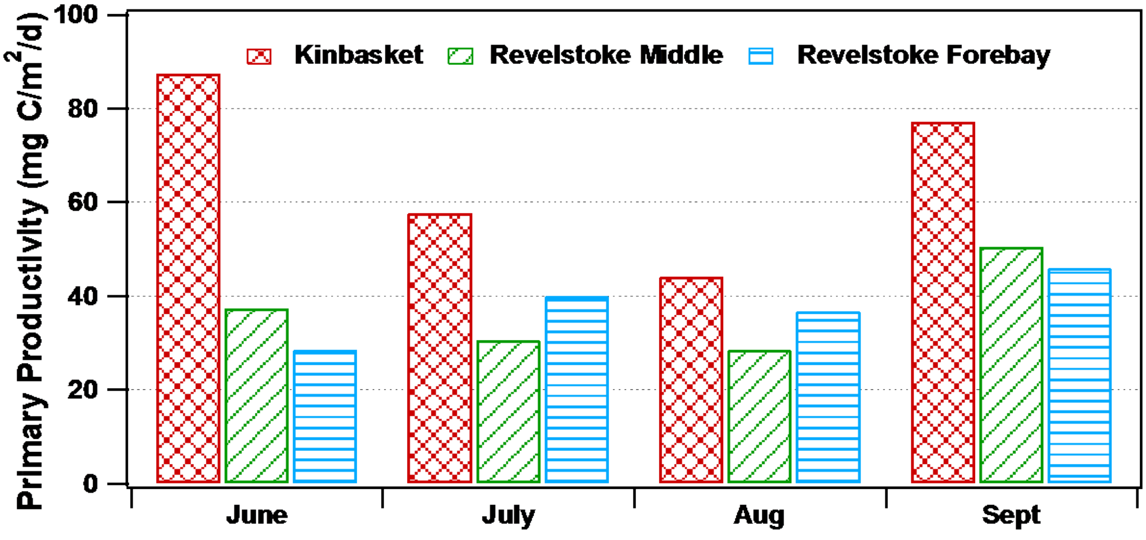

Figure 6 Primary productivity (mg C/m^2/d) in Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2013.

As was observed in early years, production in Kinbasket and Revelstoke in 2013 was dominated by phytoplankton less than 20.0 µm in size. Picoplankton and nanoplankton, phytoplankton less than 20.0 µm in size, accounted for 79% of the total production which is an increase from 69% in 2012 and similar to 83% measured in 2011 (Figure 6 and Harris, 2011, 2012). At Revelstoke Middle and Revelstoke Forebay the picoplankton and nanoplankton fractions accounted for 78% and 80% respectively which is similar to the relative contribution of these size classes in 2011 and 2012 (Figure 6 and Harris, 2011, 2012). Microplankton were the least productive fraction, accounting for on average 25% of total production which is also similar to previous study years (Harris, 2011, 2012).

In Kinbasket, picoplankton were the most productive fraction followed closely by nanoplankton and then microplankton (Figure 7). The relative contribution was relatively static from June through to August but in September production dynamics changed considerable shifting to a system clearly dominated by small sized picoplankton. This change in the size dynamics of primary productions suggests that conditions favored the growth of small cells which generally indicates limitation of nutrients given that small cells are favored when nutrients are scarce. Microplankton production was also dynamic in Kinbasket Reservoir accounting for between 24% to 28% of total production from June to August but dropping to a low of 9% in September, again suggesting changing nutrient supply as the growing season progresses. In Revelstoke Middle and Revelstoke Forebay, the relative contribution of each fraction was relatively static in June and July but in August microplankton production increased dramatically to 40% at Revelstoke Middle and 35% at Revelstoke Forebay (Figure 7). This increase in the relative contribution of the microplankton fraction was also observed in the biomass data in August at both Revelstoke Middle and Revelstoke Forebay (Figure 5).

From 2009-2011 the relative importance of picoplankton production was increasing (Harris, 2011) largely due to a decrease in the relative importance of nanoplankton (Figure 8). This implied the reservoir was still in a state of deceasing productivity or oligotrophication. In 2012 and 2013, this trend was not observed and the relative contribution of picoplankton and nanoplankton were similar to the community size structure observed in 2010 (Figure 8).

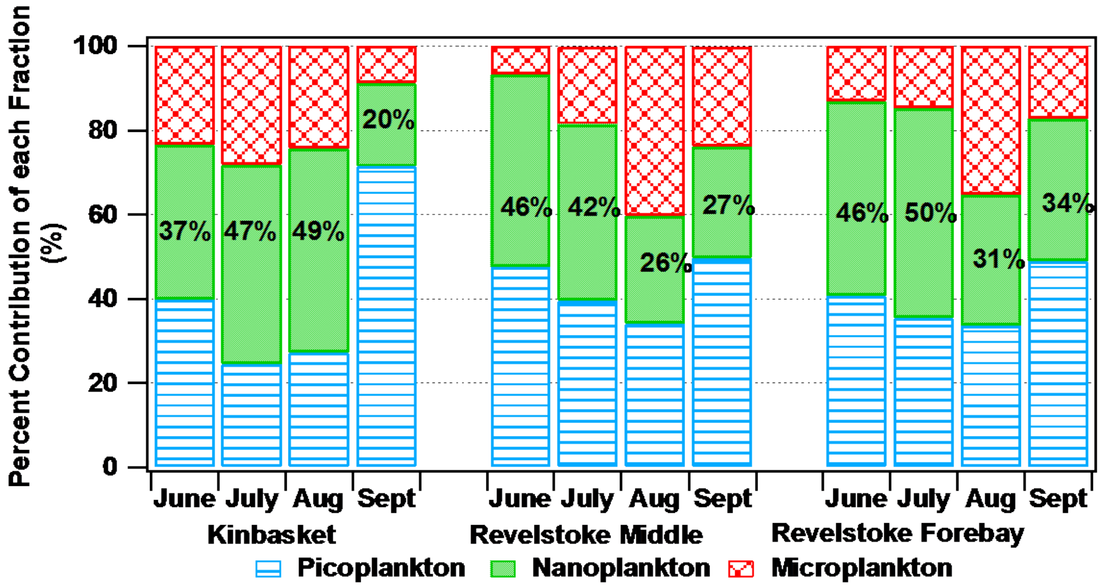

Figure 7 Relative contribution of picoplankton (0.2-2 µm), nanoplankton (2-20 µm), and microplankton (>20 µm) to primary productivity in Kinbasket and Revelstoke in 2013.

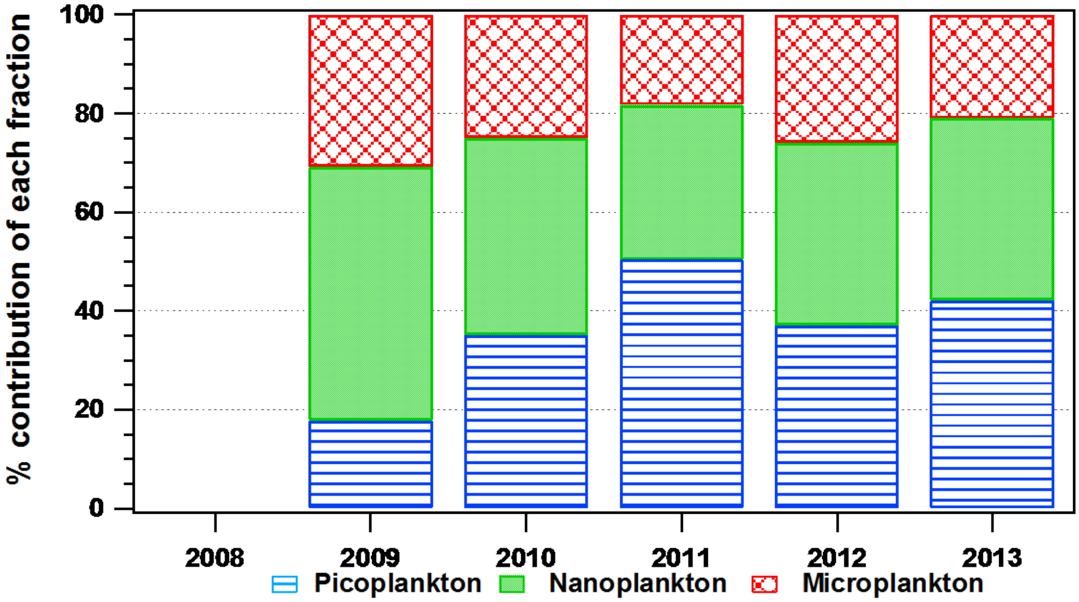

Figure 8 Mean annual contribution of each fraction to primary productivity in Columbia Basin in 2009-2013. Note: Monthly means for Kinbasket and Revelstoke were averaged.

Discussion

The food web in aquatic ecosystems is influenced by a number of complex factors including lake geomorphology, climatology based on it locations and a diverse range of physical and chemical parameters such as light, temperature, flow and nutrients. In addition, human interactions have influenced the functional relationships and productivity of aquatic ecosystems. It is important that we characterize the current state of the aquatic ecosystem in order to gain an understanding of how the ecosystem dynamics are controlled and how the aquatic ecosystem responds to these diverse factors including hydroelectric reservoir operations. This increased understanding of the functional dynamics of the reservoir will advance our knowledge which in turn will allow water managers to predict ecosystem responses to future operational changes. This report summaries data collected on the base the food chain, the phytoplankton community, which is just one component of the much larger monitoring program that encompasses physical flow dynamics and chemical dynamics. Ultimately, the integration of the findings from each component of the monitoring program will lead to a comprehensive understanding of the limnology of Kinbasket and Revelstoke Reservoirs.

Primary productivity is the foundation of all food webs and sets the upper threshold for productivity at upper trophic levels. The results of this study confirm earlier findings of extremely low phytoplankton biomass of <30 mg/m^2 in Kinbasket and ~15 mg/m^2 in Revelstoke and low rates of primary productivity of ~60 mg C/m^2/d in Kinbasket and <40 mg C/m^2/d. Approximately 90% of the biomass and 82% of the primary productivity in the two reservoirs was composed of phytoplankton less than 20 µm in size which is not surprising given the low rates of productivity in these reservoirs. Kinbasket and Revelstoke was dominated by small cells which is likely due to the high rates of growth due to the favorable surface area/volume ratios that allow small cells to outcompete larger cells for nutrients. Primary productivity was on average two fold higher in Kinbasket than in Revelstoke Reservoir and in fact for the first time in the study period, the mean primary productivity in Kinbasket Reservoir of 62.8 mg C/m^2/d exceeded the threshold for Wetzel`s ultra-oligotrophic state and was classified at the lower end of oligotrophic state-albeit the production was that the extreme low end of oligotrophic range. It appears that light conditions have improved slightly in 2013 compared to 2012 but as was seen in previous years light attenuation was higher in Revelstoke than in Kinbasket Reservoir. The low attenuation coefficients (~0.26) and deep euphotic zones (~15 m) suggest that light availability is not responsible for the low rates of primary productivity.

Wetzel (2001) uses ranges of primary productivity and related characteristics such as chlorophyll concentrations to classify different trophic categories ranging from ultraoligotrophic to hypereutrophic types. Using this approach, the chlorophyll and primary productivity data clearly classify Kinbasket and Revelstoke Reservoirs as ultraoligotrophic. All measurements to date clearly indicate that Kinbasket/Revelstoke Reservoirs productivity is low and similar to many other large oligotrophic and ultra-oligotrophic lakes and reservoirs in British Columbia (Table 2). This study confirms the low productivity status of Kinbasket and Revelstoke Reservoirs and provides a clearer understanding of the size structure of the phytoplankton communities which will aid in our understanding of trophic web dynamics and the sustainability of the fish communities.

Table 2 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
Elsie Reservoir, BC	8.1	13.9	Perrin and Harris 2005
Kinbasket Forebay	26.2	66.7	Current study
Revelstoke Middle	14.7	36.8	Current study
Revelstoke Forebay	15.5	37.8	Current study
Williston, embayment	10.3	32.6	Harris et al. 2005
Williston, pelagic	7.6	34.3	Stockner et al. 2001
Slocan	26.3	59.3	Harris 2002
Okanagan	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

Table A1 Raw chlorophyll and primary productivity data for 2013

Station	Date	Depth (m)	Filter Size (µm)	Chl (mg/m^3)	PP mg/C/m^3/hr	PP mgC/m^3/day
KB	19-Jun-13	0	0.2	1.78	0.47	10.80
KB	19-Jun-13	1	0.2	1.98	0.52	11.99
KB	19-Jun-13	2	0.2	1.99	0.36	8.46
KB	19-Jun-13	5	0.2	1.39	0.36	8.45
KB	19-Jun-13	10	0.2	1.43	0.12	2.88
KB	19-Jun-13	15	0.2	1.63	0.05	1.18
KB	19-Jun-13	17	0.2	1.52	0.04	0.85
KB	19-Jun-13	0	2.0	0.92	0.32	7.47
KB	19-Jun-13	1	2.0	0.82	0.31	7.19
KB	19-Jun-13	2	2.0	0.79	0.30	6.96
KB	19-Jun-13	5	2.0	0.85	0.20	4.67
KB	19-Jun-13	10	2.0	0.79	0.06	1.42
KB	19-Jun-13	15	2.0	0.74	0.02	0.53
KB	19-Jun-13	17	2.0	0.78	0.01	0.25
KB	19-Jun-13	0	20.0	0.23	0.10	2.24
KB	19-Jun-13	1	20.0	0.27	0.12	2.79
KB	19-Jun-13	2	20.0	0.18	0.11	2.51
KB	19-Jun-13	5	20.0	0.15	0.09	2.09
KB	19-Jun-13	10	20.0	0.14	0.02	0.58
KB	19-Jun-13	15	20.0	0.18	0.004	0.09
KB	19-Jun-13	17	20.0	0.16	0.003	0.08
KB	24-Jul-13	0	0.2	1.25	0.26	2.19
KB	24-Jul-13	1	0.2	1.37	0.51	4.36
KB	24-Jul-13	2	0.2	1.19	0.46	3.89
KB	24-Jul-13	5	0.2	1.70	0.46	3.91
KB	24-Jul-13	10	0.2	1.16	0.43	3.62
KB	24-Jul-13	15	0.2	1.74	0.32	2.67
KB	24-Jul-13	17	0.2	0.81	0.17	1.45
KB	24-Jul-13	0	2.0	0.60	0.18	1.56
KB	24-Jul-13	1	2.0	0.60	0.30	2.54
KB	24-Jul-13	2	2.0	0.63	0.37	3.13
KB	24-Jul-13	5	2.0	0.82	0.39	3.29
KB	24-Jul-13	10	2.0	1.07	0.33	2.77
KB	24-Jul-13	15	2.0	1.21	0.21	1.76
KB	24-Jul-13	17	2.0	1.05	0.11	0.93
KB	24-Jul-13	0	20.0	0.20	0.08	0.65
KB	24-Jul-13	1	20.0	0.22	0.10	0.82
KB	24-Jul-13	2	20.0	0.29	0.13	1.10
KB	24-Jul-13	5	20.0	0.38	0.14	1.19
KB	24-Jul-13	10	20.0	0.50	0.12	1.04
KB	25-Jul-13	15	20.0	0.42	0.08	0.70
KB	26-Jul-13	17	20.0	0.37	0.07	0.57
KB	21-Aug-13	0	0.2	3.06	0.16	1.02
KB	21-Aug-13	1	0.2	1.92	0.52	3.22

KB	21-Aug-13	2	0.2	2.49	0.36	2.23
KB	21-Aug-13	5	0.2	0.67	0.44	2.74
KB	21-Aug-13	10	0.2	0.98	0.52	3.22
KB	21-Aug-13	15	0.2	3.38	0.29	1.78
KB	21-Aug-13	18	0.2	1.93	0.20	1.22
KB	21-Aug-13	0	2.0	3.09	0.18	1.13
KB	21-Aug-13	1	2.0	1.78	0.32	1.97
KB	21-Aug-13	2	2.0	1.74	0.28	1.77
KB	21-Aug-13	5	2.0	2.11	0.32	2.02
KB	21-Aug-13	10	2.0	1.45	0.35	2.17
KB	21-Aug-13	15	2.0	1.49	0.24	1.52
KB	21-Aug-13	18	2.0	4.11	0.13	0.81
KB	21-Aug-13	0	20.0	0.13	0.03	0.18
KB	21-Aug-13	1	20.0	0.11	0.11	0.68
KB	21-Aug-13	2	20.0	0.13	0.09	0.57
KB	21-Aug-13	5	20.0	0.11	0.13	0.78
KB	21-Aug-13	10	20.0	0.35	0.13	0.78
KB	21-Aug-13	15	20.0	0.30	0.06	0.37
KB	21-Aug-13	18	20.0	0.27	0.04	0.24
KB	19-Sep-13	0	0.2	1.04	0.19	1.41
KB	19-Sep-13	1	0.2	0.98	0.15	1.15
KB	19-Sep-13	2	0.2	0.95	0.27	2.01
KB	19-Sep-13	5	0.2	1.05	0.69	5.19
KB	19-Sep-13	10	0.2	1.01	0.55	4.11
KB	19-Sep-13	15	0.2	1.21	0.49	3.67
KB	19-Sep-13	20	0.2	1.28	0.62	4.66
KB	19-Sep-13	0	2.0	0.67	0.11	0.82
KB	19-Sep-13	1	2.0	0.59	0.20	1.51
KB	19-Sep-13	2	2.0	0.64	0.17	1.27
KB	19-Sep-13	5	2.0	0.58	0.13	0.94
KB	19-Sep-13	10	2.0	0.59	0.15	1.15
KB	19-Sep-13	15	2.0	0.73	0.10	0.73
KB	19-Sep-13	20	2.0	0.64	0.01	0.07
KB	19-Sep-13	0	20.0	0.12	0.06	0.46
KB	19-Sep-13	1	20.0	0.10	0.01	0.10
KB	19-Sep-13	2	20.0	0.09	0.05	0.38
KB	19-Sep-13	5	20.0	0.10	0.004	0.03
KB	19-Sep-13	10	20.0	0.11	0.01	0.10
KB	19-Sep-13	15	20.0	0.11	0.09	0.70
KB	19-Sep-13	20	20.0	0.14	0.02	0.17
RM	20-Jun-13	0	0.2	1.87	0.44	6.34
RM	20-Jun-13	1	0.2	1.88	0.35	5.06
RM	20-Jun-13	2	0.2	1.70	0.36	5.16
RM	20-Jun-13	5	0.2	1.05	0.25	3.51
RM	20-Jun-13	10	0.2	1.46	0.08	1.14
RM	20-Jun-13	13	0.2	0.73	0.02	0.25
RM	20-Jun-13	0	2.0	0.45	0.22	3.14
RM	20-Jun-13	1	2.0	0.42	0.19	2.77

RM	20-Jun-13	2	2.0	0.49	0.20	2.87
RM	20-Jun-13	5	2.0	0.38	0.13	1.81
RM	20-Jun-13	10	2.0	0.53	0.03	0.49
RM	20-Jun-13	13	2.0	0.41	0.02	0.29
RM	20-Jun-13	0	20.0	0.03	0.02	0.26
RM	20-Jun-13	1	20.0	0.03	0.02	0.33
RM	20-Jun-13	2	20.0	0.03	0.02	0.32
RM	20-Jun-13	5	20.0	0.03	0.02	0.24
RM	20-Jun-13	10	20.0	0.04	0.01	0.12
RM	20-Jun-13	13	20.0	0.05	0.00	0.03
RM	25-Jul-13	0	0.2	0.54	0.19	1.65
RM	25-Jul-13	1	0.2	0.69	0.46	4.01
RM	25-Jul-13	2	0.2	0.77	0.31	2.68
RM	25-Jul-13	5	0.2	1.02	0.34	2.91
RM	25-Jul-13	10	0.2	1.43	0.21	1.81
RM	25-Jul-13	13	0.2	1.43	0.12	1.03
RM	25-Jul-13	0	2.0	0.34	0.12	1.07
RM	25-Jul-13	1	2.0	0.24	0.26	2.28
RM	25-Jul-13	2	2.0	0.27	0.22	1.94
RM	25-Jul-13	5	2.0	0.42	0.19	1.69
RM	25-Jul-13	10	2.0	0.54	0.12	1.07
RM	25-Jul-13	13	2.0	0.66	0.06	0.55
RM	25-Jul-13	0	20.0	0.05	0.04	0.31
RM	25-Jul-13	1	20.0	0.05	0.07	0.58
RM	25-Jul-13	2	20.0	0.03	0.07	0.58
RM	25-Jul-13	5	20.0	0.06	0.08	0.67
RM	25-Jul-13	10	20.0	0.08	0.03	0.27
RM	25-Jul-13	13	20.0	0.08	0.001	0.01
RM	22-Aug-13	0	0.2	0.89	0.20	1.49
RM	22-Aug-13	1	0.2	1.00	0.48	3.58
RM	22-Aug-13	2	0.2	1.06	0.52	3.82
RM	22-Aug-13	5	0.2	1.04	0.47	3.49
RM	22-Aug-13	10	0.2	1.00	0.07	0.48
RM	22-Aug-13	12	0.2	0.77	0.01	0.07
RM	22-Aug-13	0	2.0	0.73	0.15	1.11
RM	22-Aug-13	1	2.0	0.63	0.31	2.31
RM	22-Aug-13	2	2.0	0.66	0.32	2.34
RM	22-Aug-13	5	2.0	0.72	0.33	2.45
RM	22-Aug-13	10	2.0	0.58	0.03	0.24
RM	22-Aug-13	12	2.0	0.21	0.02	0.17
RM	22-Aug-13	0	20.0	0.23	0.12	0.92
RM	22-Aug-13	1	20.0	0.24	0.23	1.68
RM	22-Aug-13	2	20.0	0.20	0.22	1.64
RM	22-Aug-13	5	20.0	0.24	0.19	1.38
RM	22-Aug-13	10	20.0	0.18	0.02	0.12
RM	22-Aug-13	12	20.0	0.12	0.003	0.02
RM	18-Sep-13	0	0.2	0.93	0.23	2.14
RM	18-Sep-13	1	0.2	0.64	0.54	5.12

RM	18-Sep-13	2	0.2	0.61	0.42	3.91
RM	18-Sep-13	5	0.2	1.31	0.59	5.57
RM	18-Sep-13	10	0.2	1.25	0.31	2.93
RM	18-Sep-13	13	0.2	1.60	0.18	1.71
RM	18-Sep-13	0	2.0	0.76	0.15	1.38
RM	18-Sep-13	1	2.0	0.11	0.23	2.19
RM	18-Sep-13	2	2.0	0.60	0.25	2.34
RM	18-Sep-13	5	2.0	0.63	0.30	2.85
RM	18-Sep-13	10	2.0	0.34	0.16	1.51
RM	18-Sep-13	13	2.0	0.63	0.02	0.16
RM	18-Sep-13	0	20.0	0.11	0.07	0.67
RM	18-Sep-13	1	20.0	0.11	0.15	1.42
RM	18-Sep-13	2	20.0	0.12	0.11	1.02
RM	18-Sep-13	5	20.0	0.12	0.11	1.04
RM	18-Sep-13	10	20.0	0.18	0.09	0.87
RM	18-Sep-13	13	20.0	0.16	0.05	0.50
RF	21-Jun-13	0	0.2	0.58	0.34	3.93
RF	21-Jun-13	1	0.2	0.90	0.27	3.20
RF	21-Jun-13	2	0.2	0.93	0.25	2.90
RF	21-Jun-13	5	0.2	0.71	0.23	2.66
RF	21-Jun-13	10	0.2	0.92	0.11	1.28
RF	21-Jun-13	15	0.2	0.81	0.02	0.18
RF	21-Jun-13	0	2.0	0.35	0.18	2.08
RF	21-Jun-13	1	2.0	0.29	0.16	1.86
RF	21-Jun-13	2	2.0	0.31	0.16	1.86
RF	21-Jun-13	5	2.0	0.43	0.14	1.70
RF	21-Jun-13	10	2.0	0.52	0.05	0.64
RF	21-Jun-13	15	2.0	0.39	0.01	0.13
RF	21-Jun-13	0	20.0	0.04	0.03	0.40
RF	21-Jun-13	1	20.0	0.04	0.04	0.46
RF	21-Jun-13	2	20.0	0.03	0.03	0.40
RF	21-Jun-13	5	20.0	0.06	0.03	0.39
RF	21-Jun-13	10	20.0	0.06	0.01	0.14
RF	21-Jun-13	15	20.0	0.07	0.001	0.01
RF	23-Jul-13	0	0.2	0.90	0.22	1.55
RF	23-Jul-13	1	0.2	0.94	0.43	3.03
RF	23-Jul-13	2	0.2	0.92	0.42	2.99
RF	23-Jul-13	5	0.2	0.93	0.42	2.97
RF	23-Jul-13	10	0.2	0.87	0.31	2.19
RF	23-Jul-13	15	0.2	1.02	0.27	1.88
RF	23-Jul-13	17	0.2	0.81	0.12	0.82
RF	23-Jul-13	0	2.0	0.38	0.15	1.09
RF	23-Jul-13	1	2.0	0.26	0.26	1.87
RF	23-Jul-13	2	2.0	0.21	0.29	2.08
RF	23-Jul-13	5	2.0	0.20	0.31	2.19
RF	23-Jul-13	10	2.0	0.31	0.22	1.58
RF	23-Jul-13	15	2.0	0.42	0.09	0.65
RF	23-Jul-13	17	2.0	0.32	0.05	0.38

RF	23-Jul-13	0	20.0	0.06	0.05	0.37
RF	23-Jul-13	1	20.0	0.06	0.09	0.63
RF	23-Jul-13	2	20.0	0.04	0.09	0.64
RF	23-Jul-13	5	20.0	0.07	0.10	0.72
RF	23-Jul-13	10	20.0	0.04	0.03	0.19
RF	23-Jul-13	15	20.0	0.02	0.00	0.00
RF	23-Jul-13	17	20.0	0.04	0.01	0.05
RF	20-Aug-13	0	0.2	0.81	0.24	2.24
RF	20-Aug-13	1	0.2	2.53	0.51	4.77
RF	20-Aug-13	2	0.2	1.43	0.60	5.61
RF	20-Aug-13	5	0.2	1.54	0.35	3.30
RF	20-Aug-13	10	0.2	1.52	0.18	1.66
RF	20-Aug-13	12	0.2	1.24	0.06	0.56
RF	20-Aug-13	0	2.0	0.68	0.18	1.69
RF	20-Aug-13	1	2.0	0.87	0.36	3.33
RF	20-Aug-13	2	2.0	0.79	0.39	3.67
RF	20-Aug-13	5	2.0	1.66	0.26	2.48
RF	20-Aug-13	10	2.0	0.87	0.08	0.75
RF	20-Aug-13	12	2.0	0.84	0.03	0.30
RF	20-Aug-13	0	20.0	-	0.11	1.00
RF	20-Aug-13	1	20.0	-	0.25	2.37
RF	20-Aug-13	2	20.0	0.29	0.18	1.68
RF	20-Aug-13	5	20.0	0.29	0.14	1.34
RF	20-Aug-13	10	20.0	0.22	0.04	0.34
RF	20-Aug-13	12	20.0	0.24	0.02	0.20
RF	20-Sep-13	0	0.2	1.76	0.42	3.63
RF	20-Sep-13	1	0.2	1.13	0.53	4.65
RF	20-Sep-13	2	0.2	1.63	0.50	4.37
RF	20-Sep-13	5	0.2	1.56	0.58	5.06
RF	20-Sep-13	10	0.2	0.88	0.17	1.51
RF	20-Sep-13	12	0.2	0.73	0.59	5.15
RF	20-Sep-13	0	2.0	0.62	0.24	2.09
RF	20-Sep-13	1	2.0	0.55	0.28	2.45
RF	20-Sep-13	2	2.0	0.69	0.36	3.14
RF	20-Sep-13	5	2.0	0.61	0.34	2.96
RF	20-Sep-13	10	2.0	0.34	0.06	0.50
RF	20-Sep-13	12	2.0	0.20	0.02	0.14
RF	20-Sep-13	0	20.0	0.12	0.08	0.69
RF	20-Sep-13	1	20.0	0.12	0.09	0.81
RF	20-Sep-13	2	20.0	0.13	0.11	0.96
RF	20-Sep-13	5	20.0	0.14	0.12	1.04
RF	20-Sep-13	10	20.0	0.22	0.02	0.21
RF	20-Sep-13	12	20.0	0.09	0.00	0.00

Appendix B Integrated Chlorophyll and Primary Productivity

Table B1 Integrated chlorophyll *a* for Kinbasket and Revelstoke Reservoir in 2013.

	Chlorophyll a (mg Chl *a*/m^2)		
Month	**KB**	**RM**	**RF**
June	26.7	17.4	12.5
July	23.8	14.5	15.7
Aug	32.4	12.0	18.5
Sept	21.9	15.0	15.3
Mean	26.2	14.7	15.5

Table B2 Total daily primary productivity (mg C/m^2/d) in Kinbasket and Revelstoke in 2002 and 2008-2013.

Year	Month	KB	RM	RF
2002	August	77.6	-	-
2008	July	84.4	33.6	51.8
2008	August	42.2	9.6	13.4
2008	Sept	25.3	11.0	18.8
2009	June	29.5	11.6	6.9
2009	July	11.0	12.1	29.8
2009	August	16.5	12.6	11.9
2009	Sept.	13.1	10.4	0.5*
2010	June	14.8	27.1	32.5
2010	July	35.7	24.4	9.9
2010	Aug	43.9	33.8	17.4
2010	Sept.	72.9	29.5	33.8
2011	June	22.8	24.1	21.6
2011	July	41.4	36.3	25.9
2011	August	-	25.8	20.5
2011	Sept.	-	44.2	44.2
2012	June	12.9	5.6	10.6
2012	July	38.1	10.7	34.7
2012	August	25.0	25.8	21.8
2012	Sept.	44.6	19.0	48.9
2013	June	87.5	37.5	28.5
2013	July	57.8	30.6	40.0
2013	August	44.2	28.5	36.7
2013	Sept.	77.2	50.6	45.9
2008	Mean	50.6	6.0	9.3
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
2013	Mean	66.7	36.8	37.8

Appendix 6

Phytoplankton
Kinbasket and Revelstoke Reservoirs, 2013

Darren Brandt
Advanced Eco-Solutions

PHYTOPLANKTON POPULATIONS IN KINBASKET AND REVELSTOKE RESERVOIRS, UPPER COLUMBIA BASIN, BRITISH COLUMBIA – 2013

PREPARED FOR:

BC Hydro
1200 Powerhouse Rd.
Revelstoke, BC
V0E 2S0

By

Advanced Eco-Solutions Inc.
25011 E. Trent Ave. Ste. A
P.O. Box 201
Newman Lake, WA 99025

February 2014

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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 2013. 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 April-August of 2013. Samples from three stations in Revelstoke Reservoir (Revelstoke-Forebay, Revelstoke-Mid and Revelstoke-Upper) were taken monthly from April to September in 2013. 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 2013 is compatible with the previous sampling methodology; however, the taxa richness could be higher in the composited samples from 2010 through 2013 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.

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 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 – 2013

A complete list of the taxa identified in Kinbasket and Revelstoke Reservoirs in 2013 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 blue-greens (cyanophytes)were the most abundant group in the epilimnion, followed by flagellates (chryso/cryptophytes), with greens (chlorophytes), diatoms (bacillariophytes), 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 greens, flagellates and blue-greens, followed by diatoms, and dinoflagellates (Figure 2). Peak phytoplankton density occurred at the Columbia Station in May (18,017 cells/mL) (Figure 3). The Forebay Station had the lowest phytoplankton density at 4,244 cells/mL in April. On a seasonal average the Wood, Columbia and Canoe stations had similar mean phytoplankton densities. The Wood station 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 2013

Station	Group	April	May	June	July	August	Seasonal Average
Kin-Canoe	Blue-greens	2,732	4,016	5,960	3,520	4,480	4,142
	Coccoid Greens, Desmids, etc.	154	293	553	333	122	291
	Diatoms	41	81	138	146	98	101
	Dinoflagellates	0	16	73	73	57	44
	Flagellates	2,797	3,374	5,065	2,781	2,285	3,260
	Sum of All Groups	**5,724**	**7,781**	**11,789**	**6,854**	**7,041**	**7,838**
Kin-Columbia	Blue-greens	1,935	8,366	4,090	3,659	3,179	4,246
	Coccoid Greens, Desmids, etc.	268	374	171	138	154	221
	Diatoms	49	569	24	89	154	177
	Dinoflagellates	8	8	33	49	65	33
	Flagellates	2,244	8,700	3,919	3,057	3,122	4,208
	Sum of All Groups	**4,504**	**18,017**	**8,236**	**6,992**	**6,675**	**8,885**
Kin-Forebay	Blue-greens	2,195	3,675	4,244	3,114	3,081	3,262
	Coccoid Greens, Desmids, etc.	98	179	333	138	398	229
	Diatoms	33	81	138	179	57	98
	Dinoflagellates	8	24	81	65	73	50
	Flagellates	1,911	2,748	2,854	2,342	1,927	2,356
	Sum of All Groups	**4,244**	**6,708**	**7,651**	**5,838**	**5,537**	**5,995**
Kin-Wood	Blue-greens	2,756	5,586	4,488	3,423	2,537	3,758
	Coccoid Greens, Desmids, etc.	325	431	886	179	171	398
	Diatoms	0	65	171	106	57	80
	Dinoflagellates	41	8	89	49	57	49
	Flagellates	3,073	5,846	3,968	2,789	2,220	3,579
	Sum of All Groups	**6,195**	**11,935**	**9,602**	**6,545**	**5,041**	**7,864**

Table 2 Kinbasket Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2013

Station	Group	April	May	June	July	August	Seasonal Average
Kin-Canoe	Blue-greens	0.0168	0.0414	0.1004	0.0588	0.0436	0.0522
	Coccoid Greens, Desmids, etc.	0.0110	0.0241	0.1185	0.0286	0.0384	0.0441
	Diatoms	0.0037	0.0152	0.0169	0.0748	0.0381	0.0297
	Dinoflagellates	0.0000	0.0037	0.0150	0.0179	0.0085	0.0090
	Flagellates	0.0271	0.0350	0.0827	0.0370	0.0360	0.0436
	Sum of All Groups	**0.0585**	**0.1193**	**0.3335**	**0.2171**	**0.1647**	**0.1786**
Kin-Columbia	Blue-greens	0.0195	0.0590	0.0792	0.0556	0.0481	0.0523
	Coccoid Greens, Desmids, etc.	0.0308	0.0479	0.0149	0.0171	0.0404	0.0302
	Diatoms	0.0067	0.0691	0.0022	0.0524	0.0663	0.0394
	Dinoflagellates	0.0004	0.0033	0.0073	0.0081	0.0118	0.0062
	Flagellates	0.0272	0.0869	0.0597	0.0498	0.0635	0.0574
	Sum of All Groups	**0.0847**	**0.2661**	**0.1634**	**0.1831**	**0.2301**	**0.1855**
Kin-Forebay	Blue-greens	0.0205	0.0433	0.0833	0.0472	0.0301	0.0449
	Coccoid Greens, Desmids, etc.	0.0134	0.0253	0.0479	0.0217	0.1071	0.0431
	Diatoms	0.0037	0.0124	0.0136	0.0819	0.0339	0.0291
	Dinoflagellates	0.0033	0.0041	0.0183	0.0061	0.0094	0.0082
	Flagellates	0.0273	0.0446	0.0485	0.0446	0.0398	0.0410
	Sum of All Groups	**0.0681**	**0.1296**	**0.2115**	**0.2016**	**0.2202**	**0.1662**
Kin-Wood	Blue-greens	0.0248	0.0479	0.0691	0.0506	0.0475	0.0480
	Coccoid Greens, Desmids, etc.	0.0255	0.0732	0.3028	0.0676	0.0666	0.1071
	Diatoms	0.0000	0.0048	0.0302	0.0858	0.0130	0.0268
	Dinoflagellates	0.0114	0.0004	0.0130	0.0110	0.0488	0.0169
	Flagellates	0.0393	0.0673	0.0660	0.0531	0.0394	0.0530
	Sum of All Groups	**0.1009**	**0.1936**	**0.4811**	**0.2680**	**0.2154**	**0.2518**

Figure 1 **Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between April - August 2013 derived from the 2, 5, 10 meter laboratory composites**

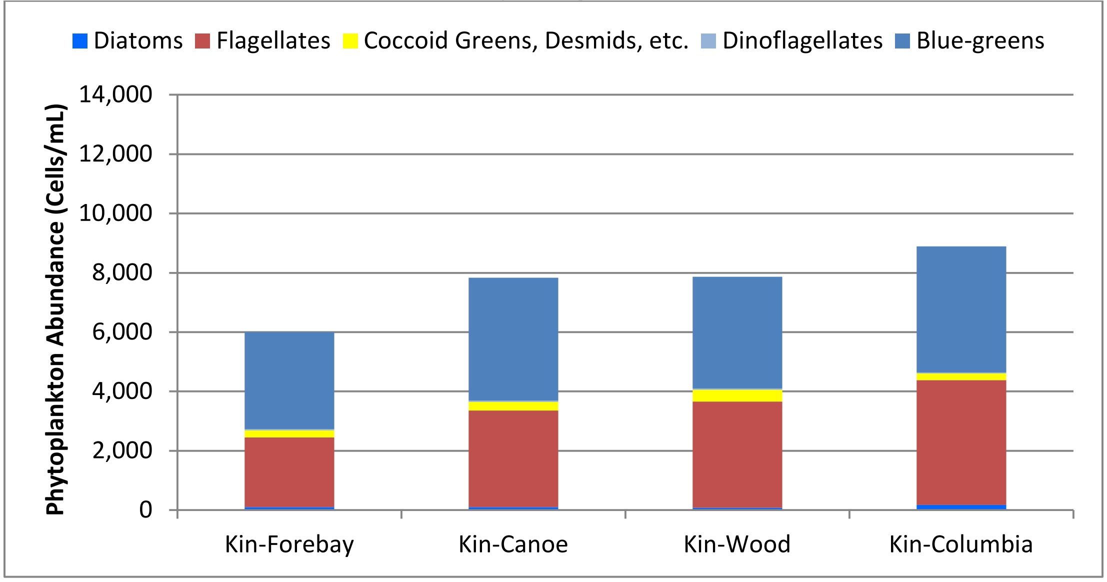


Figure 2 **Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between April - August 2013 derived from the 2, 5, and 10 meter laboratory composites**

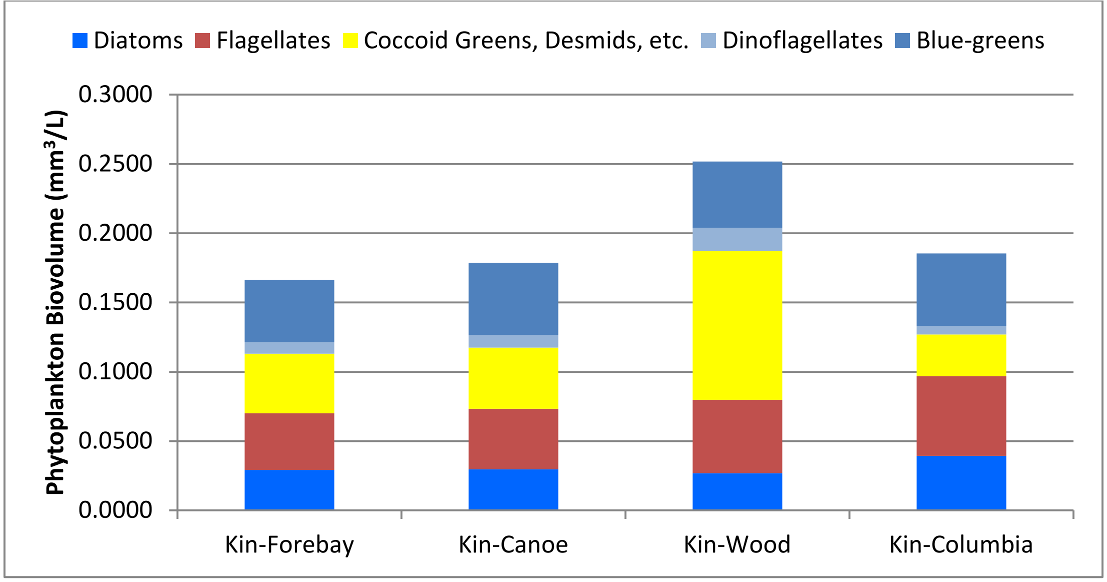


Figure 3 Kinbasket mean epilimnetic phytoplankton density by month

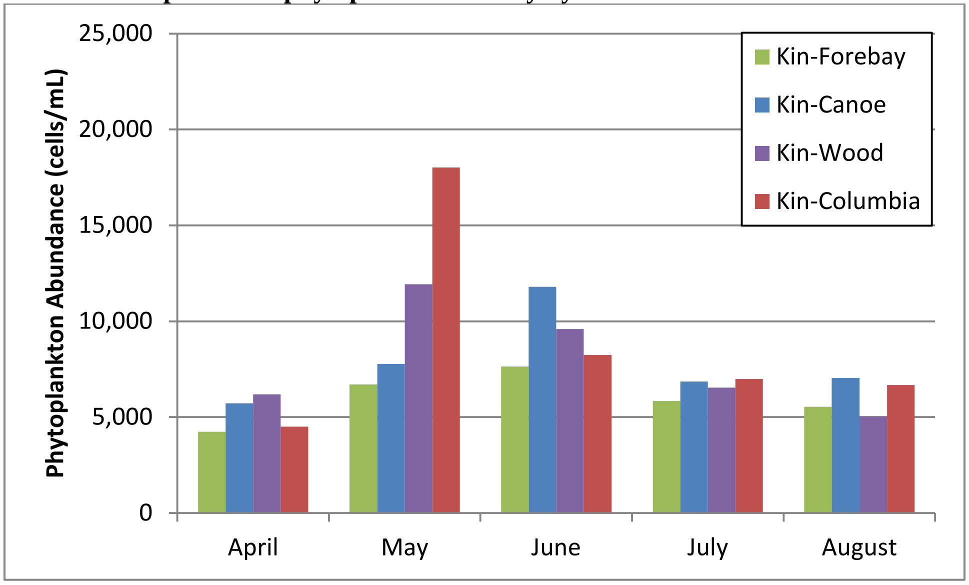
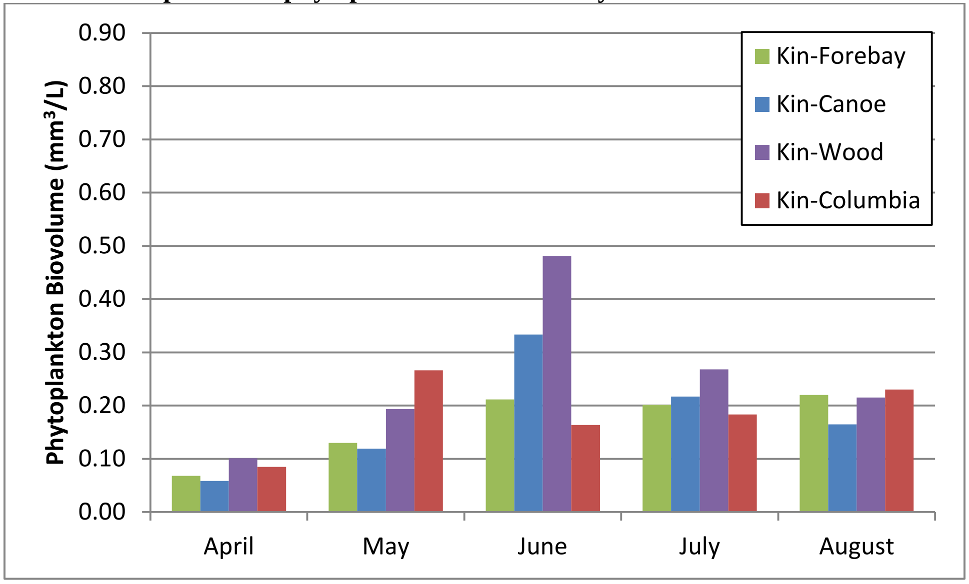


Figure 4 Kinbasket mean epilimnetic phytoplankton biovolume by month



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 (9,525 cells/mL compared to 7,646 cells/mL). Based on biovolume, the taxonomic group making up the largest percentage of the phytoplankton community are the flagellates and blue-greens followed by greens, diatoms and dinoflagellates (Table 4 and Figure 6).

Peak phytoplankton density and biovolume occurred at the Upper station in May (21,464 cells/mL and 0.8504 mm^3/L) (Figure 7 and Figure 8). The Forebay station had the lowest phytoplankton density (3,000 cells/mL), and biovolume (0.0541 mm^3/L) in July.

Table 3 Revelstoke Reservoir mean phytoplankton density (Cells/mL) by group and month from the 2, 5 and 10 meter laboratory composites 2013

Station	Group	April	May	June	July	Aug	Sept	Seasonal Average
Rev-Forebay	Blue-greens	2,236	3,642	2,024	1,423	8,659	8,626	4,435
	Coccoid Greens, Desmids, etc.	228	781	309	65	301	195	313
	Diatoms	106	98	24	0	33	24	47
	Dinoflagellates	41	106	49	16	130	98	73
	Flagellates	1,837	3,537	1,797	1,496	5,098	4,057	2,970
	Sum of All Groups	**4,447**	**8,163**	**4,203**	**3,000**	**14,220**	**13,001**	**7,839**
Rev-Mid	Blue-greens	2,374	8,317	4,756	2,789	3,854	3,675	4,294
	Coccoid Greens, Desmids, etc.	122	699	496	301	163	130	318
	Diatoms	24	98	49	8	16	0	33
	Dinoflagellates	57	106	138	57	106	114	96
	Flagellates	2,878	6,586	4,293	2,472	2,748	2,545	3,587
	Sum of All Groups	**5,456**	**15,806**	**9,732**	**5,626**	**6,886**	**6,464**	**8,328**
Rev-Upper	Blue-greens	2,220	11,139	5,870	5,602	7,033	7,586	6,575
	Coccoid Greens, Desmids, etc.	317	537	236	325	309	122	308
	Diatoms	57	179	146	16	16	24	73
	Dinoflagellates	8	81	65	114	171	98	89
	Flagellates	2,455	9,529	5,350	4,399	4,740	5,659	5,355
	Sum of All Groups	**5,057**	**21,464**	**11,667**	**10,456**	**12,269**	**13,488**	**12,400**

Table 4 Revelstoke Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2013

Station	Group	April	May	June	July	Aug	Sept	Seasonal Average
Rev-Forebay	Blue-greens	0.0344	0.0755	0.0395	0.0174	0.0893	0.0665	0.0538
	Coccoid Greens, Desmids, etc.	0.0234	0.3044	0.0418	0.0081	0.0856	0.0193	0.0804
	Diatoms	0.0113	0.0112	0.0038	0.0000	0.0252	0.0041	0.0093
	Dinoflagellates	0.0106	0.0195	0.0081	0.0008	0.0094	0.0163	0.0108
	Flagellates	0.0296	0.0723	0.0355	0.0277	0.0939	0.0730	0.0553
	Sum of All Groups	**0.1092**	**0.4829**	**0.1288**	**0.0541**	**0.3034**	**0.1791**	**0.2096**
Rev-Mid	Blue-greens	0.0270	0.1116	0.0878	0.0466	0.0619	0.0497	0.0641
	Coccoid Greens, Desmids, etc.	0.0191	0.1228	0.0627	0.0242	0.0123	0.0271	0.0447
	Diatoms	0.0036	0.0117	0.0044	0.0002	0.0016	0.0000	0.0036
	Dinoflagellates	0.0085	0.0167	0.0183	0.0057	0.0110	0.0057	0.0110
	Flagellates	0.0456	0.0974	0.0721	0.0481	0.0489	0.0466	0.0598
	Sum of All Groups	**0.1039**	**0.3601**	**0.2453**	**0.1247**	**0.1357**	**0.1291**	**0.1831**
Rev-Upper	Blue-greens	0.0324	0.0884	0.0981	0.0714	0.0591	0.0726	0.0703
	Coccoid Greens, Desmids, etc.	0.0344	0.1101	0.0432	0.0530	0.0431	0.0368	0.0534
	Diatoms	0.0080	0.0256	0.0153	0.0033	0.0089	0.0098	0.0118
	Dinoflagellates	0.0033	0.0211	0.0118	0.0142	0.0171	0.0077	0.0125
	Flagellates	0.1820	0.6052	0.4136	0.2666	0.2639	0.2559	0.3312
	Sum of All Groups	**0.2600**	**0.8504**	**0.5820**	**0.4085**	**0.3922**	**0.3827**	**0.4793**

Figure 5 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between April - September 2013 derived from the 2, 5, and 10 meter laboratory composites

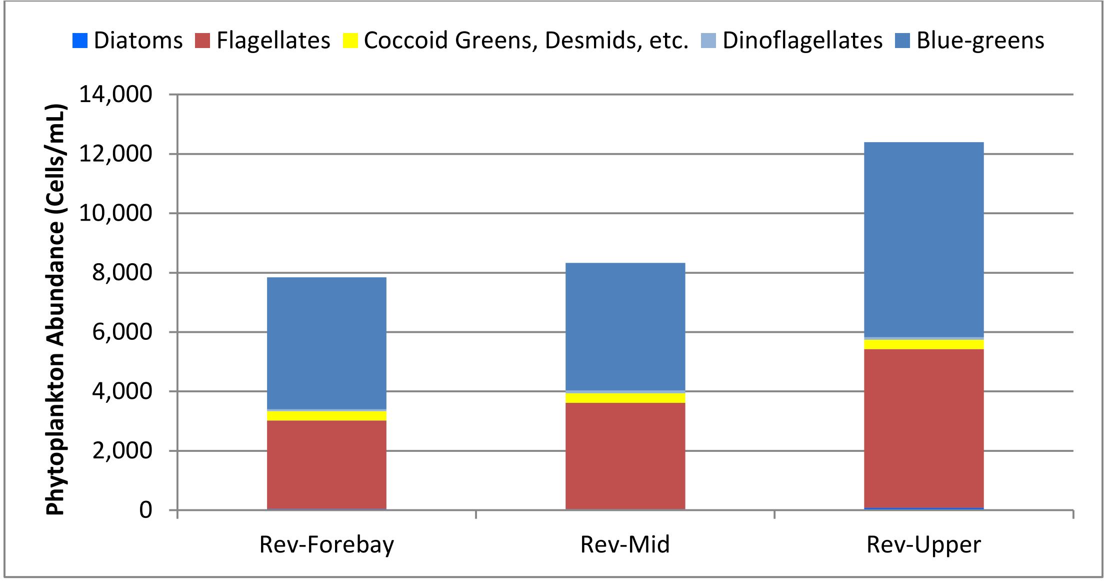


Figure 6 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2013 derived from the 2, 5, and 10 meter laboratory composites

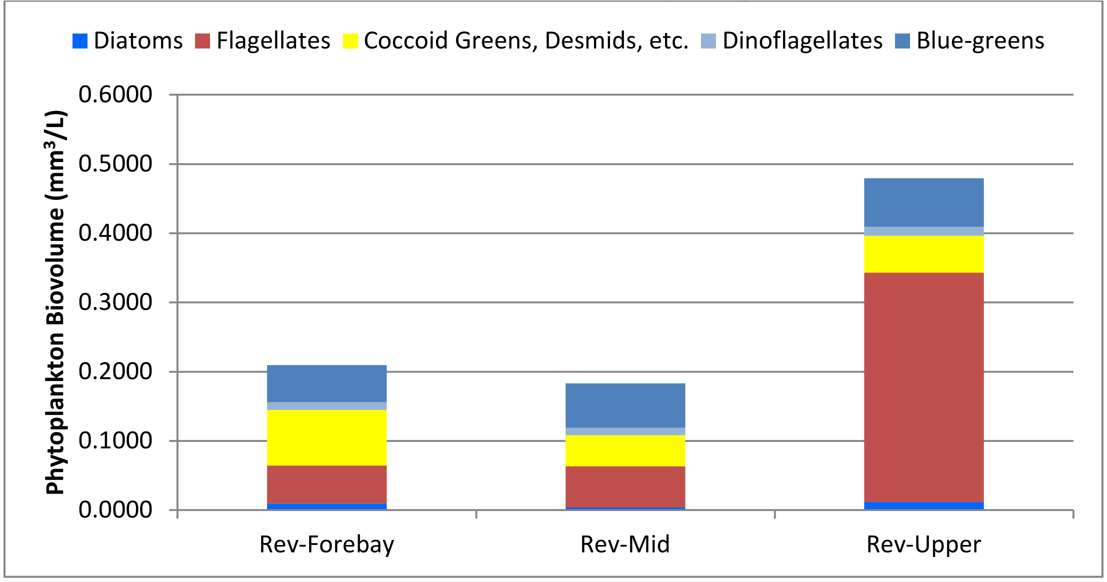


Figure 7 Revelstoke mean epilimnetic phytoplankton density by month

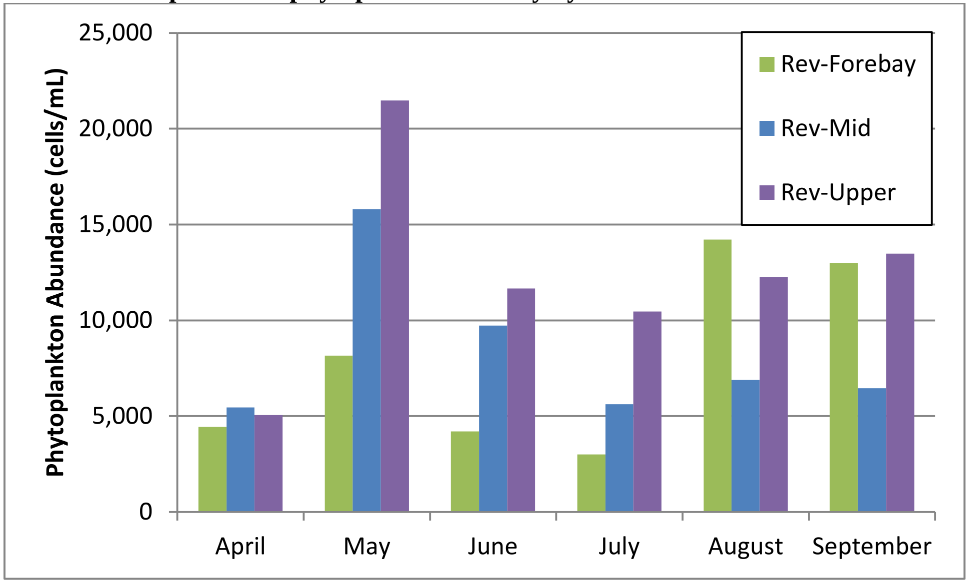
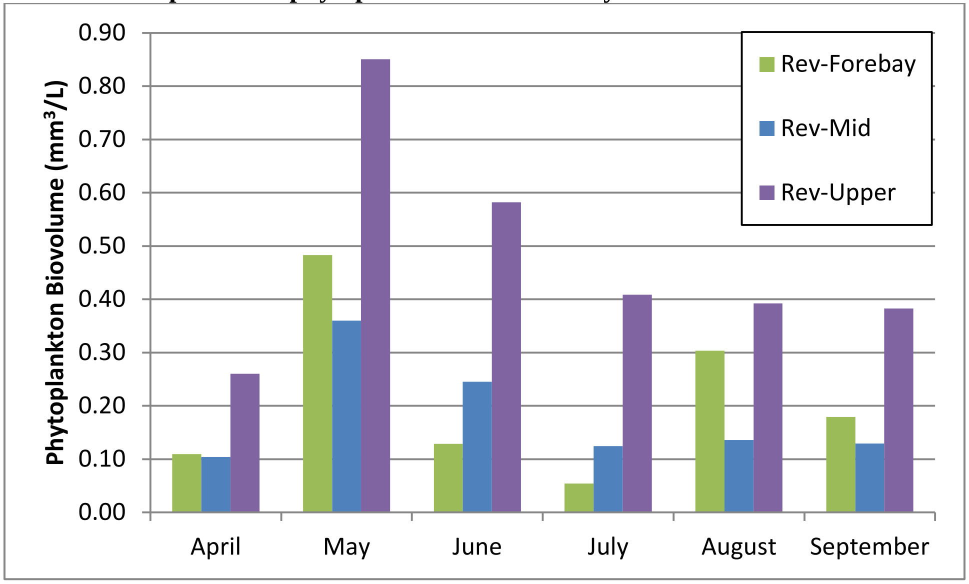


Figure 8 Revelstoke mean epilimnetic phytoplankton biovolume by month



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, greens, blue-greens and flagellates were the largest contributors followed by diatoms and dinoflagellates (Table 6 and Figure 10). The Wood station had the highest seasonal average phytoplankton density (9,330 cells/mL); but the highest seasonal average of biovolume occurred in the Columbia Arm(0.1800 mm^3/L). The months of June and July had the highest hypolimnetic phytoplankton cell densities (Figure 11).

Table 5 Kinbasket Reservoir phytoplankton density (Cells/mL) by group and month from the 15, and 25 meter laboratory composites in 2013

Station	Group	April	May	June	July	August	Seasonal Average
Kin-Canoe	Blue-greens	2,110	4,025	5,951	3,086	3,647	3,764
	Coccoid Greens, Desmids, etc.	37	73	256	171	110	129
	Diatoms	12	49	110	61	110	68
	Dinoflagellates	0	0	134	73	110	63
	Flagellates	1,927	2,842	4,073	2,585	2,646	2,815
	Sum of All Groups	**4,086**	**6,988**	**10,525**	**5,976**	**6,622**	**6,839**
Kin-Columbia	Blue-greens	1,524	2,756	4,829	4,256	3,561	3,386
	Coccoid Greens, Desmids, etc.	281	317	244	85	195	224
	Diatoms	61	366	0	85	134	129
	Dinoflagellates	12	12	98	49	85	51
	Flagellates	1,866	3,061	4,439	3,659	2,976	3,200
	Sum of All Groups	**3,744**	**6,512**	**9,610**	**8,135**	**6,952**	**6,991**
Kin-Forebay	Blue-greens	2,256	2,707	4,476	2,659	2,073	2,834
	Coccoid Greens, Desmids, etc.	195	232	378	183	195	237
	Diatoms	24	73	134	73	244	110
	Dinoflagellates	12	0	24	49	73	32
	Flagellates	2,525	1,939	2,671	2,220	2,073	2,285
	Sum of All Groups	**5,012**	**4,951**	**7,683**	**5,183**	**4,659**	**5,498**
Kin-Wood	Blue-greens	2,268	3,134	5,305	9,220	4,927	4,971
	Coccoid Greens, Desmids, etc.	159	220	232	122	281	202
	Diatoms	12	24	73	73	85	54
	Dinoflagellates	0	12	73	49	98	46
	Flagellates	2,439	2,659	4,134	7,622	3,427	4,056
	Sum of All Groups	**4,878**	**6,049**	**9,818**	**17,086**	**8,817**	**9,330**

Table 6 Kinbasket Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2013

Station	Group	June	July	August	Sept	Oct	Seasonal Average
Kin-Canoe	Blue-greens	0.0231	0.0277	0.0945	0.0473	0.0530	0.0491
	Coccoid Greens, Desmids, etc.	0.0049	0.0081	0.0622	0.0323	0.0370	0.0289
	Diatoms	0.0009	0.0159	0.0216	0.0305	0.0110	0.0160
	Dinoflagellates	0.0000	0.0000	0.0238	0.0165	0.0140	0.0109
	Flagellates	0.0174	0.0201	0.0684	0.0287	0.0424	0.0354
	Sum of All Groups	**0.0463**	**0.0718**	**0.2705**	**0.1553**	**0.1574**	**0.1403**
Kin-Columbia	Blue-greens	0.0150	0.0199	0.0872	0.0642	0.0585	0.0489
	Coccoid Greens, Desmids, etc.	0.0421	0.0423	0.0241	0.0375	0.0710	0.0434
	Diatoms	0.0122	0.0594	0.0000	0.0854	0.0454	0.0405
	Dinoflagellates	0.0049	0.0049	0.0091	0.0067	0.0128	0.0077
	Flagellates	0.0273	0.0430	0.0379	0.0434	0.0445	0.0392
	Sum of All Groups	**0.1014**	**0.1695**	**0.1583**	**0.2372**	**0.2322**	**0.1797**
Kin-Forebay	Blue-greens	0.0149	0.0490	0.0735	0.0550	0.0496	0.0484
	Coccoid Greens, Desmids, etc.	0.0146	0.0368	0.0496	0.0251	0.0877	0.0428
	Diatoms	0.0073	0.0124	0.0127	0.0509	0.0215	0.0210
	Dinoflagellates	0.0049	0.0000	0.0012	0.0067	0.0122	0.0050
	Flagellates	0.0363	0.0187	0.0304	0.0342	0.0552	0.0350
	Sum of All Groups	**0.0781**	**0.1168**	**0.1674**	**0.1719**	**0.2262**	**0.1521**
Kin-Wood	Blue-greens	0.0207	0.0241	0.0771	0.0723	0.0627	0.0514
	Coccoid Greens, Desmids, etc.	0.0280	0.0242	0.0333	0.0192	0.0480	0.0306
	Diatoms	0.0012	0.0045	0.0110	0.0399	0.0191	0.0152
	Dinoflagellates	0.0000	0.0006	0.0165	0.0024	0.0134	0.0066
	Flagellates	0.0334	0.0418	0.0572	0.0593	0.0478	0.0479
	Sum of All Groups	**0.0834**	**0.0953**	**0.1950**	**0.1933**	**0.1911**	**0.1516**

Figure 9 Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between April - August 2013 derived from the 15, and 25 meter laboratory composites

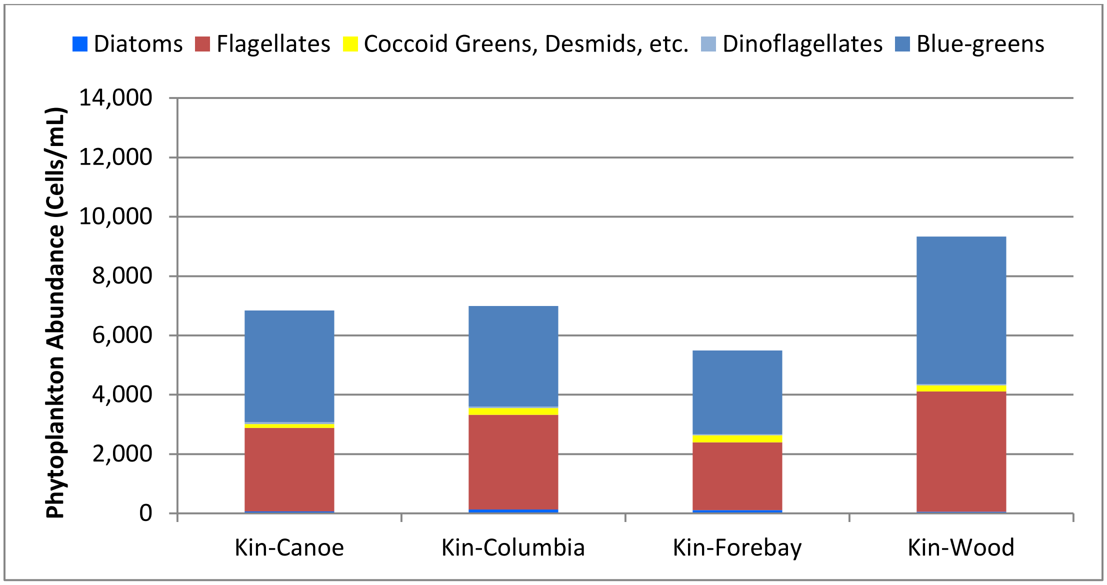


Figure 10 Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between April - August 2013 derived from the 15, and 25 meter laboratory composites

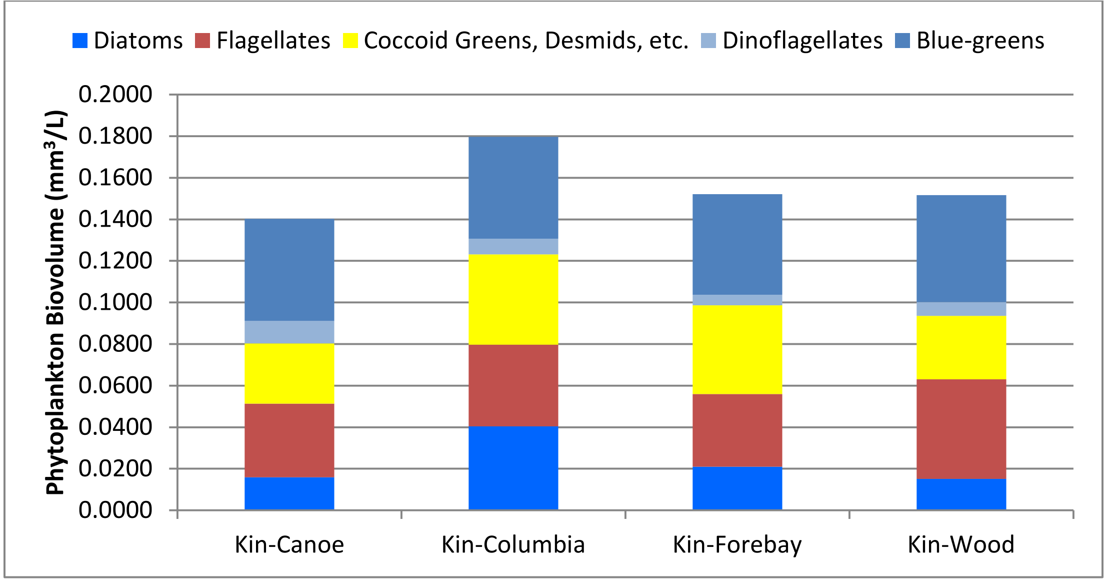


Figure 11 Kinbasket mean hypolimnetic phytoplankton density by month

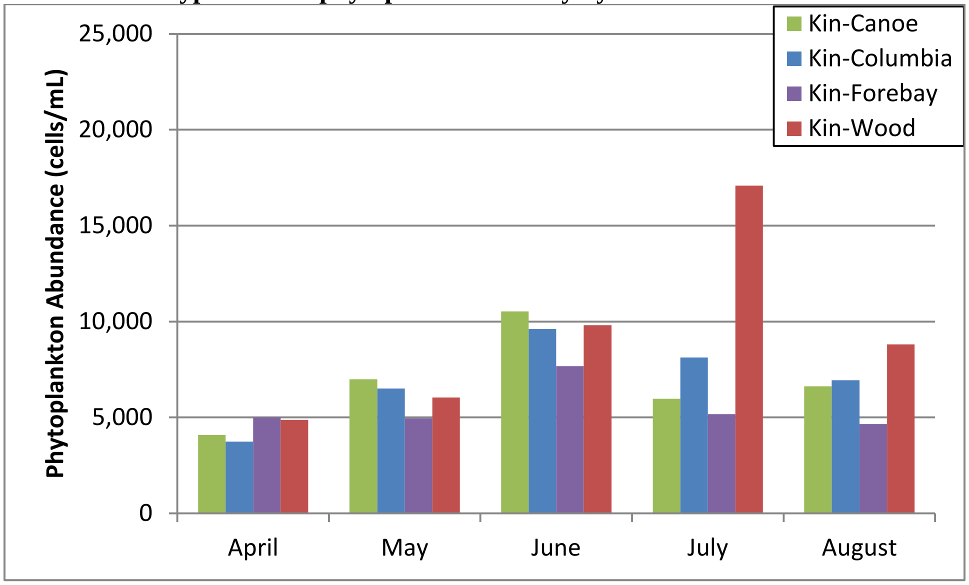
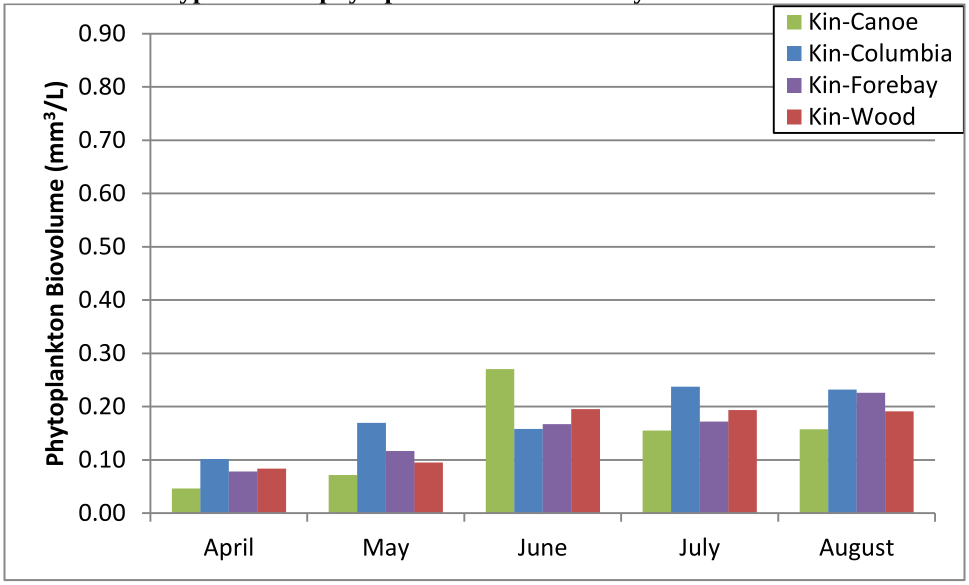


Figure 12 Kinbasket mean hypolimnetic phytoplankton biovolume by month



Revelstoke

The most abundant groups in the hypolimnion of Revelstoke Reservoir in 2013 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.

May, August and September had the highest phytoplankton density in the hypolimnion (Figure 15). Hypolimnetic biovolume was relatively consistent 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 2013

Station	Group	April	May	June	July	Aug.	Sept.	Seasonal Average
Rev-Forebay	Blue-greens	2,085	3,695	2,195	4,195	7,098	8,781	4,675
	Coccoid Greens, Desmids, etc.	85	561	256	122	256	195	246
	Diatoms	12	171	24	12	0	12	39
	Dinoflagellates	12	37	37	0	85	122	49
	Flagellates	1,415	2,525	1,976	3,305	4,086	5,281	3,098
	Sum of All Groups	**3,610**	**6,988**	**4,488**	**7,634**	**11,525**	**14,391**	**8,106**
Rev-Mid	Blue-greens	2,500	6,976	4,098	3,915	14,598	4,744	6,138
	Coccoid Greens, Desmids, etc.	305	220	146	110	110	98	165
	Diatoms	85	73	49	12	24	49	49
	Dinoflagellates	61	61	61	98	159	110	91
	Flagellates	2,598	5,269	3,915	2,781	8,549	3,683	4,466
	Sum of All Groups	**5,549**	**12,598**	**8,269**	**6,915**	**23,440**	**8,683**	**10,909**
Rev-Upper	Blue-greens	2,707	9,049	5,695	4,390	9,488	6,122	6,242
	Coccoid Greens, Desmids, etc.	317	183	85	305	427	85	234
	Diatoms	24	122	134	98	37	24	73
	Dinoflagellates	12	37	12	73	98	122	59
	Flagellates	2,610	8,964	4,683	4,012	7,086	5,159	5,419
	Sum of All Groups	**5,671**	**18,354**	**10,610**	**8,878**	**17,135**	**11,513**	**12,027**

Table 8 Revelstoke Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2013

Station	Group	April	May	June	July	Aug.	Sept.	Seasonal Average
Rev-Forebay	Blue-greens	0.0197	0.0710	0.0441	0.0463	0.0830	0.0858	0.0583
	Coccoid Greens, Desmids, etc.	0.0106	0.1005	0.0982	0.0474	0.0473	0.0493	0.0589
	Diatoms	0.0043	0.0121	0.0021	0.0012	0.0000	0.0061	0.0043
	Dinoflagellates	0.0049	0.0018	0.0061	0.0000	0.0128	0.0061	0.0053
	Flagellates	0.0170	0.0463	0.0372	0.0499	0.0490	0.0641	0.0439
	Sum of All Groups	**0.0564**	**0.2318**	**0.1876**	**0.1448**	**0.1921**	**0.2115**	**0.1707**
Rev-Mid	Blue-greens	0.0333	0.0748	0.0459	0.0711	0.1196	0.0633	0.0680
	Coccoid Greens, Desmids, etc.	0.0409	0.0621	0.0225	0.0142	0.0413	0.0399	0.0368
	Diatoms	0.0127	0.0037	0.0066	0.0012	0.0049	0.0067	0.0060
	Dinoflagellates	0.0116	0.0030	0.0116	0.0091	0.0079	0.0055	0.0081
	Flagellates	0.0346	0.0601	0.0418	0.0385	0.0962	0.0588	0.0550
	Sum of All Groups	**0.1331**	**0.2038**	**0.1285**	**0.1342**	**0.2699**	**0.1743**	**0.1740**
Rev-Upper	Blue-greens	0.0639	0.0948	0.0876	0.0530	0.1030	0.0836	0.0810
	Coccoid Greens, Desmids, etc.	0.0650	0.0766	0.0393	0.0318	0.1466	0.1007	0.0767
	Diatoms	0.0024	0.0241	0.0205	0.0537	0.0146	0.0070	0.0204
	Dinoflagellates	0.0006	0.0104	0.0006	0.0079	0.0091	0.0104	0.0065
	Flagellates	0.0381	0.0902	0.0577	0.0438	0.0820	0.0848	0.0661
	Sum of All Groups	**0.1700**	**0.2961**	**0.2057**	**0.1901**	**0.3554**	**0.2864**	**0.2506**

Figure 13 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between April - September 2013 derived from the 15, and 25 meter laboratory composites

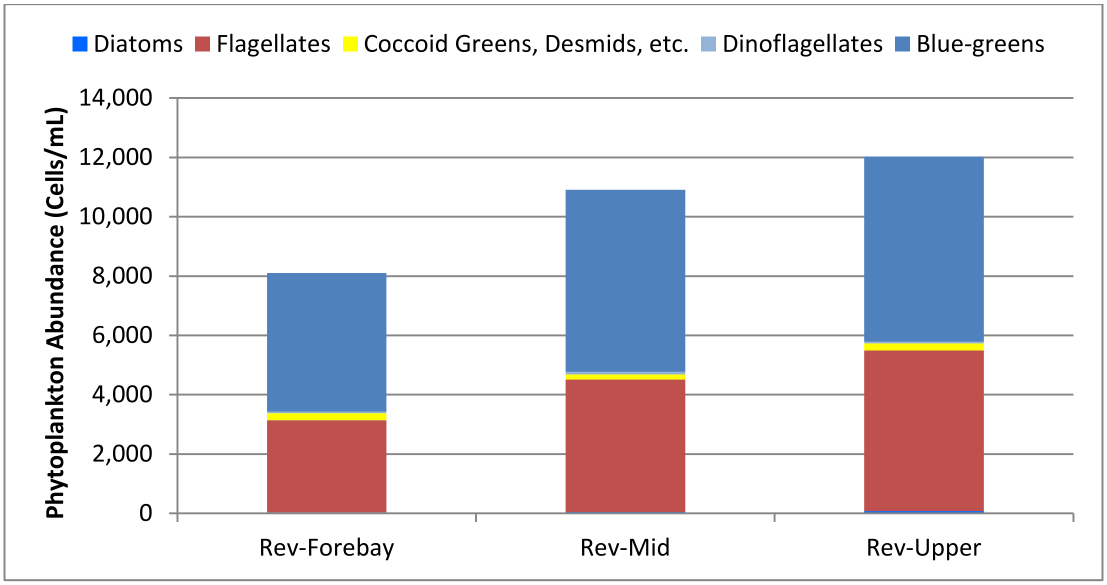


Figure 14 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between April - September 2013 derived from the 15, and 25 meter laboratory composites

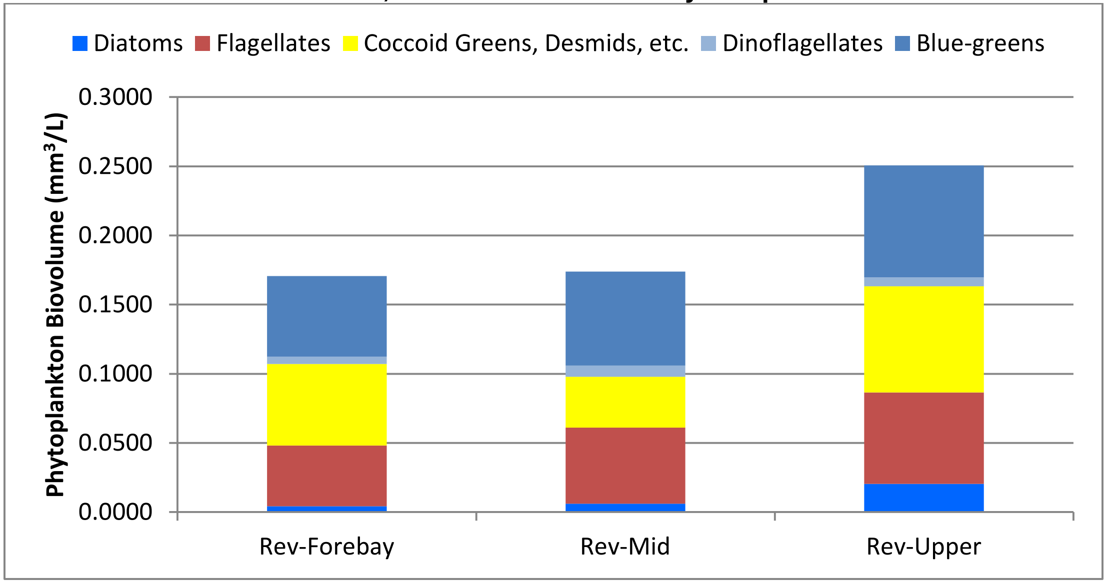


Figure 15 Revelstoke mean hypolimnetic phytoplankton density by month

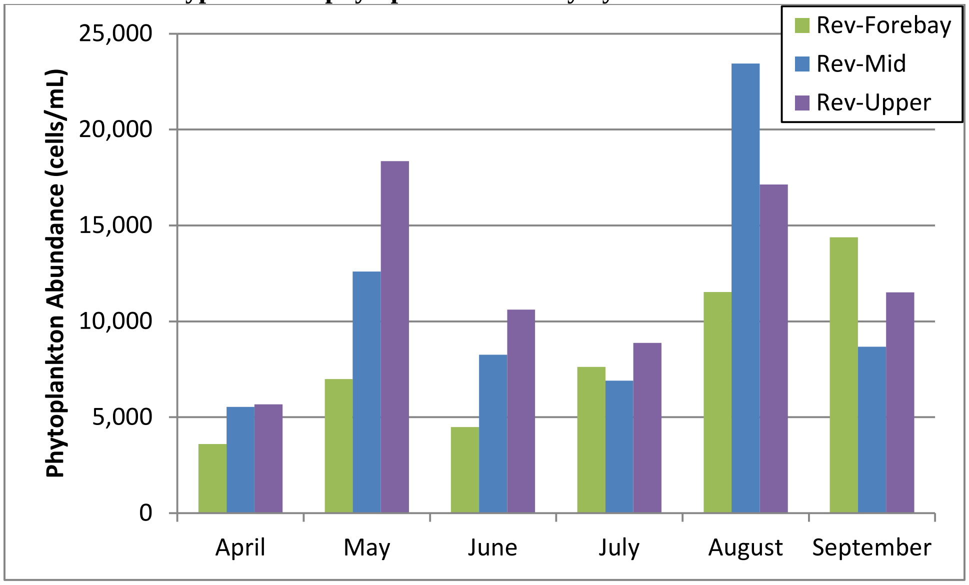
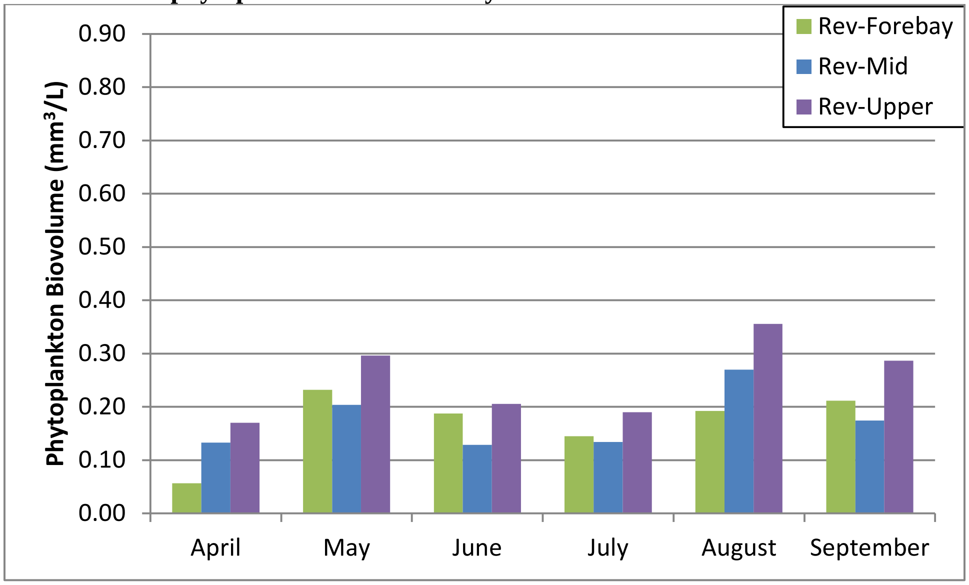


Figure 16 Revelstoke mean phytoplankton biovolume by month



3.3 Vertical Distribution- Phytoplankton Density and Biovolume – 2013

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 2013 sampling season.

Kinbasket

There was a slight decrease in phytoplankton density with depth in 2013. 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 2 meters, then decreases with depth. The reduction in biovolume in samples greater than 5 meters in depth is most pronounced in greens and diatoms (Figure 18).

Figure 17 Average phytoplankton density (Cells/mL), by depth and group, in Kinbasket Reservoir between April - August 2013

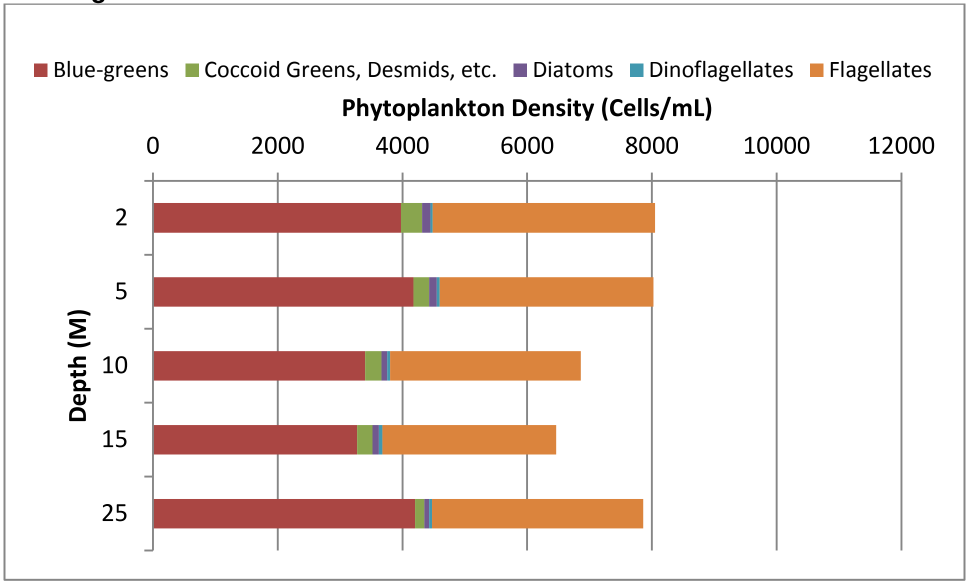
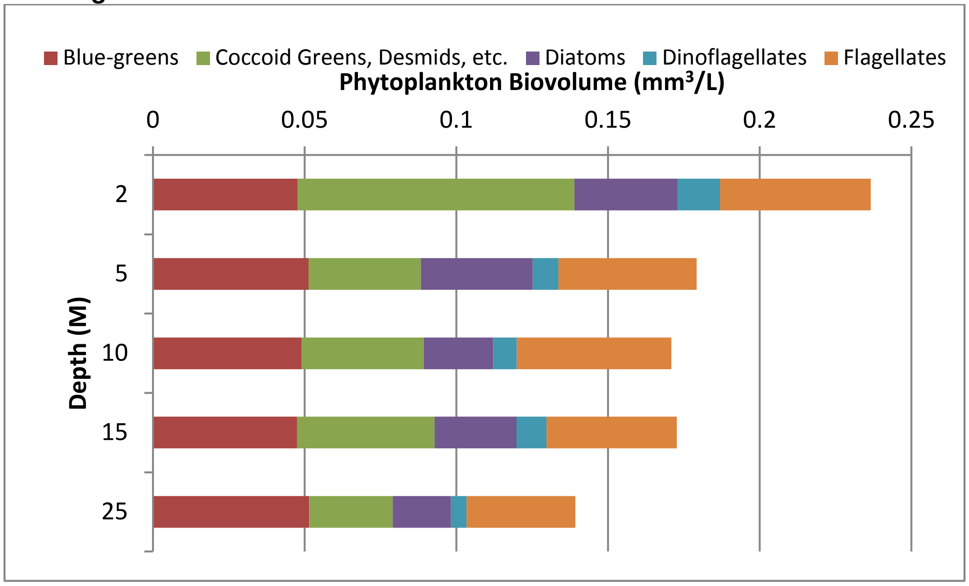


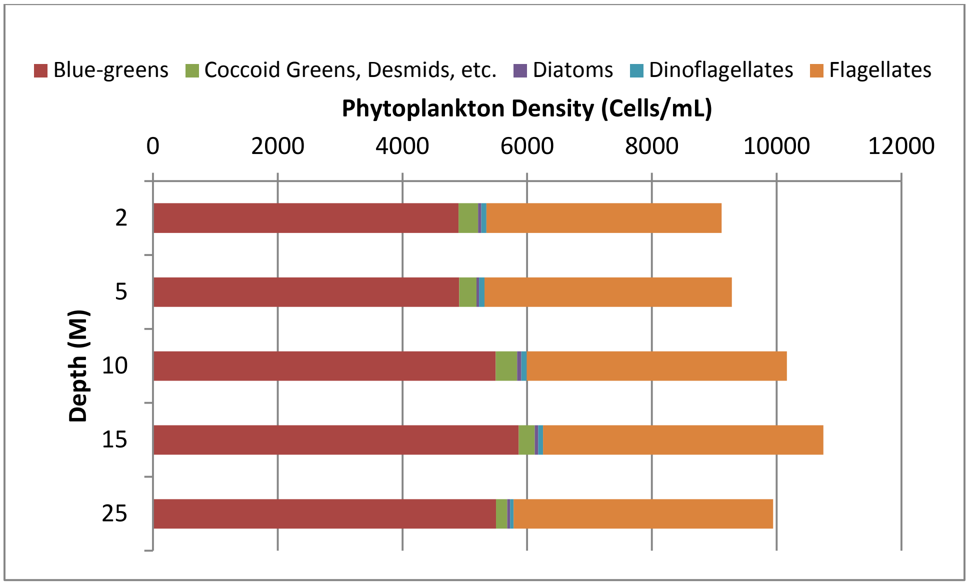
Figure 18 Average phytoplankton biovolume (mm^3/L), by depth and group, in Kinbasket Reservoir between April - August 2013



Revelstoke

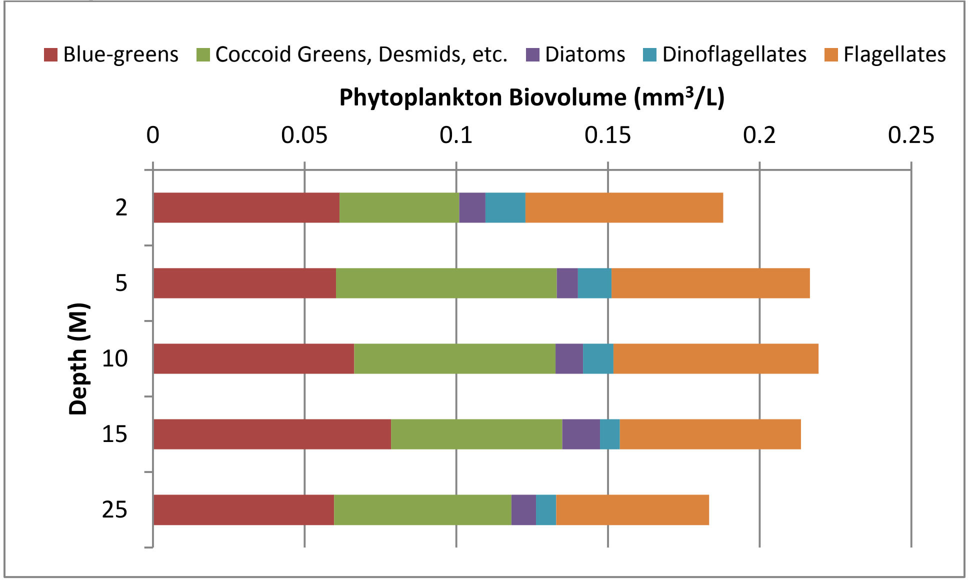
In Revelstoke there is a slight increase in cell density with depth. This increase is due to increases in Synechococcus (coccoids) and small micro-flagellates. The most abundant group at all depths were the blue-greens and flagellates. Dinoflagellate and diatoms were the least abundant groups (Figure 19).

Figure 19 Average phytoplankton density (Cells/mL), by depth, in Revelstoke Reservoir between April - September 2013



The greatest average biovolume in Revelstoke Reservoir was at 10 meters. Flagellates, greens and blue-greens were the greatest contributors to the phytoplankton biovolume within in the system. Dinoflagellates and diatoms were the groups had the lowest average biovolumes (Figure 20).

Figure 20 Average phytoplankton biovolume (mm^3/L), by depth and group, in Revelstoke Reservoir between April - September 2013



3.4 Phytoplankton in 2008-2013

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

Kinbasket

Inter-annual comparison of the average total density and total biovolume of phytoplankton suggests that there has been an increase in phytoplankton density since 2008(Table 9). This comparison may be misleading due to the temporal variability in the sampling as well as the tendency of phytoplankton communities to exhibit relatively large inter-annual variability (Figure 21 and Figure 22).

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[ŧ]	2476	2717	5558	3586	3584
	2012	3823	4541	5522	4490	4594
	2013	5995	7838	7864	8885	7645
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
	2013	0.17	0.18	0.25	0.19	0.20

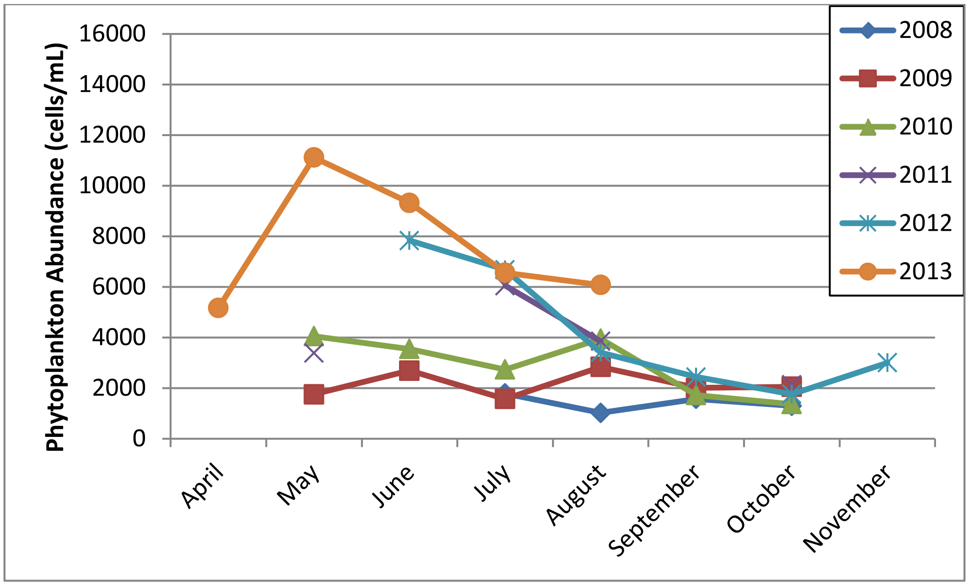


Figure 21 Monthly mean epilimnetic phytoplankton density by year for Kinbasket

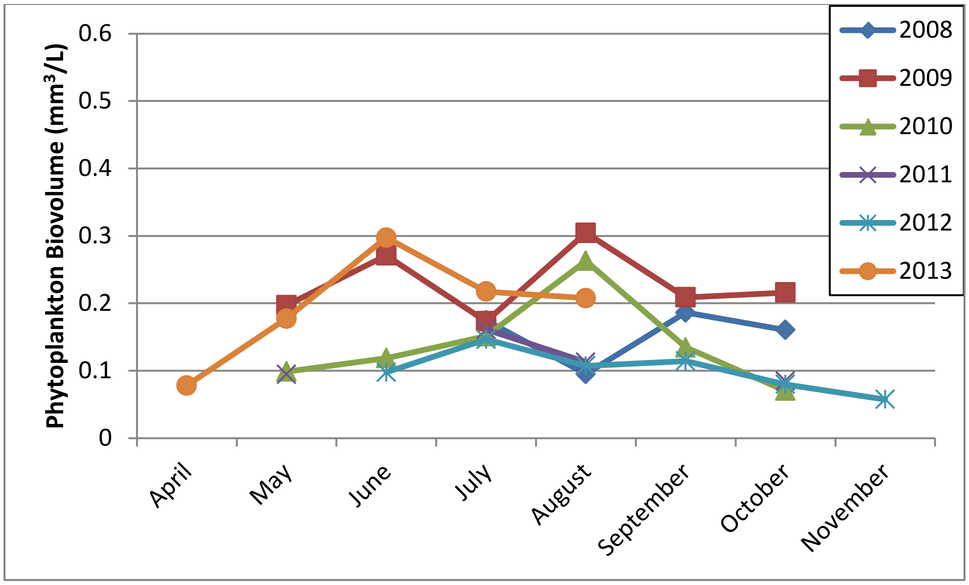


Figure 22 Monthly mean epilimnetic phytoplankton biovolume by year for Kinbasket

Revelstoke

As observed in Kinbasket there is considerable intra and inter-annual variation in phytoplankton density and to a lesser extent in biovolumes within Revelstoke (Figure 23 and Figure 24). The means cell densities have increase consistently through 2008(Table 10); however, the means appear to be driven by high densities or Synechococcus and small micro-flagellate densities that occur in one or two months of the year

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
	2013	7839	8328	12400	9523
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
	2013	0.21	0.18	0.48	0.29

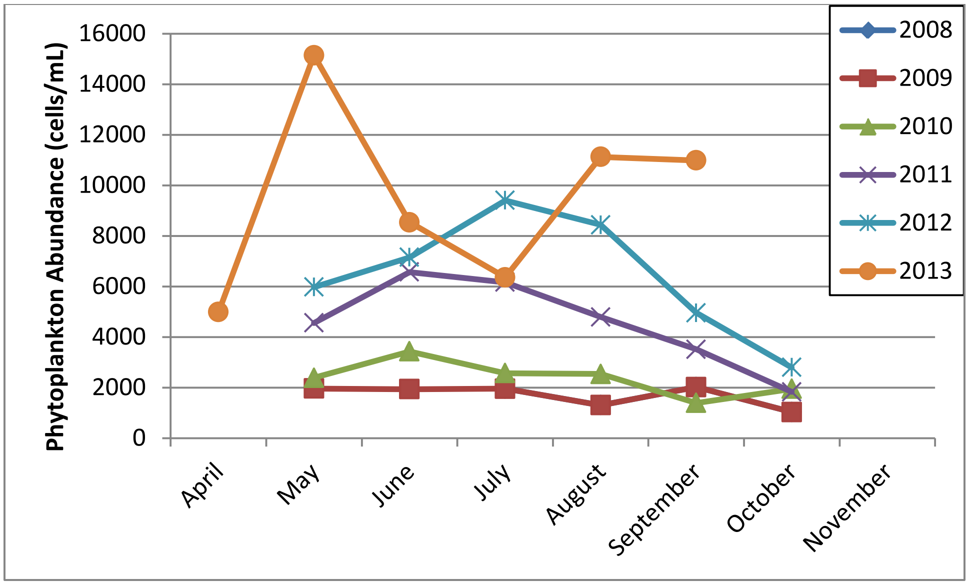


Figure 23 Monthly mean epilimnetic phytoplankton density by year for Revelstoke

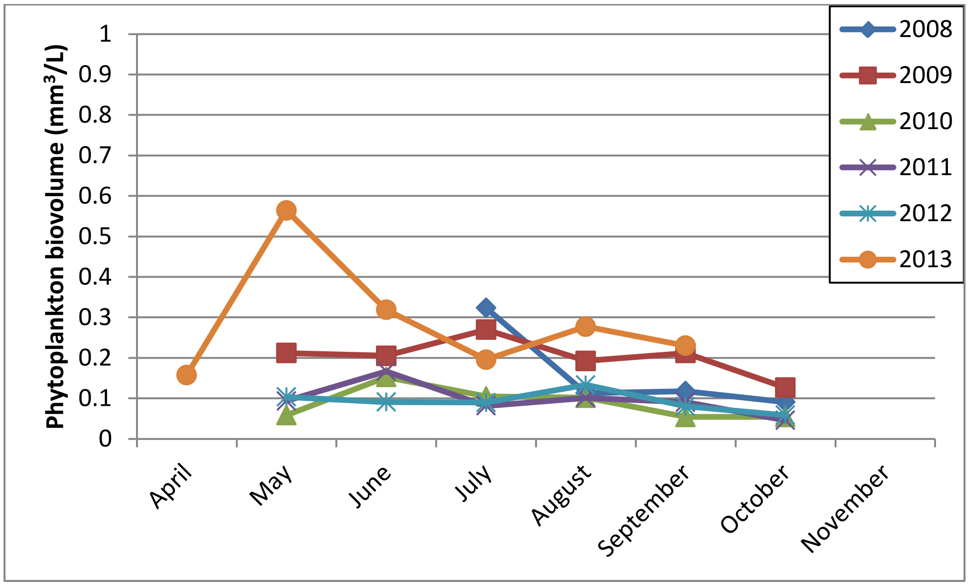


Figure 24 Monthly mean epilimnetic phytoplankton biovolume by year for Revelstoke

3.5 Bacteria and Pico-cyanobacteria Density in 2013

3.5.1 Bacteria.

Kinbasket

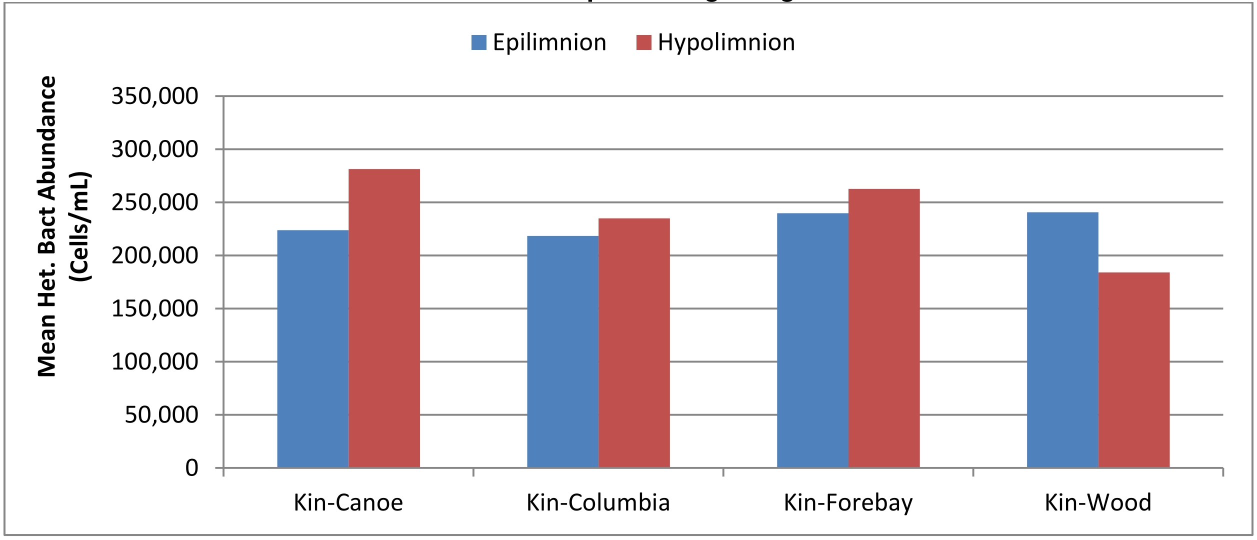
Of the four stations, the Wood (240,828 cells/mL) and Forebay (239,835 cells/mL)stations had the highest average epilimnetic densities. These densities are 60% lower than those observed in 2012 The Canoe, and Columbia stations had mean epilimnetic densities of 223,799 cells/mL and 218,355 cells/mL respectively (Table 10 and Figure 25), approximately 50% lower than 2012 levels.

Table 10 2013 Picoplankton densities

		Heterotrophic Bacteria (Cells/mL)						
		April	May	June	July	August	Sept	Avg.
Epilimnion	Kin-Canoe	172,872	116,043	311,964	147,537	370,581		223,799
	Kin-Columbia	116,043	172,474	378,529	147,537	277,191		218,355
	Kin-Forebay	190,755	206,651	229,502	272,223	300,042		239,835
	Kin-Wood	122,401	171,680	279,178	349,718	281,165		240,828
	Rev-Forebay	178,833	172,474	305,009	364,620	359,653	222,548	267,189
	Rev-Middle	104,915	259,308	303,022	122,202	240,431	244,405	212,381
	Rev-Upper	131,939	423,238	218,573		369,588	193,736	267,415
Hypolimnion	Kin-Canoe	194,729	214,599	226,522	426,218	344,750		281,364
	Kin-Columbia	132,734	154,194	347,730	166,414	374,555		235,125
	Kin-Forebay	170,885	197,908	214,599	324,880	405,354		262,725
	Kin-Wood	126,375	126,375	126,176	183,800	358,659		184,277
	Rev-Forebay	133,529	187,576	300,042	387,471	297,061	314,944	270,104
	Rev-Middle	118,427	302,029	327,860	358,659	451,056	329,847	314,646
	Rev-Upper	116,043	498,745	244,405	356,672	335,808	388,465	323,356

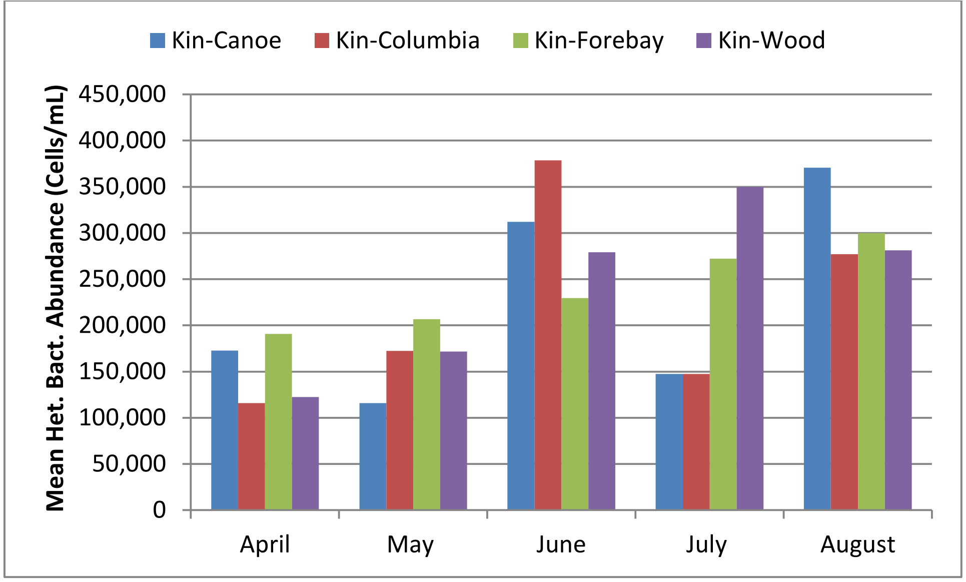
		Pico-cyano Bacteria (Cells/mL)						
		April	May	June	July	August	Sept	Avg.
Epilimnion	Kin-Canoe	16,559	15,068	27,156	20,864	22,354		20,400
	Kin-Columbia	9,935	12,916	18,214	11,425	14,406		13,379
	Kin-Forebay	24,838	21,857	29,143	20,533	11,094		21,493
	Kin-Wood	23,016	21,857	23,679	26,825	17,221		22,520
	Rev-Forebay	15,896	19,870	14,075	25,500	36,429	12,916	20,781
	Rev-Middle	10,598	22,189	15,234	19,705	24,176	16,724	18,104
	Rev-Upper	29,640	18,711	15,896		8,776	3,808	15,366
Hypolimnion	Kin-Canoe	18,711	26,163	15,399	11,591	15,068		17,387
	Kin-Columbia	9,438	13,081	9,438	8,445	14,240		10,929
	Kin-Forebay	28,646	15,565	21,361	13,578	17,718		19,374
	Kin-Wood	18,049	25,169	7,948	7,617	17,221		15,201
	Rev-Forebay	12,419	24,341	17,718	15,896	29,143	16,062	19,263
	Rev-Middle	17,387	14,903	10,101	7,948	14,240	9,604	12,364
	Rev-Upper	17,221	16,227	14,240	8,776	11,922	16,227	14,102

Figure 25 Average density (Cells/mL) of heterotrophic bacteria at four sampling stations in Kinbasket Reservoir between the months of April through August 2013



The heterotrophic bacteria densities peaked in June at the Columbia station and July at the Wood and Forebay stations (Figure 26). The highest densities observed were in the Wood Arm station. The Wood Arm station also had the highest variability between sampling events.

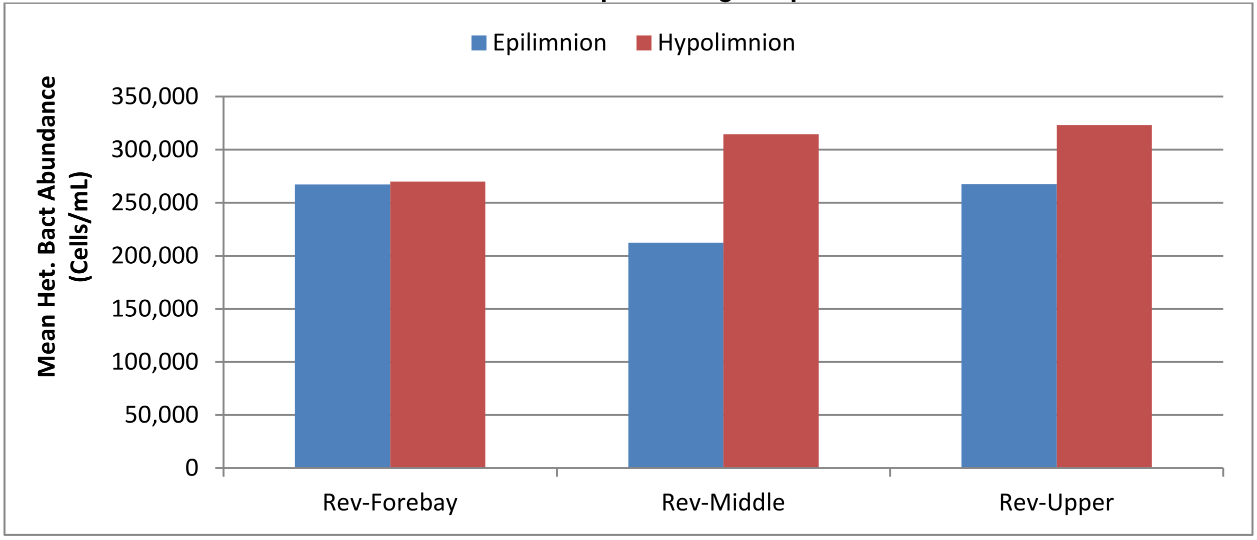
Figure 26 Kinbasket Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at four sampling stations in 2013



Revelstoke

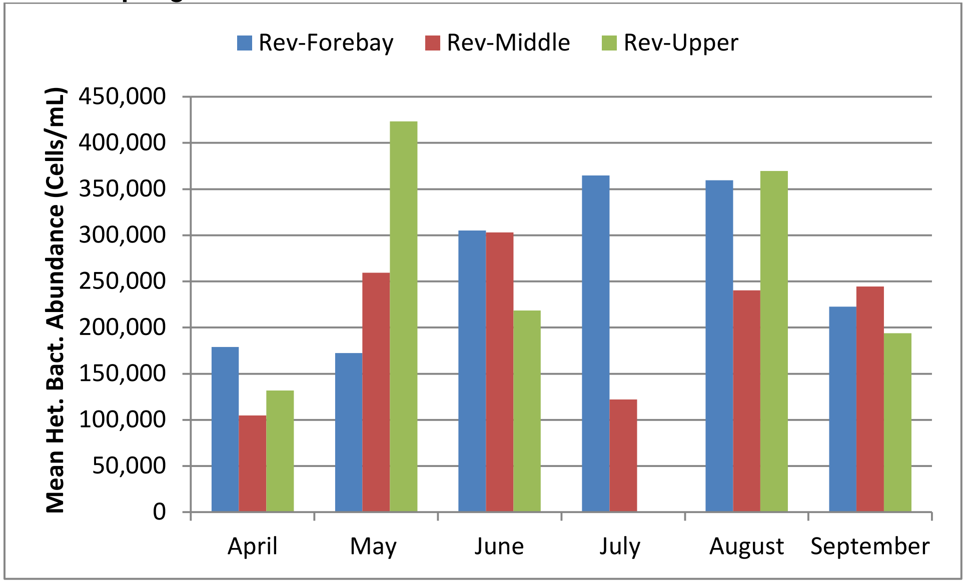
The epilimnetic average of heterotrophic bacteria ranged from 267,417 to 212,381 cells/mL (Table 10). These values are slightly lower than those observed in Kinbasket in 2013 and approximately 50% lower than observed in Revelstoke in 2012. The Upper Station had the highest epilimnion and hypolimnion densities (Figure 27).

Figure 27 Average density (Cells/mL) of heterotrophic bacteria at three sampling stations in Revelstoke Reservoir between the months of April through September 2013



The heterotrophic bacteria densities were variable across stations and months in 2013 (Figure 28).

Figure 28 Revelstoke Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at three sampling stations in 2013



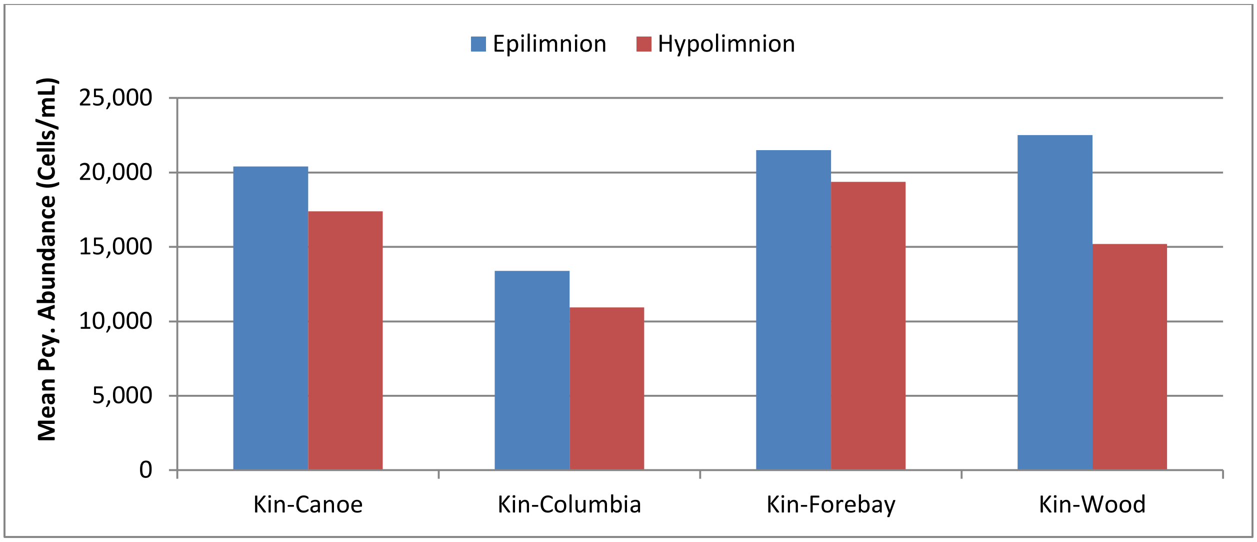
3.5.2 Pico-cyanobacteria.

Kinbasket

Total seasonal average density of epilimnetic pico-cyanobacteria in Kinbasket Reservoir was just 19,448 cells/mL. Canoe, Wood, and Forebay stations had relatively similar average epilimnetic densities (Table 10 and Figure 27). The densities observed in 2013 were considerably lower than the densities observed in 2011 and in line with the 2010 and 2012 densities.

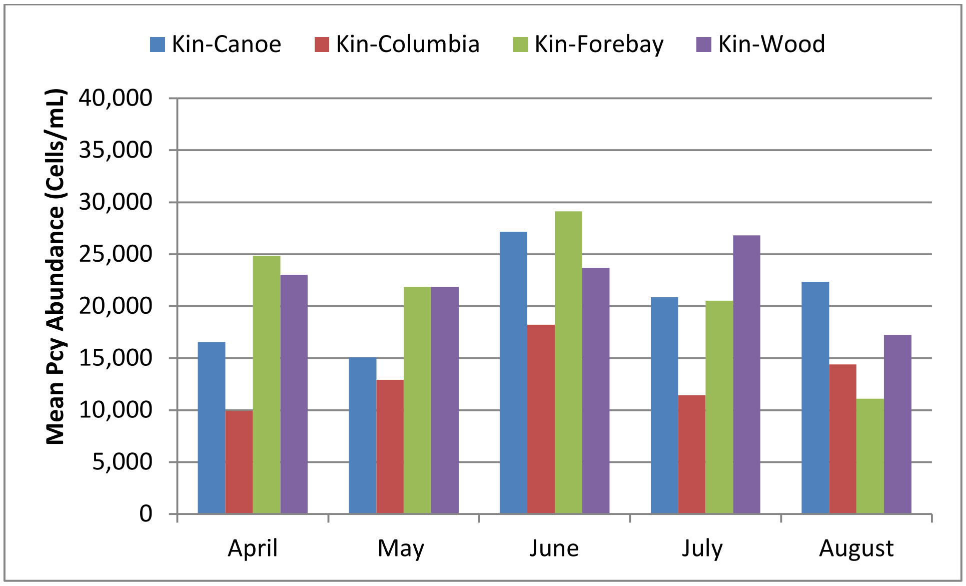
Hypolimnetic total seasonal average density of pico-cyanobacteria averaged just 15,722 cells/mL. The Columbia sampling station had the lowest average density out of the four stations (Figure 29).

Figure 29 Average density (Cells/mL) of pico-cyanobacteria at four sampling stations in Kinbasket Reservoir between the months of April through August 2013



Pico-cyano densities varied considerably by month and between stations in 2013(Figure 30).

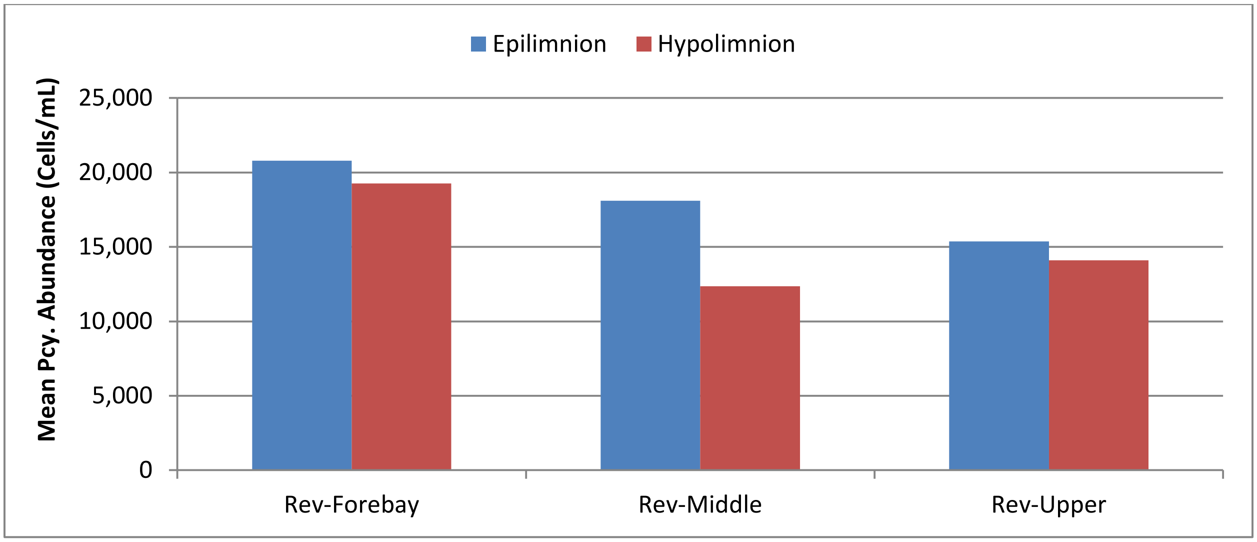
Figure 30 Average monthly density (Cells/mL) of epilimnetic pico-cyanobacteria at four sampling stations in Kinbasket Reservoir



Revelstoke

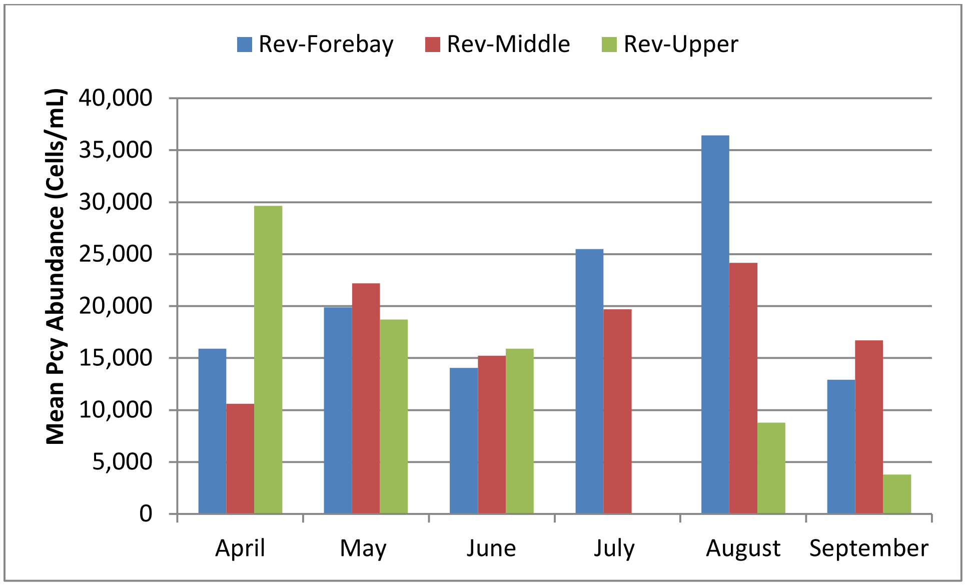
The average density in the epilimnion was approximately 18,084 cells/mL in Revelstoke Reservoir (Table 10). In the hypolimnion the average density was 15,243 cells/mL. The Forebay station had the highest average density in both the hypolimnion and epilimnion, followed by the Middle and Upper station (Figure 31).

Figure 31 Average density (Cells/mL) of pico-cyanobacteria at three sampling stations in Revelstoke Reservoir between the months of April through September 2013



The Forebay station exhibited a general increase in densities from April through August. The middle station did not have a clear monthly trend; however, the upper station's pico-cyano densities decreased consistently through the season (Figure 32). A July epilimnion sample for the upper station was not received.

Figure 32 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. Additional examination of this apparent trend needs to be examined more closely. It may be the result of different sampling time frames or short time framed blooms of individual taxa rather than a temporal trend.

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

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Appendix A.

Kinbasket and Revelstoke 2013 Taxa List and Number of Occurrences

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
Bacillariophyte	Diatoms	Asterionella formosa	13	3
		Cyclotella comta	8	1
		Cyclotella glomerata	11	1
		Cymbella sp. (medium)		2
		Eucocconeis flexella		1
		Fragilaria capucina	19	17
		Fragilaria crotonensis	12	15
		Gomphonema sp. (medium)	1	3
		Navicula sp. (medium)		1
		Nitzschia sp. (medium)	3	
		Pleurosigma sp.		1
		Rhizosolenia sp.		1
		Staurosia construens		3
		Stephanodiscus sp. (large)	37	7
		Stephanodiscus sp. (small)	2	
		Synedra acus	59	42
		Synedra nana	9	8
		Synedra rumpens	1	
		Synedra ulna	14	15
		Tabellaria flocculosa		1
Chlorophyte	Coccoid Greens, Desmids, Etc.	Aulomonas sp.		4
		Carteria sp.	1	
		Chlamydocapsa sp.	73	46
		Chlamydomonas	2	
		Coelastrum sp. (cells)	26	29
		Cosmarium sp.	19	12
		Dictyosphaerium (cells)	1	
		Elakatothrix sp.	13	5
		Euglena	19	29
		Gleotila sp.	12	4
		Gloeococcus sp.	3	1
		Golenkinia sp.	7	4
		Monomastix sp.	2	1
		Monoraphidium	7	6
		Nephroselmis	86	85
		Oocystis sp. (cells)	23	28
		Paramastix	1	6
		Phacus (medium)	7	14
		Planctonema sp.	1	
		Planktosphaeria		2
		Polytomella	1	
		Pseudosphaerocystis sp.		1
		Scenedesmus sp.	2	4
		Scourfieldia	26	38

		Sphaerocystis sp.	3	1
		Tetraedron	34	19
Chryso- & Cryptophyte	Flagellates	Bitrichia sp.	2	2
		Chromulina sp.	7	9
		Chroomonas acuta	89	87
		Chrysamoeba sp.	1	
		Chrysochromulina sp.	2	2
		Chrysococcus	89	85
		Chrysolykos sp.	8	3
		Codonomonas sp.		1
		Cryptomonas sp. (large)		1
		Cryptomonas sp. (medium)	54	58
		Cyathomonas truncata		1
		Dinobryon sp. (medium)	42	58
		Gyromitus sp.	17	29
		Kephyrion boreale	17	17
		Kephyrion sp.	72	71
		Komma sp.	71	75
		Mallomonas sp. (medium)	2	1
		Ochromonas sp.	69	72
		Pseudokephrion sp.	34	43
		Small microflagellates	100	91
		Synura (cells)	2	
		Trachelomonas sp.	35	34
		Uroglena sp. (colony)	1	
Cyanophyte	Blue-greens	Aphanothecae sp.	13	17
		Aphanothece minutissimus	1	
		Chroococcus sp. (cells)	98	90
		Limnothrix redekei (cells)	1	
		Lyngbya sp. (cells)		1
		Merismopedia sp. (cells)	50	60
		Synechococcus sp. (coccoid)	100	90
		Synechococcus sp. (rod)	98	88
		Synechocystis	24	28
Dinophyte	Dinoflagellates	Amphidinium	58	72
		Ceratium	1	
		Gymnodinium sp. (medium)	49	43
		Peridinium spp.	1	

Appendix 7

Zooplankton
Kinbasket and Revelstoke Reservoirs, 2013

Lidija Vidmanic
Limno Lab

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1. Introduction

This report summarises the zooplankton data collected in 2013, 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 April to September in Revelstoke and from April to August in Kinbasket Reservoir during 2013 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 technical problems samples could not be collected from Kinbasket reservoir in September and October and from Revelstoke in October 2013.

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

3. Results – Kinbasket Reservoir

3.1 Species Present

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

Table 1. List of zooplankton species identified in Kinbasket Reservoir in 2003-2013. “+” indicates a consistently present species and “r” indicates a rarely present species.

	2003	2004	2005	2008	2009	2010	2011	2012	2013
Cladocera									
Alona sp.						r			r
Bosmina longirostris	+	+	+	+	+	+	+	+	+
Chydorus sphaericus			+		+	+			r
Daphnia galeata mendotae	+	+	+	+	+	+	+	+	+
Daphnia rosea	+	+	+	+	+	+	+	+	+
Daphnia schoedleri	+	+	+	+	+	+	+	+	+
Diaphanosoma brachyurum		+	+		+	+		+	+
Holopedium gibberum	r			r	r	r			
Leptodora kindtii	+	+	+	+		+	+	+	+
Macrothrix sp.					r				
Scapholeberis rammneri	+	+	+	+	+	+	+	+	+
Copepoda									
Aglaodiaptomus leptopus		r		r					r
Diacyclops bicuspidatus	+	+	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+	+	+
Leptodiaptomus ashlandi		r	r		r	r	r	r	r
Leptodiaptomus sicilis	+	+	+	+	+	+	+	+	+

Nine species of Cladocera were present in 2013 (Tab. 1). *Daphnia galeata mendotae* (Birge), *Daphnia schoedleri* (Sars), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.) *Diaphanosoma brachyurum* (Lievin), *Scapholeberis rammneri* (Dumont and Pensaert) and *Leptodora kindtii* (Focke) were common, while other species were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

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

3.2 Density and Biomass

For comparison with historical data the average at Mica Forebay station in Kinbasket was used. Zooplankton density values in 2003-2013 are significantly higher than 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 increased in 2013 to 9.64 individuals/L from 7.22 individuals/L in 2012 (Fig. 2). The zooplankton density was numerically dominated by copepods, which averaged 79% of the 2013 community. *Daphnia* spp. comprised 13%, and cladocerans other than *Daphnia* 8%. Copepods were the most abundant zooplankton at all four stations. They numerically prevailed during the whole sampling season, with populations peaking in June-July. The highest copepod density was found in June at station Wood Arm with 19.40 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 3.37 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 August with 3.14 individuals/L (Fig.4). The highest density of *Daphnia* was found in August at Mica Forebay with 3.74 individuals/L. The highest density of *Daphnia* was probably occurred later in the season (September-October), however due to a technical problem samples could not be collected. The proportion of *Daphnia* density was the highest at Canoe Reach (16%), while at other stations it varied between 10 and 15%. (Fig. 5, Tab. 2)

Table 2 Seasonal average zooplankton density at four sampling stations in Kinbasket Reservoir in 2013. Density is in units of individuals/L; biomass is in units of µg/L.

		Canoe Reach	Mica Forebay	Columbia Reach	Wood Arm
Density	Copepoda	7.08	7.43	6.06	9.83
	Daphnia	1.44	1.43	1.12	1.15
	Other Cladocera	0.72	0.85	0.56	0.91
	Total	9.23	9.70	7.74	11.89
Biomass	Copepoda	9.99	12.86	9.65	13.78
	Daphnia	26.41	24.89	15.23	21.61
	Other Cladocera	1.79	1.74	1.04	2.62
	Total	38.19	39.49	25.91	38.01

Figure 1. Zooplankton density 1977-2013 at Mica Forebay in Kinbasket Reservoir.

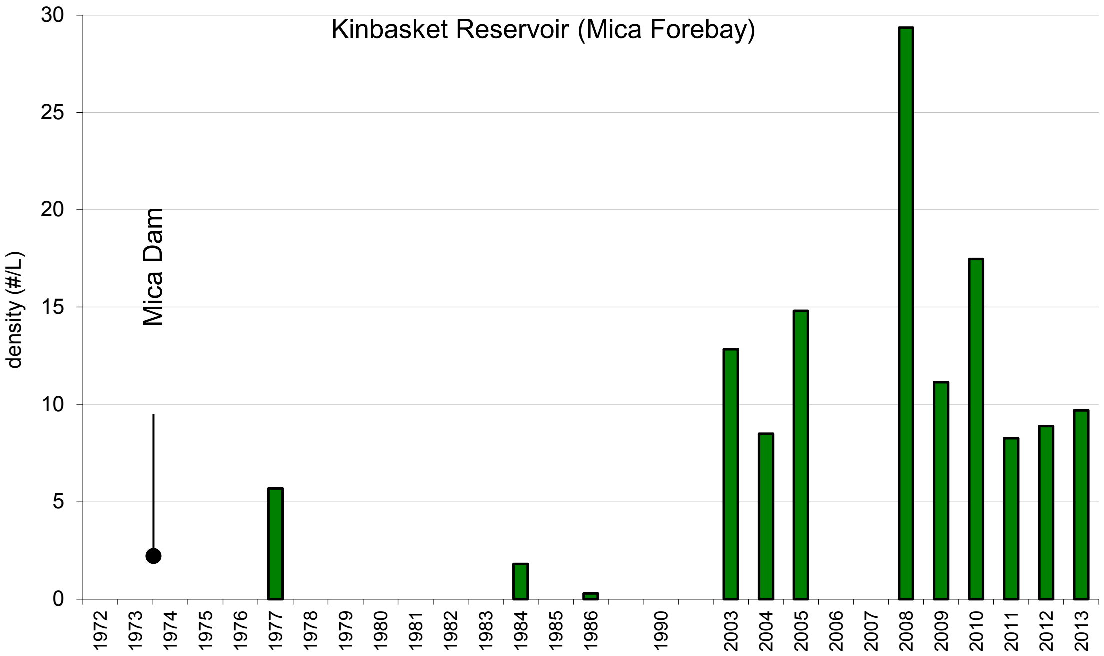
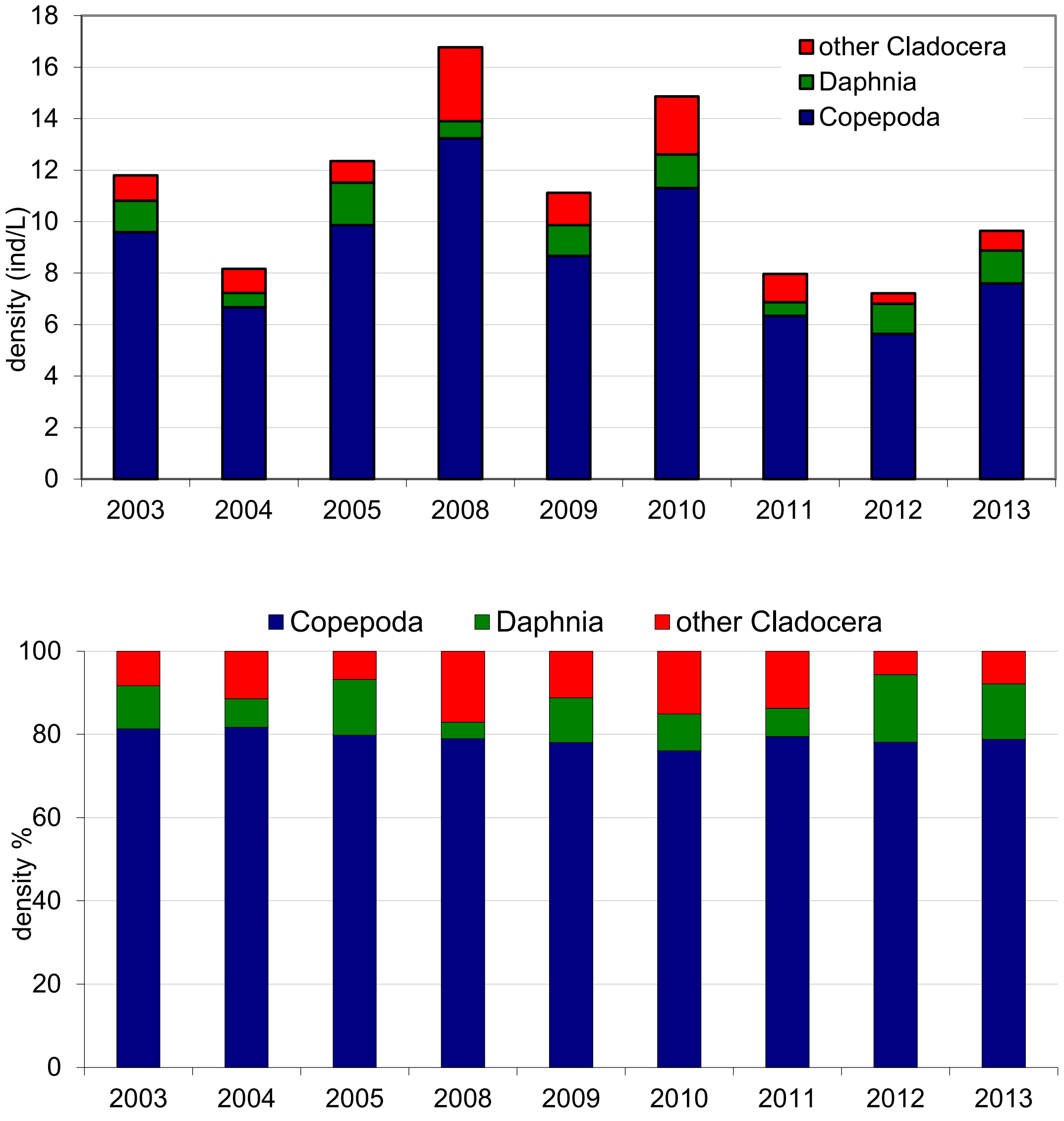


Figure 2. Seasonal average zooplankton density in Kinbasket Reservoir 2003-2013



Seasonal average total zooplankton biomass in 2013 was 35.40 µg/L (Fig.6). *Daphnia* had the highest proportion of the total biomass in the whole reservoir 62% with 22.03 µg/L. Copepods made up 33% with 11.57 µg/L, while Cladocerans other than *Daphnia* comprised only 5% of the total zooplankton biomass with 1.80 µg/L. The highest total zooplankton biomass of 92.59 µg/L was found at Wood Arm in August, when *Daphnia* comprised 80% of total biomass with 73.50 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 July and August. Among the stations the highest seasonal average *Daphnia* biomass was found at Canoe Reach where *Daphnia* contributed to 69% of the zooplankton biomass. The proportion of seasonal average *Daphnia* biomass at Mica Forebay was 63%, at Columbia Reach 59%, while at Wood Arm proportion of *Daphnia* biomass was 57% (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 2003-2009. After a decrease in 2011, zooplankton community increased in the following years. Contrary to that, zooplankton composition, density, and biomass fluctuated along a great range during the study period at the other three stations (Fig. 9).

Figure 3. Density of cladoceran and copepod zooplankton in Kinbasket Reservoir in 2003-2013

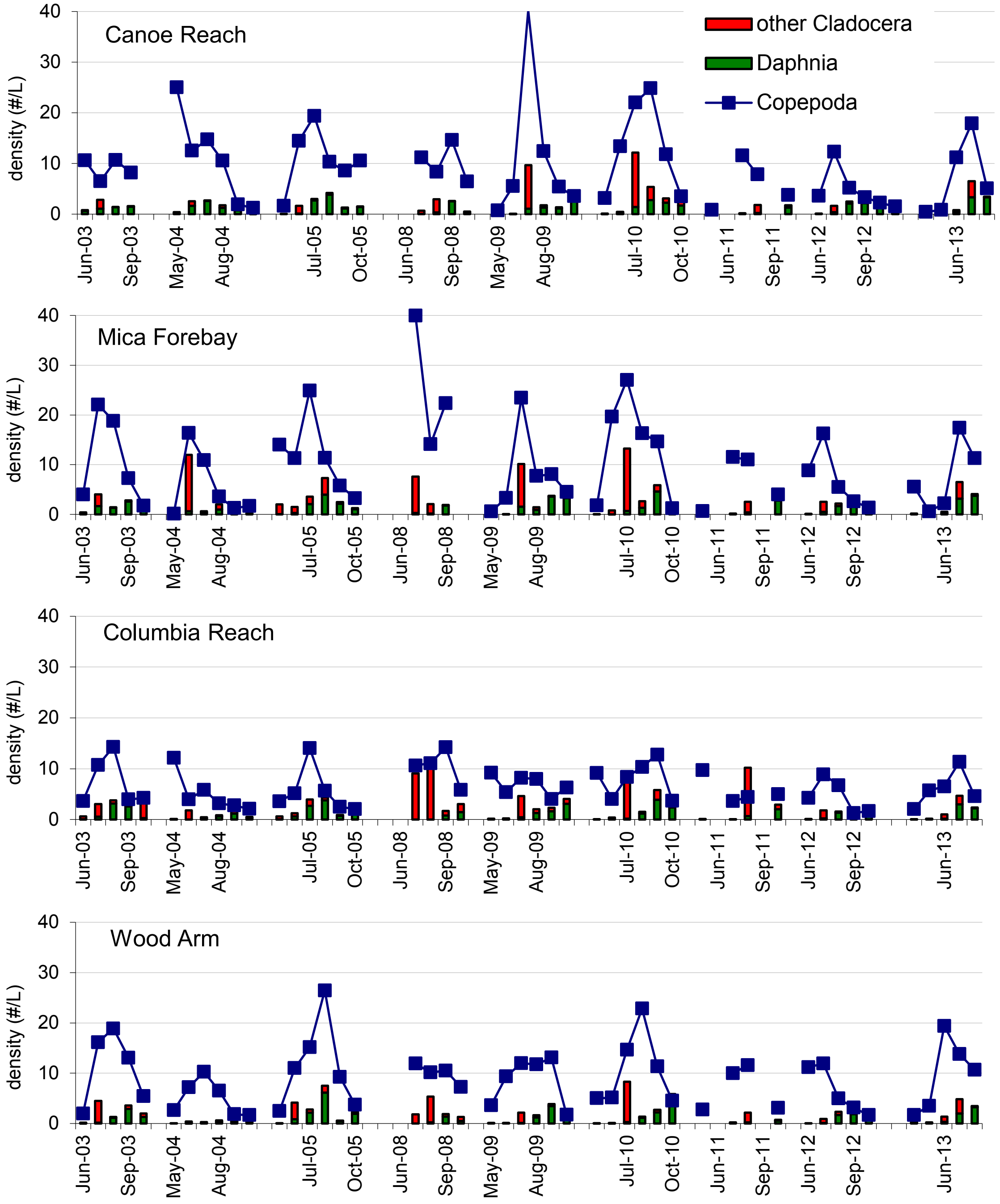


Figure 4. Monthly zooplankton density averaged for the whole Kinbasket Reservoir in 2003-2013

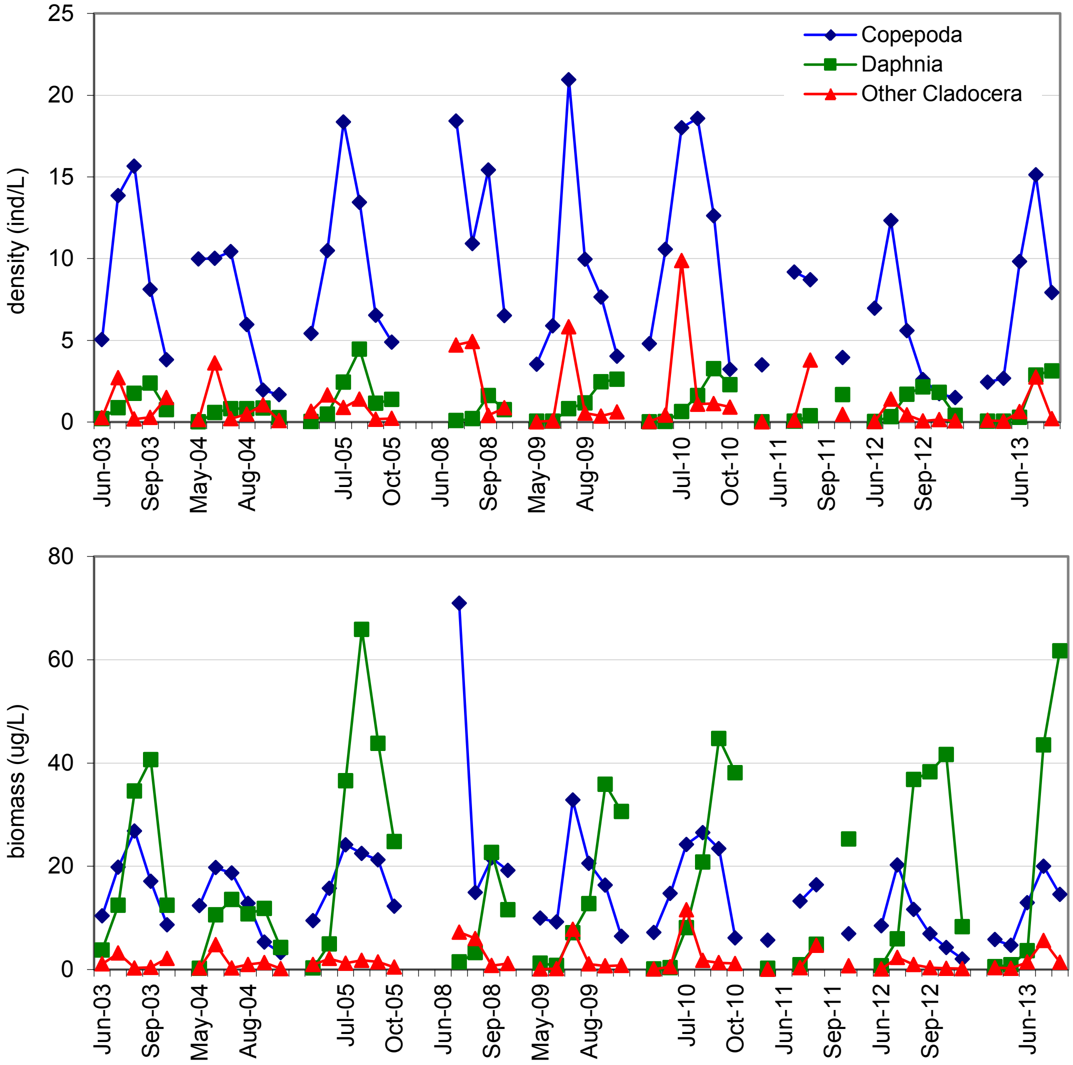


Figure 5. Seasonal average % of zooplankton density composition at four stations in Kinbasket Reservoir in 2003-2013.

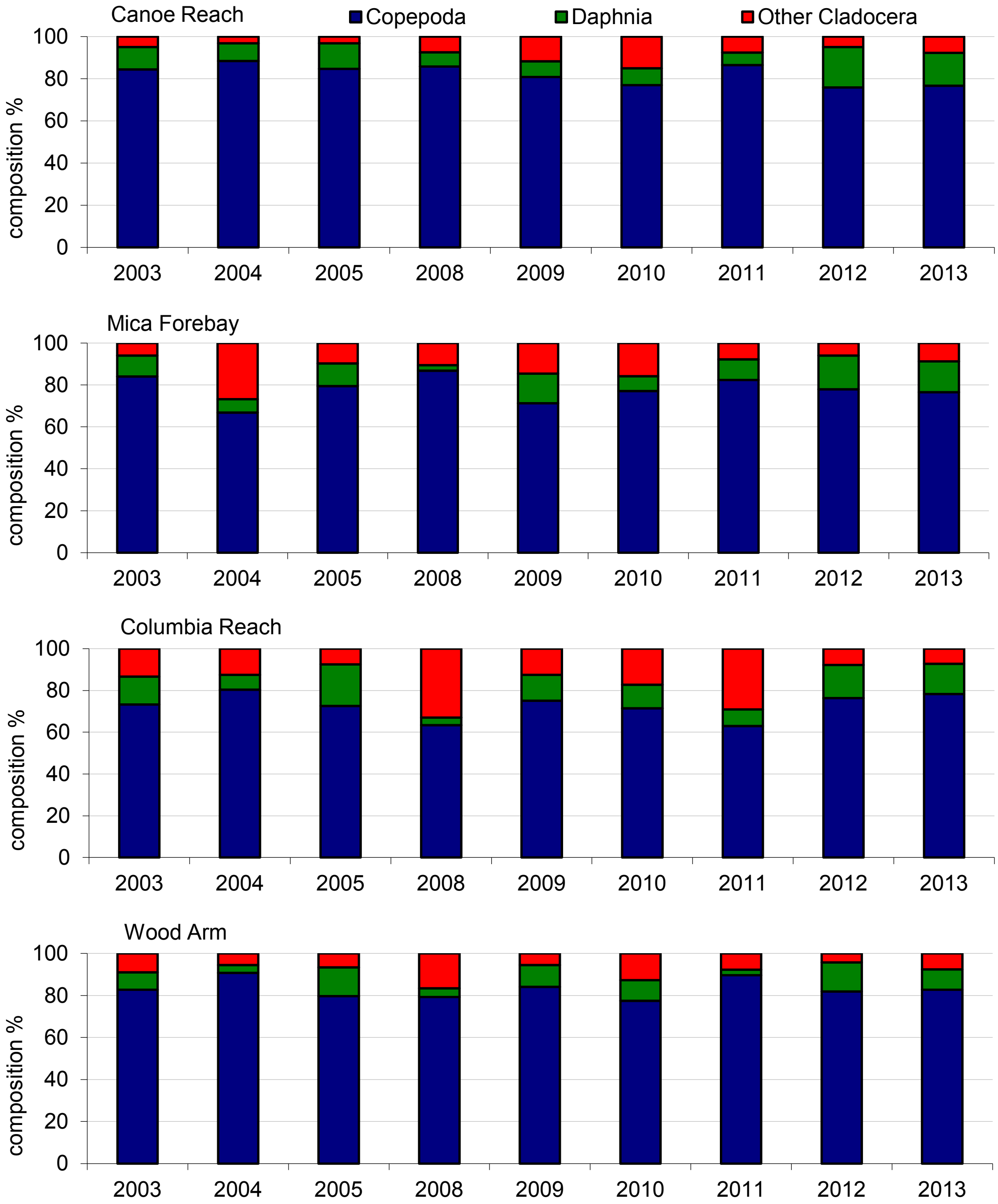


Figure 6. Seasonal average zooplankton biomass in Kinbasket Reservoir 2003-2013

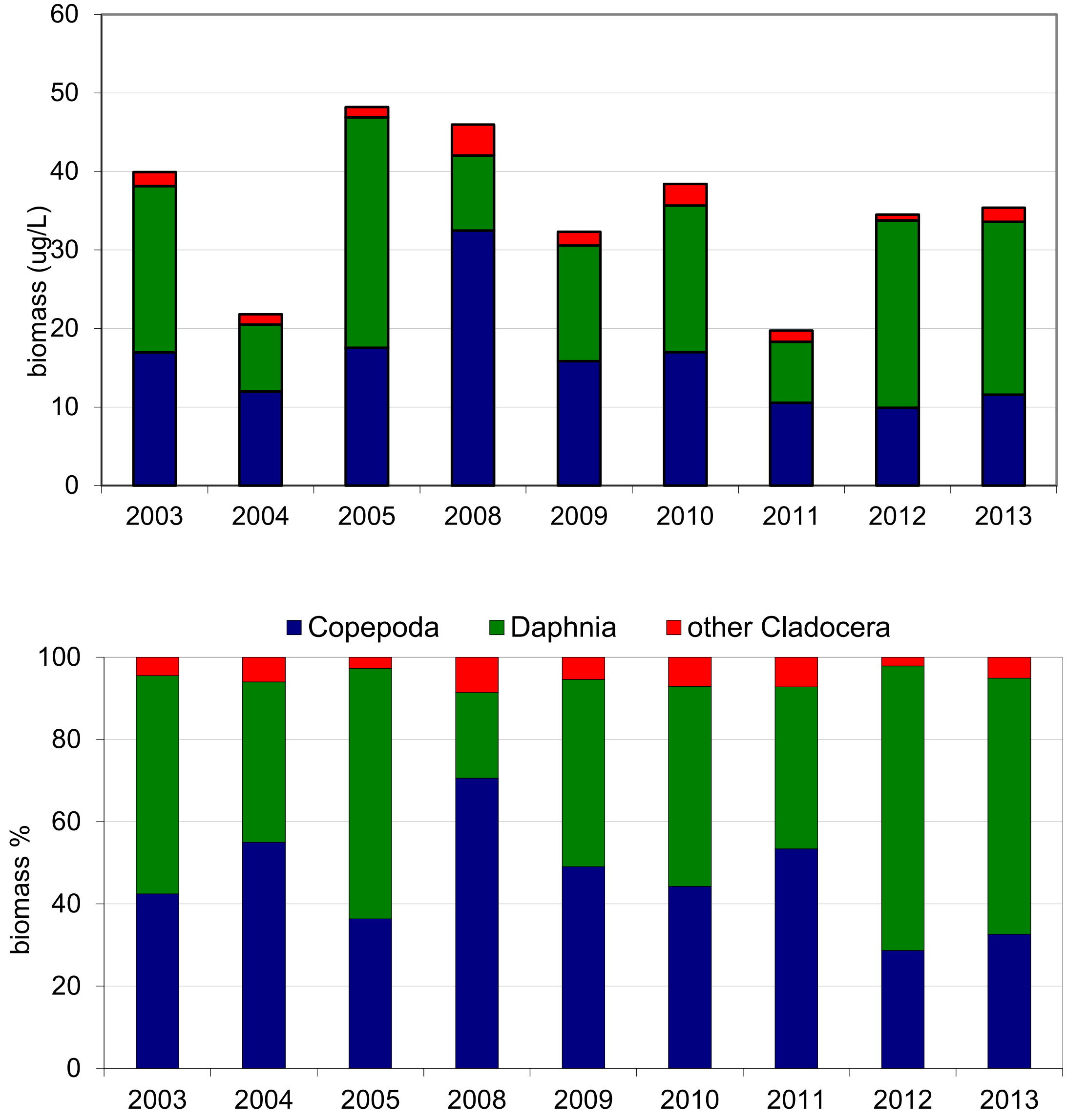


Figure 7. Biomass of cladoceran and copepod zooplankton in Kinbasket Reservoir in 2003-2013

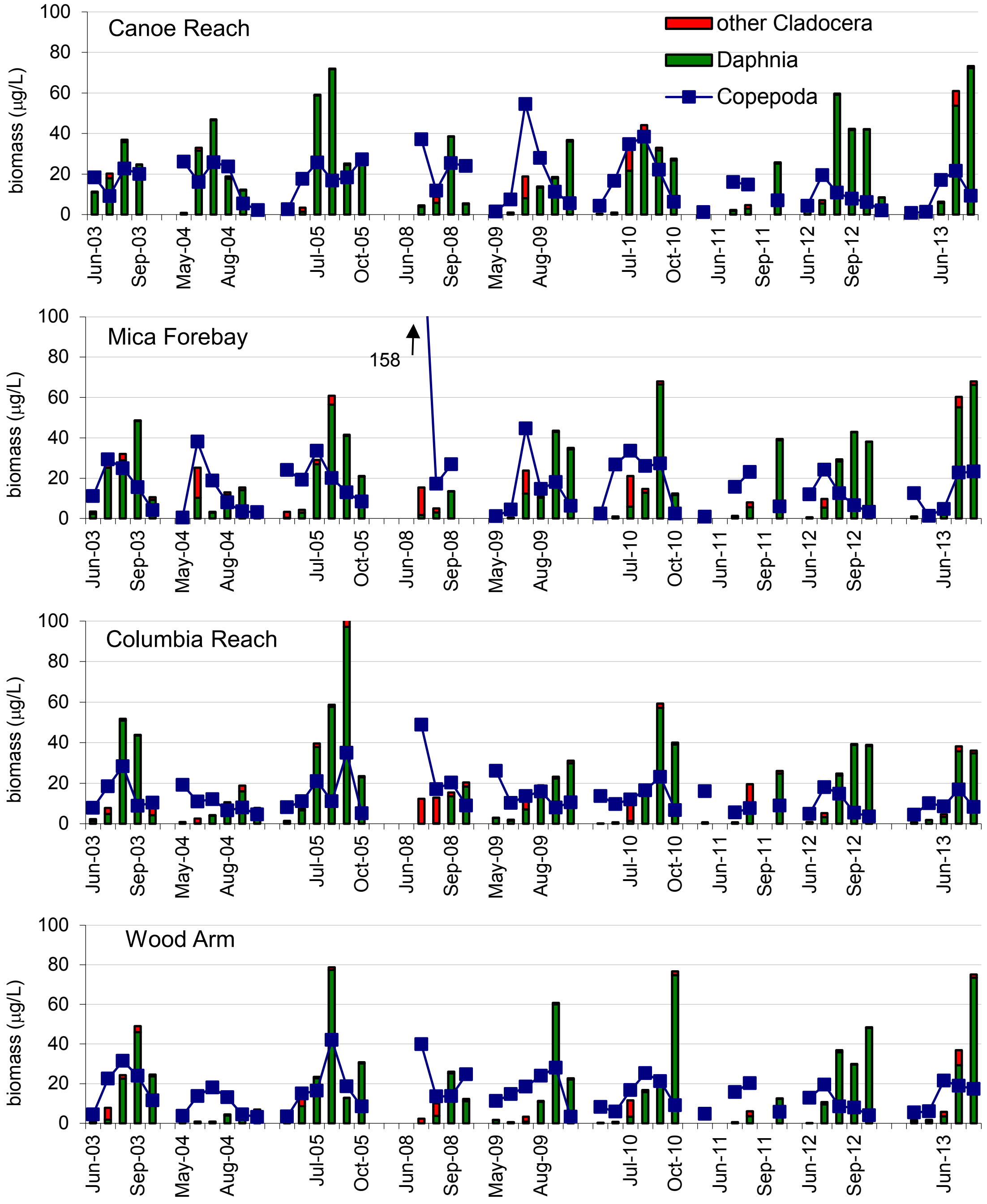


Figure 8. Seasonal average % of zooplankton biomass composition at four stations in Kinbasket Reservoir in 2003-2013

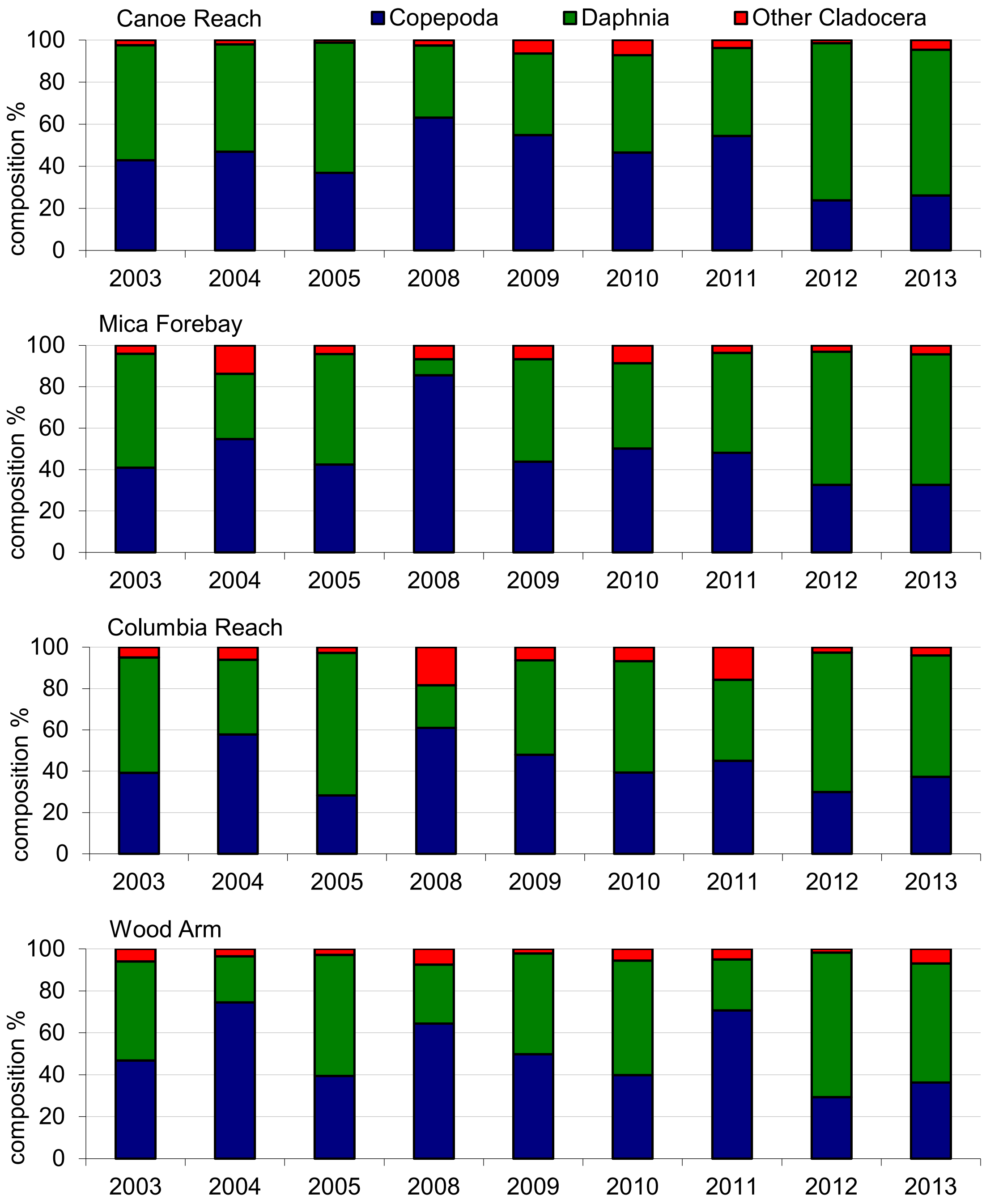
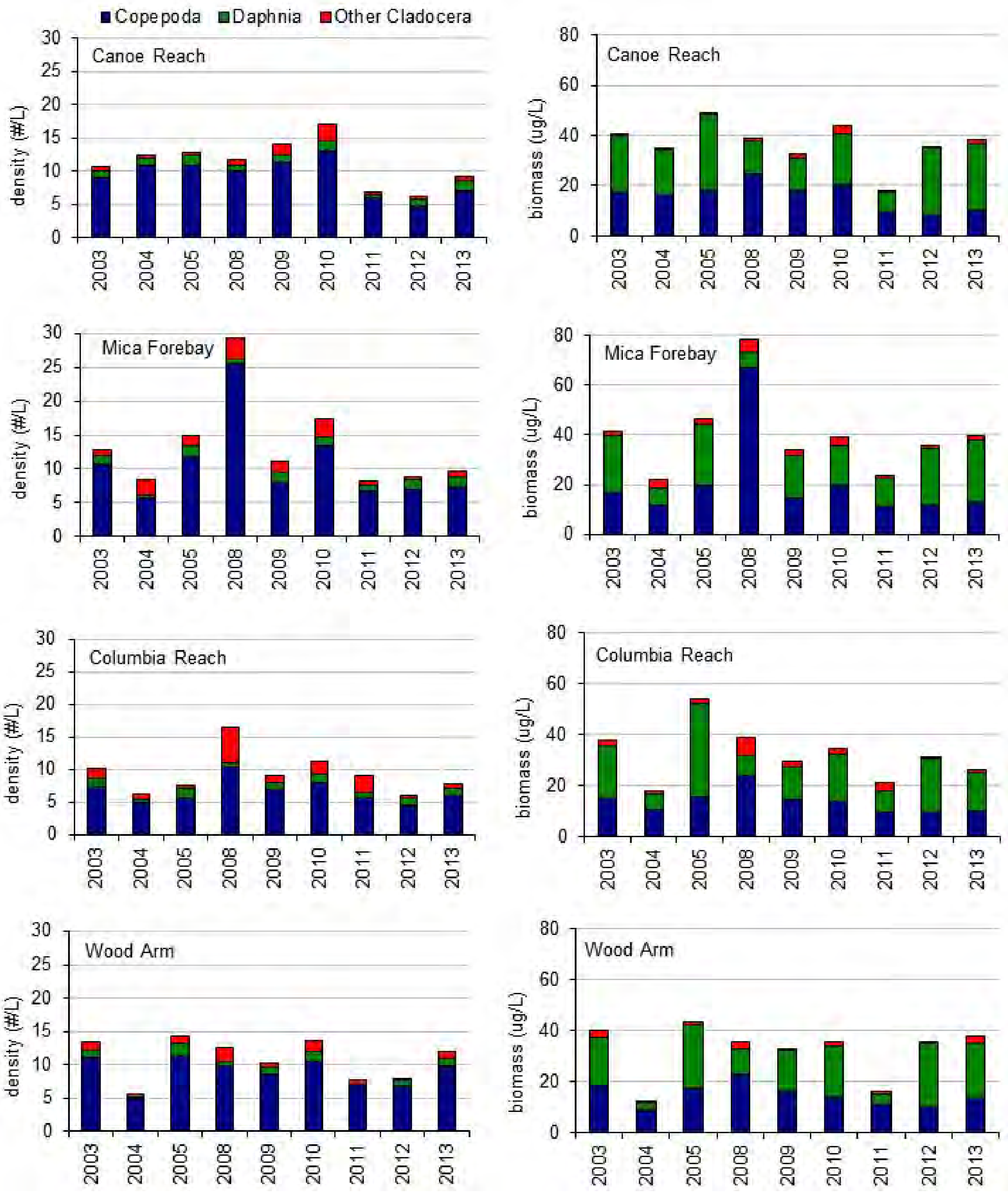


Figure 9. Annual average zooplankton density (left) and biomass (right) at four stations in Kinbasket Reservoir 2003-2013



In 2013 peak total zooplankton density occurred in July at 20.77 individuals/L while highest biomass was found in August with 77.64 µg/L (Tab. 3, Fig. 4). *Daphnia* was the most numerous in August with 3.14 individuals/L, and the highest biomass of 61.71 µg/L.

Table 3. Monthly average density and biomass of zooplankton in Kinbasket Reservoir in 2013. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		April	May	June	July	Aug.
	Copepoda	2.44	2.69	9.82	15.13	7.92
	Daphnia	0.05	0.06	0.30	2.88	3.14
	Other Cladocera*	0.11	0.06	0.64	2.77	0.21
	Total Zooplankton	2.59	2.81	10.76	20.77	11.28
Biomass		April	May	June	July	Aug.
	Copepoda	5.75	4.64	12.92	20.00	14.52
	Daphnia	0.53	0.85	3.59	43.49	61.71
	Other Cladocera**	0.35	0.21	1.41	5.60	1.41
	Total Zooplankton	6.64	5.71	17.92	69.09	77.64

*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 and biomass increased in 2013. That was a result of increased number of Copepoda and other Cladocera, while *Daphnia* decreased in number and in biomass in comparison to the previous year (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. From April to August 2013 the proportion of gravid females averaged 0.18. The highest proportions have been found at Columbia Reach 0.42 in June. On average, gravid female carry 16.93 eggs. The number of eggs per water volume averaged 2.13 eggs/L, and the number of eggs per capita averaged 0.77 eggs/individual (Tab. 4).

Table 4. Fecundity data for *D. bicuspidatus thomasi* in Kinbasket Reservoir in 2003-2013. Values are seasonal averages, calculated for samples collected between May - October 2003, 2005, 2009, 2010 and 2011, May – December 2004, July – October 2008, June – November 2012 and April – August 2013.

	2003	2004	2005	2008	2009	2010	2011	2012	2013
Proportion of gravid females	0.12	0.05	0.08	0.11	0.17	0.13	0.15	0.16	0.18
# Eggs per gravid Female	12.42	12.42	9.67	11.17	13.86	14.31	14.83	12.61	16.93
# Eggs per Litre	1.42	0.29	0.47	2.58	1.68	1.25	1.28	2.17	2.13
# Eggs per Capita	0.25	0.25	0.1	0.18	0.48	0.25	0.40	0.62	0.77

In Kinbasket Reservoir *Daphnia* gravid females were present in samples during the entire sampling season 2013. The proportion of gravid females averaged 0.16 (Tab. 5). The seasonal average number of eggs per gravid female was 2.06. Across the sampling season the number of eggs per water volume averaged 0.22 eggs/L and the number of eggs per capita averaged 0.35 eggs/individual.

Table 5. Fecundity data for *Daphnia* spp. in Kinbasket Reservoir in 2003-2013. Values are seasonal averages, calculated for samples collected between May - October 2003, 2005, 2009, 2010 and 2011, May – December 2004, July – October 2008, June – November 2012 and April – August 2013.

	2003	2004	2005	2008	2009	2010	2011	2012	2013
Proportion of gravid females	0.07	0.03	0.03	0.19	0.19	0.12	0.09	0.08	0.16
# Eggs per gravid Female	1.80	2.11	1.59	1.91	2.04	1.52	2.08	2.11	2.06
# Eggs per Litre	0.16	0.03	0.1	0.13	0.18	1.14	0.07	0.12	0.22
# Eggs per Capita	0.15	0.05	0.05	0.37	0.48	0.23	0.25	0.17	0.35

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) was 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 2013 (Tab. 6). *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), *Holopedium gibberum* (Zaddach), *Scapholeberis rammneri* (Dumont and Pensaert) and *Leptodora kindtii* (Focke) were common. Other species such as *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.*

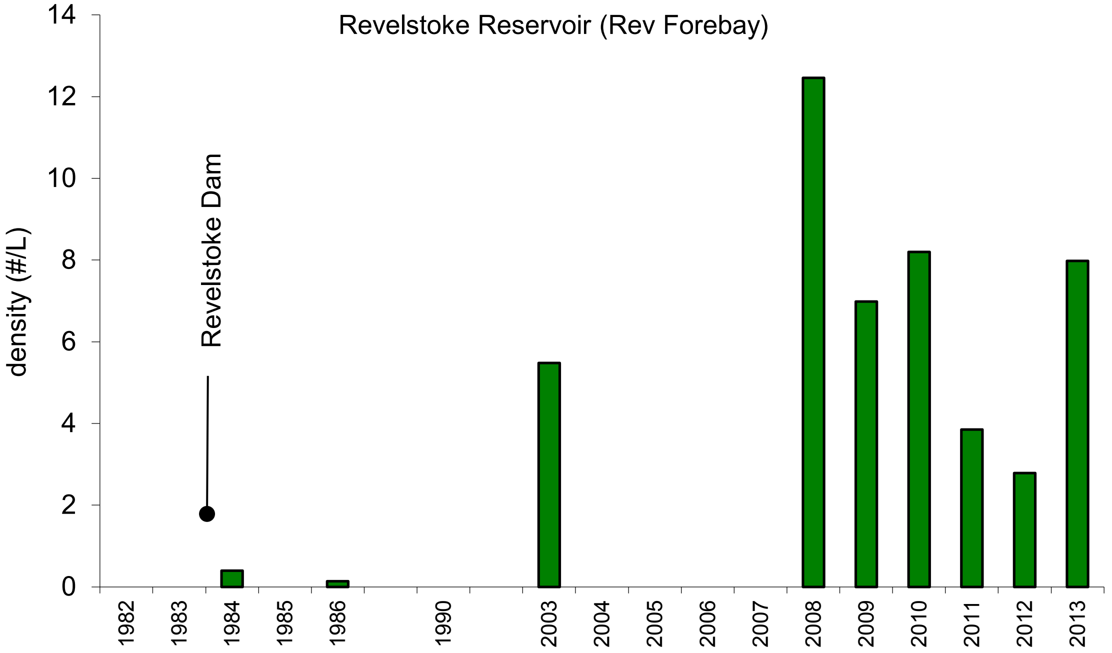
4.2 Density and Biomass

The seasonal average zooplankton densities observed in 2003, 2008-2013 were much higher than those reported for years 1984 and 1986 by Watson 1985 and Fleming and Smith 1988 (Fig. 10). For comparison with historical data the average at Rev Forebay in Revelstoke was used.

Table 6. List of zooplankton species identified in Revelstoke Reservoir in 2003-2013. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2008	2009	2010	2011	2012	2013
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 mendotae	+	+	+	+	+	+	+
Daphnia rosea	+	+	+	+	+	+	+
Daphnia pulex	+	+	+	+	+	+	+
Diaphanosoma brachyurum			r			r	r
Holopedium gibberum	+	+	+	+	+	+	+
Leptodora kindtii	+	+	+	+	+	+	+
Scapholeberis rammneri	r	r	r	r	r	r	+
Copepoda							
Diacyclops bicuspidatus	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+	+	+	+
Leptodiaptomus sicilis	+	+	+	+	+	+	+

Figure 10. Zooplankton density 1984-2013 at Rev Forebay in Revelstoke Reservoir



The zooplankton community was primarily composed of copepods, which made up 74% of the zooplankton density and 20% of the zooplankton biomass during the studied period in 2013. *Daphnia* accounted for 14% of the density and 69% of the biomass during the same time period, while other cladocerans comprised 12% of density and 11% of zooplankton biomass (Fig. 11 and 12).

Figure 11. Seasonal average composition of zooplankton density in Revelstoke Reservoir in 2003, 2008 – 2013

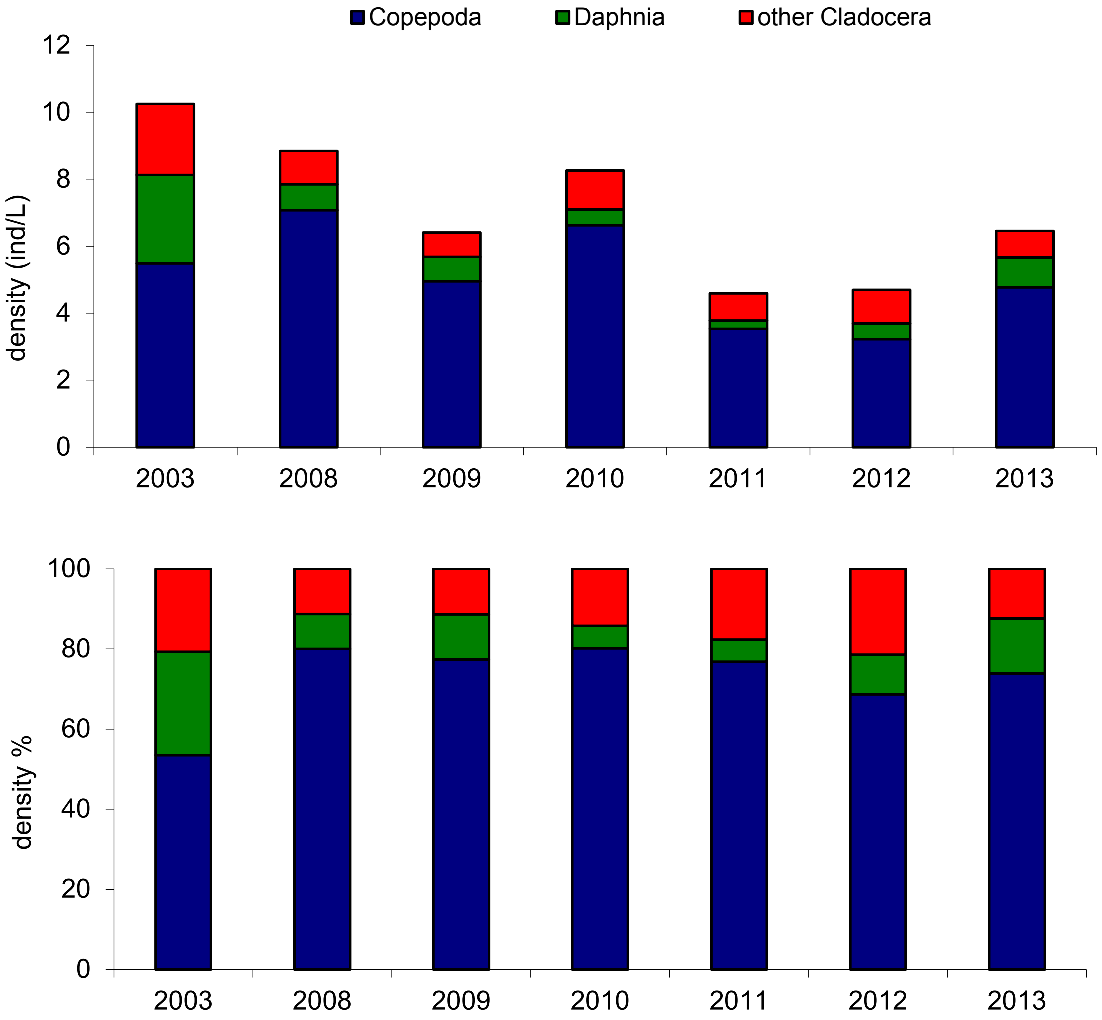
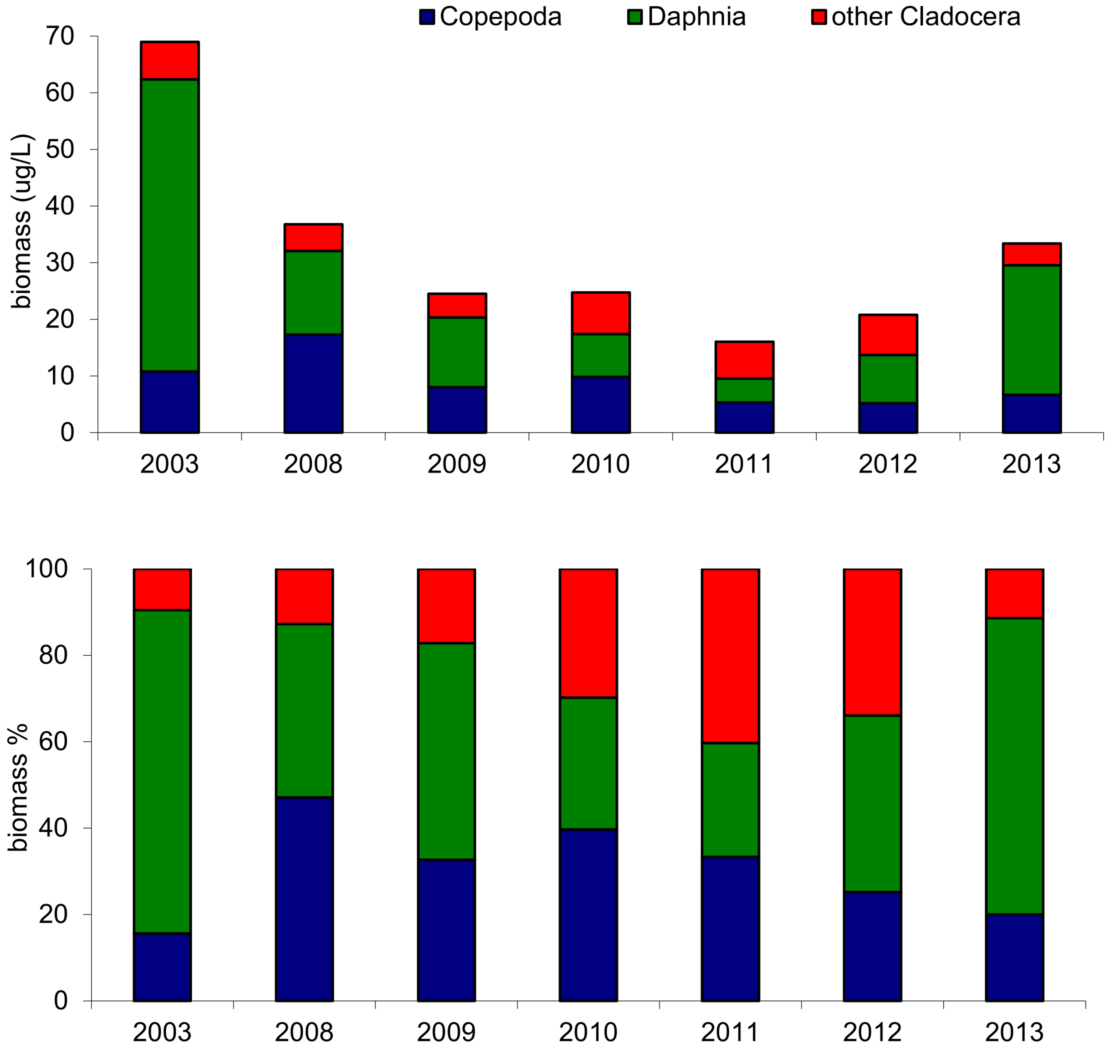


Figure 12. Seasonal average composition of zooplankton biomass in Revelstoke Reservoir in 2003, 2008 – 2013



The seasonal average zooplankton density in 2013 (April to September) was 6.46 individuals/L. Copepods were the most abundant with 4.77 individuals/L. Annual average density of *Daphnia* was 0.89 individuals/L, while density of other Cladocera (mainly *Bosmina* and *Holopedium*) was 0.80 individual/L. (Tab. 7, Fig. 11). Total zooplankton biomass, averaged for the whole reservoir was 33.40 µg/L. Copepods contributed 20% of the total zooplankton biomass with annual average biomass of 6.67 µg/L. *Daphnia* and other cladocerans made up 69% and 11%, with 22.90 µg/L, and 3.82 µg/L of the total zooplankton biomass (Tab. 7; Fig. 12).

Table 7. Annual average zooplankton abundance and biomass in Revelstoke Reservoir 2003-2013. Data are averaged for May to October in 2003, 2009, 2010, 2011, 2012, July to October in 2008 and April to September 2013.

		2003	2008	2009	2010	2011	2012	2013
Density	Copepoda	5.49	7.08	4.96	6.63	3.53	3.23	4.77
	Daphnia	2.64	0.77	0.72	0.47	0.25	0.47	0.89
	other Cladocera	2.12	1.00	0.73	1.17	0.81	1.01	0.80
	Total	10.25	8.85	6.41	8.27	4.59	4.70	6.46

		2003	2008	2009	2010	2011	2012	2013
Biomass	Copepoda	10.79	17.32	8.02	9.83	5.35	5.23	6.67
	Daphnia	51.56	14.75	12.30	7.56	4.23	8.50	22.90
	other Cladocera	6.61	4.69	4.22	7.37	6.47	7.05	3.82
	Total	68.96	36.76	24.54	24.76	16.05	20.78	33.40

The seasonal average zooplankton densities in Revelstoke Reservoir increased in comparison to the previous year. The highest zooplankton density averaged for the whole reservoir was in July with 13.70 individuals/L (Fig. 13). Seasonal average zooplankton biomass in 2013 increased in comparison to the previous year (Tab. 7). The highest zooplankton biomass averaged for the whole reservoir was found in July with 81.50 µg/L. Among the stations, the highest total zooplankton density and biomass were seen at Dam Forebay in July with 16.35 individuals/L and 101.02 µg/L (Fig. 14 and 15).

Figure 13. Monthly average zooplankton density (top) and biomass (bottom) in Revelstoke Reservoir in 2003, 2008 – 2013

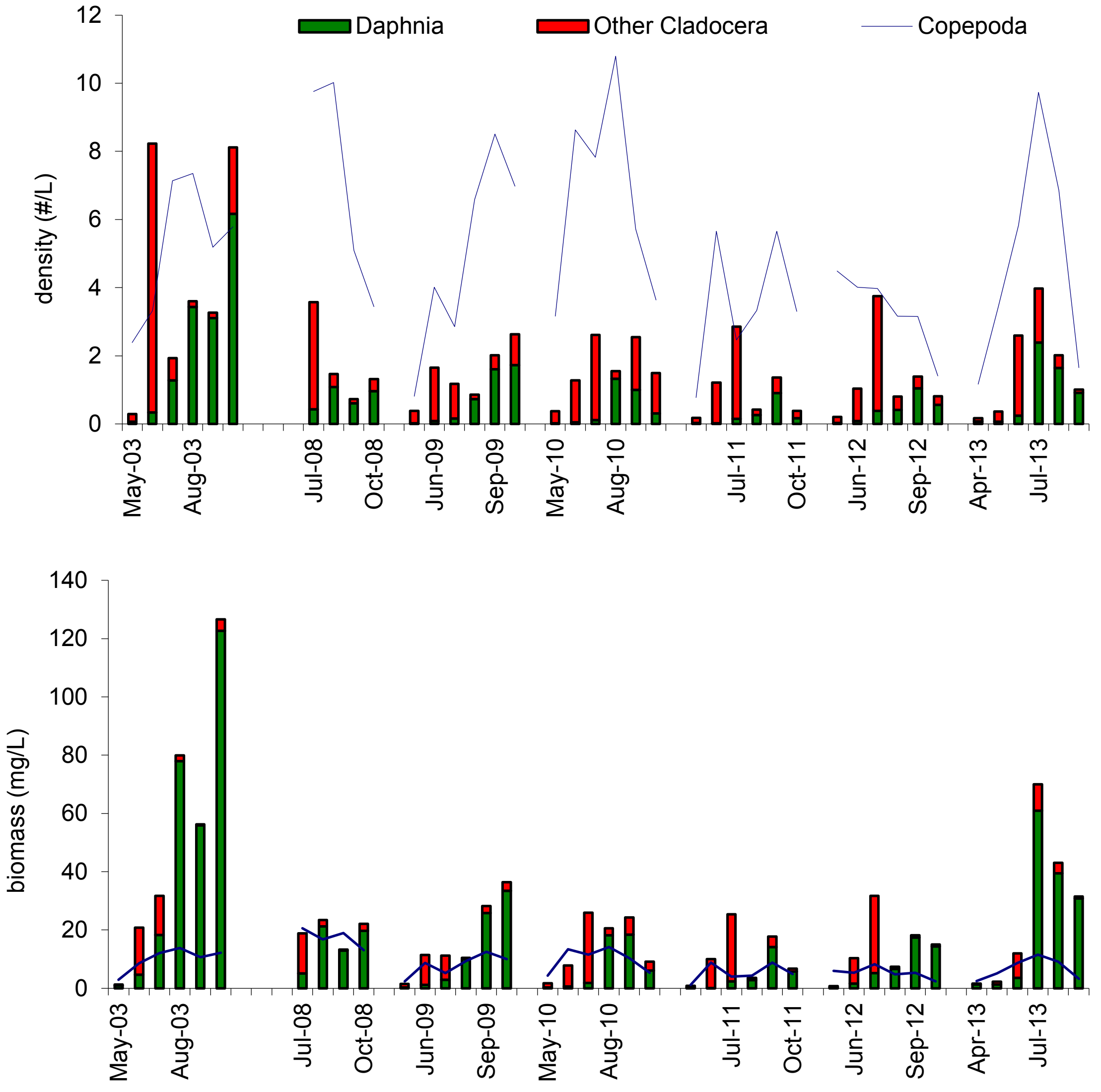


Figure 14. Zooplankton density at 3 stations in Revelstoke Reservoir 2003, 2008 – 2013

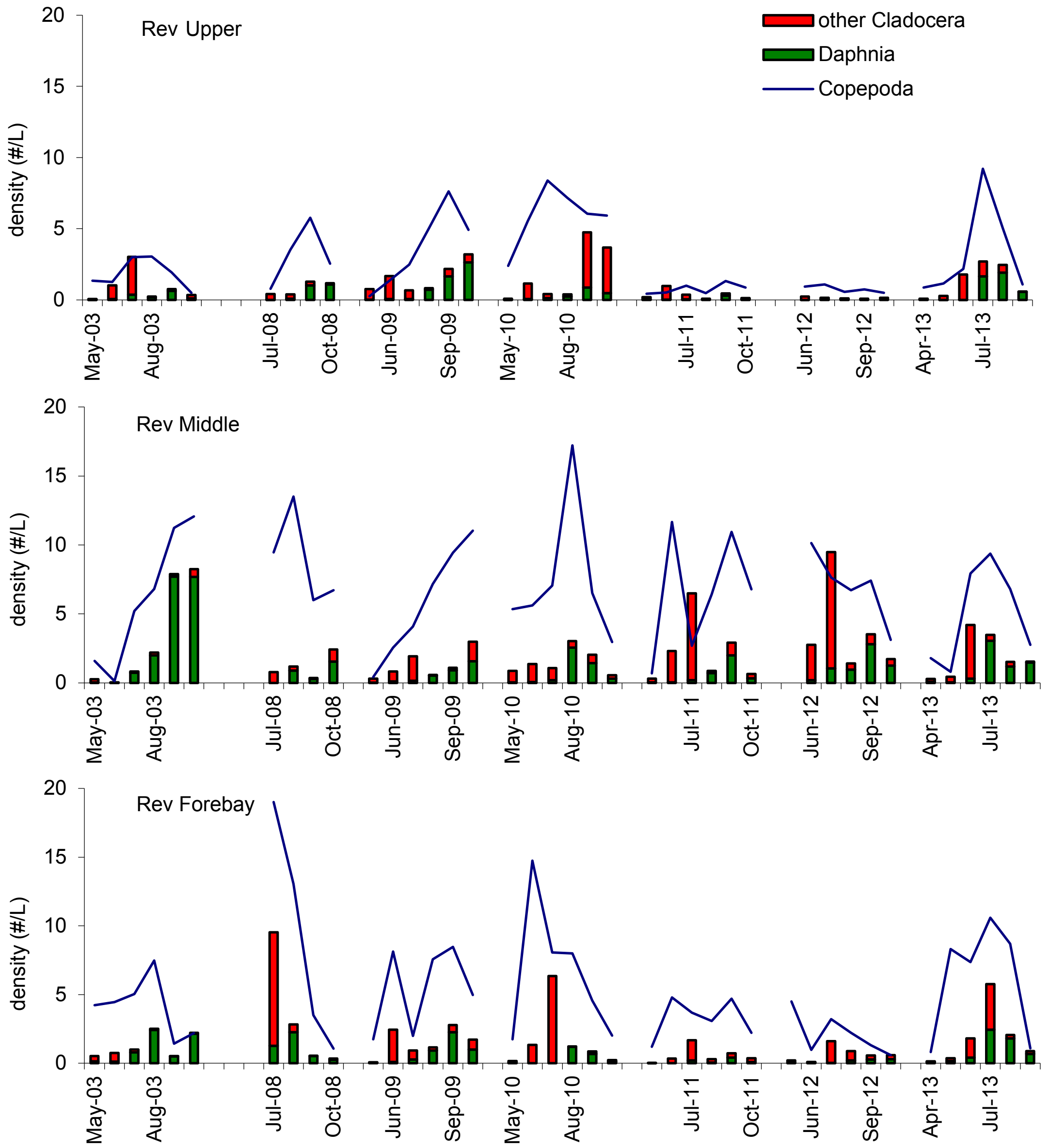
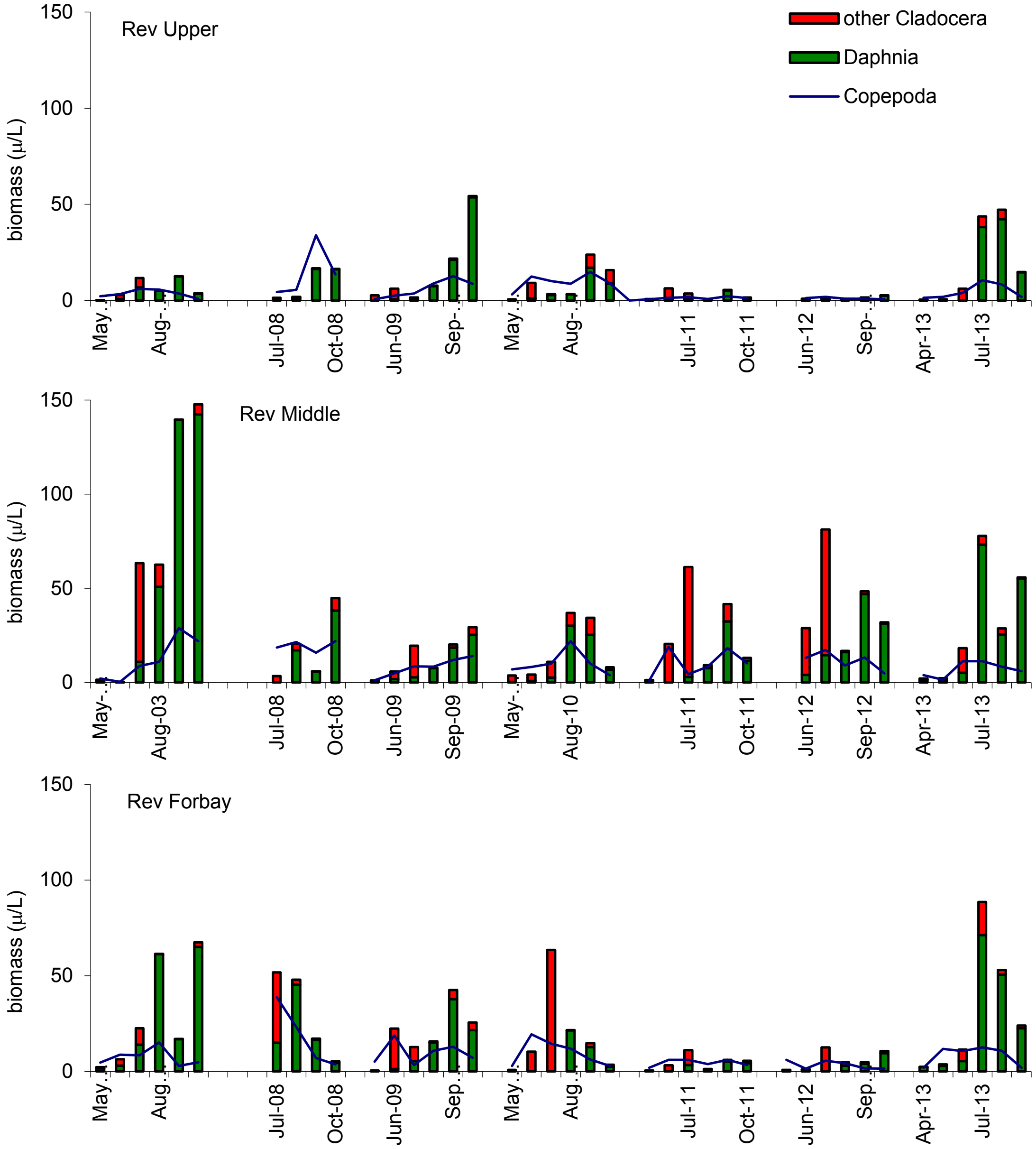


Figure 15. Zooplankton biomass at 3 stations in Revelstoke Reservoir 2003, 2008 – 2013



During 2013 sampling season Copepods were the most numerous in July with 9.73 individuals/L consisting mainly of *D. bicuspidatus thomasi.* They numerically prevailed during the whole sampling season, with the most numerous populations found at station in Upper Lake (Fig. 14).

The pattern of seasonal changes of zooplankton density and biomass was similar to the pattern in previous sampling seasons. In each year number of Copepoda increased at the beginning of the summer, reaching its maximum in July-August, and decreasing during the fall. *Daphnia* density increased at the end of the sampling season, while number of other Cladocera peaked in July (Fig. 13). Other Cladocerans were composed mainly of *Holopedium* and *Bosmina*, averaging 0.13 and 0.65 individuals/L respectively, in the whole reservoir. In June 2013, at station Mid Lake the number of other cladocerans was the highest in the season due to a peak of *Bosmina* with 3.72 individuals/L. In terms of biomass, other cladocerans contributed 11% to the total zooplankton biomass. Their biomass was less than 2 µg/L at each station at the beginning and at the end of 2013 sampling season, while in June, July and August the biomass of other cladocerans fluctuated between 2 µg/L and 17 µg/L (Fig. 15).

The number of *Daphnia* was low during the entire sampling season in 2013. It was less than 2 individual/L at each station except in July at stations Mid Lake and Dam Forebay when *Daphnia* density increased to 3.06 individuals/L and 2.45 individuals/L respectively. Although *Daphnia* were present in samples during the entire season, they accounted for 0.1 to 34% of the zooplankton community from April to September. Its density was relatively low averaging 0.01 to 3.06 individual/L at all three stations (Fig. 14). However, *Daphnia* biomass was the highest of three zooplankton groups averaging 22.90 µg/L of the sampling season (Fig. 12). The highest *Daphnia* biomass was found at Rev Middle station with 73.21 µg/L in July, when *Daphnia* accounted for 82% of the total zooplankton biomass at that time (Fig. 15).

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. 13). Copepods dominated numerically during the entire sampling season. 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 from July to September.

During 2013 peak total zooplankton density occurred in July with 13.70 individuals/L (Tab. 8, Fig. 13). The peak total zooplankton biomass occurred also in July with 81.50 µg/L, when *Daphnia* biomass reached its peak with 60.91 µg/L comprising 75% 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 and near the dam (Fig. 14 and 15).

Table 8. Monthly average density and biomass of zooplankton in Revelstoke Reservoir in 2013. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		April	May	June	July	Aug.	Sept.
	Copepoda	1.16	3.42	5.83	9.73	6.86	1.65
	Daphnia	0.07	0.07	0.24	2.39	1.64	0.91
	Other Cladocera*	0.10	0.30	2.36	1.59	0.37	0.10
	Total Zooplankton	1.33	3.79	8.42	13.70	8.87	2.65
Biomass		April	May	June	July	Aug.	Sept.
	Copepoda	2.43	5.05	8.65	11.49	9.17	3.25
	Daphnia	1.31	1.33	3.57	60.91	39.51	30.80
	Other Cladocera**	0.34	0.88	8.40	9.10	3.52	0.69
	Total Zooplankton	4.08	7.27	20.61	81.50	52.20	34.74

*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 2013. Gravid females in Revelstoke Reservoir comprise 0-37% of the female population in 2013. From April to September the proportion of gravid females averaged 0.22. The highest proportion has been found in May at the Dam Forebay station 0.37. On average, gravid female carry up to about 17.17 eggs (Tab. 9). Across the sampling season the number of eggs per water volume averaged 1.39 eggs/L. The number of eggs per capita averaged 0.86 eggs/individual.

Table 9. Fecundity data for *D. bicuspidatus thomasi* in Revelstoke Reservoir in 2003-2013. Values are seasonal averages, calculated for samples collected between July and October in 2008, May to October in 2003, 2009 - 2012, and April to September in 2013.

	2003	2008	2009	2010	2011	2012	2013
Proportion of gravid females	0.19	0.18	0.15	0.13	0.16	0.16	0.22
# Eggs per gravid Female	15.64	11.18	15.17	17.36	18.51	14.80	17.17
# Eggs per Litre	3.18	1.54	1.06	1.18	0.65	1.06	1.39
# Eggs per Capita	0.88	0.54	0.89	0.31	0.60	0.49	0.86

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. The proportion of gravid females averaged 0.20 in 2013 (Tab. 10). The seasonal average number of eggs per gravid female was 2.57. Across the sampling season the number of eggs per water volume averaged 0.22 eggs/L, and the number of eggs per capita averaged 0.48 eggs/individual over the study period in 2013.

Table 10. Fecundity data for *Daphnia* spp. in Revelstoke Reservoir 2003-2013. Values are seasonal averages, calculated for samples collected between July and October in 2008, May to October in 2003, 2009 - 2012, and April to September in 2013.

	2003	2008	2009	2010	2011	2012	2013
Proportion of gravid females	0.11	0.20	0.13	0.09	0.09	0.08	0.20
# Eggs per gravid Female	2.67	2.66	2.00	1.76	2.41	2.36	2.57
# Eggs per Litre	0.32	0.16	1.15	0.07	0.05	0.09	0.22
# Eggs per Capita	0.35	0.46	0.28	0.18	0.27	0.21	0.48

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 2013 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 2013 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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Appendix 8

Moorings
Kinbasket and Revelstoke Reservoirs, 2013

Roger Pieters and Greg Lawrence
University of British Columbia

Moorings,
Kinbasket and Revelstoke Reservoirs, 2013

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

[1] Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C. V6T 1Z4
[2] Civil Engineering, University of British Columbia, Vancouver, B.C. V6T 1Z4

Acoustic release (yellow) with attached SBE56 (white) in back of the boat, 29 Aug 2013

Prepared for

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

January 18, 2016

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1. Introduction

This report provides an update on 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 the moorings are presented.

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 locations: the forebay of Revelstoke Reservoir, and the forebay of Kinbasket Reservoir. The goal is to collect data from these two base locations throughout the duration of the project. Instruments have been moored, for example, at the mid and upper sampling 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, which are important to understanding pelagic productivity.

2. Methods

In 2012, a trial of four different types of moorings was undertaken in the forebay of Revelstoke Reservoir during the summer of 2012. In October 2012, six moorings were deployed in both Revelstoke and Kinbasket Reservoirs over the 2012-2013 winter. 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, 2012 and 2013

	Name	Date	Description
1	Rev FB BOOM TB	18 Jul – 11 Oct 2012	Line from log boom near dam, trial line of Onset Tidbits
2	Rev FB SUB	16 Aug – 11 Oct 2012	Subsurface mooring
3	Rev FB SPAR	16 Aug – 11 Oct 2012	Spar mooring
4	Rev FB PROF	11 Sep – 11 Oct 2012	Profiler
5	Rev FB SUB	11 Oct 2012 - 26 Aug 2013	Subsurface mooring
6	Rev FB BOOM	11 Sep 2012 - 26 Aug 2013	Line from log boom near dam
7	Rev MID SUB	12 Sep 2012 - 26 Aug 2013	Subsurface mooring
8	Rev UP SUB	12 Sep 2012 - 26 Aug 2013	Subsurface mooring
9	Kin FB SUB	13 Sep 2012 - 30 Aug 2013	Subsurface mooring
10	Kin FB BOOM	13 Sep 2012 - 30 Aug 2013	Line from log boom near dam

Table 2.2 Location of moorings, 2012 and 2013

	Name	UTM Easting(11U)/Northing	Latitude/ Longitude
1	Rev FB BOOM	416,518E 5,656,309N	51° 3.134 N 118° 11.464 W
2	Rev FB SUB	416,942E 5,657,543N	51° 3.804 N 118° 11.119 W
3	Rev FB SPAR	416,846E 5,657,294N	51° 3.668 N 118° 11.197 W
4	Rev FB PROF	417,057E 5,657,845N	51° 3.968 N 118° 11.024 W
5	Rev FB SUB	416,926E 5,657,518N	51° 3.790 N 118° 11.132 W
6	Rev FB BOOM	416,468E 5,656,304N	51° 3.131 N 118° 11.507 W
7	Rev MID SUB	398,452E 5,699,022N	51° 25.997 N 118° 27.652 W
8	Rev UP SUB	385,521E 5,731,847N	51° 43.550 N 118° 39.451 W
9	Kin FB SUB	393,754E 5,772,744N	52° 5.702N 118° 33.058 W
10	Kin FB BOOM	392,322E 5,771,049N	52° 4.772 N 118° 34.280 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, weight 7.0 kg/100m, average strength 3000 kg). The line was chosen to be buoyant, have good handling, low abrasion and little stretch.

Each of the sub-surface moorings made use of an Interocean Model 111 acoustic release. The release is located just above the anchor; upon receiving a coded acoustic signal, the release disconnects from the anchor, and the float carries the mooring and release to the surface. This allows for recovery of the mooring without the anchor, and makes it possible to recover the moorings from a smaller boat without the need for a crane. An extended-life battery option enables 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 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 of the line to keep it vertical.

REV FB SUB This is a subsurface mooring; the float is below the water surface. In Revelstoke there is little water level variation so the float can be located a few meters below the surface, and depending on water clarity, the float can 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 mooring line is anchored at the bottom, it does not rise and fall with changes in water level, but remains 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 ice. 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 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), and rise on a regular basis (e.g. every 10 days) to collect a profile of temperature, conductivity and other parameters; upon 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 collecting daily CTD profiles for more than one year. Once recovered, the data is uploaded, and the batteries are changed for the next deployment. These floats each have a Seabird SBE 41cp CTD and a Seapoint turbidity meter.

3. Revelstoke

REV FB BOOM TB (Figure 3.1) All ten moorings were successfully deployed, recovered and uploaded. The first to be deployed was a trial line of Onset Tidbits, hung from the log boom in the forebay of Revelstoke Dam (REV FB BOOM TB) 18 July to 11 October 2012. The Onset Tidbit is similar to the Onset HWTP used in the other moorings. Temperature data measured by instruments attached to this mooring are shown in Figure 3.1. 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 (Figure 3.1). On top of this seasonal pattern, there are other variations on a variety of time scales, the most notable of which are 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 on 22 August 2012 (day 1696.67) to 12.1 °C after 17 hours (see inset, Figure 3.1). This colder 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 at 16:00 on 15 August 2012 (day 1689.67) rose to 16.7 °C over 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.

REV FB BOOM (Figure 3.2) On 11 September 2012, a line of HWTPs, was hung from the Revelstoke Dam log boom as part of the base mooring in Revelstoke Forebay. These instruments were moored until 26 August 2013. The temperature from 1 to 6 m was similar over most of the year. Occasionally, daily stratification occurred within 1 to 6 m, where the temperature at 1 m was either warmer (in summer) or cooler (in winter). For example, the highest temperature at 1 m was 20.9 °C at 19:00 on 3 August 2013, which then cooled back down to the temperature of the deeper sensors, 20.1 °C by 04:00 the following morning. Similarly, the coldest temperature at 1 m was 2.5 °C at 06:00 on 24 March 2013 which then warmed back up to the temperature of the deeper sensors, 3.0 °C by 09:00.

REV FB SUB (Figure 3.3) Data shown came from two moorings: (1) 16 August to 11 October 2012, and (2) 11 October 2012 to 26 August 2013. The temperatures measured by the instruments on the REV FB SUB mooring are shown in Figure 3.3; temperature recorders were at nominal depths (relative to full pool) of 4.4 to 124 m. The mooring shows the seasonal temperature cycle:

- The warm surface layer cools and deepens from August to December, 2012.
- Fall turnover begins on 25 December 2012 (day 1821) and the entire reservoir cools from 5.8 °C to a minimum of 3.0 °C around 4 March 2013 (day 1890).
- Spring turnover begins around 4 March 2013 (day 1890) as the entire reservoir warms from 3.0 °C to almost 4.0 °C on 16 April 2013 (day 1933).

- Persistent temperature stratification occurs after 16 April 2013 (day 1933), and the summer stratification develops.

As in REV FB BOOM, the summer stratification at shallower depths is modulated by internal waves. The temperature at the bottom (124 m) is comparatively steady, rising very slowly by ~0.1 °C/month, which is similar to that observed in other deep lakes.

REV FB SPAR (Figure 3.4) The spar mooring was deployed from 16 August to 11 October 2012. The temperatures measured at 5 depths using this mooring are shown in Figure 3.4. 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.

REV FB PROF (Figure 3.5) The profiler was deployed from 11 September to 11 October 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 3.5. The black bars mark the 1% light level determined from the CTD surveys (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 of 2012, 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 2012 (Pieters and Lawrence, 2014a). By October 2012, remnants of this low salinity water are observed near the surface, and at a band around 60 m depth (Figure 3.5b).

In mid-July 2012, a big change occurred with the sudden increase of deep outflow from Kinbasket Reservoir, with flow rates increasing from less than 100 m^3/s to greater than 1500 m^3/s. This outflow was cool, was slightly more saline (>60 mg/L), and had elevated turbidity, and forms an interflow along the length of the reservoir centered around 30 m depth (for further details, see Pieters and Lawrence 2012, 2014abc).

From the CTD 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 included two periods of time 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 to 14 September 2012, and about a quarter of the interflow depth was in the photic zone for about 5 days from 30 September to 4 October 2012. This suggests that nutrients in the interflow may be able to contribute to pelagic productivity.

REV MID SUB (Figure 3.6) This mooring was deployed from 12 September 2012 to 26 August 2013 at the MID sampling station near Downie Arm. At this location, about halfway up Revelstoke Reservoir, turnover occurred earlier around 10 November 2012 (day 1776, Figure 3.6), well before the forebay mixed to 86 m on 15 December 2012 (day 1811, Figure 3.3). In addition, fall turnover at the MID mooring showed more periods of temporary stratification than did the forebay, including slightly longer and cooler periods of reverse stratification, with a minimum temperature of 1.9 °C at 6.4 m on 24 January 2013 (day 1851). Summer temperature stratification began after the reservoir reached ~4 °C on 16 April 2013 (day 1933), the same date as at the forebay.

REV UP SUB (Figure 3.7) This mooring was deployed from 12 September 2012 to 26 August 2013 near the UP sampling station. This station is not only shallower but more riverine, showing less temperature stratification than at the MID and FB sites. At the start of the mooring there was little temperature stratification, and fall turnover began on 4 October 2012 (day 1739). During fall turnover, the temperature showed fewer periods of secondary stratification than at the MID and FB moorings. However, unlike the MID and FB moorings, the temperature at the UP mooring did not cool monotonically but included periods of 5 -10 days when the entire water column warmed, possibly due to the influence of upstream inflow. During spring turnover, the shallower water column warmed faster than at the MID and FB moorings, and summer stratification began sooner, on 31 March 2013 (day 1917).

4. Kinbasket

KIN FB BOOM (Figure 4.1) Because of the large water level variation in Kinbasket Reservoir, the subsurface mooring was made shorter to stay below the minimum water level, and the boom mooring was made longer to measure temperature above the minimum water level. Unfortunately, the instruments on the boom mooring below 2 m were lost (likely due to a shackle that was not closed tightly enough). Data from the remaining two instruments are plotted in Figure 4.1, and show a seasonal cycle similar to that in Revelstoke Reservoir.

KIN FB SUB (Figure 4.2) Data from 40 to 180 m depth are shown in Figure 4.2. The surface layer mixed to 80 m depth by 22 December 2013 (day 1818), and this surface layer reached 4 °C around 15 January 2013 (day 1842). However, the 0 to 80 m layer then cooled below 4 °C to develop reverse stratification, without mixing with water below 100 m depth. A slight salinity stratification was observed in the CTD profiles; for example, on 23 April 2013, the conductivity increased from ~150 μS/cm at 100 m to 180 μS/cm at the bottom (Figure B1c, Pieters and Lawrence 2016). This conductivity difference was sufficient to prevent fall turnover, not including pressure effects which also begin to resist fall turnover below ~150 m depth. Complete spring turnover also did not occur; rather, the top 80 m warmed through 4 °C leaving the deep temperature at 3.6 °C. The deep water gradually warmed through the summer, suggesting a small degree of exchange with water above 100 m. Note, that the deep water remained well oxygenated (e.g. Figure B1e, Pieters and Lawrence 2016).

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Figure 2.1 Revelstoke Forebay Moorings, 2012

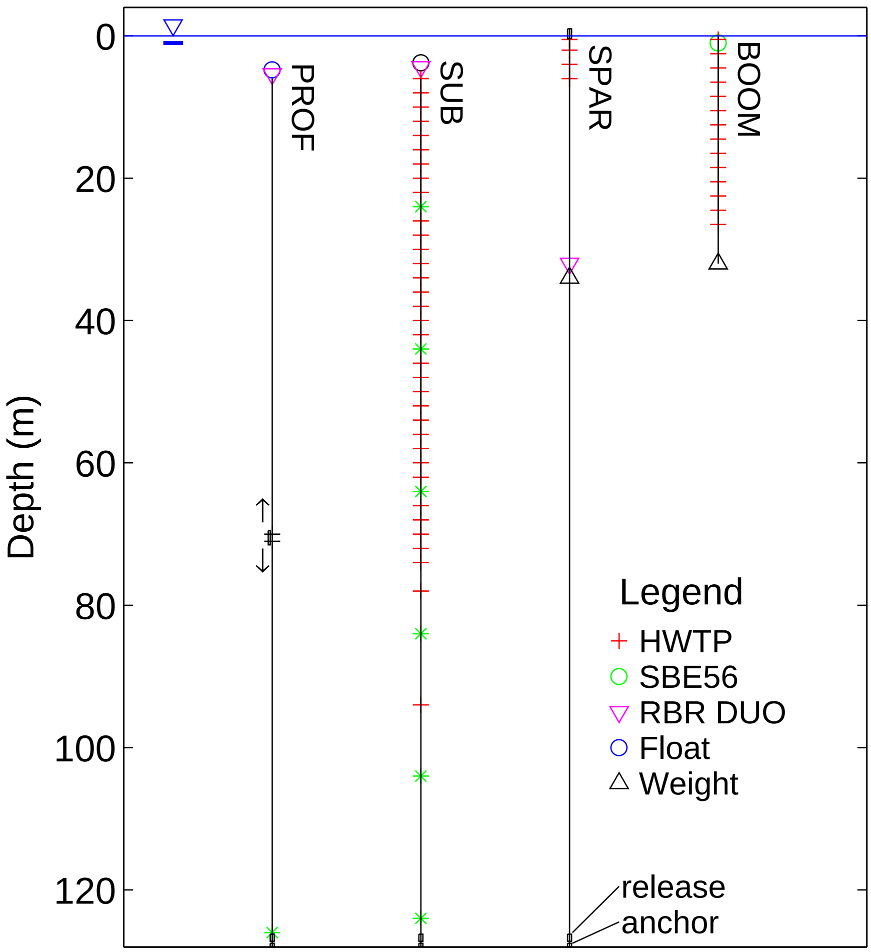

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Figure 3.1 REV−FB−BOOM, Jul 18 − Oct 11, 2012

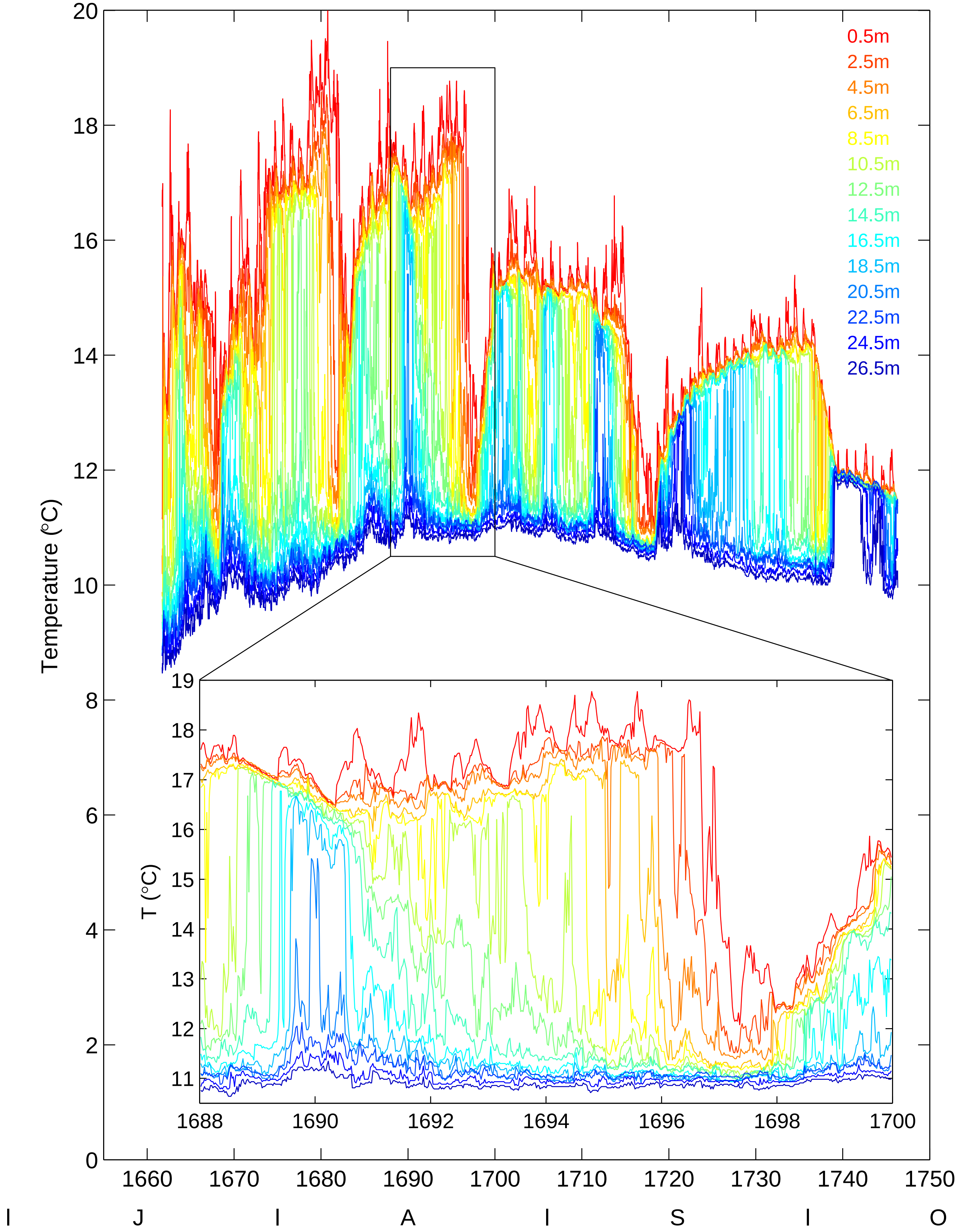

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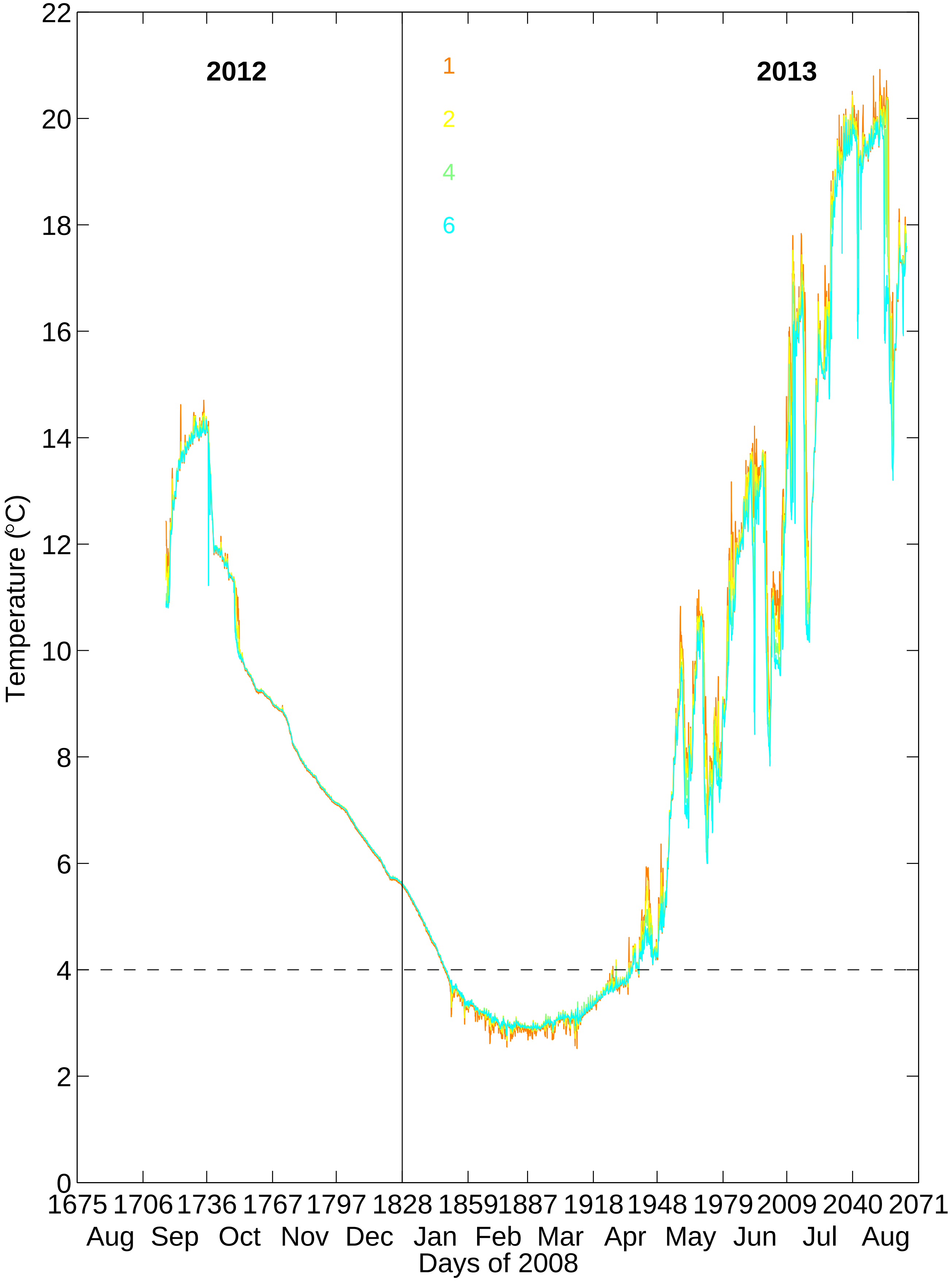
Figure 3.2 Revelstoke Forebay Boom Mooring, 2012−2013



/ocean/rpieters/kr/moor/plot13/plotlineall.m fig= 4 2016−Jan−16

Figure 3.3 Revelstoke Forebay Subsurface Mooring, 2012−2013

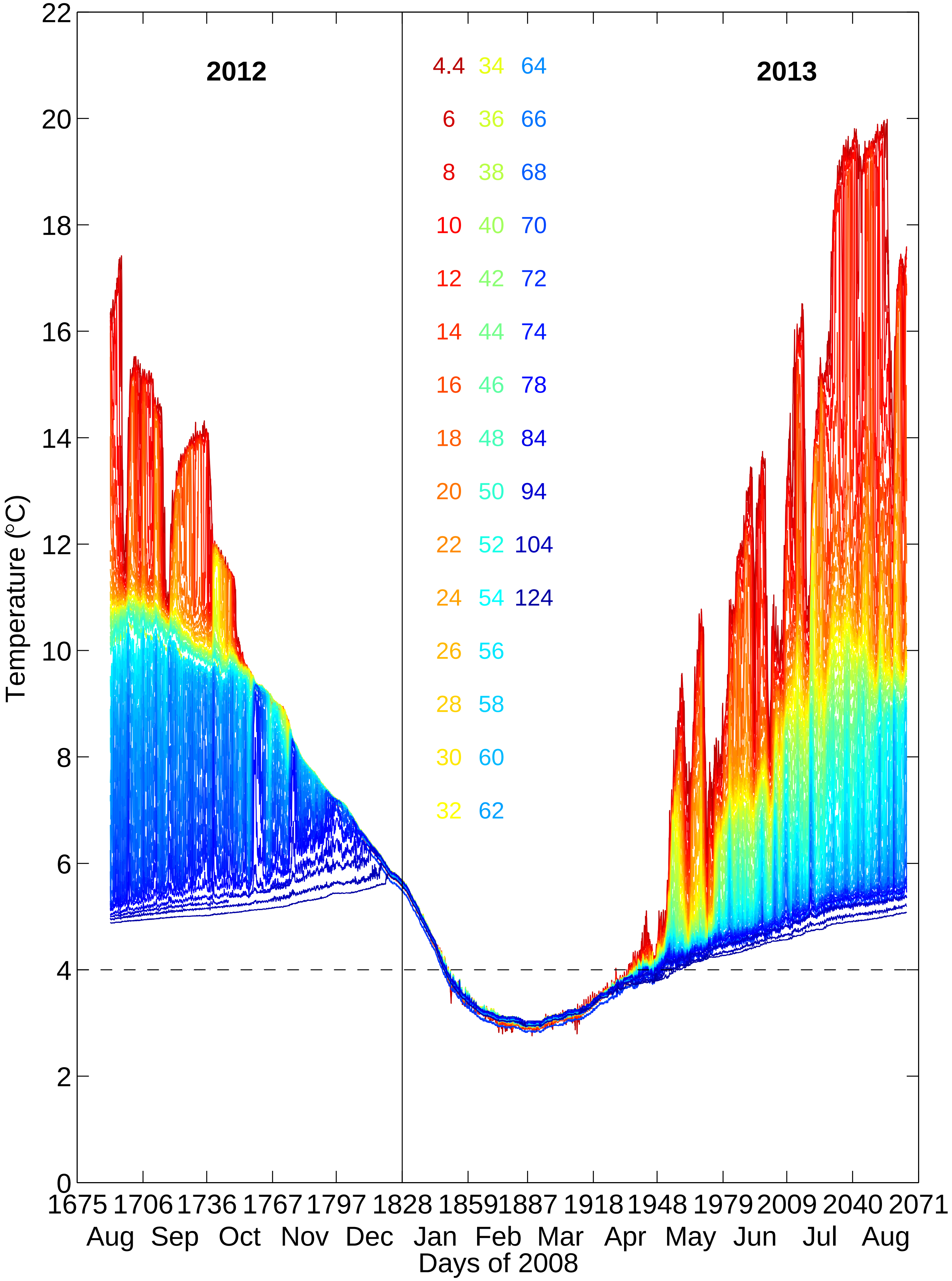


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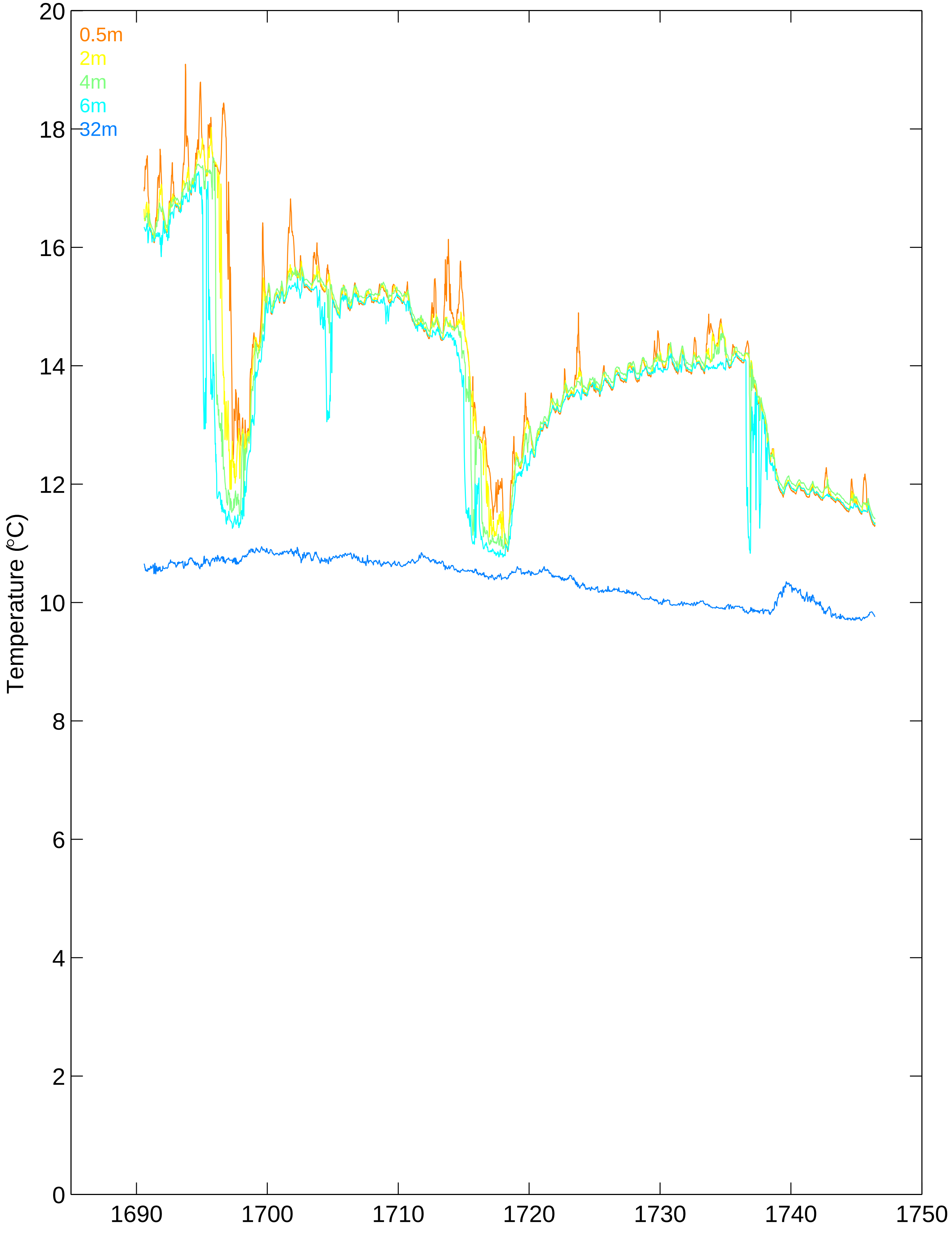
Figure 3.4 REV−FB−SPAR, Aug 16 − Oct 11, 2012

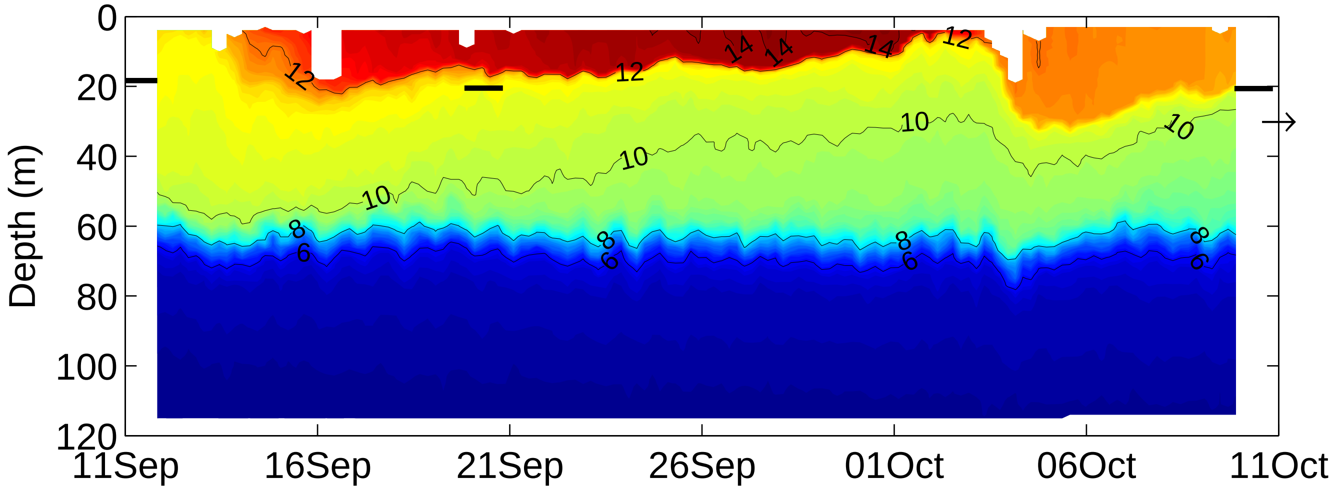


I A I S I O

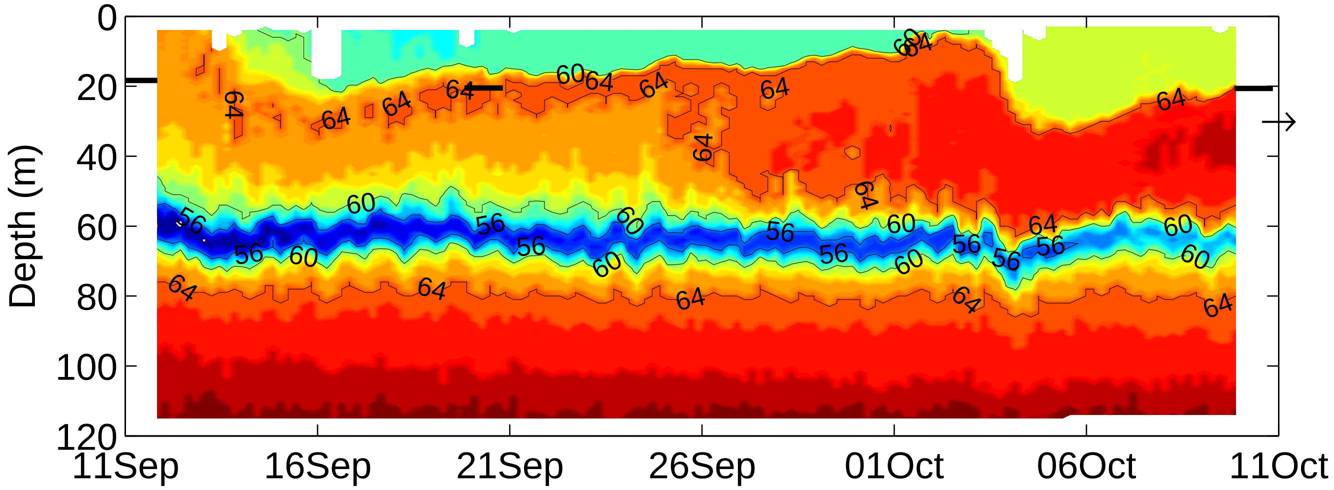
/ocean/rpieters/kr/moor/plot12/plotline30.m fig= 3 2014−Oct−28

Figure 3.5 REV−FB−PROF, 11Sep−11Oct, 2012 (day 1716−1746)

(a) T (°C)



(b) S (mg/L)



(c) Turbidity (NTU)

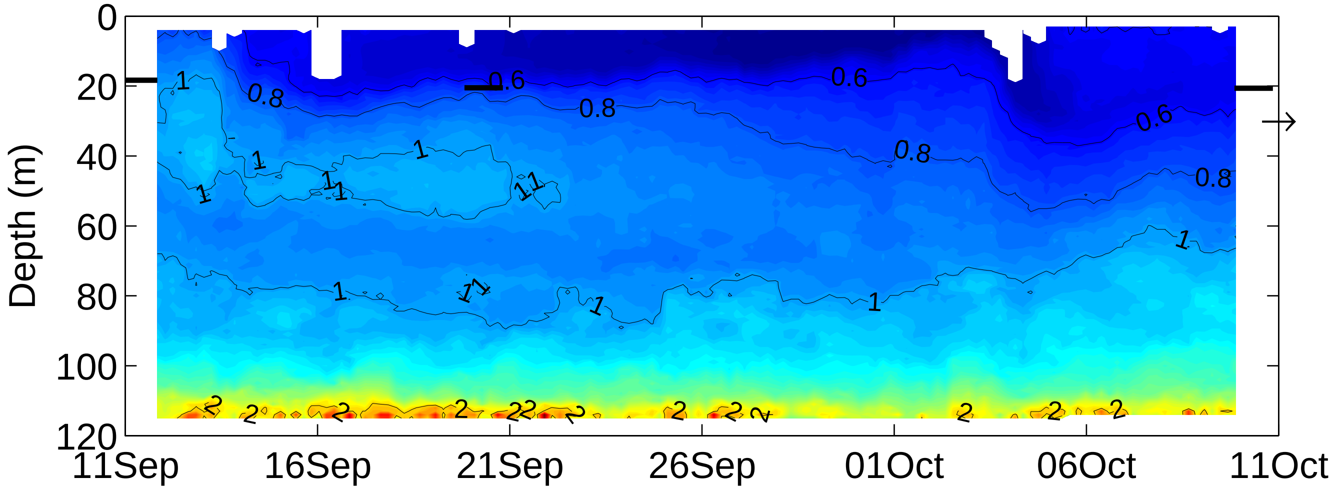


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Figure 3.6 Revelstoke Mid Subsurface Mooring, 2012−2013

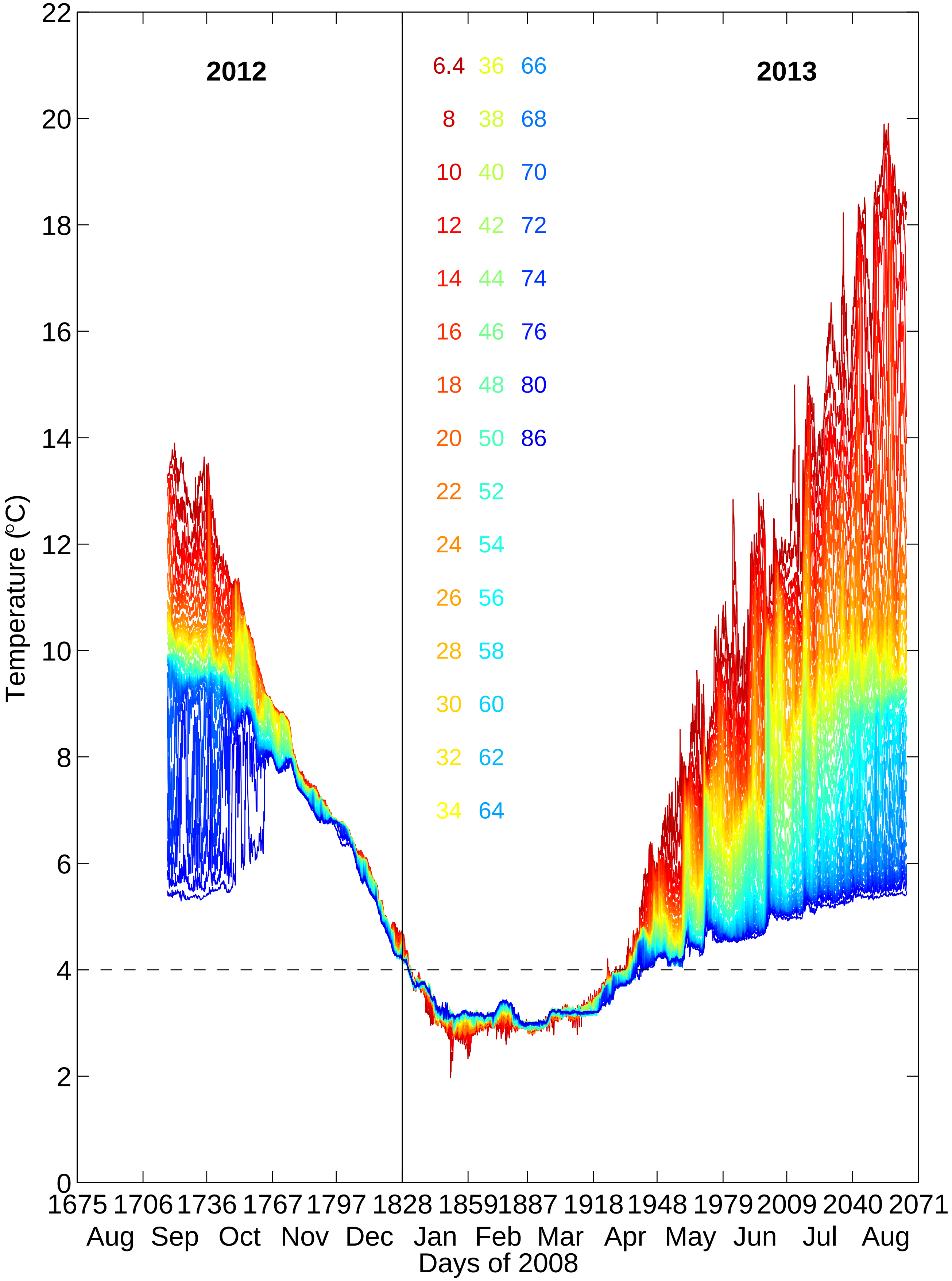

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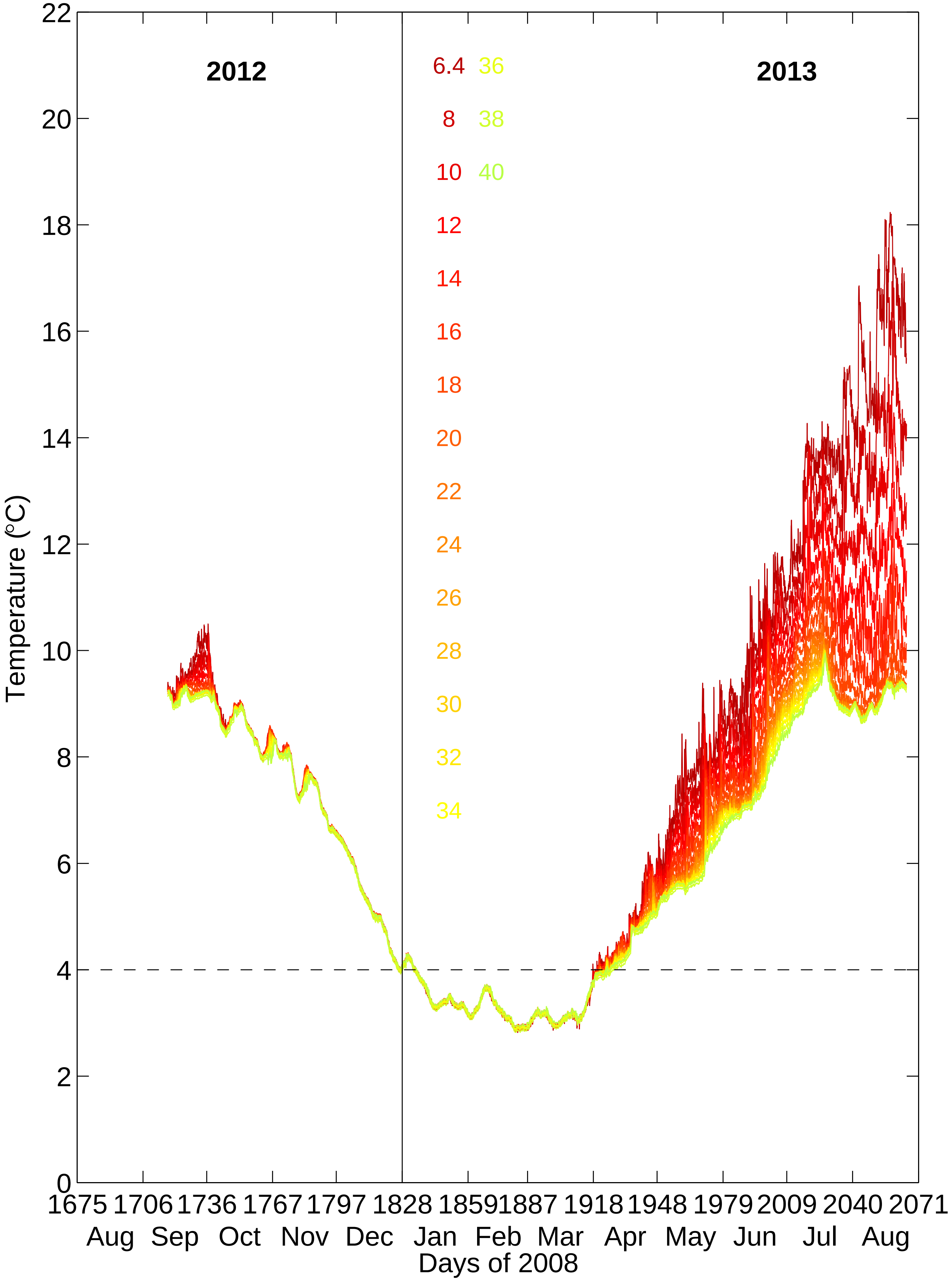
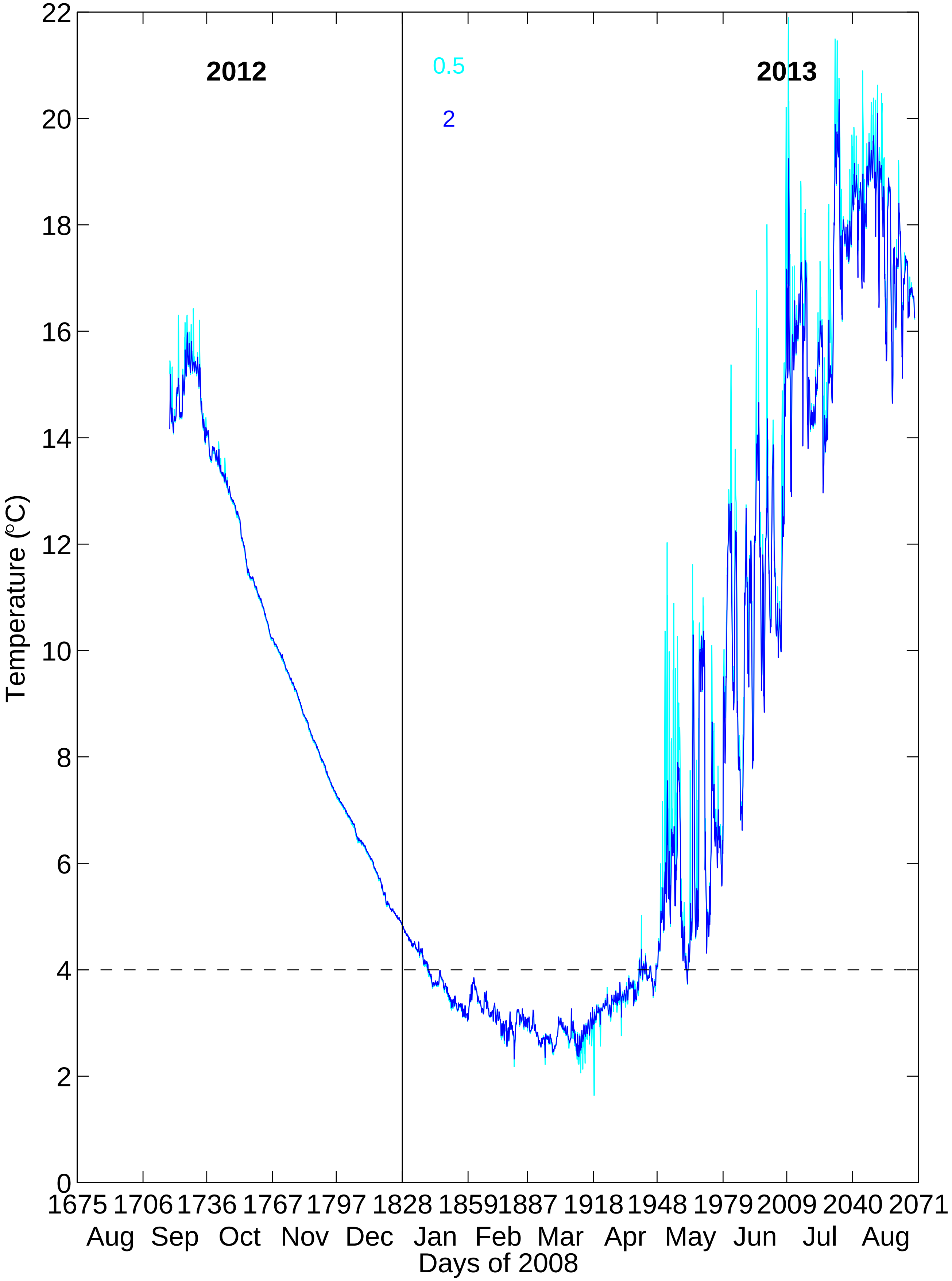
Figure 3.7 Revelstoke Up Subsurface Mooring, 2012−2013



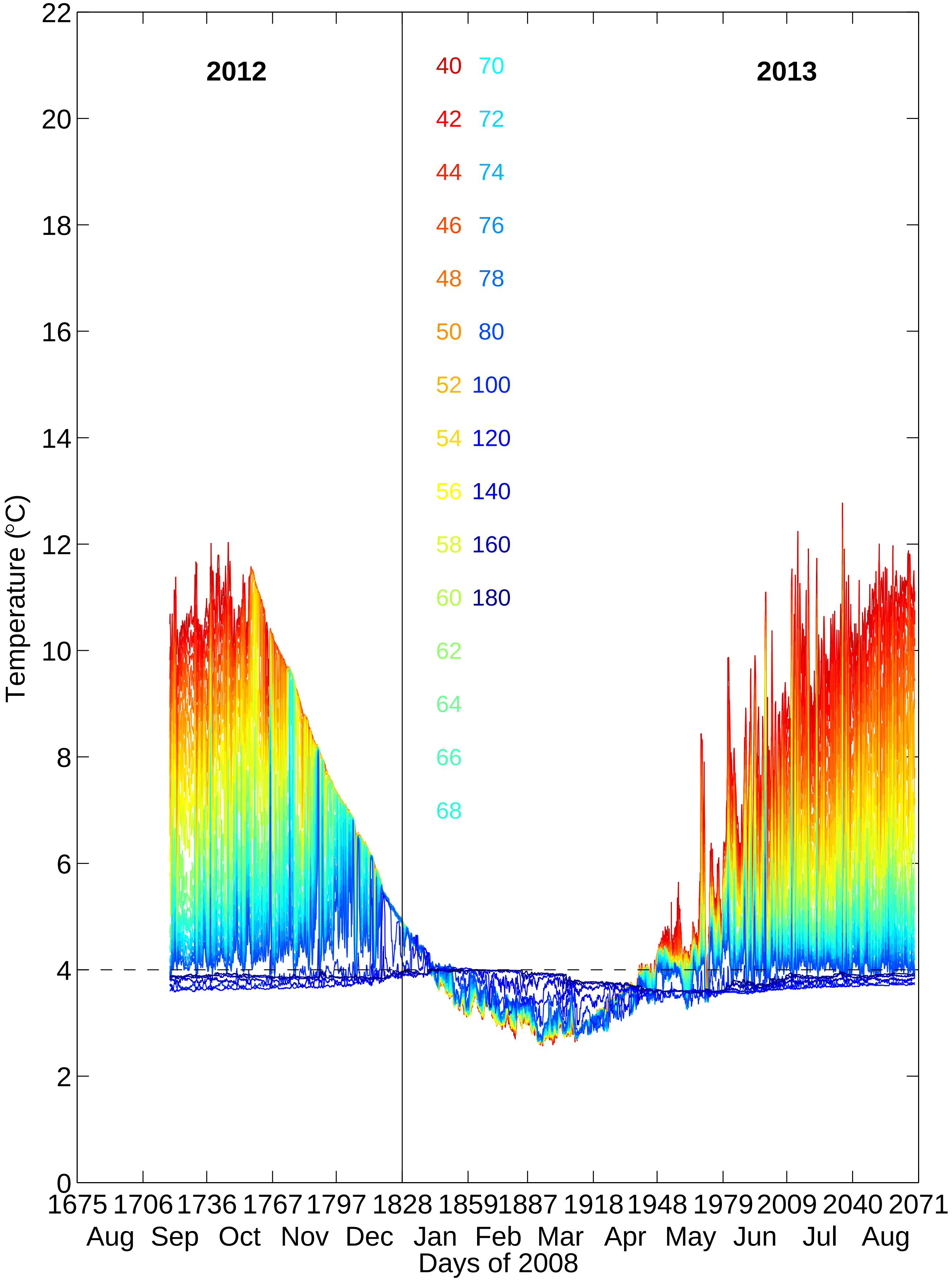
/ocean/rpieters/kr/moor/plot13/plotlineall.m fig= 3 2016−Jan−16

Figure 4.1 Kinbasket Forebay Boom Mooring, 2012−2013



/ocean/rpieters/kr/moor/plot13/plotlineall.m fig= 6 2016−Jan−16

Figure 4.2 Kinbasket Forebay Sub Mooring, 2012−2013



/ocean/rpieters/kr/moor/plot13/plotlineall.m fig= 5 2016−Jan−16