Columbia River Project Water Use Plan

Kinbasket Fish and Wildlife Information Management Plan

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring

Implementation Year 9

Reference: CLBMON-3 and CLBMON-56

Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring –*Year 9 and Year 5 (2016)*

Study Period: 2016

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Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring
Year 9 (2016) Progress Report

View from Kinbasket Columbia Station to Main Pool, Sep 2016

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

Suggested Citation for Progress Report:

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Suggested citation format for individual reports contained within:

Harris, S. and J. Sarchuk. 2018. Primary productivity in Kinbasket and Revelstoke Reservoirs, 2016. Prepared for BC Hydro, Water Licence Requirements. 14 pp. + apps. Appendix 4 *in* Bray, K. 2018. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 9 (2016). BC Hydro, Environment. Study No. CLBMON-3 and CLBMON-56.

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1.0 Introduction

This report summarises the Year 9 (2016) 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 fifth year of this study was implemented in 2016 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 30, 2016, to discuss progress on the management questions, evaluate the sampling program to date, and set the 2016 (Year 9) work plan. The monitoring program is 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 synthesis reports covering 2008-2011 has been completed (Bray et al. 2013); the next synthesis report covering data to 2015 is in preparation. A final report for the study will be prepared following the final year of field data collection.

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 ninth annual report presents a study overview followed by individual progress reports for the physical processes and biological components of the 2016 sampling year as per previous progress reports (Bray 2017, 2016a, 2016b, 2014, 2013, 2012; BC Hydro 2011a; BC Hydro 2010). Also included is the fifth annual report for CLBMON-56 (Appendix 8). More specific information pertaining to individual year monitoring results is contained in these reports.

In Year 9 (2016) regular reservoir monthly sampling began in April and concluded in October at four stations in Kinbasket reservoir and three stations in Revelstoke reservoir (Figure 1). Sampling sessions on Kinbasket reservoir were conducted at reservoir elevations between 729.9 m and 751.5 m (Figure 2). Sampling protocols remained largely unchanged from the previous year although total nitrogen was added to the suite of water chemistry parameters (Table 1). Equipment failure resulted in the loss of sampling sessions in June at KIN Columbia, KIN Wood, KIN Canoe, and REV Upper) and abbreviated discrete depth sampling at other stations. All other sampling was completed.

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

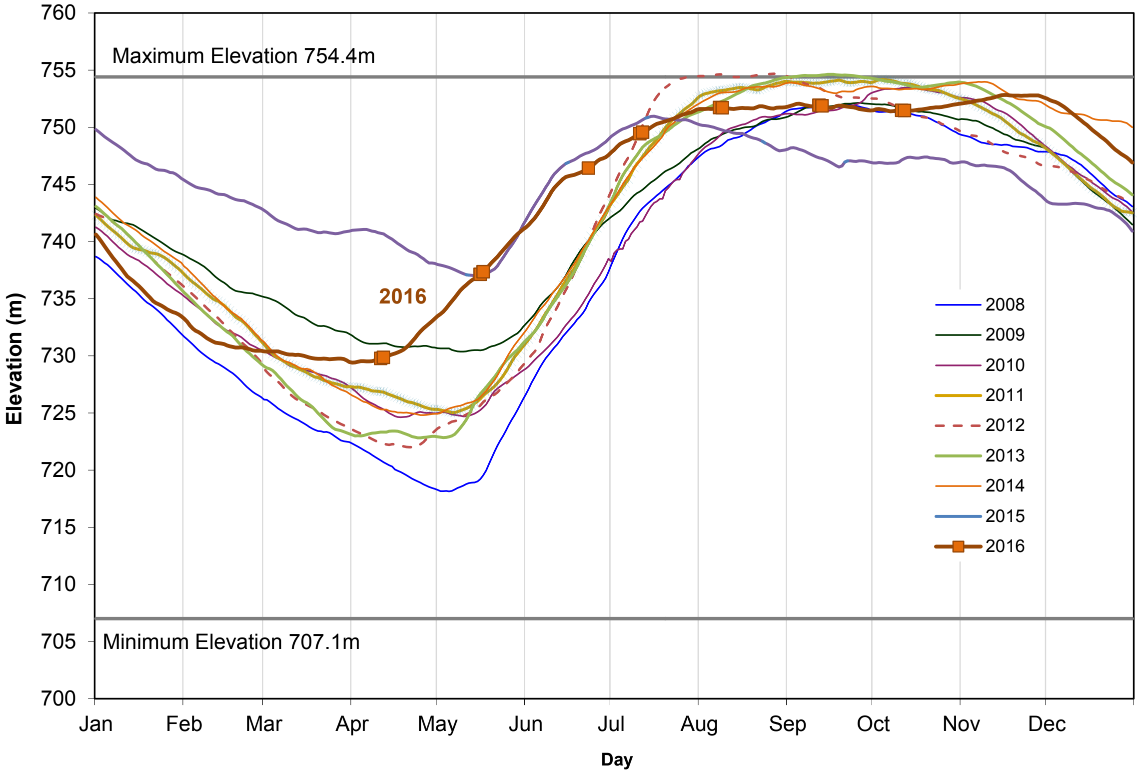

Figure 2. Kinbasket Reservoir elevation and sampling dates, 2016. Elevations for 2008-2015 are shown for comparison.

Table 1. Summary of Kinbasket and Revelstoke Reservoirs field sampling program 2016.

Parameter (Analyses)	**Sampling Frequency**	**Method**	**Details**	**Stations** (Figure 1)								
				KIN Forebay	**KIN Canoe**	**KIN Wood Arm**	**KIN Col Reach**	**KIN Main Pool**	**REV Upper**	**REV Middle**	**REV Forebay**	**Tribs**
Weather Station (temp, ppt, BP, RH, PAR, wind)	Hourly/daily	Fixed Data logger		Mica dam							Rev Dam crest	
Profile (DO, temp, cond, chl a, PAR, turbidity) +Secchi	**Apr-Oct** Monthly (7)	Seabird +Secchi	0 to 60m+ (to within 5 m of bottom)	√	√	√	√	√	√	√	√	
Water Chem - Reservoir TP, SRP, TDP, cond, NO_2+NO_3, TN, alk, pH, turb, silica	**Apr-Oct** Monthly (7)	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, NO_2+NO_3, TN, pH, alk, turb, temp	5 reference tribs* once in Mar/Apr/Jul/Aug/S/O/N/D; twice in May/Jun	Bucket	Surface grab									√
Temperature - Tributaries	Hourly	Data logger/WSC gauge	Ref tribs* + Bush R, Camp Ck, Col R at Fairmont									√
Temperature - Reservoir	Continuous	Data logger	Moored arrays, surface to bottom	√					√	√	√	
Phytoplankton	**Apr-Oct** Monthly (7)	Bottle	2, 5, 10, 15, 25 m	√	√	√	√		√	√	√	
Bacteria	**Apr-Oct** Monthly (7)	Bottle	Two composites of 2,5,10m and 15,20,25m	√	√	√	√		√	√	√	
Zooplankton	**Apr-Oct** Monthly (7)	Wisconsin net 2 hauls per site	0-30m	√	√	√	√		√	√	√	
C^{14}	**June-Sep** Monthly (4)	3 size fractions	0,1,2,5,10,12,15m	√**						√	√	

* Columbia River at Donald, Beaver River, Mica outflow, Goldstream River, Revelstoke outflow

**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, 2016

Roger Pieters and Greg Lawrence
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Hydrology of Kinbasket and Revelstoke Reservoirs, 2016

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Mica Dam, 24 August 2016

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Contents

List of Figures

1. Introduction

The hydrology of Kinbasket and Revelstoke Reservoirs is described in this report, with a focus on flow in 2016. This report updates Pieters et al. (2017) and provides context for the ongoing BC Hydro project entitled "Kinbasket and Revelstoke Ecological Productivity Monitoring (CLBMON-3 and CLBMON-56)".

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 total area drained by the Columbia River, but contributes 27% of the total flow in the Columbia River. 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 and along 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. 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 a 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, 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 1944-2016 from WSC station 08NB005, entitled "Columbia River at Donald". This station is located roughly 15 km upstream of Kinbasket Reservoir.

Results

Figure 3.1a shows the daily flows for 1944-2016. 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 1944-2016 was 171 m^3/s.

The daily flows are shown in Figure 3.2 for years 2001-2016, which include the years with hydroacoustic surveys of kokanee abundance (2003-2015). Also shown for comparison in each panel is the daily mean flow for 1944-2016. 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 3.2.2b);
- in 2012, flow from June until mid-August was much higher than average (Figure 3.2.2d); and
- in 2016 the freshet was early but the flow during summer (July to August) was below average (Figure 3.2.2.h).

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 1971-2016 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 1976-2016.

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 approximately 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 was generally low, and most of the freshet inflow was stored in the reservoir. However, once the reservoir has almost filled, outflow was increased, thereby releasing the tail of the freshet and resulting in an increase in flow during the late summer. A second broad peak occurred during the winter as water was released for hydroelectric generation.

The discharge from Mica Dam for 2001-2016 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 2015 the flow is unusual, with significantly higher flows from April to mid-May, and mid-June to mid-September. In 2016, the spring flow returned to pattern of recent years with very low flow from April to early June. Note, in some years, outflow was also below average through late summer and early fall, e.g. 2008, 2009, 2010 and 2013. In contrast, 2012 had very high flow in July and August.

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 1986-2016, data were available from WSC station 08ND025, entitled “Revelstoke Project Outflow”.

Results

The daily discharge for 1955-2016 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 (Figure 5.1b). Post-impoundment outflow is distributed more evenly throughout the year with minor peaks in the summer and winter (Figure 5.1c).

The Revelstoke discharge for 2001-2016 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. Like the outflow from Kinbasket Reservoir, the outflow from Revelstoke was significantly higher from May to September 2015. In 2016, the outflow from Revelstoke was closer to average. In 2016, the non-power outflow (spill) from Revelstoke was zero except for brief periods in April and May.

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 of all of the tributaries are compared for each of the years 2008 to 2016 in Figures 6.5 to 6.13, respectively, along with those of the Columbia River at Donald and the Columbia River at Revelstoke. The hydrographs for the tributaries are very similar, and generally resemble the flow of the uncontrolled Columbia River at Donald. Note that above average flows in June and July 2012 occurred at all sites.

Table 6.1 Gauged tributaries flowing into the Columbia River

Station #	Station Name	Year	Drainage Area (km^2)	Annual Mean Flow (m^3/s)	Yield (m/yr)
08NB019	Beaver River near the Mouth	1985-2015	1150	42.1	1.16
08NB014	Gold River above Palmer Creek	1973-2015	427	18.2	1.35
08ND012	Goldstream River below Old Camp Creek	1954-2015	938	39.0	1.31
08ND013	Illecillewaet River at Greeley	1963-2015	1170	52.9	1.42

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. In 2014 and 2015, a freshet peaked in mid to late May (Figures 6.11 and 6.12). In 2016, the freshet was early, but the local inflow was below average from mid-June to mid-August.

7. Kinbasket Reservoir Water Level

Data

Daily water level data were available for 1974-2016 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 1980-2016 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 1974-2016. Note the rise in water level in the first two years following the completion of the dam in 1973. Figure 7.1b shows the mean daily post-impoundment water level for 1977-2016.

The water level in Kinbasket Reservoir for 2001-2016 is shown in Figure 7.2 and generally followed the post-impoundment mean level with a few exceptions: in 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 and 2014, 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. In 2015, water level was not drawn down as quickly or as far as in previous years, and as a result, the water level was above average for January to July. In 2016, the water level was also not drawn down as far and was slightly above average for May to July.

Figure 7.3 shows the annual minimum and maximum water level for Kinbasket Reservoir, 1977-2016. 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. 1992-1994) and at other times it is relatively high (e.g. during the study period 2008-2015).

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 and in 2015, the minimum water level occurred significantly later than average (red, Figure 7.3c). In 2015, the reservoir remained at very high water level, which had not been seen since early 1983 (red, Figure 7.3b). In 2016, the reservoir came to an early minimum.

8. Revelstoke Water Level

Data

Daily water level data were available for 1984-2016 from the BC Hydro station located in the Revelstoke forebay.

Results

Figure 8.1a shows the water level of Revelstoke Reservoir for 1984-2016. 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 1988-2016. The water level varies by only a few meters, as the reservoir is operated run of the river.

The water level for years 2001-2016 is shown in Figure 8.2, together with the mean post-impoundment level averaged from 1988-2016. The water levels generally followed the post-impoundment mean levels. From 2012 to early 2014 there were a number of brief drawdowns below normal minimum, for example in January and November 2013 (Figure 8.2.2f). Water levels below normal minimum were not observed through the rest of 2014 or in 2015. In 2016 there was one brief drawdown just below the minimum water level in early May.

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 1976-2016. 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 2001-2016 is shown without smoothing in Figure 9.2. The flow in recent years, 2008 to 2014, generally followed the mean, although flow in 2012 was above average from June to July. In 2015, flow to storage was below average both in early spring (April to May) and late summer (July to August). The flow to storage was reduced because the water level had not drawn down as far as usual in spring 2015.

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 Inflow

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, and as a result it is subject to considerable error, and can be very noisy. Large spikes in the data are often followed by a large correcting dip. While negative local inflow is not physical (water flowing up a river), the negative values shown are typically balanced by the positive spikes.

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 1989-2016. 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 2001-2016. The data were lightly filtered with three passes of a 3 point moving average, and 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 10.3.2a), and in July 2012 the local flow to Revelstoke Reservoir declined before the others (Figure 10.3.2e).

The local flow to Revelstoke Reservoir is compared to the main inflow to Revelstoke Reservoir 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 2016

The El-Nino/Southern Oscillation ENSO index (Wolter, 2012) and the size of winter snow packs (BCRFC, 2016) 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 - Mar 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 High inflow event during late September
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 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

2014 El Nino (Apr - Aug 2014)
Upper Columbia Region Snow Basin Index (April 1st), 123%
Flow average

2015 Strong El Nino (Mar - Dec 2015)
Upper Columbia Region Snow Basin Index (April 1st), 86%
Flow below average (after early and high freshet mid-May to mid-June)
High inflow event during late September
High outflow from Kinbasket Reservoir, April to September

2016 Strong El Nino (Mar 2015 - May 2016)
Upper Columbia Region Snow Basin Index (April 1st), 99%
Flow average (mid-Apr to mid-May slightly above average; mid-Jun to end Jul, slightly below average)
Mica outflow average

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

The summer, including those of 2008 to 2014 and 2016 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 4.2.2). In 2010, this low outflow period extended to the end of July (Figure 4.2.2c). 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.

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; Figure 10.4.2). Note that 2015 was an exception, as outflow from Mica Dam remained very high in mid-April to mid-May when it was low in previous years, and high from mid-June onward (Figure 4.2.2h).

Acknowledgements

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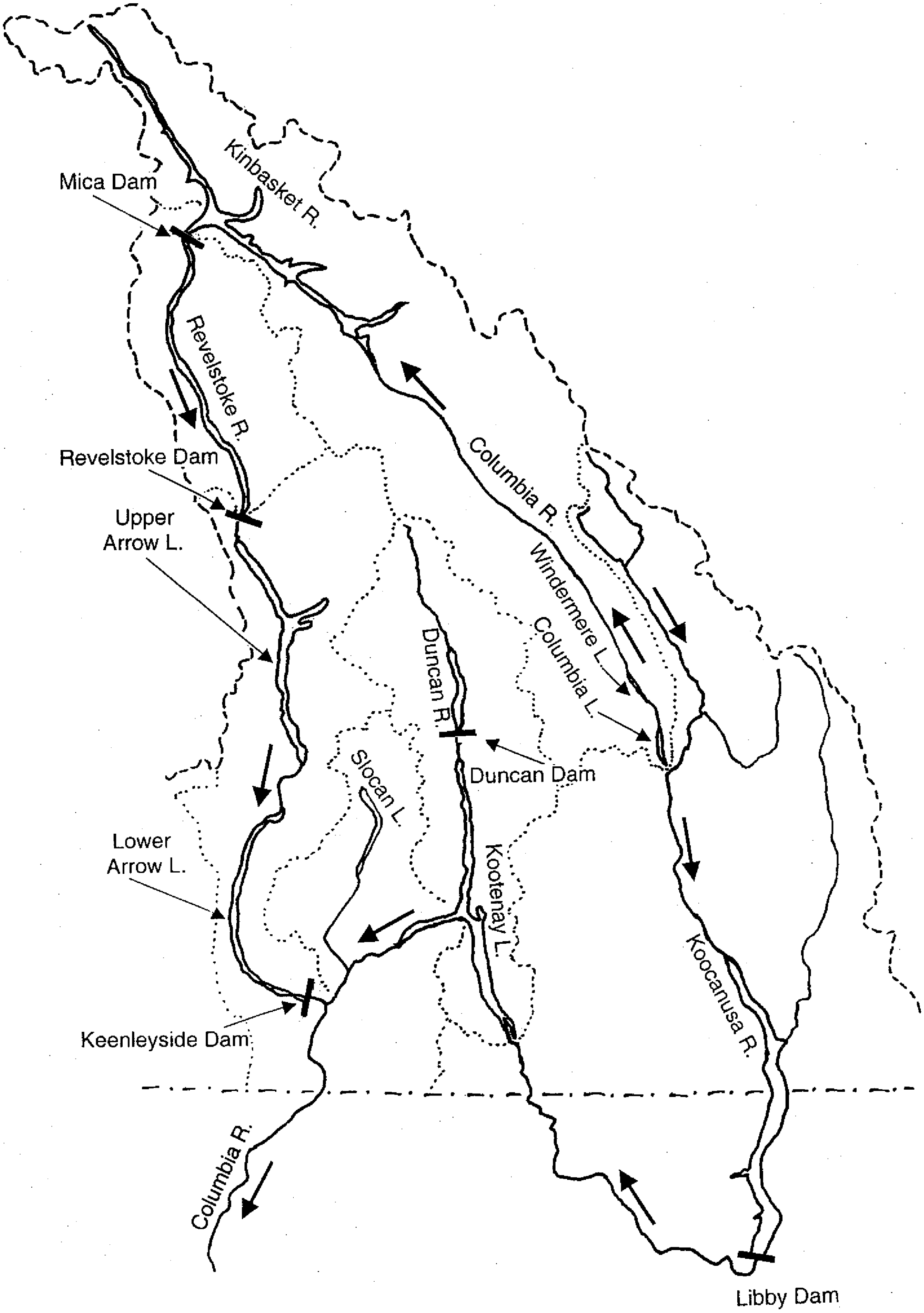


Figure 1.1. Upper Columbia River Basin

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

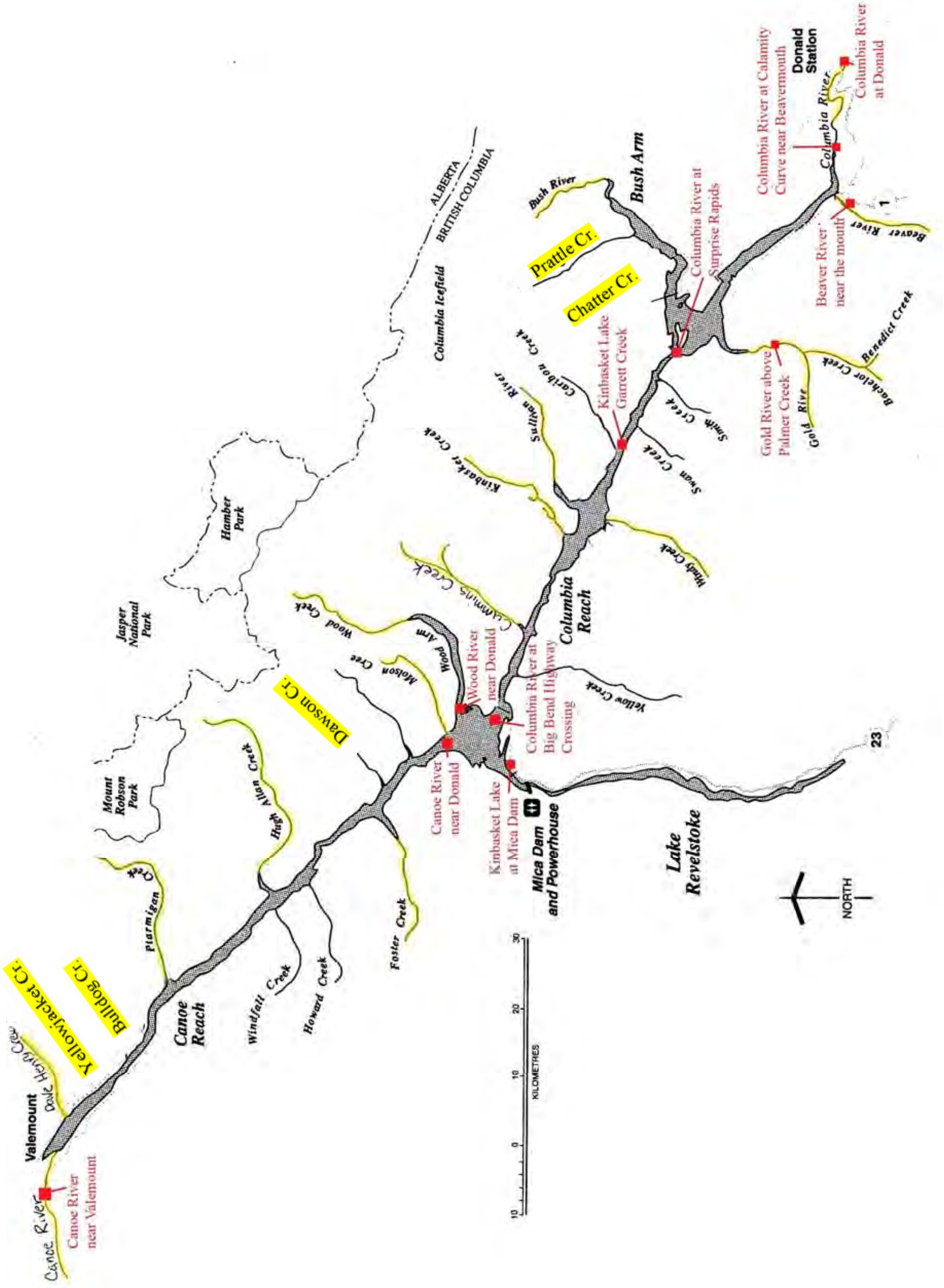
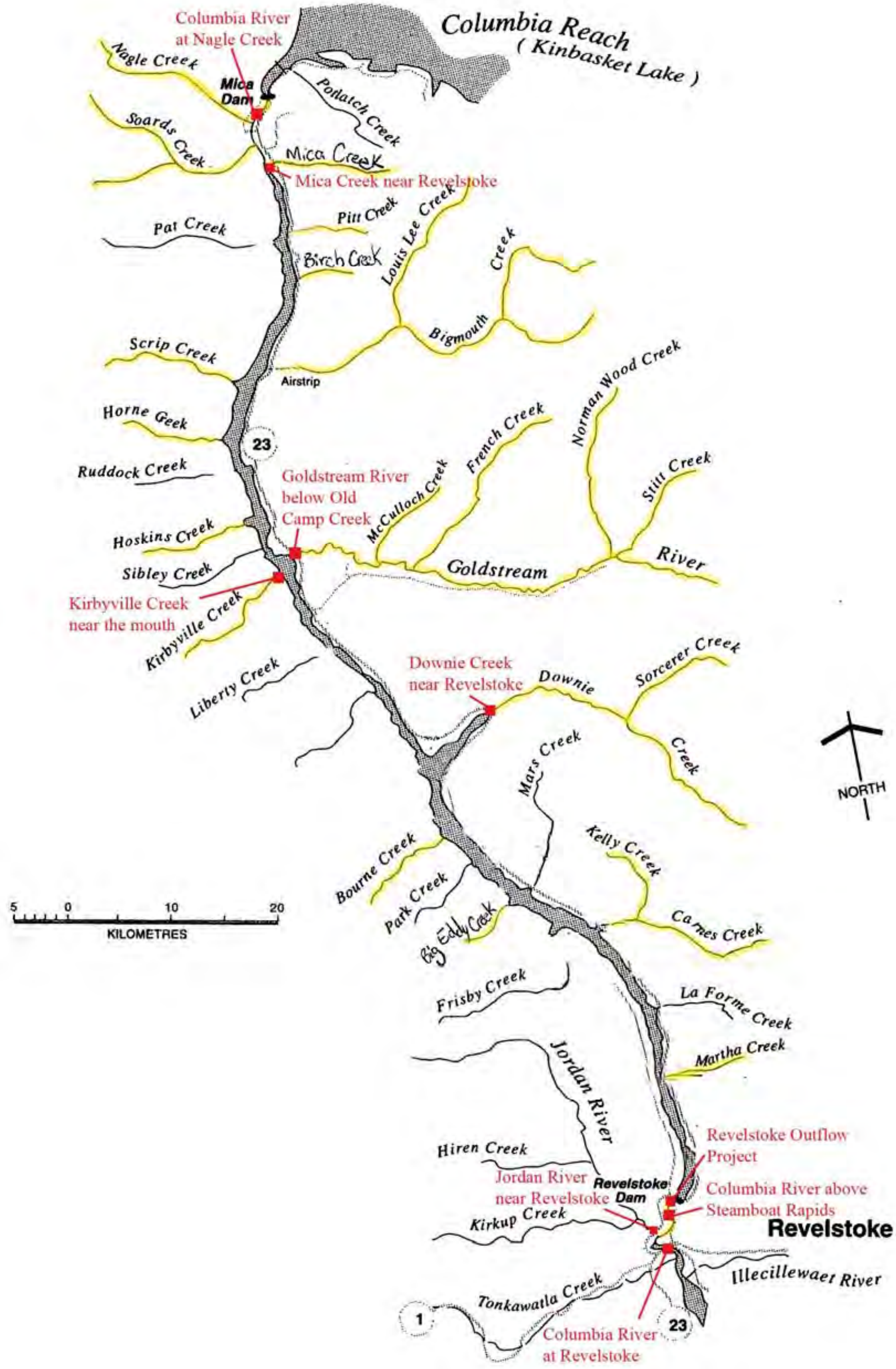


Figure 1.3 Revelstoke Reservoir with gauging stations (RED) and sampled tributaries (YELLOW).



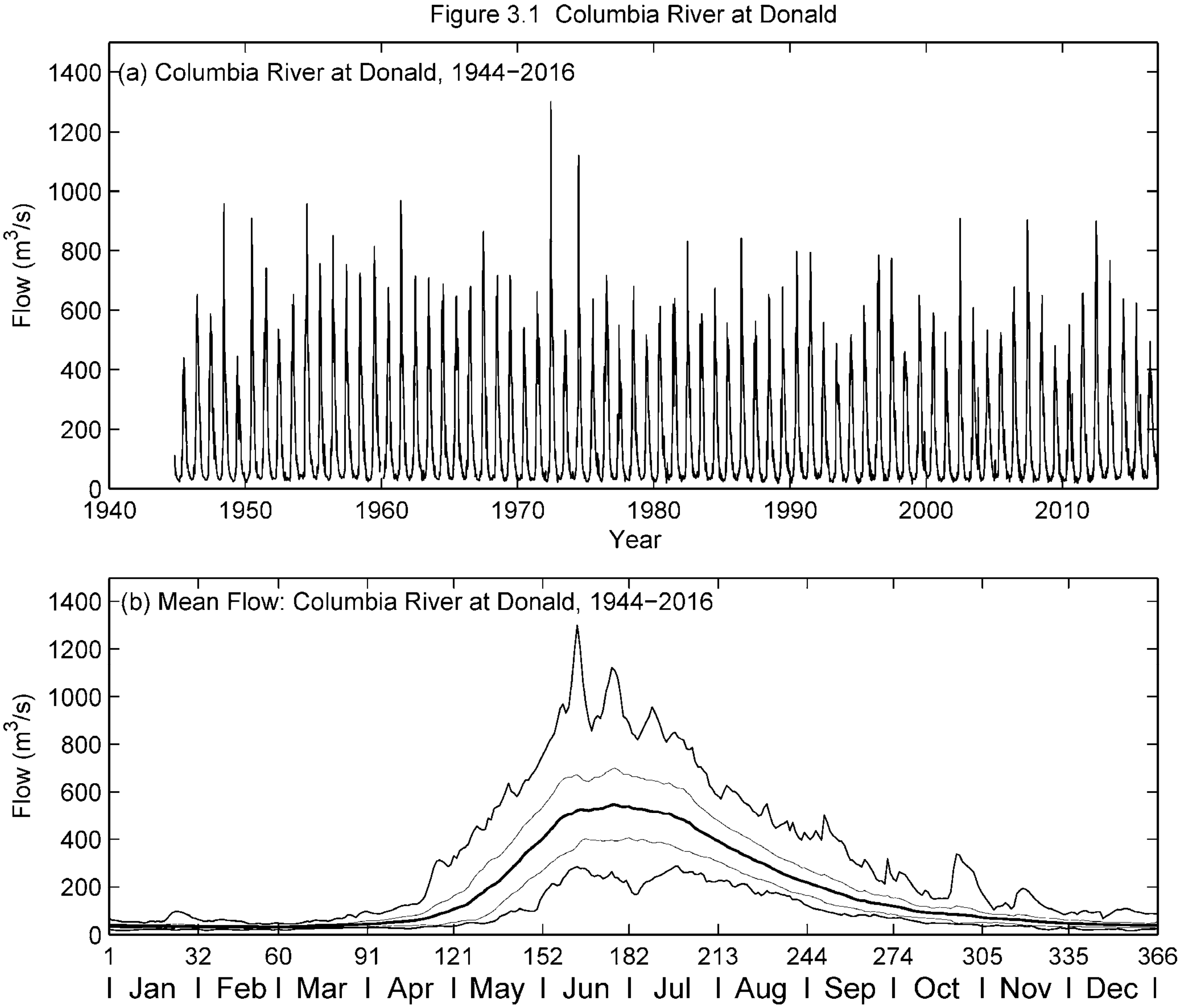


Figure 3.1. **(a)** WSC station 08NB005, "Columbia River at Donald", 1944-2016. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

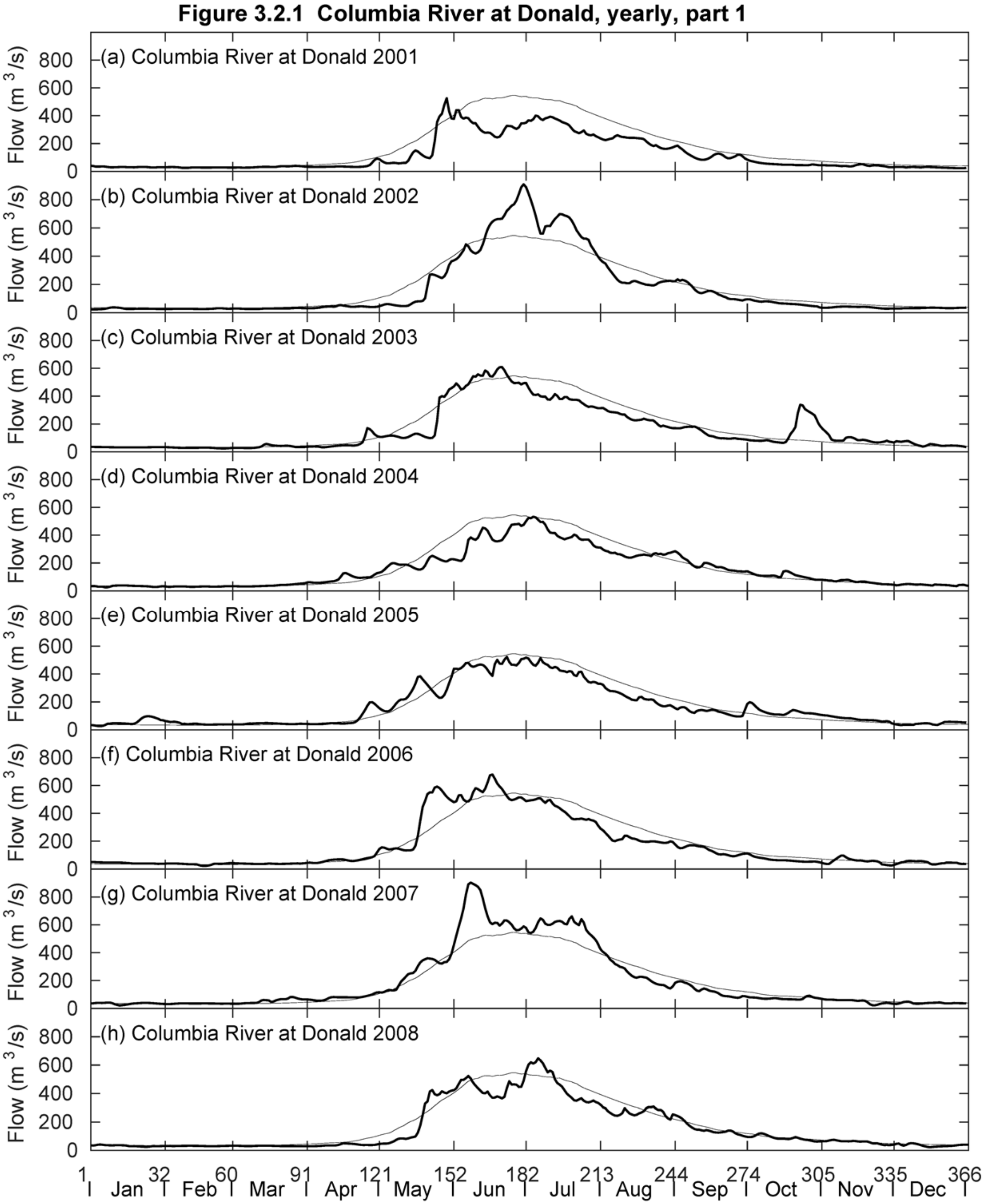


Figure 3.2.1. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2016 (light line) is shown for comparison.

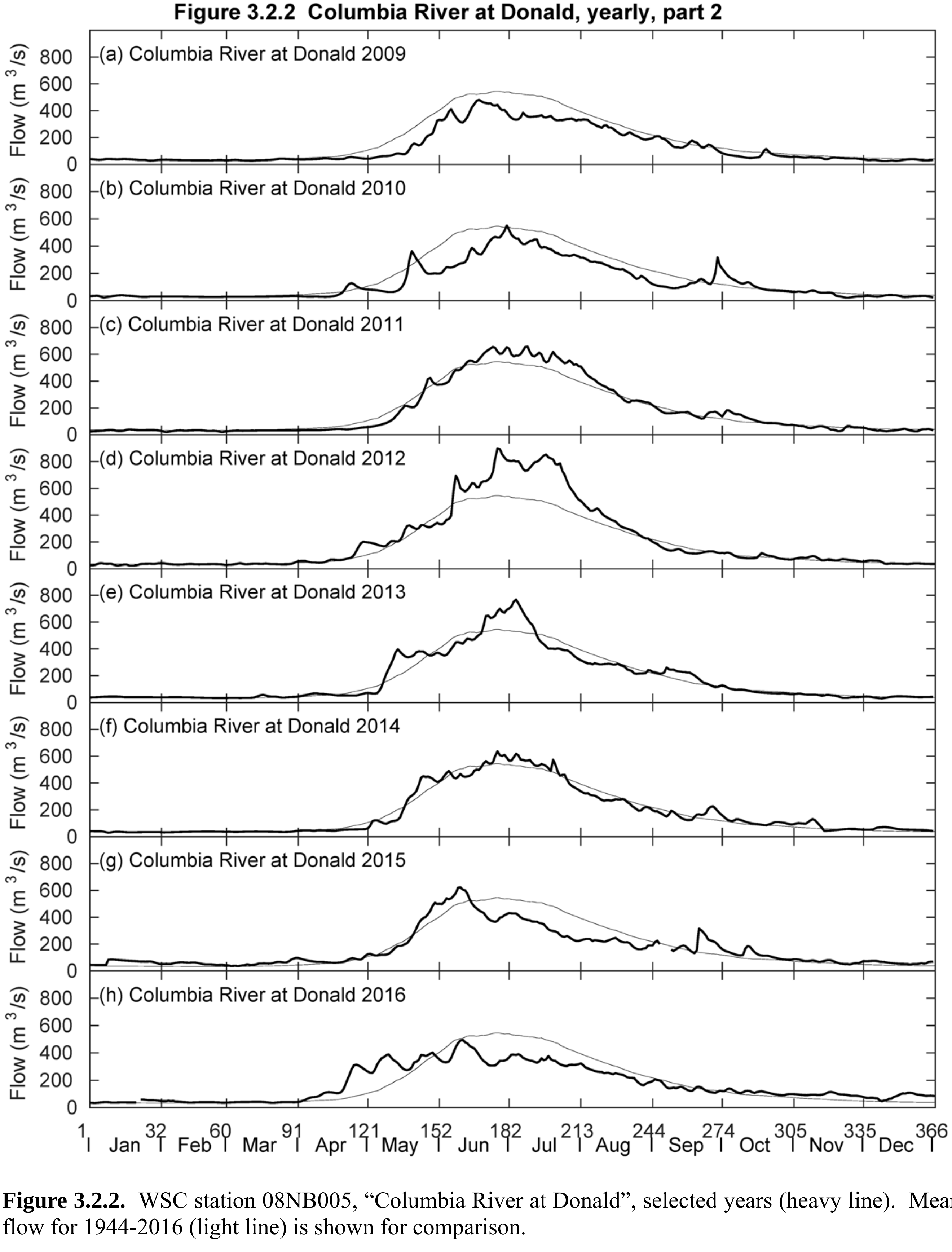


Figure 3.2.2. WSC station 08NB005, "Columbia River at Donald", selected years (heavy line). Mean flow for 1944-2016 (light line) is shown for comparison.

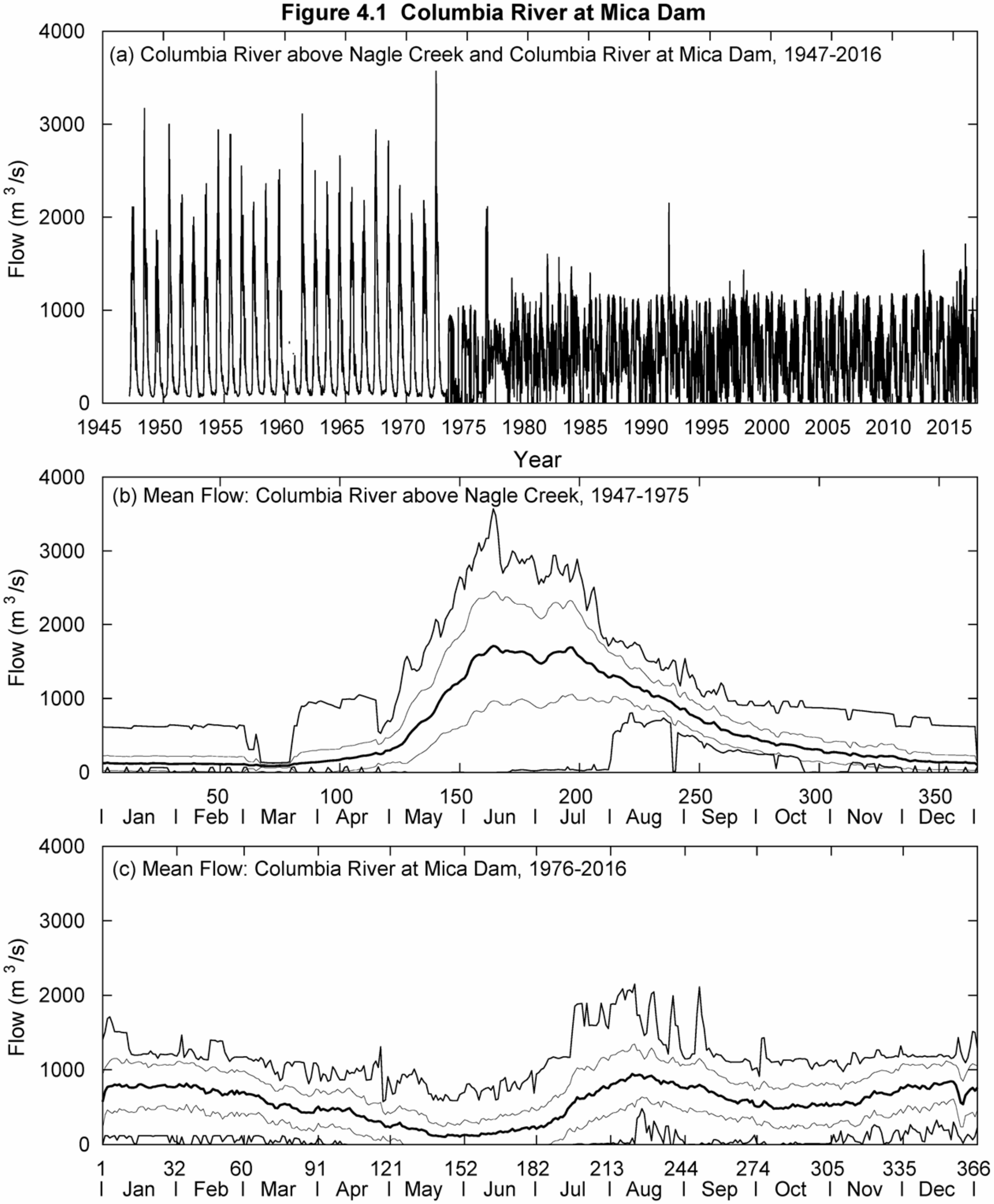


Figure 4.1. **(a)** WSC station 08ND007, "Columbia River above Nagle Creek", 1947-1975 and BC Hydro station "Columbia River at Mica Dam Outflow", 1976-2016. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

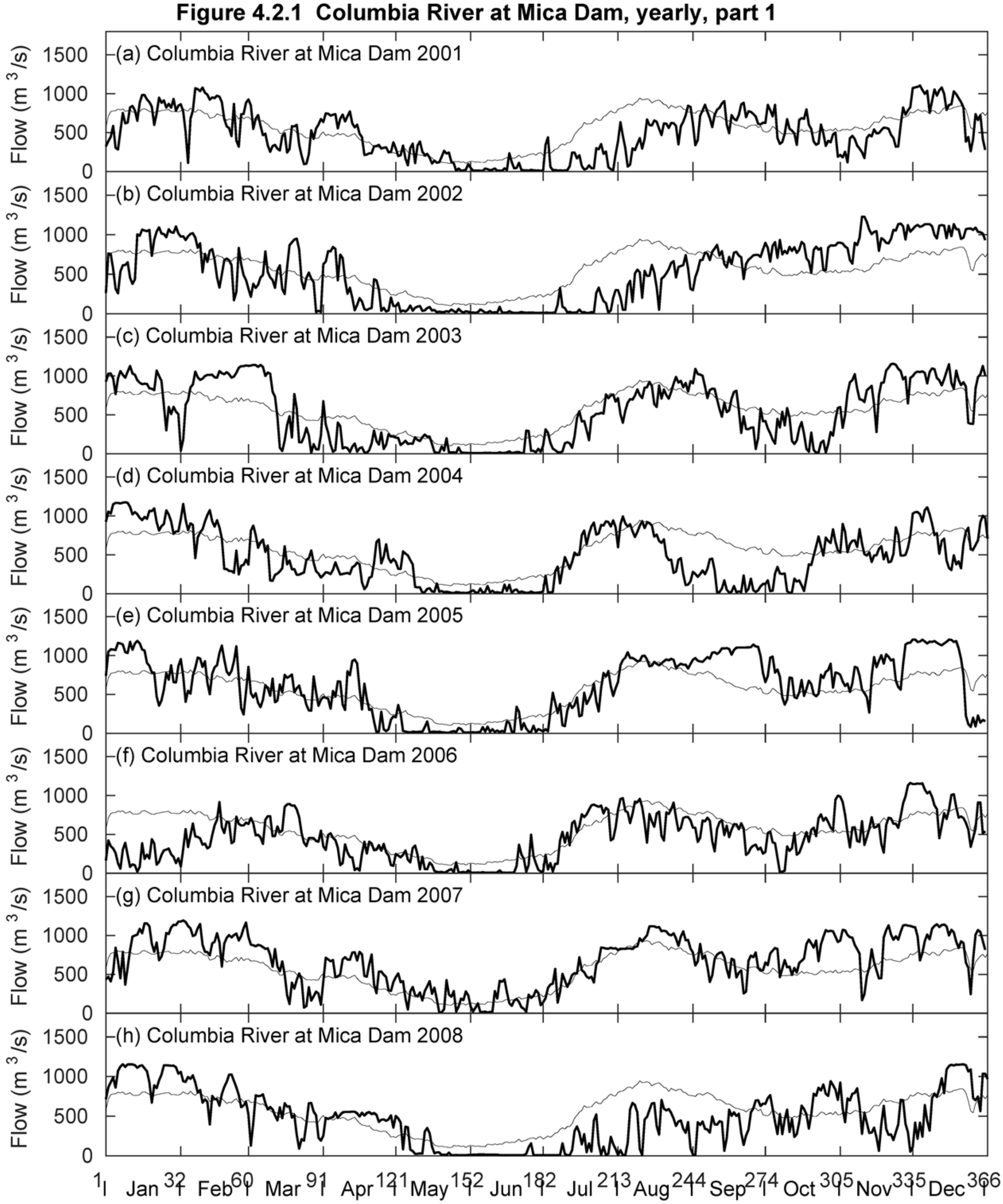


Figure 4.2.1. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2016 (light line) is shown for comparison.

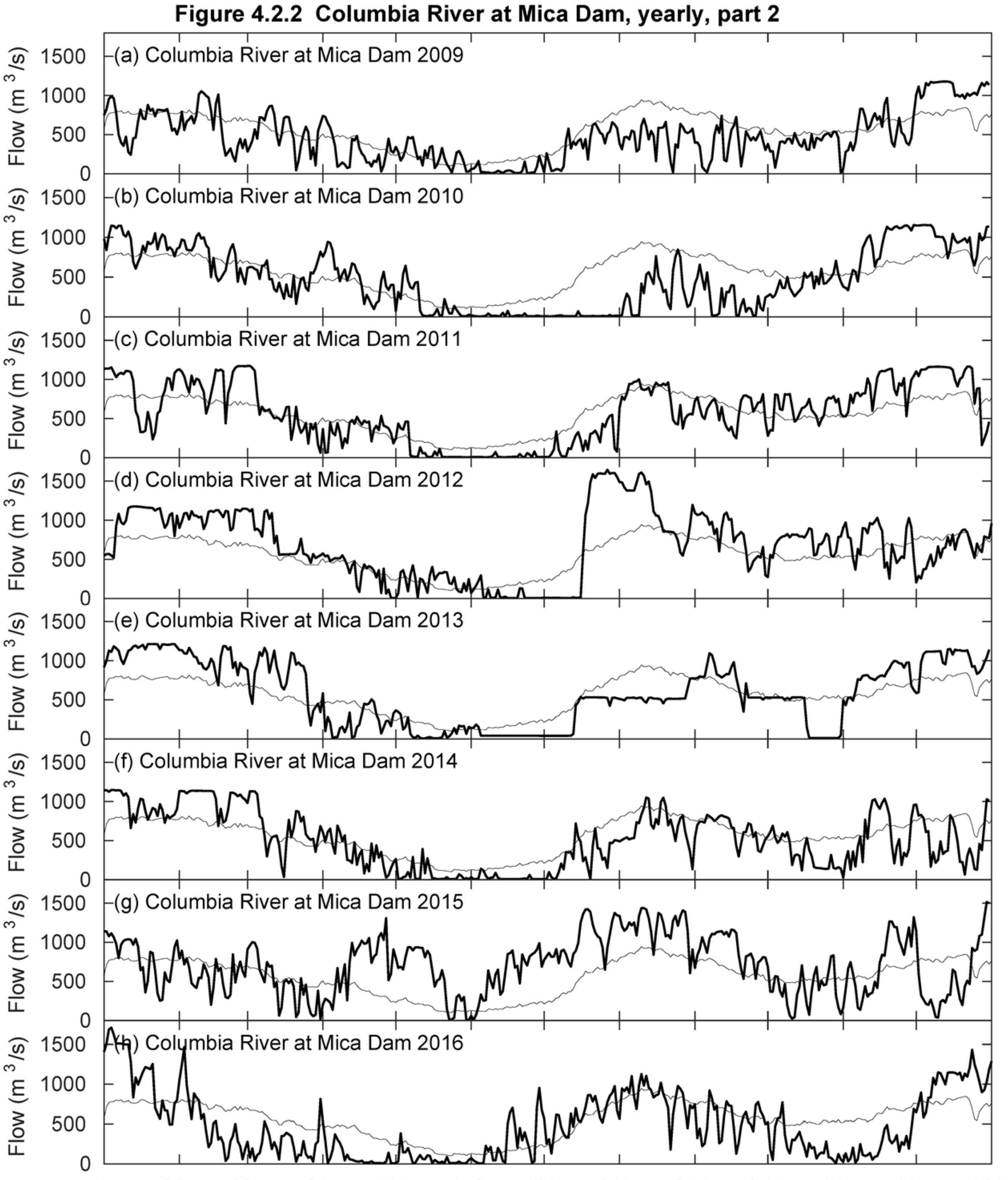


Figure 4.2.2. BC Hydro station "Columbia River at Mica Dam Outflow", selected years (heavy line). Mean flow for 1976-2016 (light line) is shown for comparison.

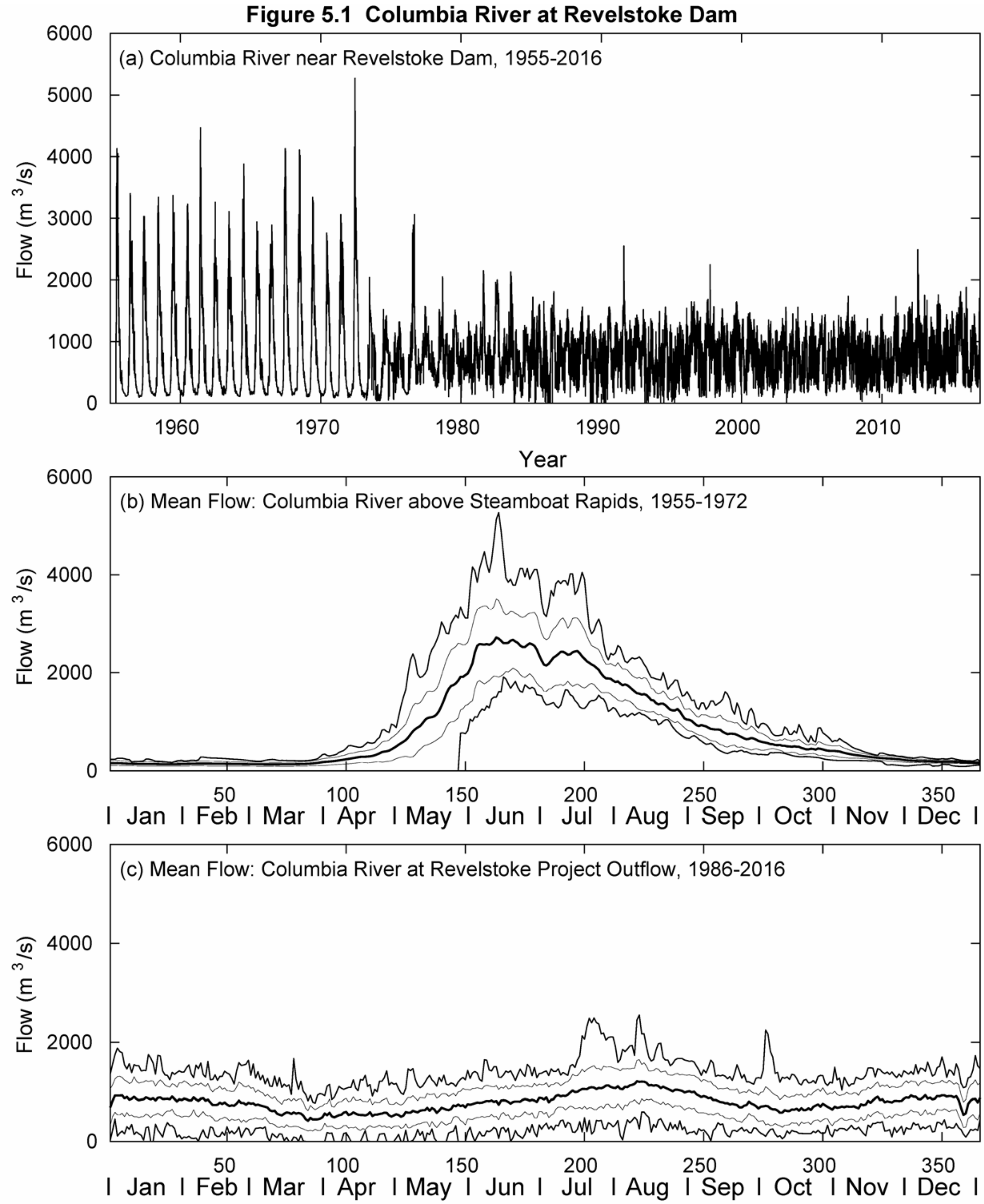


Figure 5.1. **(a)** WSC station 08ND011, “Columbia River above Steamboat Rapids”, 1955-1985 and WSC station 08ND025, “Revelstoke Project Outflow”, 1986-2016. **(b)** Mean pre-impoundment flow for the years indicated. **(c)** Mean post-impoundment flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

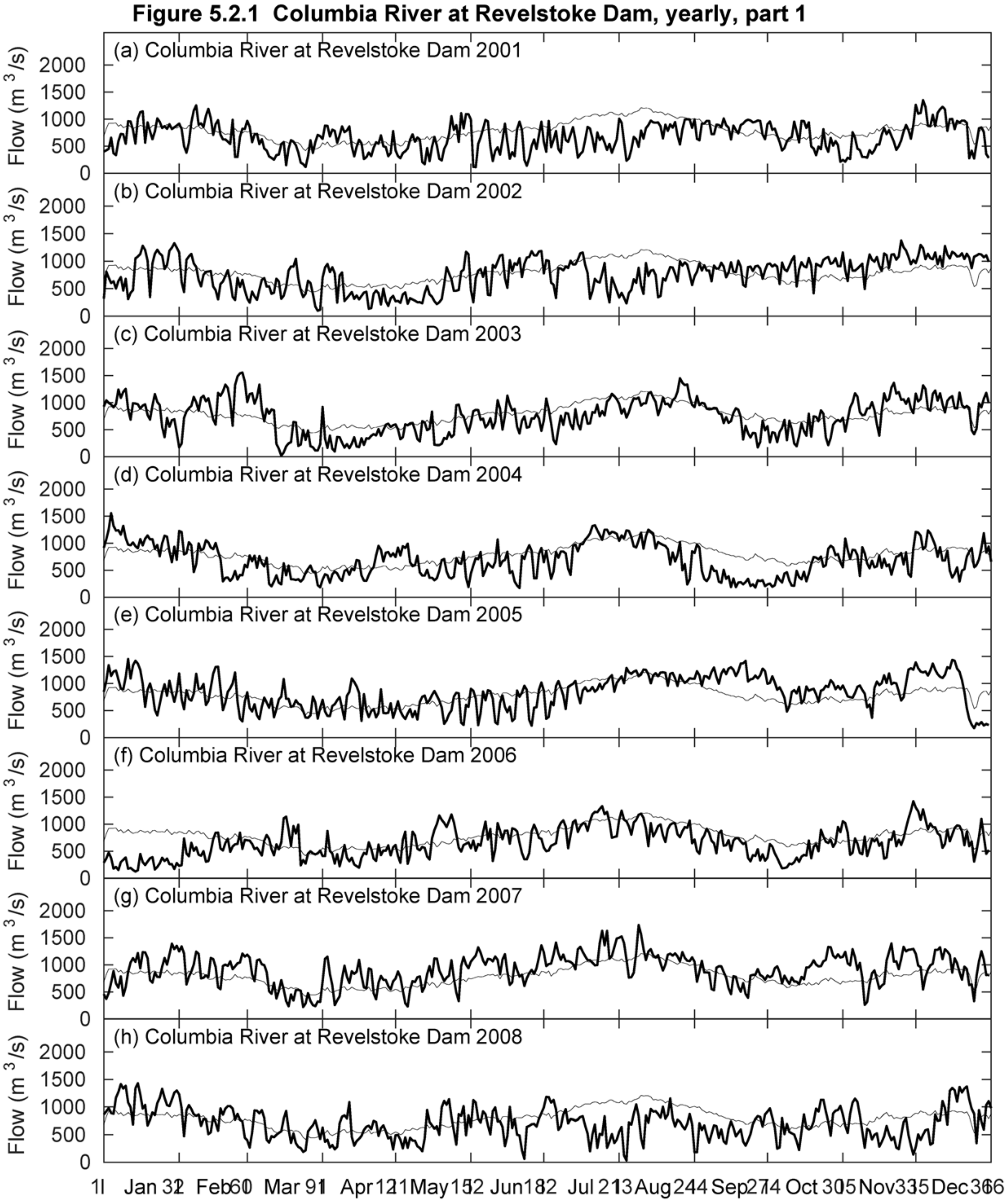


Figure 5.2.1. WSC station 08ND025, "Revelstoke Project Outflow", selected years (heavy line). Mean flow for 1986-2016 (light line) is shown for comparison.

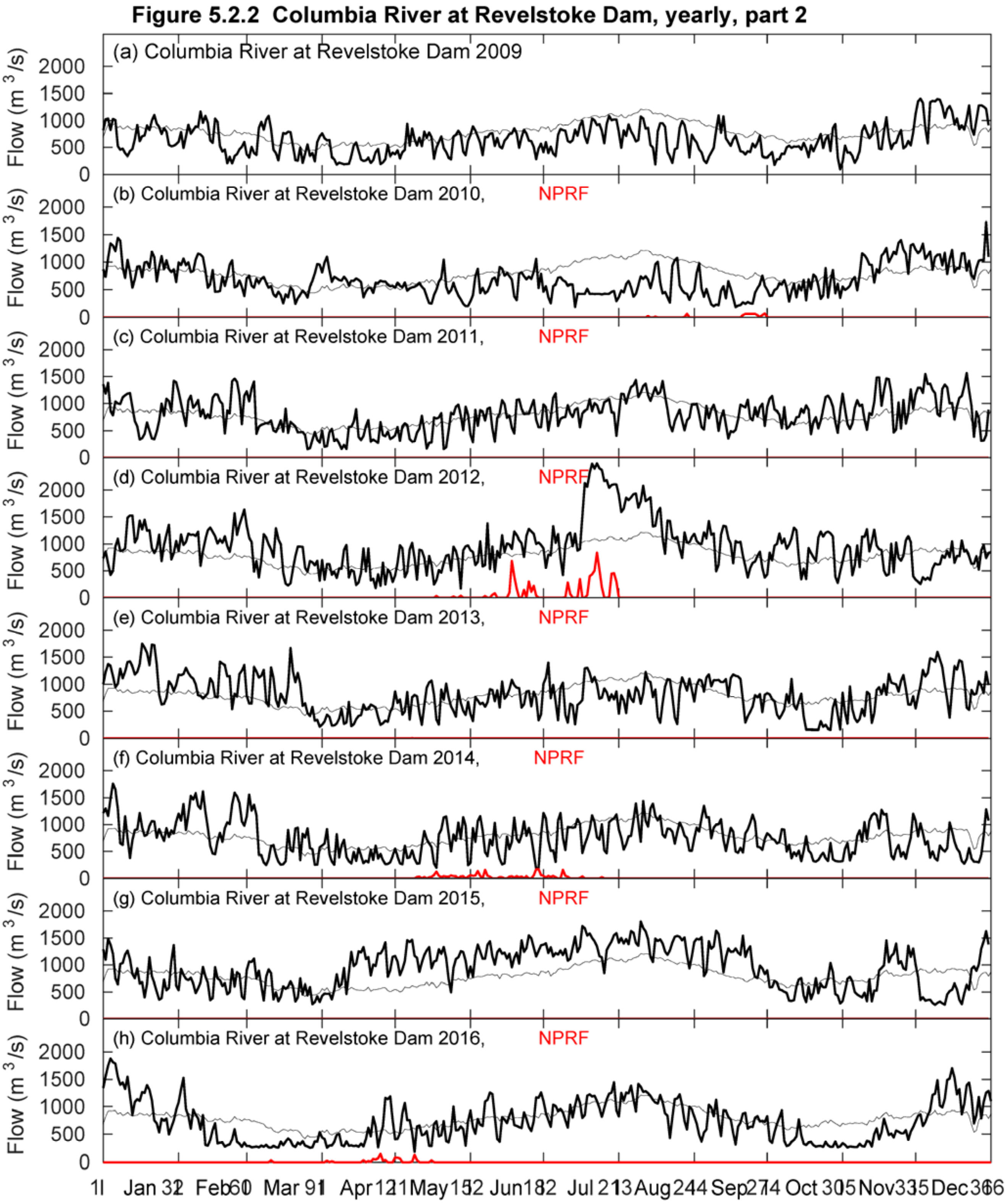


Figure 5.2.2. WSC station 08ND025, "Revelstoke Project Outflow", selected years (heavy line). Mean flow for 1986-2016 (light line) is shown for comparison. NPRF (RED) marks non-power flow (spill).

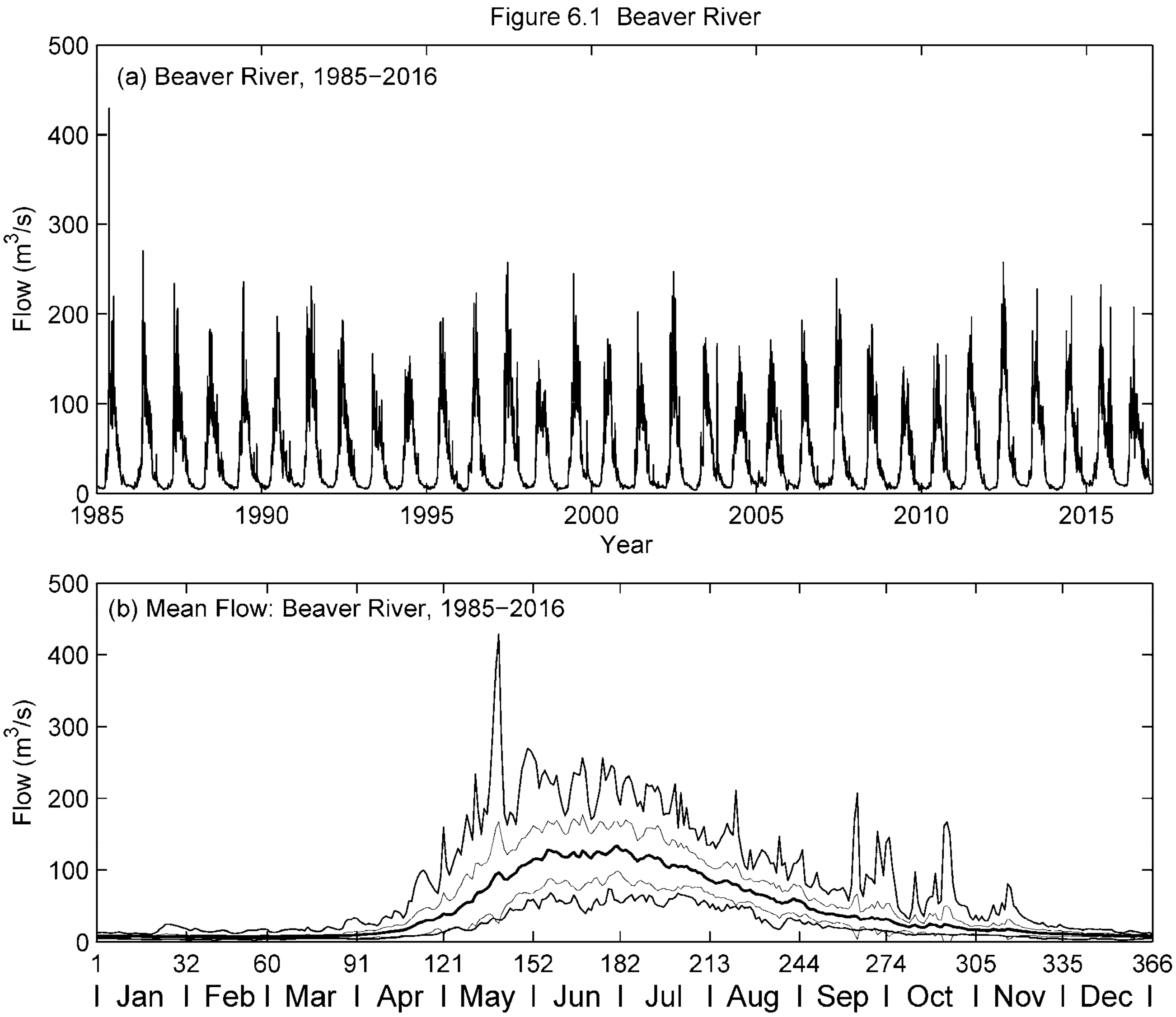


Figure 6.1. **(a)** WSC station 08NB019, "'Beaver River near the Mouth", 1985-2016. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

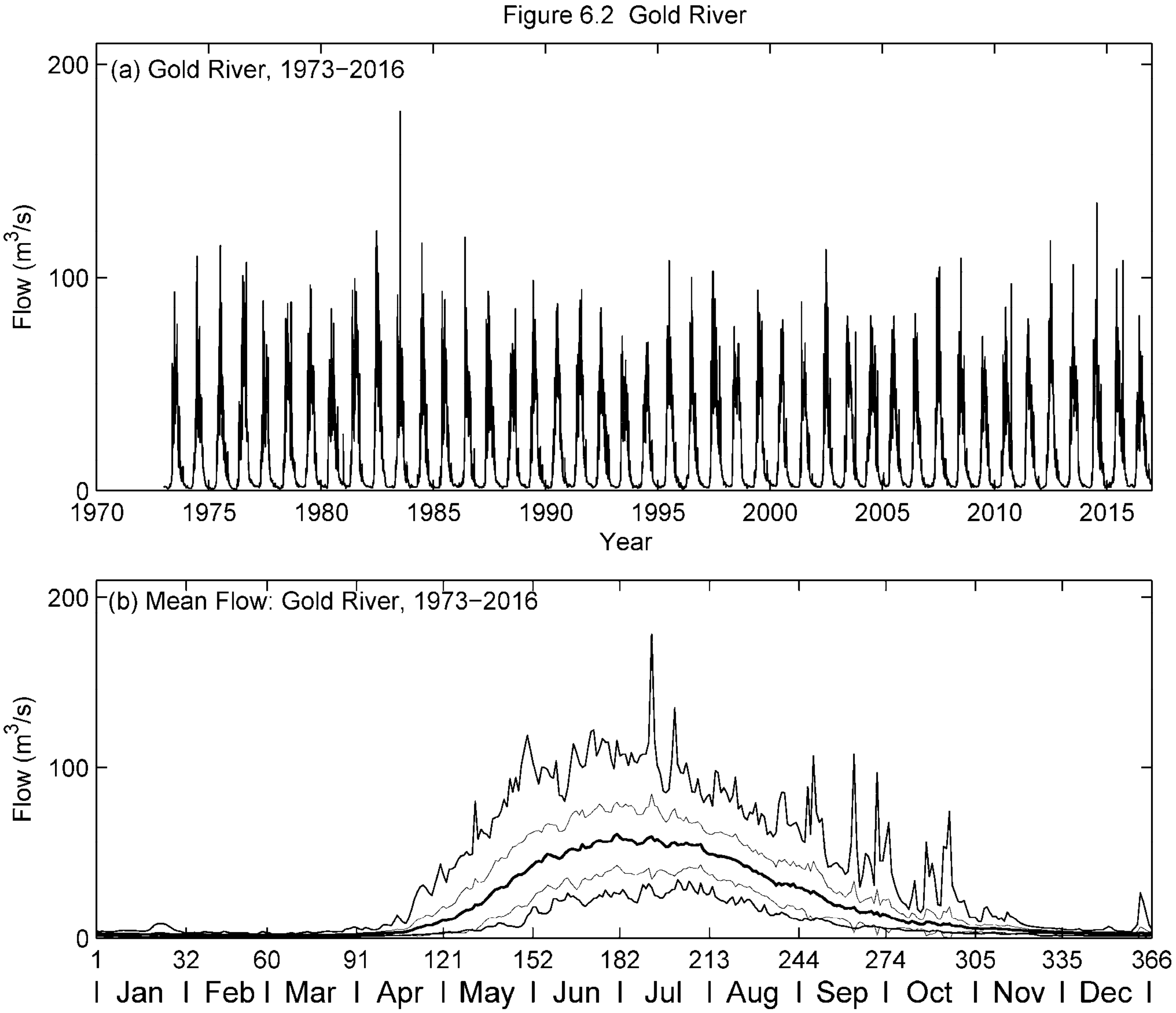


Figure 6.2. **(a)** WSC station 08NB014, "Gold River above Palmer Creek", 1973-2016. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

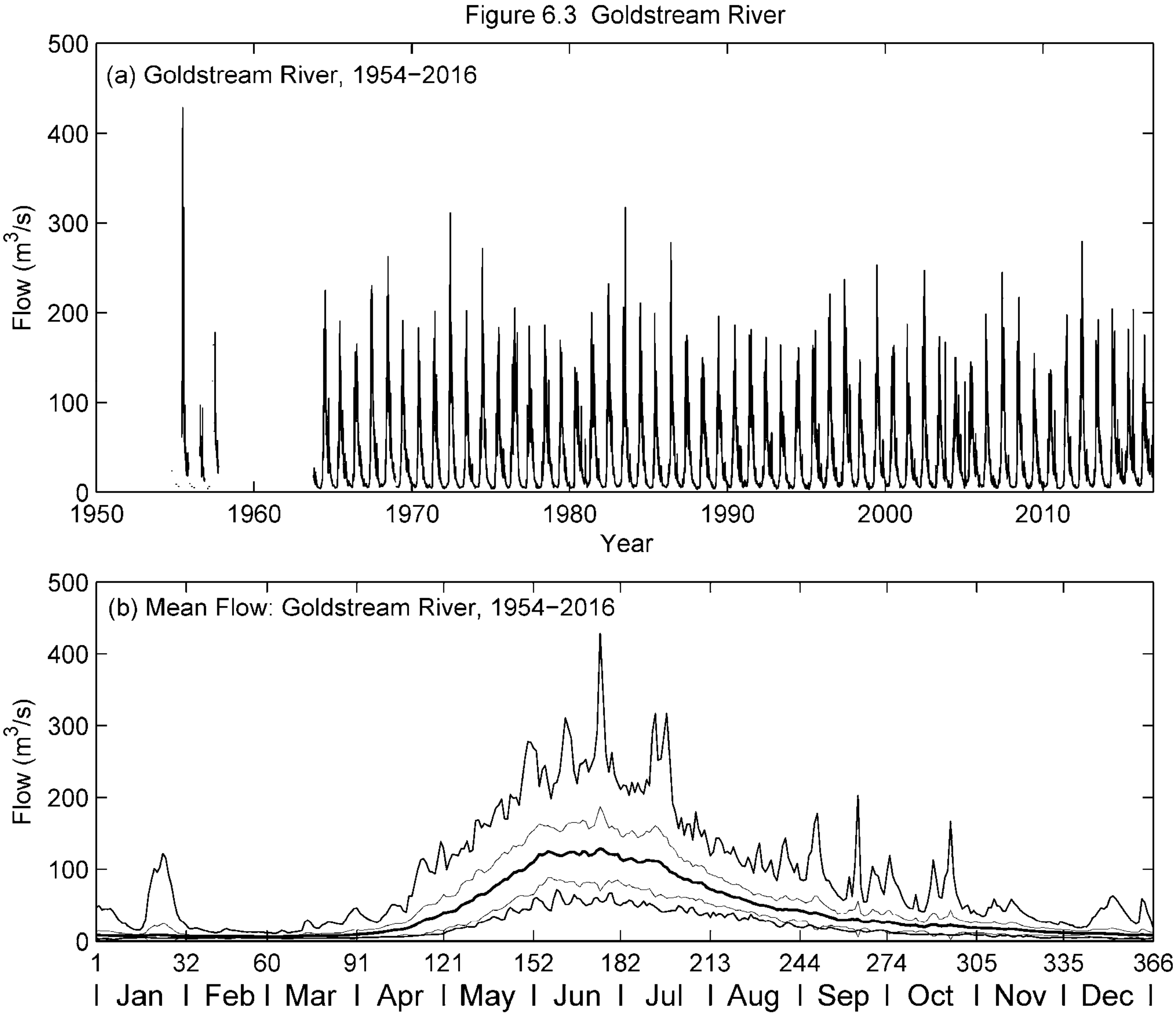


Figure 6.3. **(a)** WSC station 08ND012, "Goldstream River below Old Camp Creek", 1954-2016. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

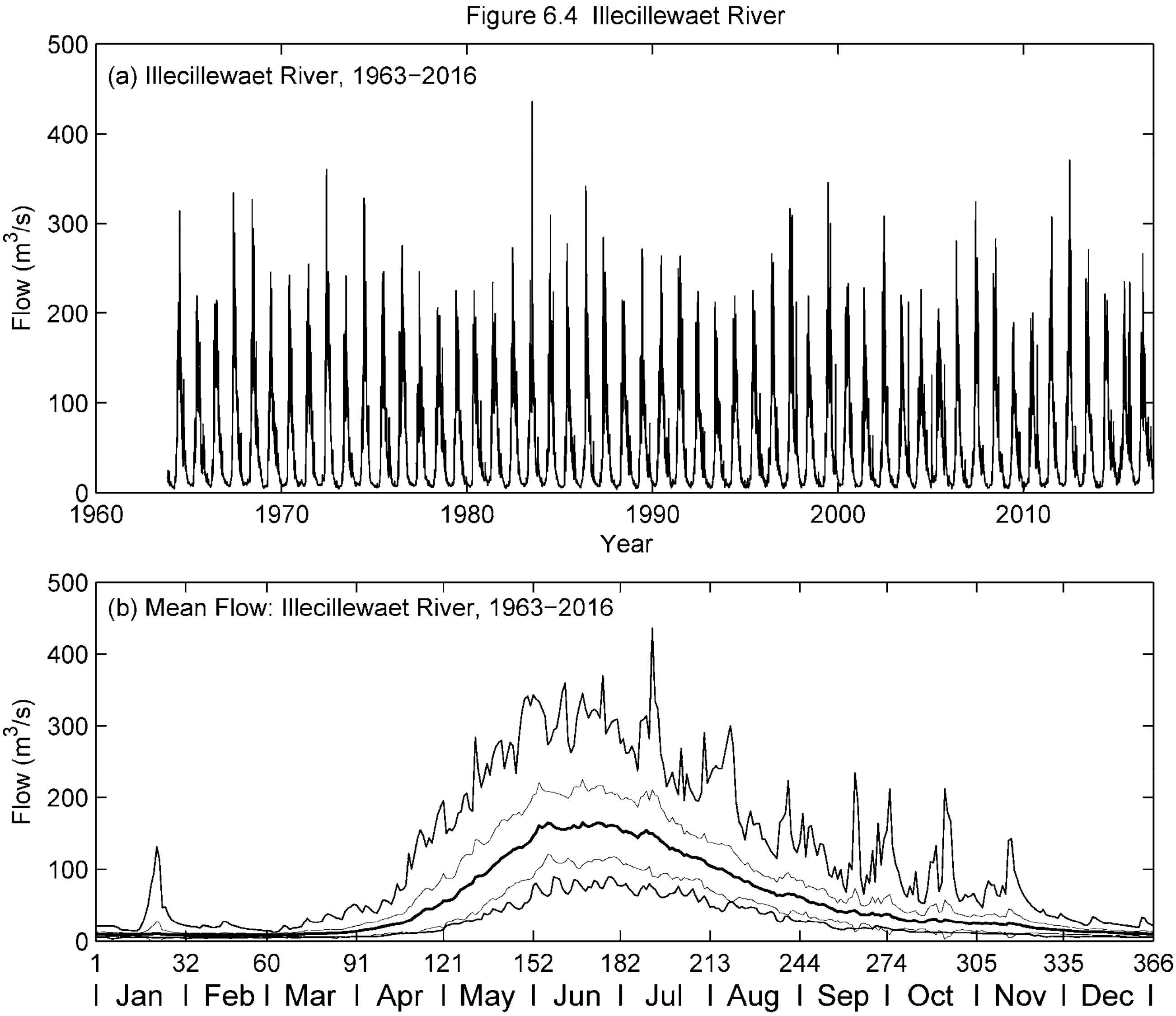


Figure 6.4. **(a)** WSC station 08ND013, "Illecillewaet River at Greeley", 1963-2016. **(b)** Mean flow for the years indicated. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

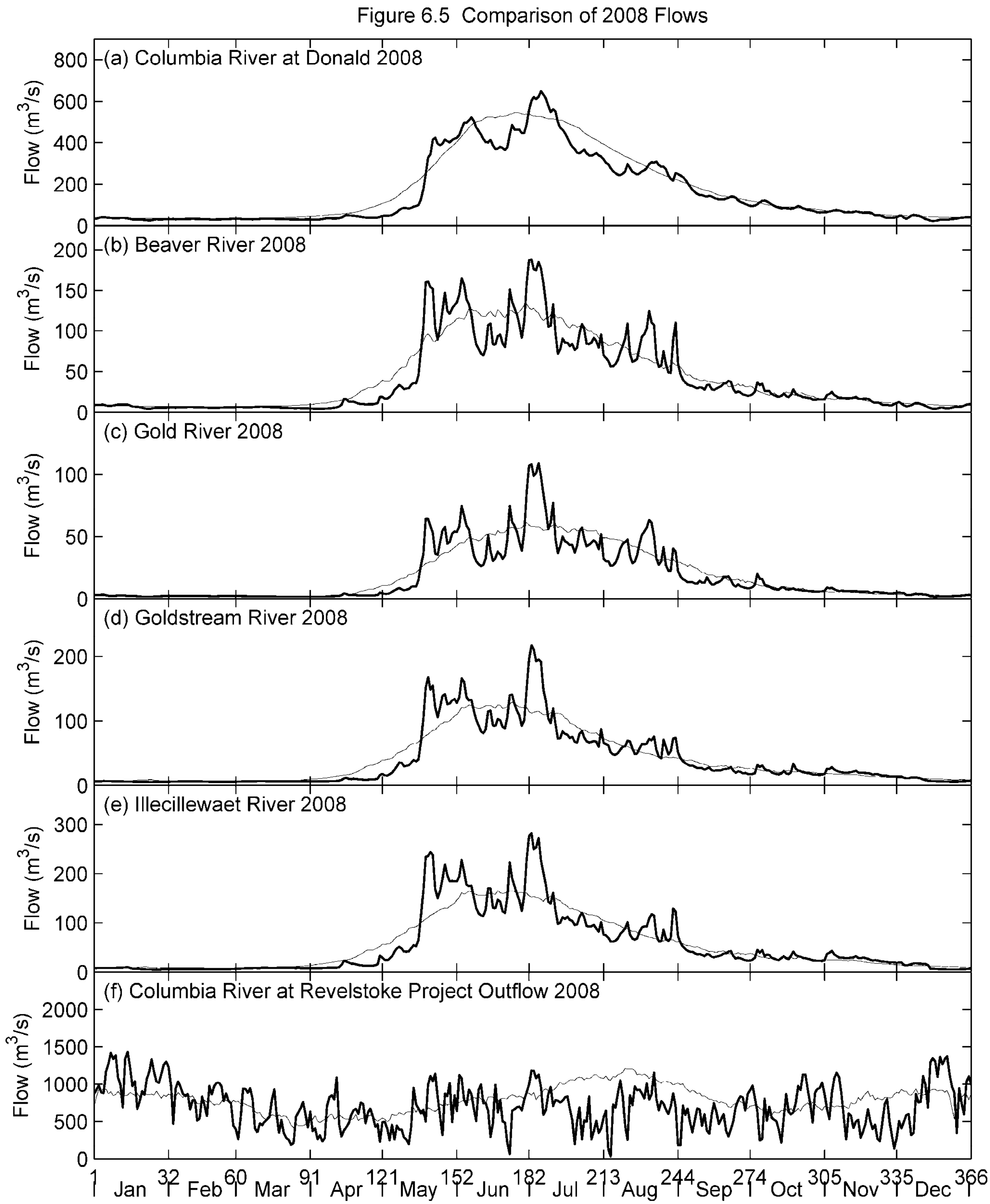


Figure 6.5. Comparison of flows in 2008 for the stations indicated (heavy line). Mean flows for a**)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

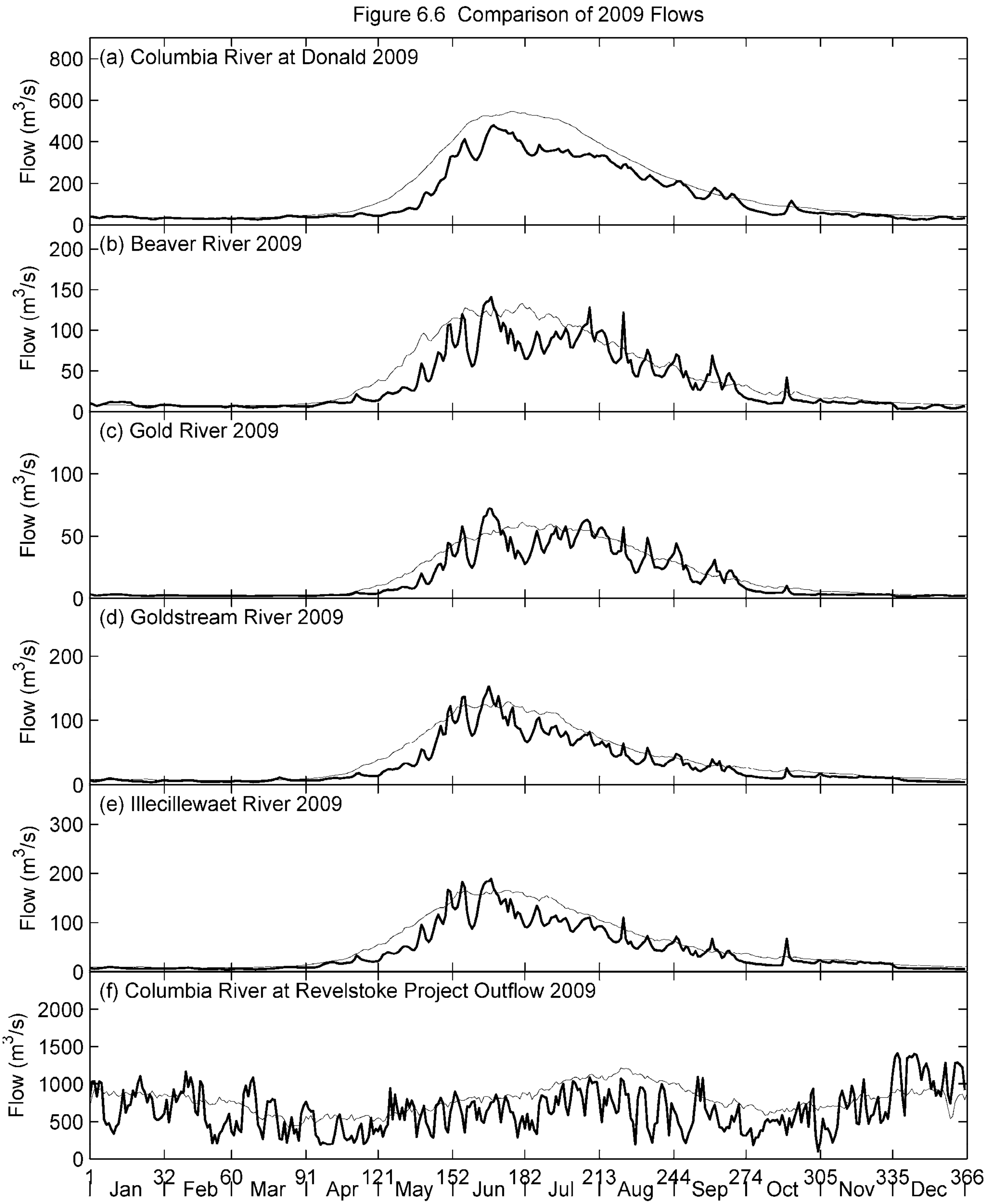


Figure 6.6. Comparison of flows in 2009 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

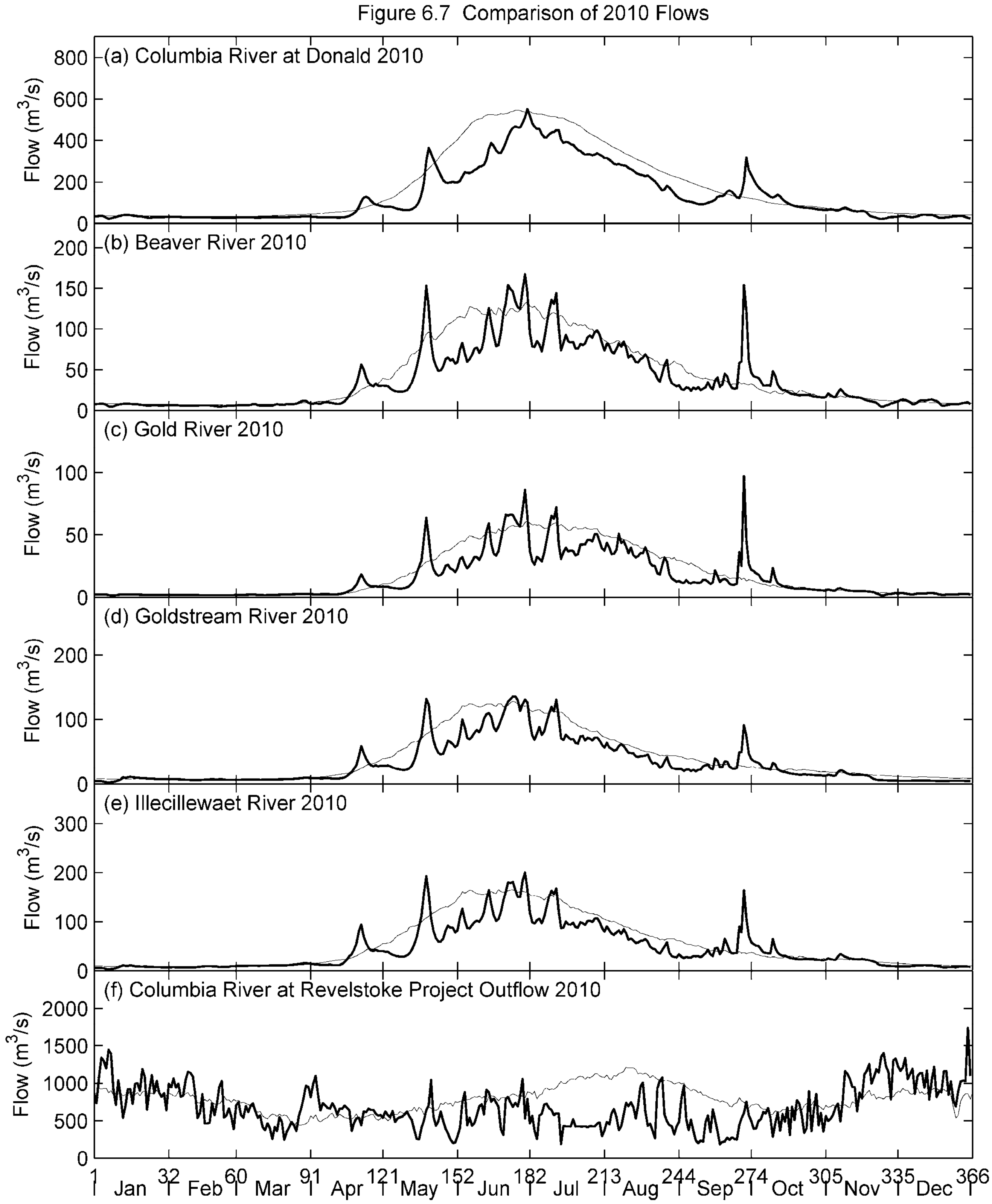


Figure 6.7. Comparison of flows in 2010 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

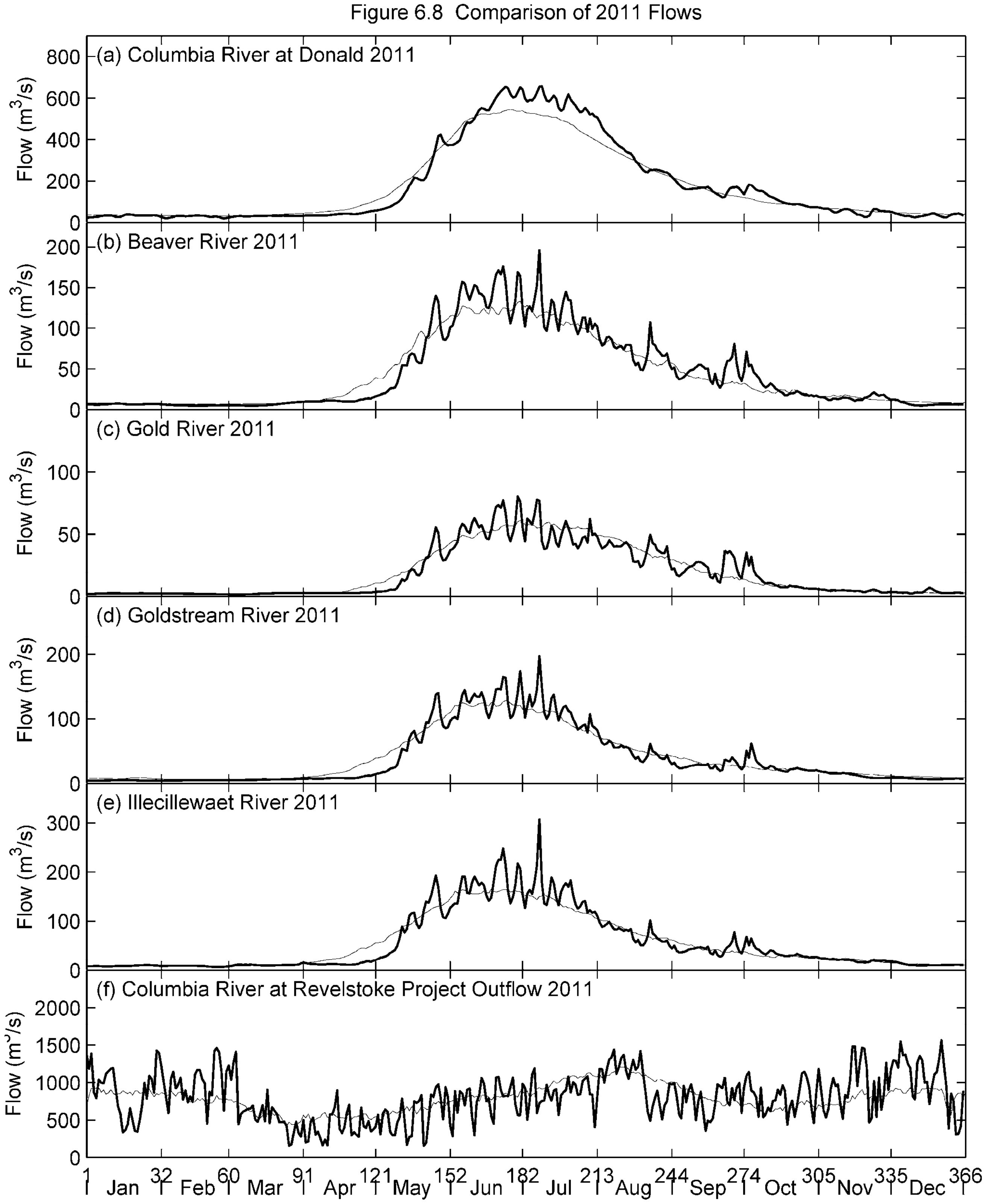


Figure 6.8. Comparison of flows in 2011 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

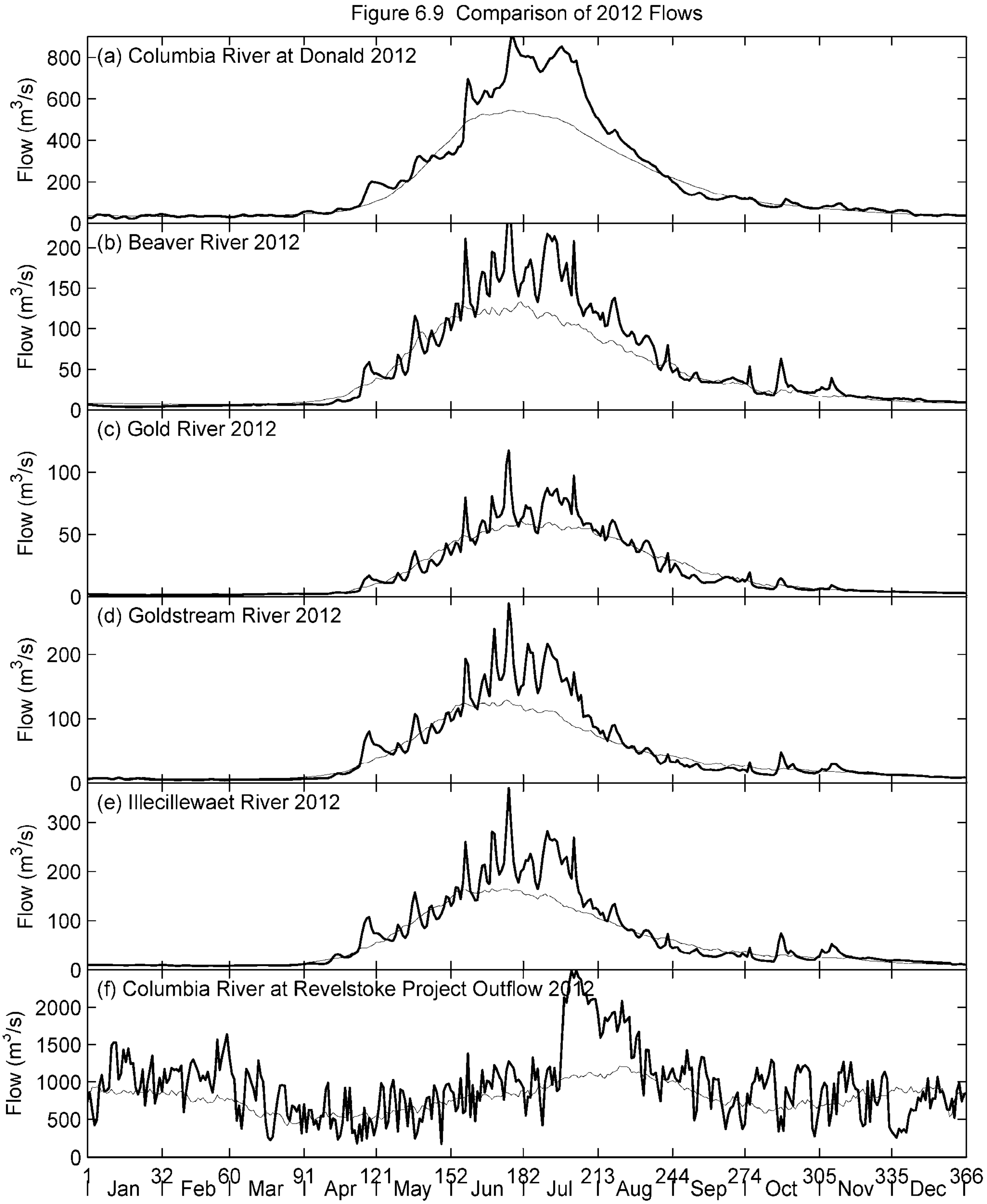


Figure 6.9. Comparison of flows in 2012 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

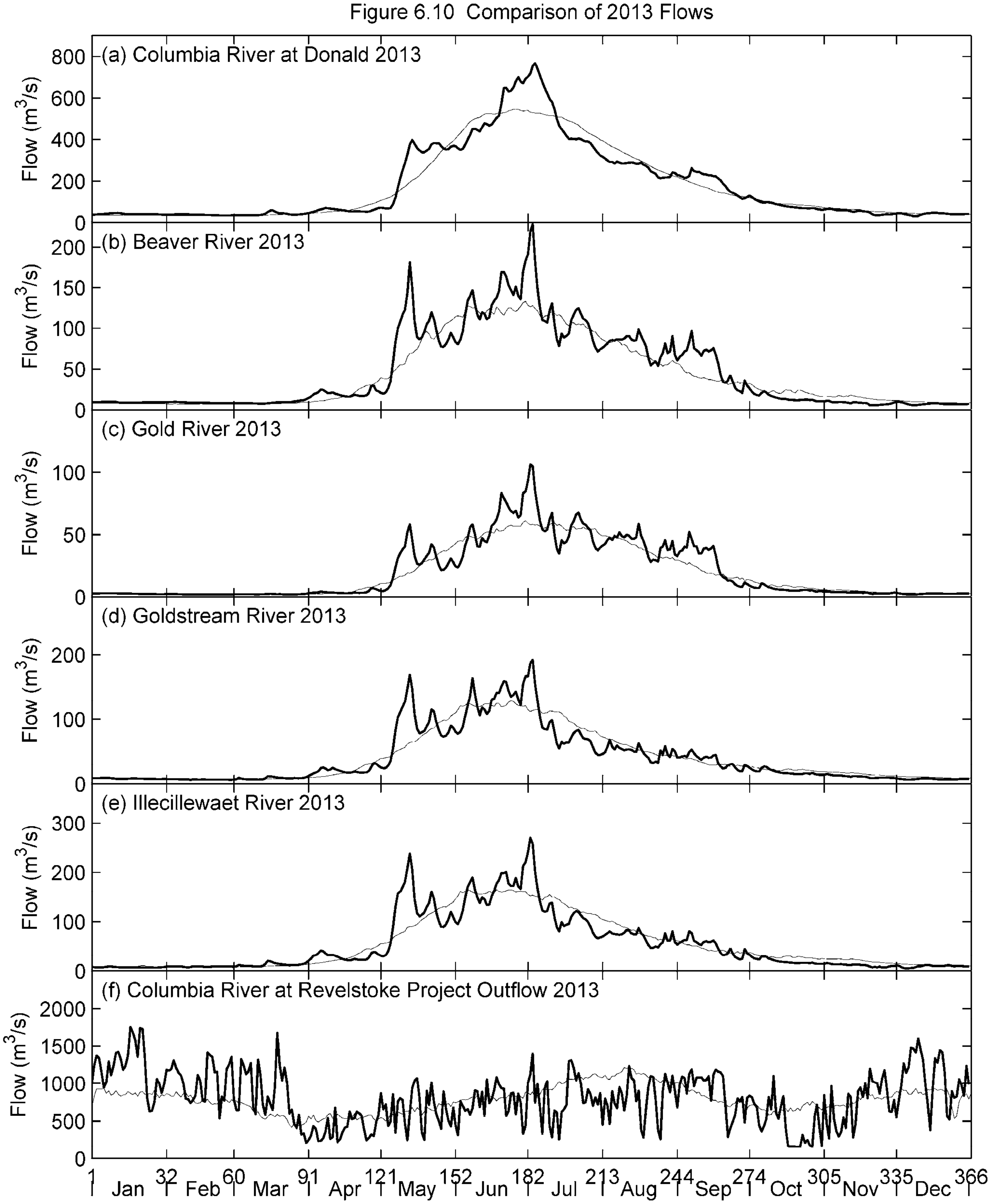


Figure 6.10. Comparison of flows in 3 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

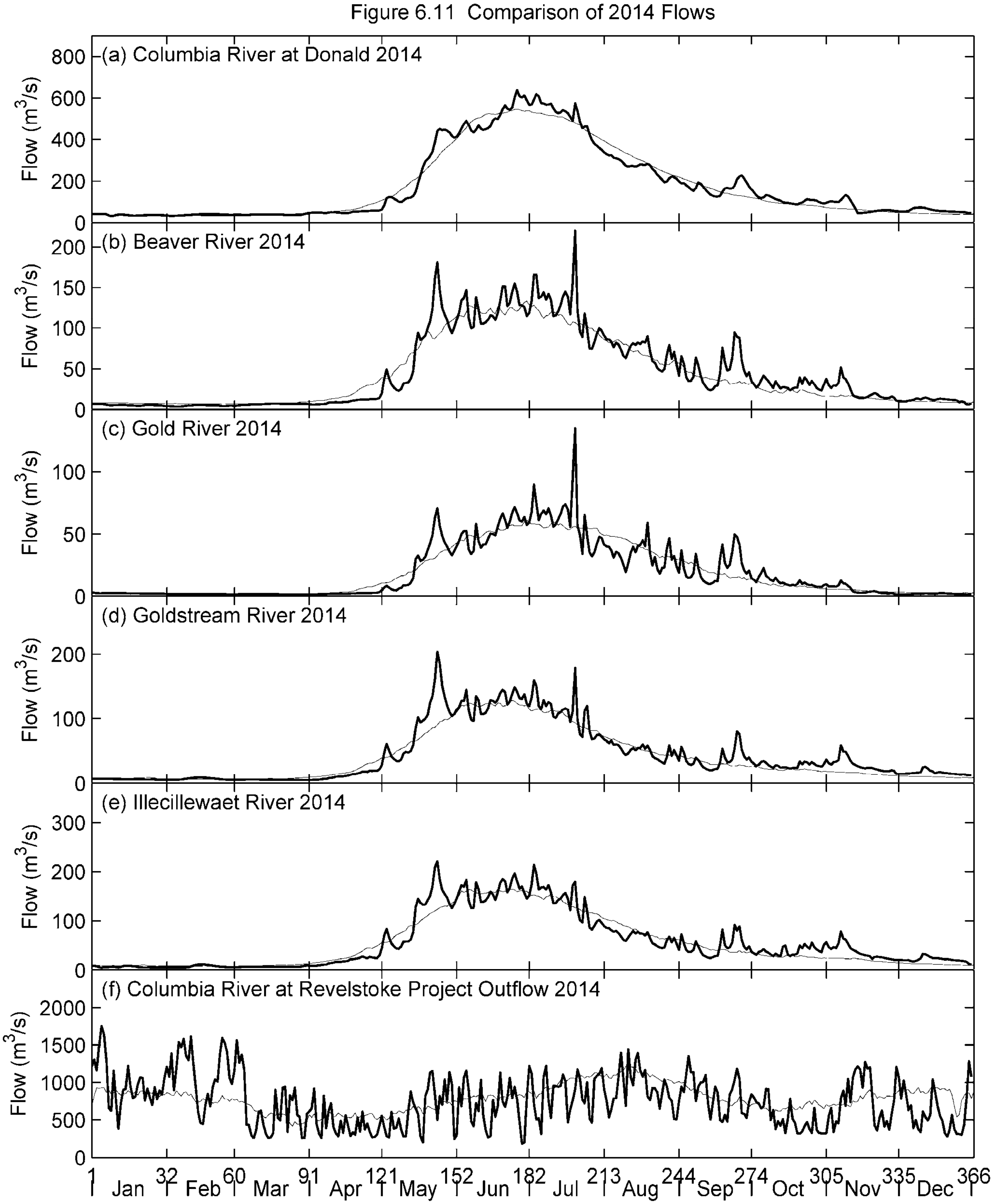


Figure 6.11. Comparison of flows in 2014 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

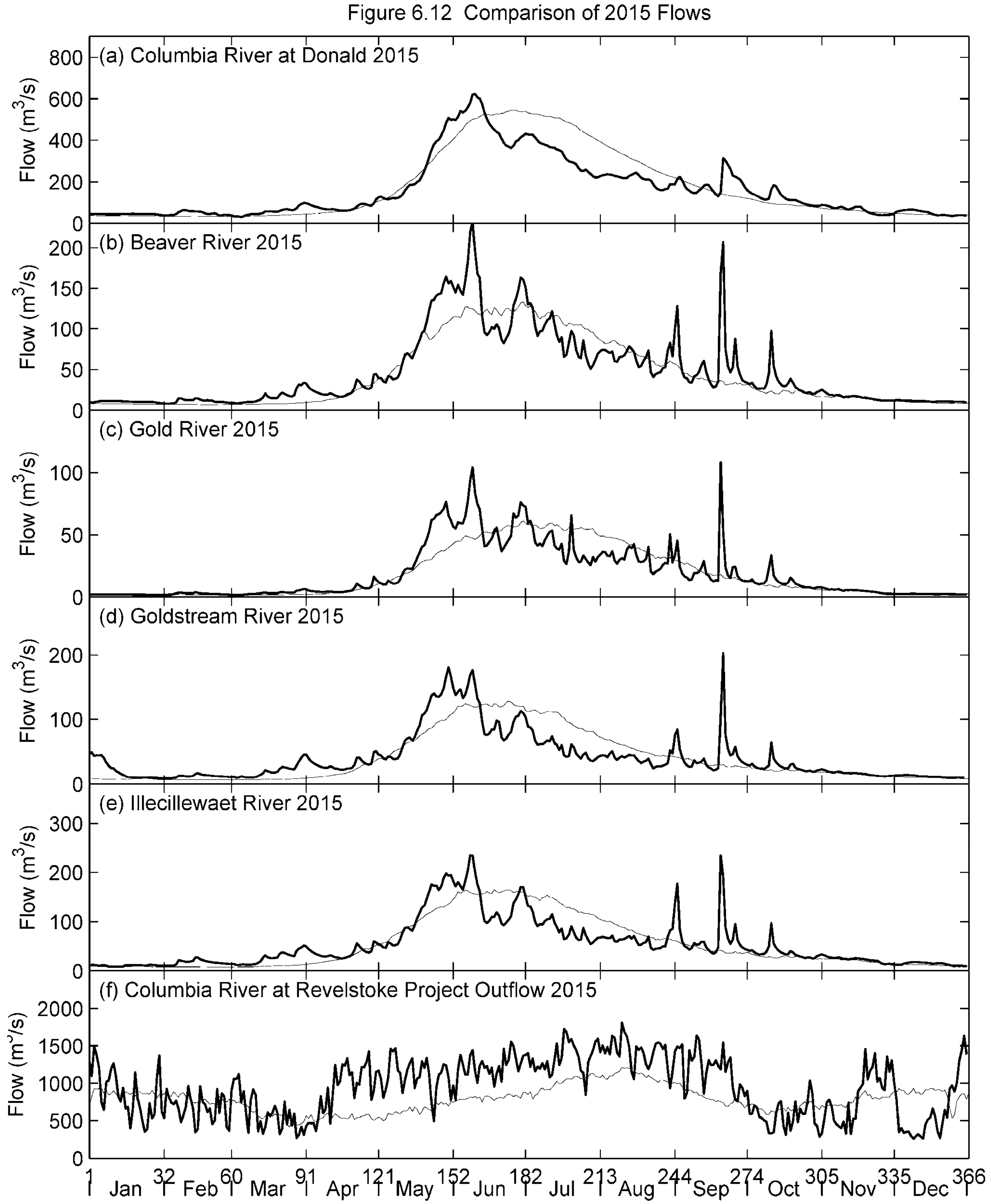


Figure 6.12. Comparison of flows in 2015 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

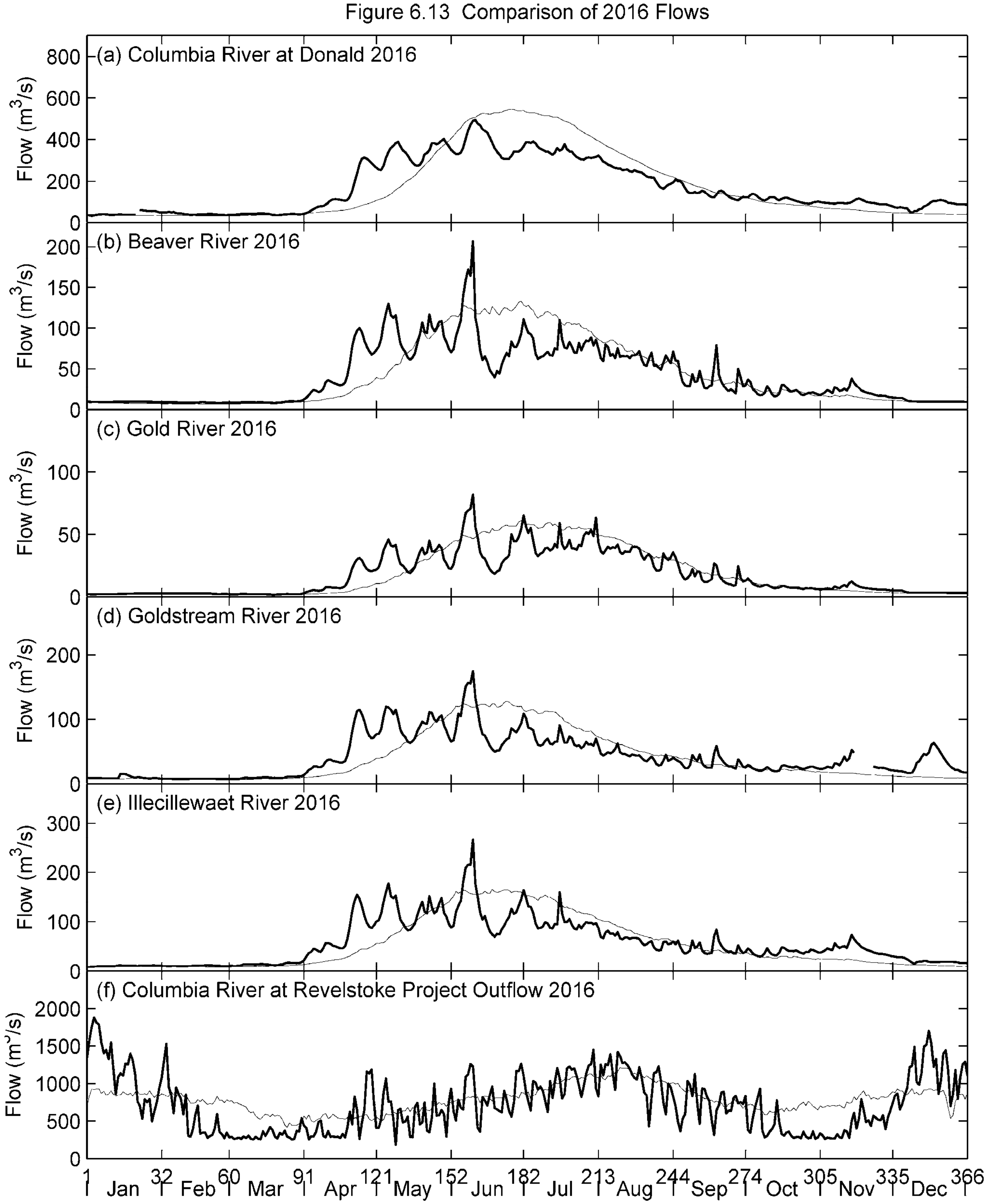


Figure 6.13. Comparison of flows in 2016 for the stations indicated (heavy line). Mean flows for **a)** 1944-2016 **b)** 1985-2016 **c)** 1973-2016 **d)** 1954-2016 **e)** 1963-2016 **f**) 1986-2016 (light line).

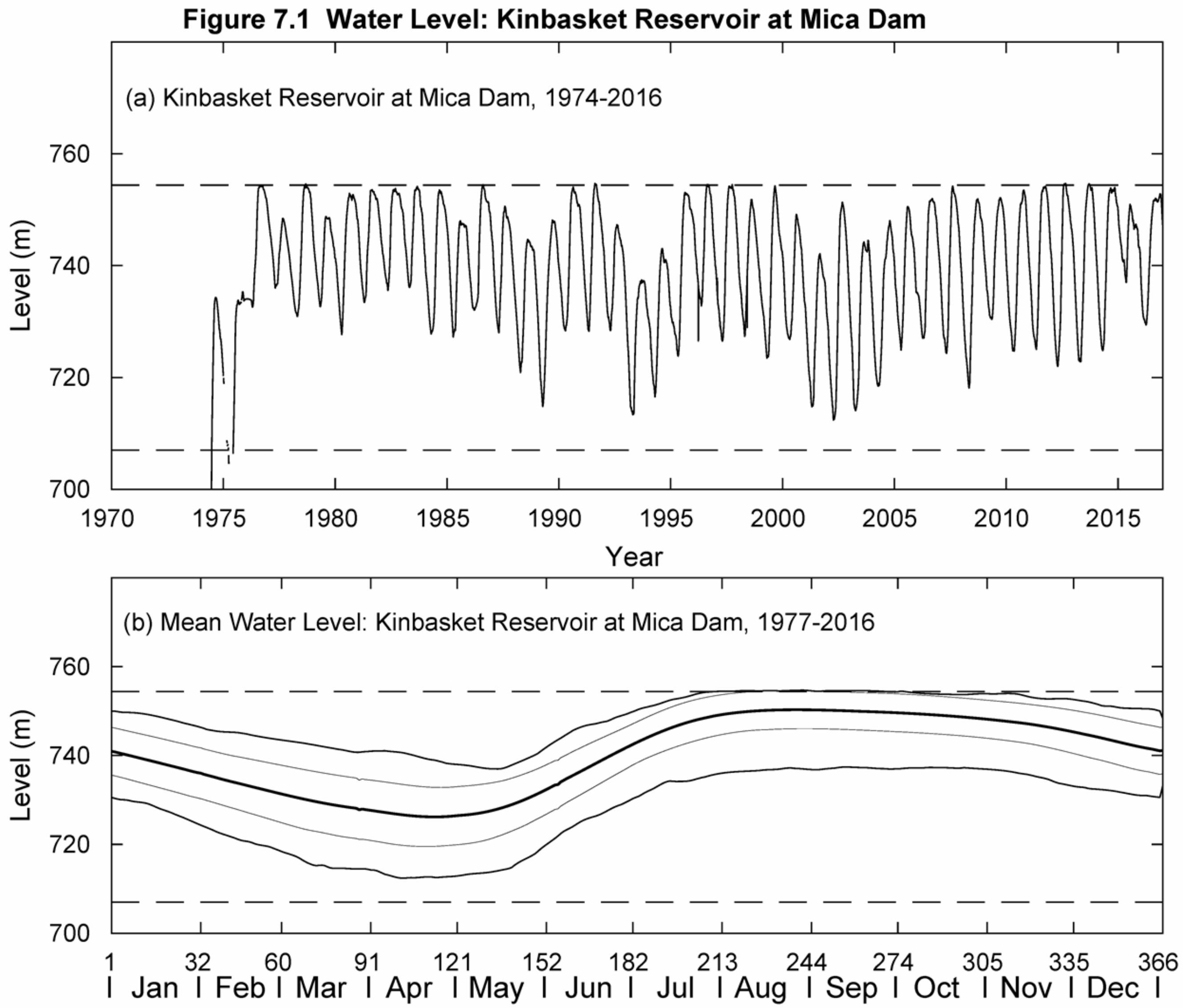


Figure 7.1. **(a)** WSC station 08ND017 "Kinbasket Lake at Mica Dam", 1974-2016. **(b)** Mean daily water level for 1977-2016. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

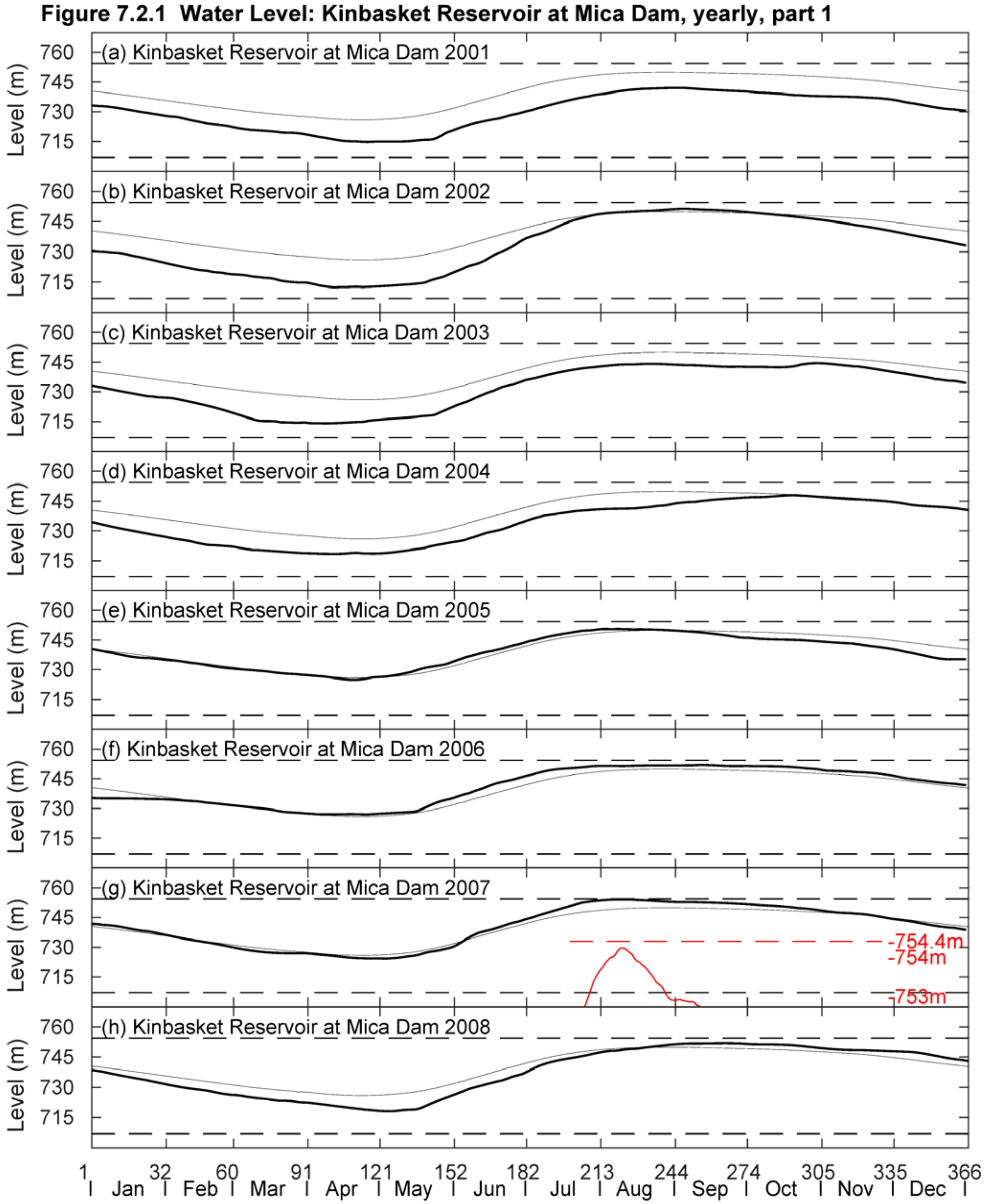


Figure 7.2.1. Water levels for WSC station 08ND017 "Kinbasket Lake at Mica Dam", selected years (heavy line). Mean daily water level for 1977-2016 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.

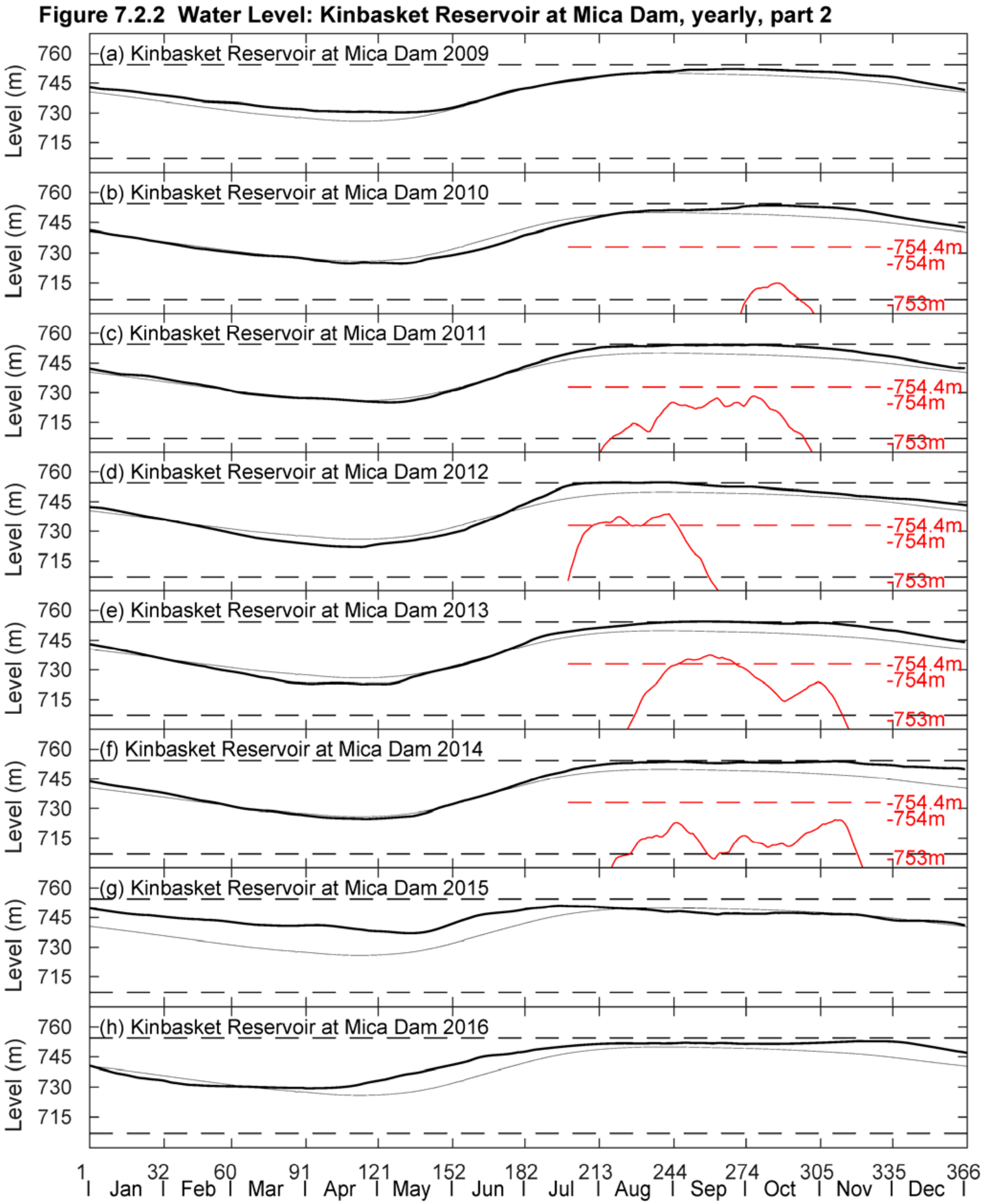
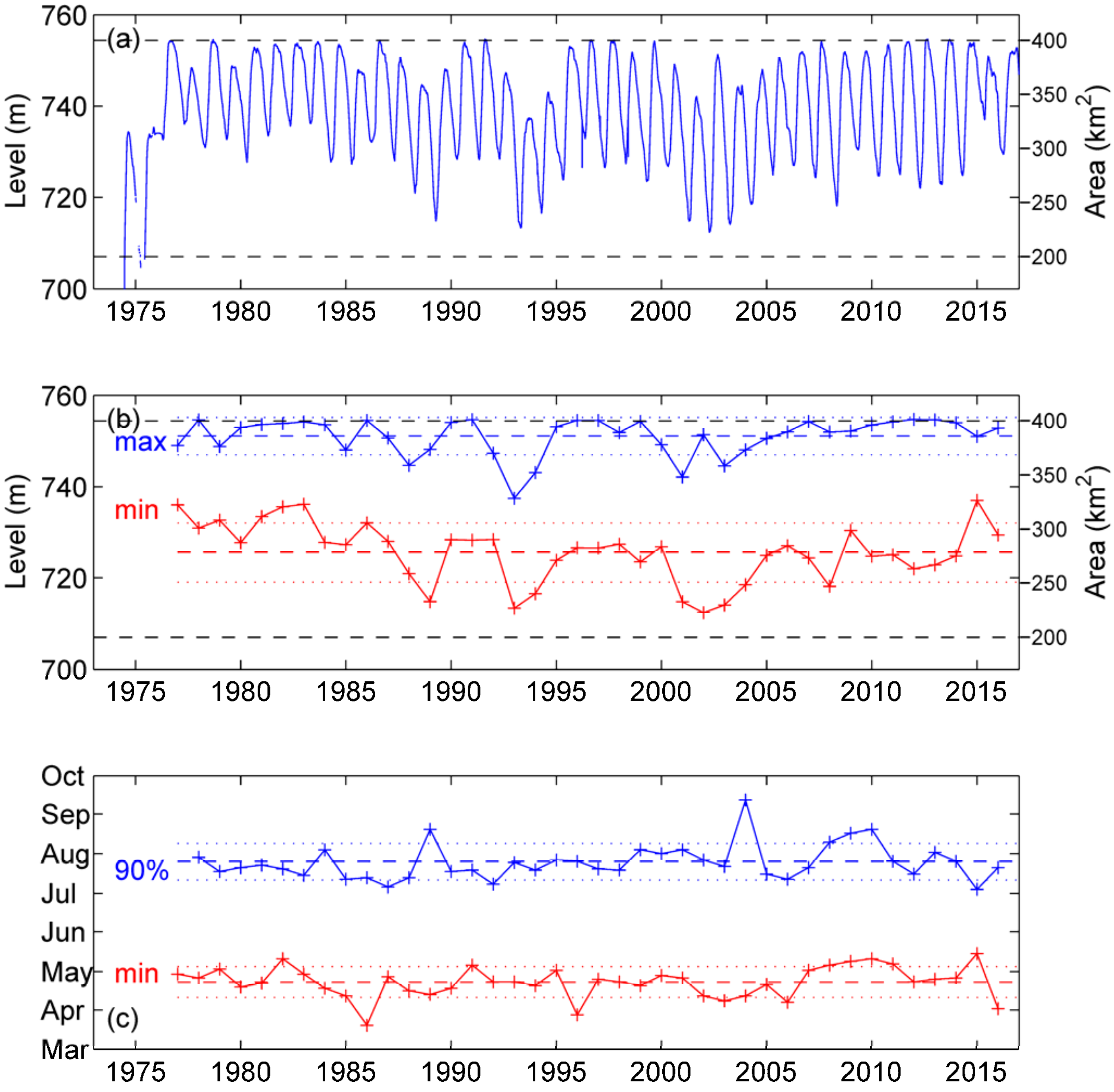


Figure 7.2.2. Water levels for WSC station 08ND017 "Kinbasket Lake at Mica Dam", selected years (heavy line). Mean daily water level for 1977-2016 (light line) is shown for comparison. Data for 2-30 April 2007 replaced with that from Kinbasket Lake below Garrett Creek. Dash lines mark the normal minimum and maximum elevation.



/ocean/rpieters/kr/flow/plot16/fig73syn.m fig= 4 2017−Dec−15

Figure 7.3 (a) Water level in Kinbasket Reservoir, 1973-2016. Black dash lines mark normal minimum and maximum water level. (b) Minimum (red) and maximum (blue) water level for 1977-2016. (c) Date of minimum (red), 90% maximum (blue) water level for 1977-2016. 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.

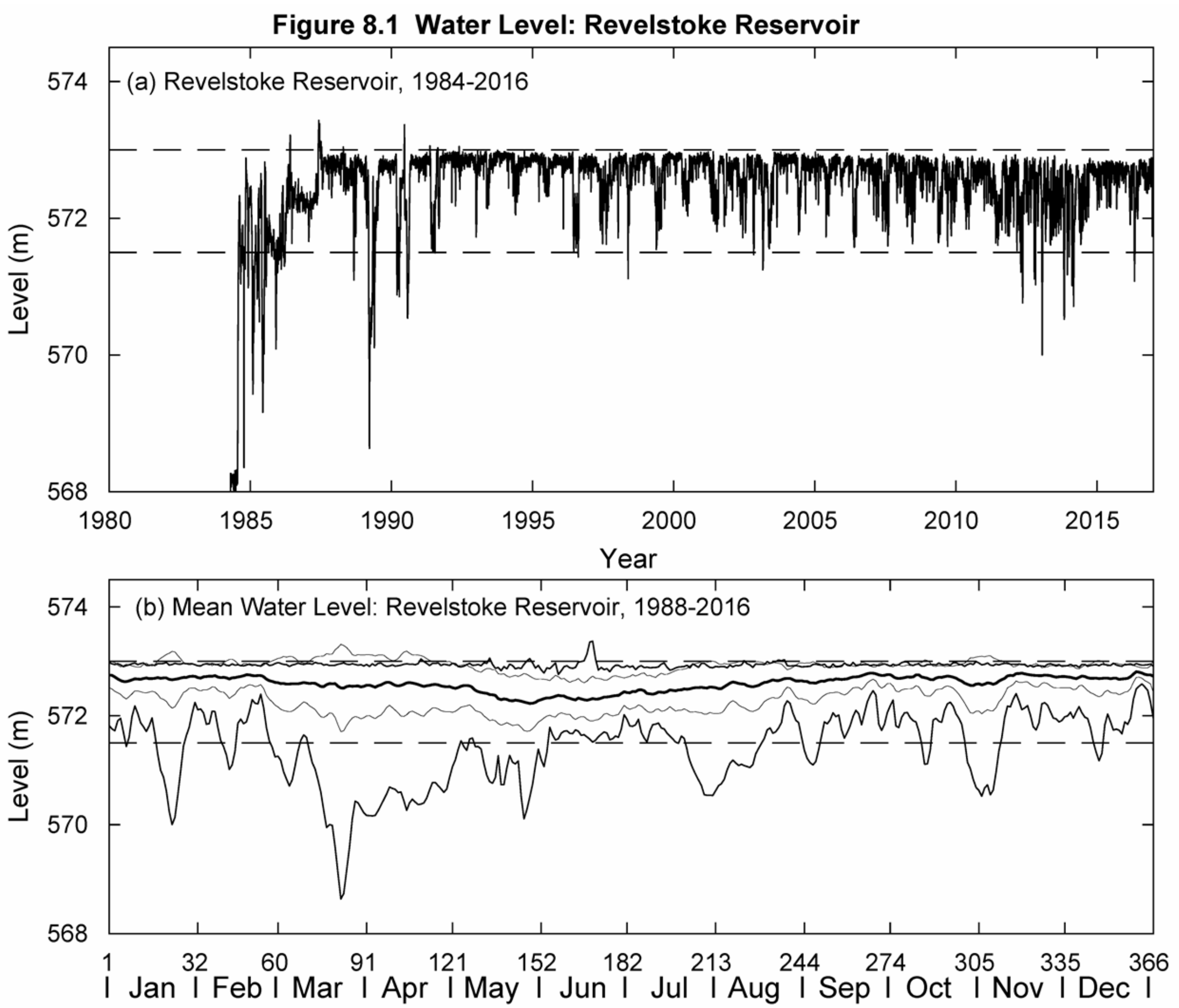


Figure 8.1. **(a)** BC Hydro station "Revelstoke Lake Forebay", 1984-2016. **(b)** Mean daily water level for 1988-2016. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines). Dash lines mark the normal minimum and maximum elevation.

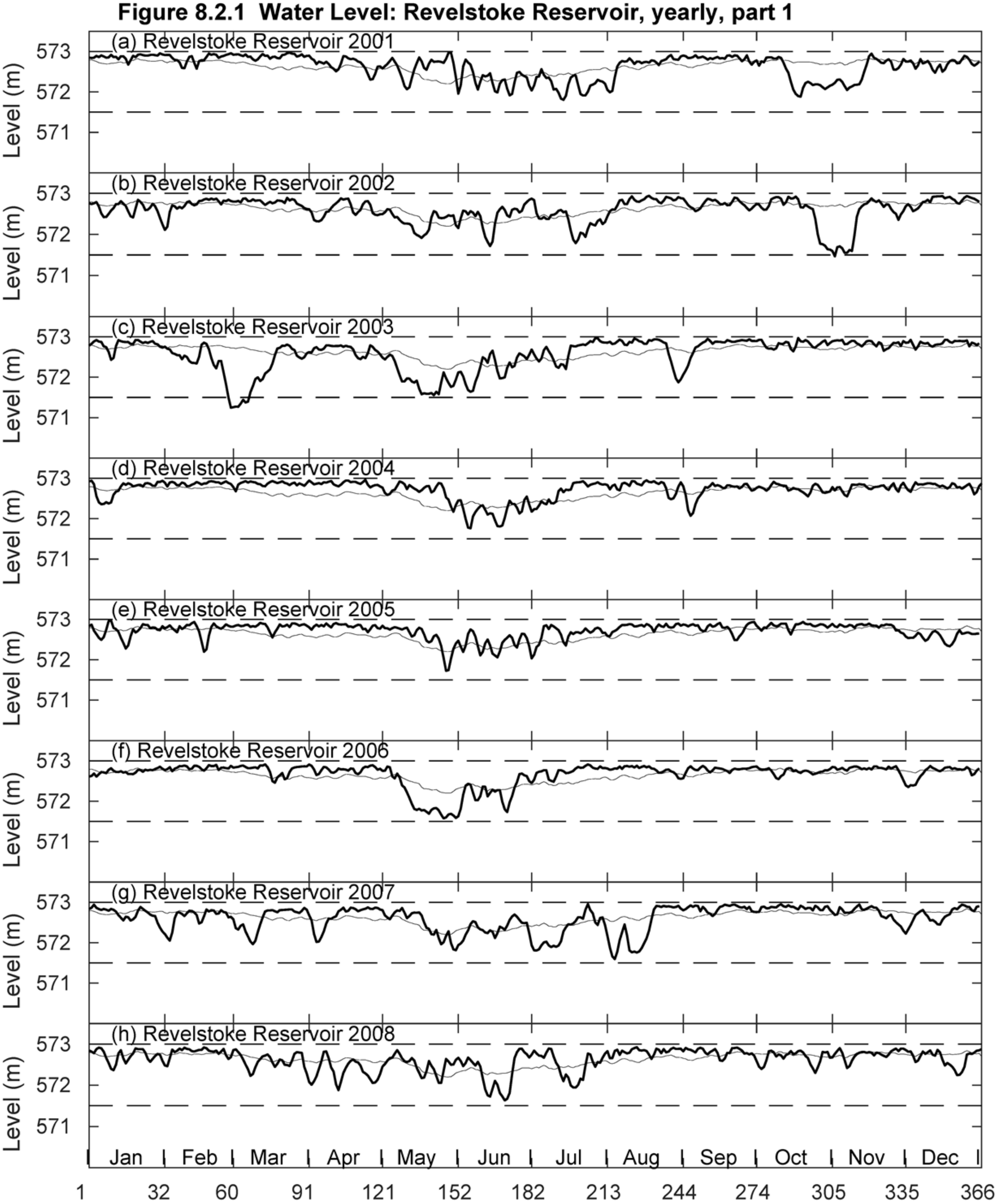


Figure 8.2.1. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2016 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

Figure 8.2.2 Water Level: Revelstoke Reservoir, yearly, part 2

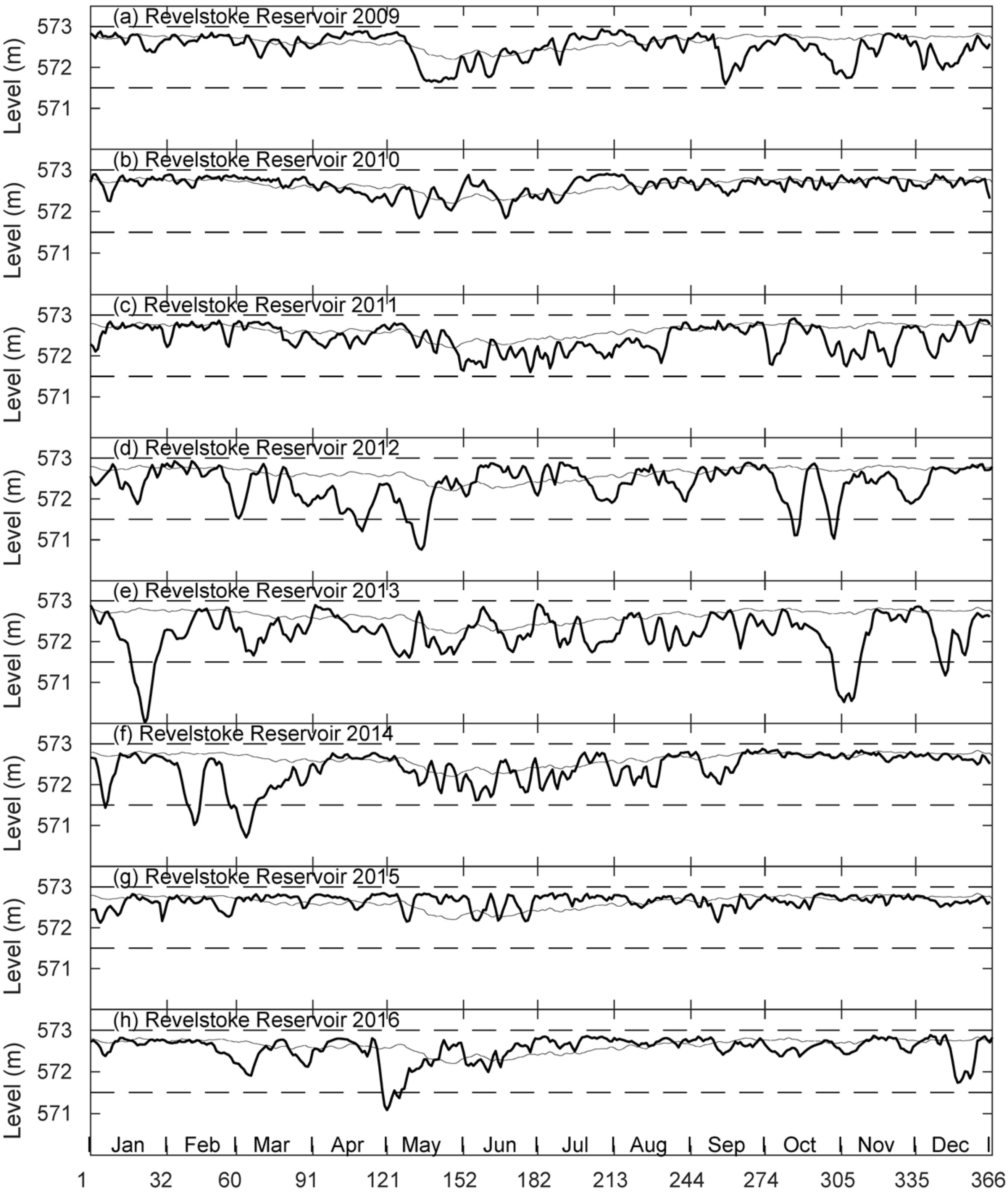


Figure 8.2.2. BC Hydro station "Revelstoke Lake Forebay", selected years (heavy line). Mean daily water level for 1988-2016 (light line) is shown for comparison. Dash lines mark the normal minimum and maximum elevation.

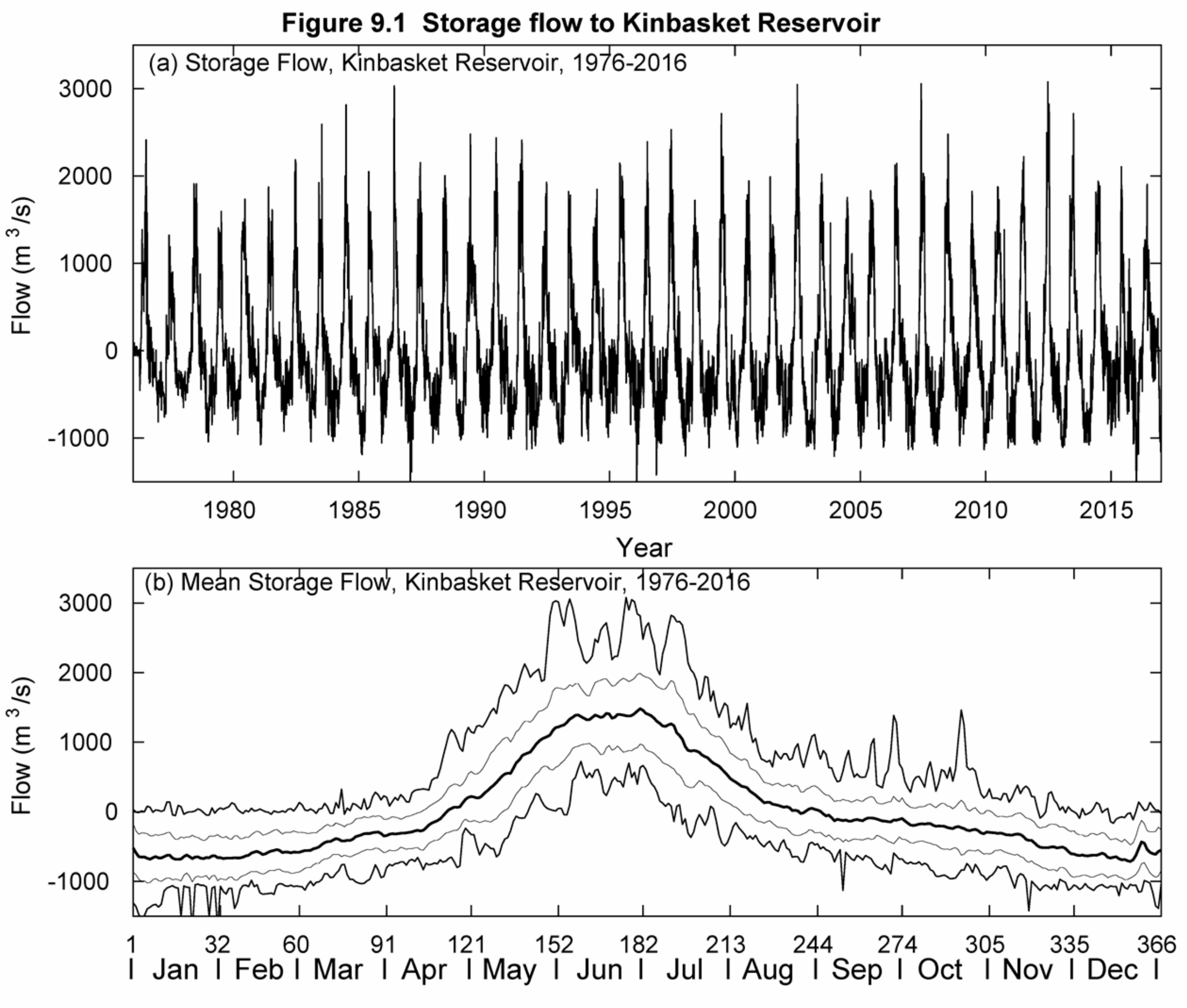


Figure 9.1. **(a)** Storage flow to Kinbasket Reservoir, 1976-2016. **(b)** Mean daily storage flow for 1976-2016. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

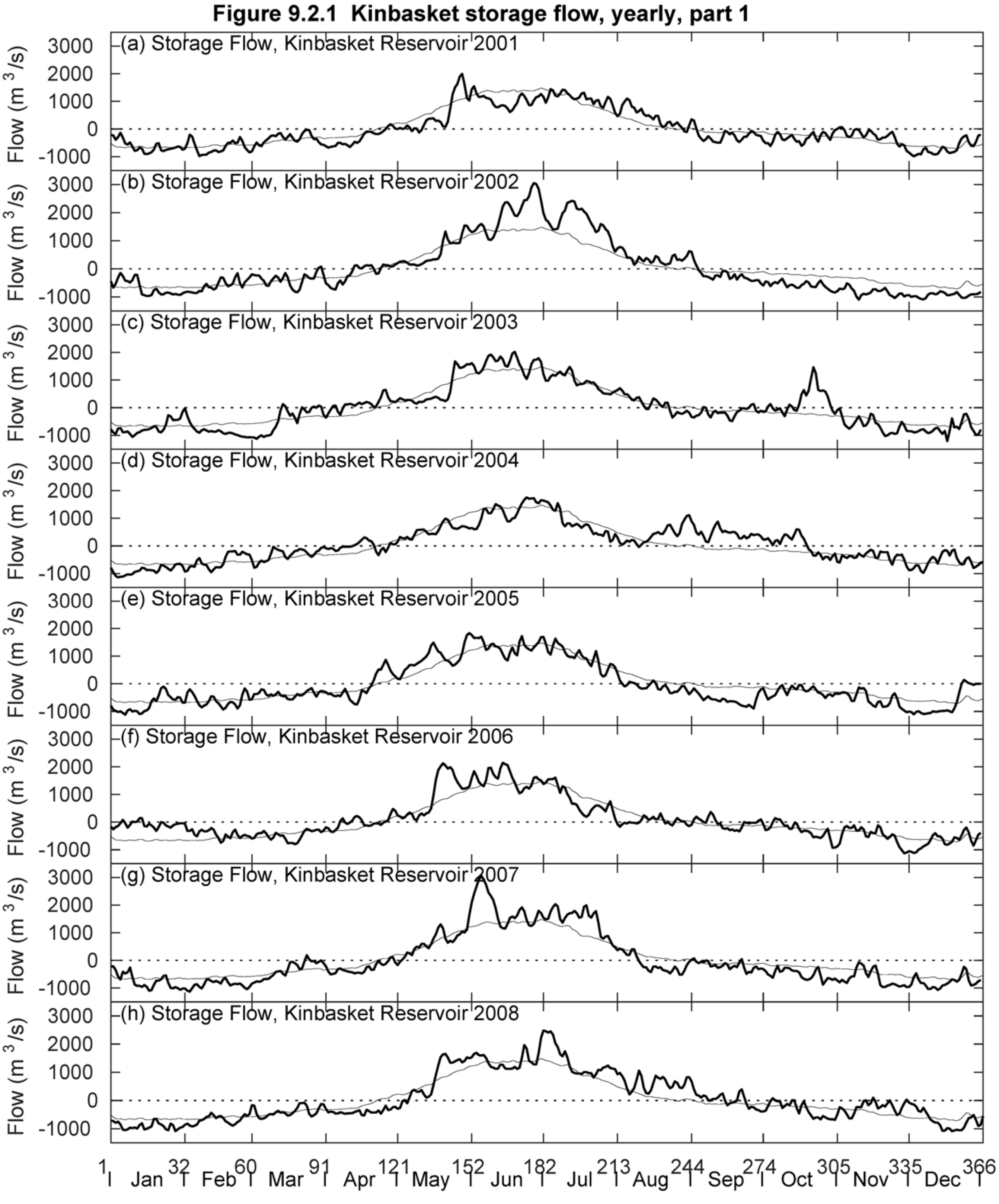


Figure 9.2.1. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2016 (light line) is shown for comparison.

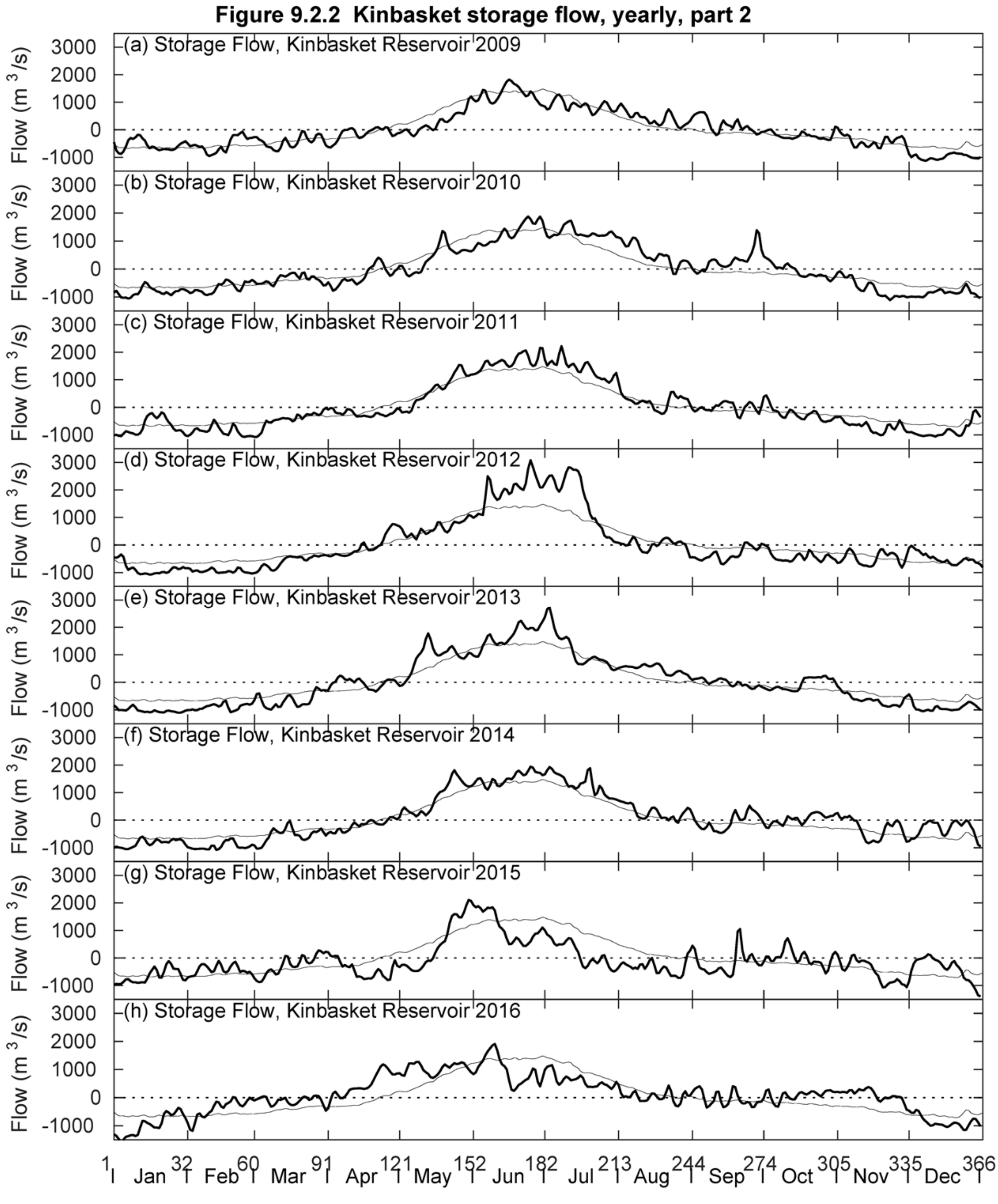


Figure 9.2.2. Storage flow to Kinbasket Reservoir, selected years (heavy line). Mean daily storage flow for 1976-2016 (light line) is shown for comparison.

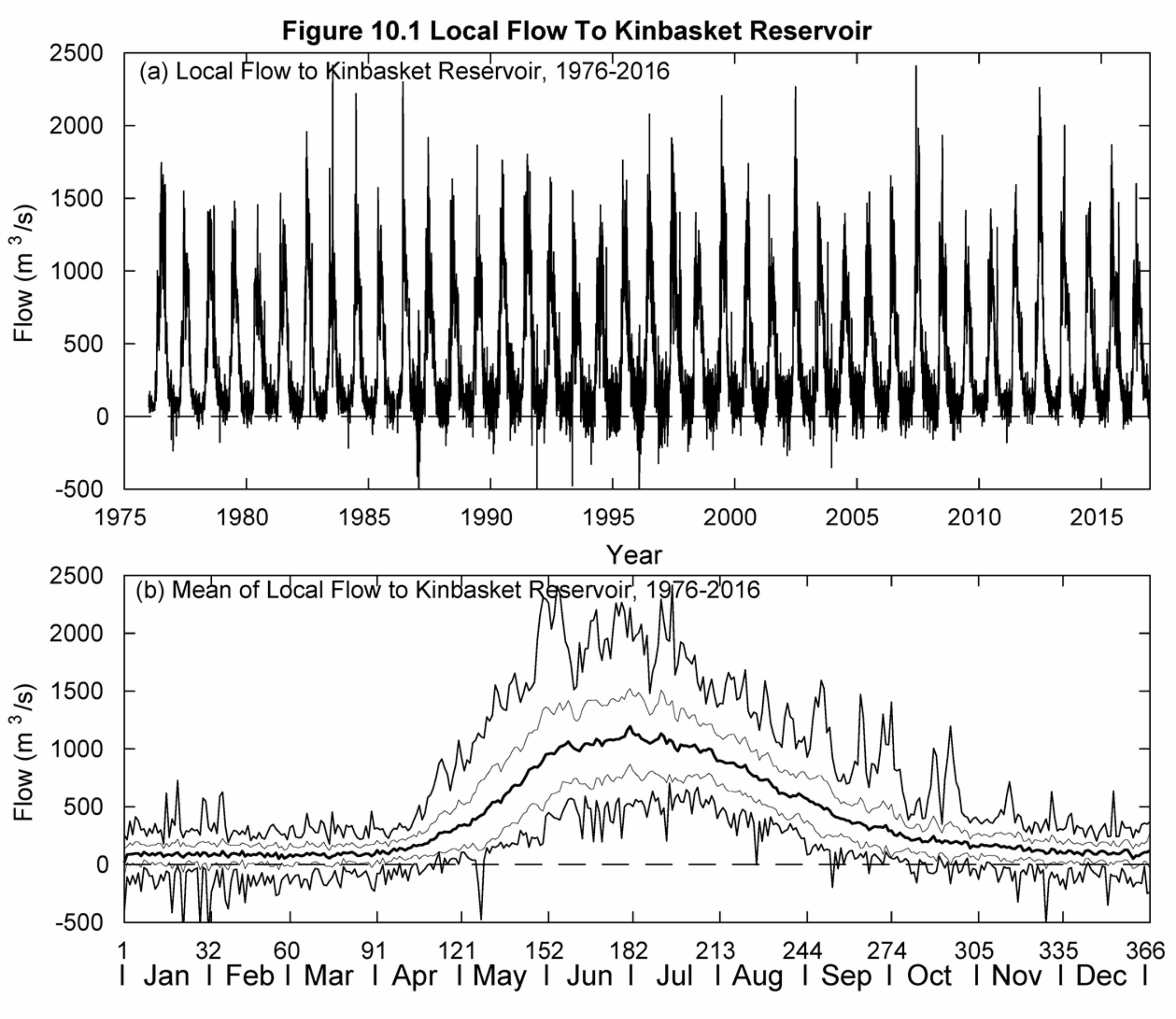


Figure 10.1. **(a)** Local flow to Kinbasket Reservoir, 1976-2016. **(b)** Mean daily local flow for 1976-2016. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

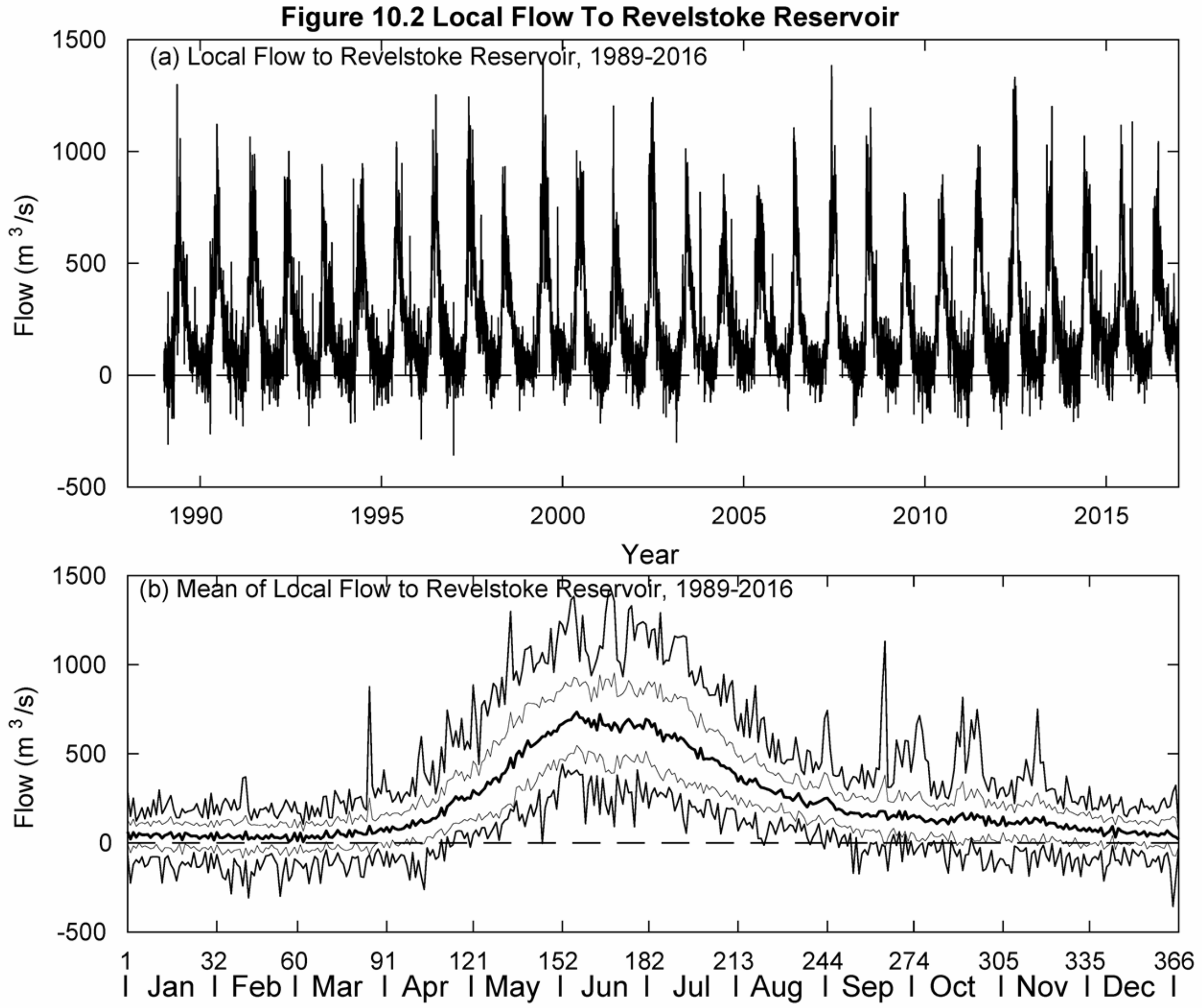


Figure 10.2. **(a)** Local flow to Revelstoke Reservoir, 1976-2016. **(b)** Mean daily local flow for 1976-2016. Mean (heavy line), maximum and minimum (medium lines) and mean ± one standard deviation (light lines).

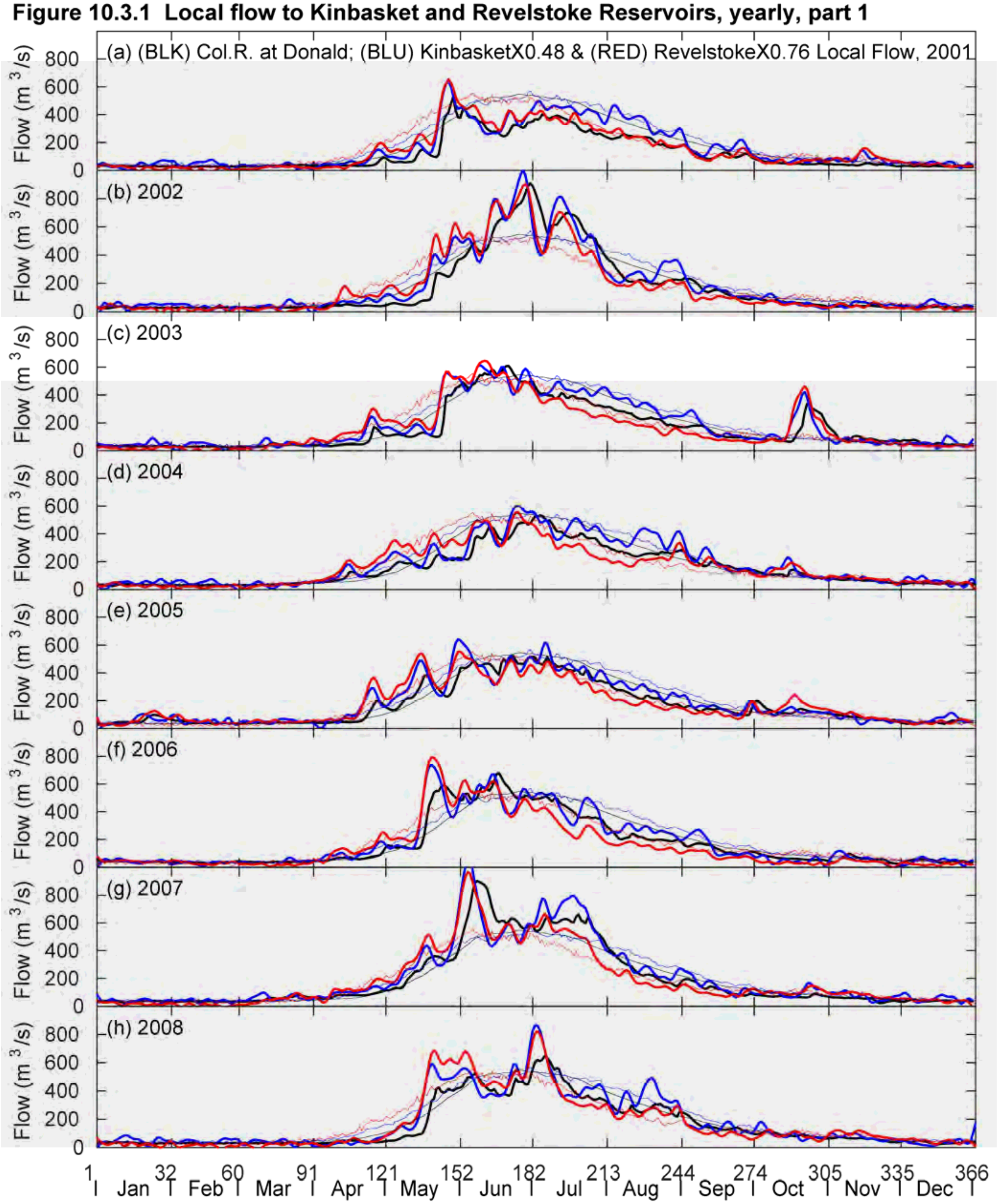


Figure 10.3.1. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2016 (light line) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

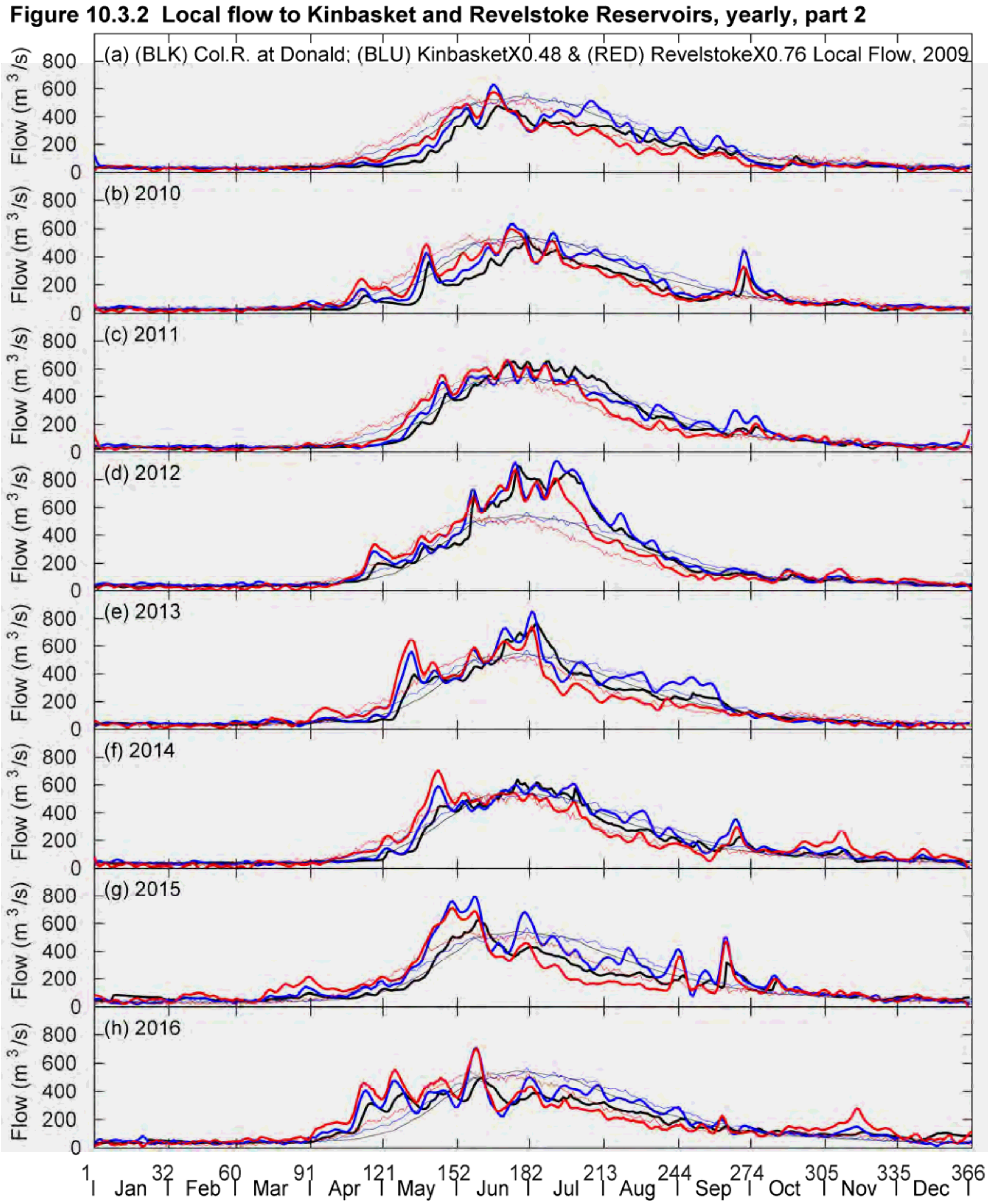


Figure 10.3.2. Local flow to Kinbasket and Revelstoke Reservoirs, selected years. The Columbia River at Donald, for the given year and the mean for 1944-2016 (light line) are shown for comparison. Local flows were scaled for comparison to the Columbia at Donald.

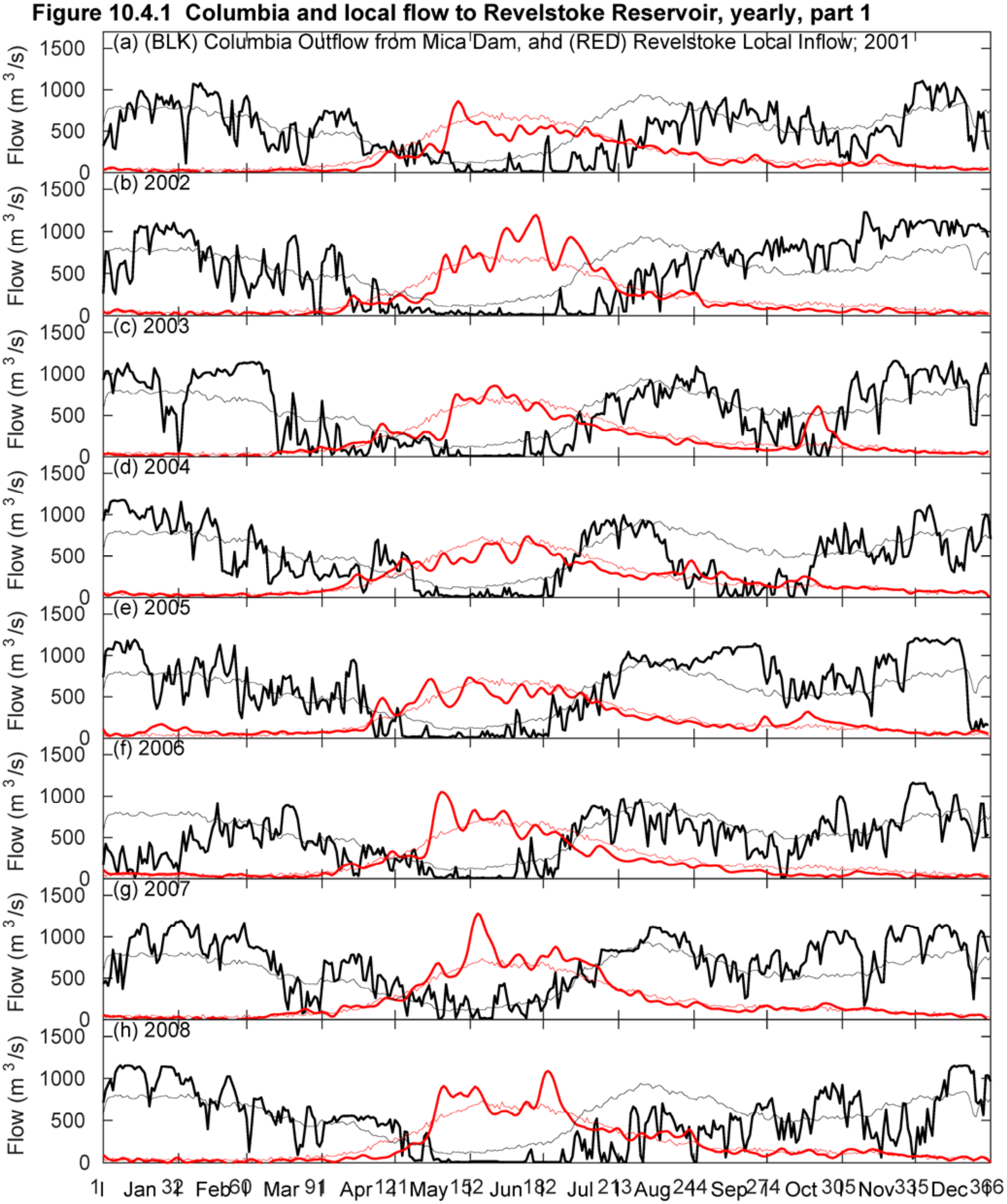


Figure 10.4.1. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison.

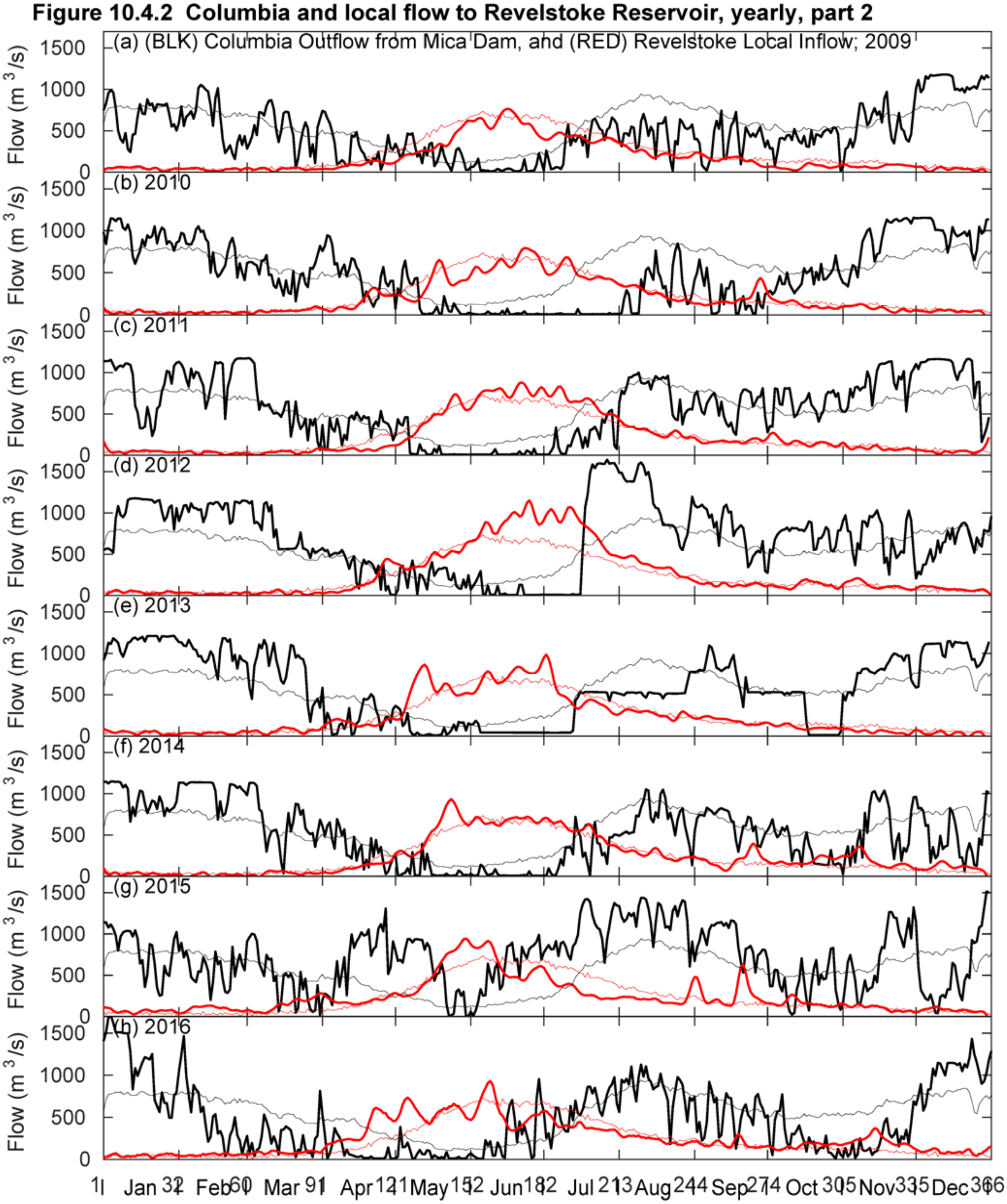


Figure 10.4.2. Comparison of the Columbia River at Mica dam to the local inflow to Revelstoke Reservoir, selected years. The mean flows (light lines) are shown for comparison.

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)

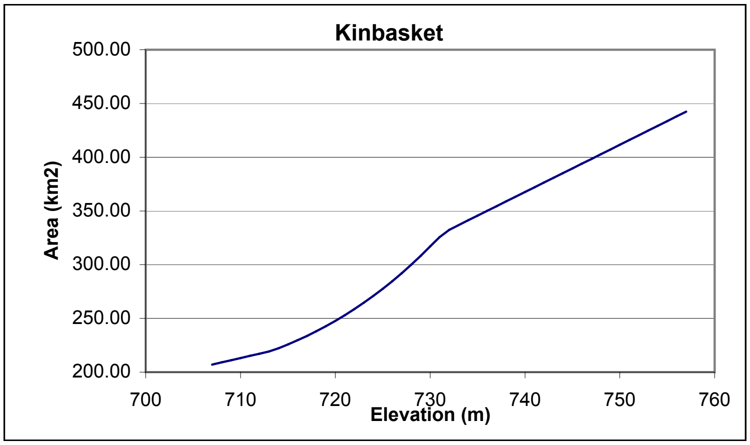
Revelstoke Reservoir Elevations

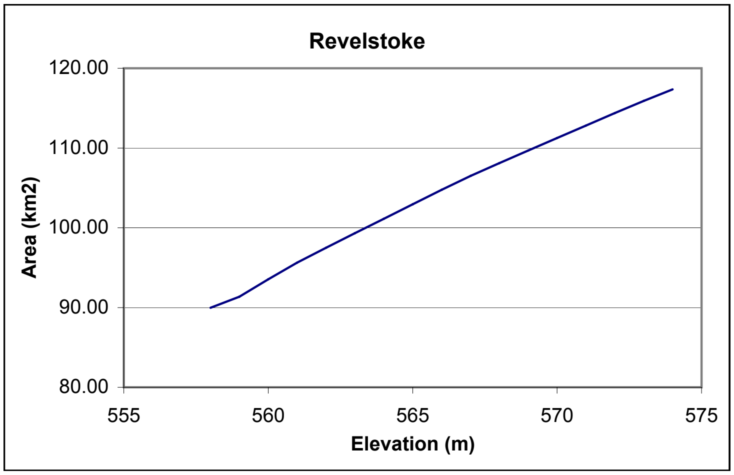
Elevation (ft)	Elevation (m)	Storage (Mm^3)	Area (km^2)	Comments
1894.0	577.6			Crest of dam
1885.0	574.6	5449.4	118.2	DSI, Dam Safety Incident level when spill gates are open. Expected maximum reservoir level during the PMF inflow event (7100 m3/s, 250,000 cfs)
1880.0	573.0	5264.8	116.0	Nmax, Normal 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, 2016

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

Tributary Water Quality
Kinbasket and Revelstoke Reservoirs, 2016

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Revelstoke Reservoir, 2 June 2016

Prepared for

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

January 3, 2018

Contents

List of Figures

1. Introduction

This report examines water quality data collected from tributaries to Kinbasket and Revelstoke Reservoirs in 2016. These data were collected as part of the ongoing BC Hydro project entitled "CLBMON-3 Kinbasket and Revelstoke Ecological Productivity Monitoring".[*]

Two types of tributary samples have been collected:

1. Reference tributaries were sampled from April to November. Regular sampling of reference tributaries began in 2009 (Pieters *et al.,* 2011-2017); here we report on the data from the reference tributaries in 2016.
2. Surveys of several 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), and on 6 May 2013 (Pieters *et al.* 2016). A survey was not conducted in 2014 to 2016; see previous reports for details of tributary surveys.

2. Methods

Reference Tributary sample collection

There are five reference tributaries: Columbia River at Donald, Goldstream River, Beaver River, Kinbasket Reservoir (Mica Dam) Outflow, and Revelstoke Reservoir (Revelstoke Dam) Outflow. In 2016, Downie Creek, a major inflow to Revelstoke Reservoir, was added as a reference tributary. In the past, the Columbia River at Donald, Goldstream River, Kinbasket Outflow, and Revelstoke Outflow 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. The Columbia River at Donald was sampled near the Highway 1 Bridge. Mica outflow was sampled at the bridge downstream of the dam. Goldstream River and Downie Creek enter the east side of Revelstoke Reservoir, and were sampled from Highway 23. Revelstoke outflow was sampled below the dam. Coordinates for the sample locations are given in Appendix 2.

The Beaver River was sampled at the east gate of Glacier National Park by Environment Canada, and this location represents about half of the total drainage of the Beaver River. Additional sampling of the Beaver River by BC Hydro began in 2013, at sampling sites near the confluence with the Kinbasket Reservoir. Beaver River was sampled near

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

Kinbasket Resort when the water level in the reservoir was low, but as the water level increased, the sampling location moved upstream; see Appendix 2 for detail.

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. From 2008 to 2012, samples were analyzed by the Cultus Lake Salmon Research Laboratory, Department of Fisheries and Oceans (4222 Columbia Valley Highway, Cultus Lake, British Columbia). From 2013 to 2016 samples were analyzed by Maxxam Analytics (4606 Canada Way, Burnaby, 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)	$mgCaCO_3/L$	Alk	0.5 $mgCaCO_3/L$
Water Temperature (T)	^oC	T	

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

3. Reference Tributaries

Intensive sampling of the reference tributaries began in 2009. Comparison of the 2009 through 2016 data is shown for April to November in Figures 3.1 to 3.7. The exception is Figure 3.3 for the Beaver River, which is plotted from January to December as data were available throughout the year.

Columbia River at Donald (Figure 3.1)

The Columbia River at Donald is a major inflow into Kinbasket Reservoir. Water quality data for 2009 to 2016 are shown in Figures 3.1. River flow is shown in Figure 3.1a; flow is dominated by spring freshet which peaks from early June to mid-July.

The temperature of the Columbia River at Donald, having wound its way through the Rocky Mountain Trench, was relatively warm peaking at 15 - 18 ºC in July and August each year (Figure 3.1b). The conductivity (C25), shown in Figure 3.1c, declined through the freshet to about half of the spring value by mid-summer (Figure 3.1c). The turbidity was highly variable (Figure 3.1d), while pH remained slightly alkaline throughout the sampling period (Figures 3.1e).

In a well oxygenated environment such as a river, nitrite will be low, and data for nitrate and nitrite (NN) gives the nitrate concentration. Nitrate concentrations in the Columbia River at Donald declined rapidly after the onset of freshet (Figure 3.1f). For example, nitrate declined by a factor of 4 from a high of 246 µg/L on 26 April 2016 to a low of 55 µg/L on 26 July 2016.

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 reflects depletion of the supply of nitrate from the snowpack and from shallow soil water pools before the end of freshet (Sebestyen *et al*., 2008).

Soluble reactive phosphorus (SRP), also known as orthophosphate (OP) or phosphate (PO_4), was low and variable over the years (Figure 3.1g). The SRP values ranged from < 1 to 5.3 µg/L in 2016. The detection limit for SRP was 1 µg/L.

Total dissolved phosphorus (TDP) values showed little variability in 2016, with values ranging from < 2 to 3.2 µg/L (Figure 3.1h). The detection limit for TDP was 2 µg/L.

Total phosphorus (TP) ranged from 2.3 to 107.1 µg/L in 2008 to 2016; the values ranged from 4.7 to 45 µg/L in 2016 (Figure 3.1i). Particulate phosphorus can be estimated as the difference between total phosphorus and total dissolved phosphorus, PP = TP - TDP. In glacially dominated systems, with high turbidity, much of the total phosphorus measured may have been extracted from particulate minerals (e.g. apatite) by the step in the analysis in which the sample undergoes digestion with persulphate (Appendix 1). As a result, for tributaries with high PP, it is likely that much of this phosphorus is of low biological availability.

In 2016, the values for the NN:TDP ratio (by weight) in the Columbia at Donald were all > 10, suggesting tributary nutrients were phosphorus limited. However, this was not always the case in previous years; at times the NN:TDP ratio fell below 10 during the summer. In particular, in the summer of 2012, the NN:TDP ratios below 10 persisted until late October (Figure 3.1j). Low tributary nitrate during summer may result in nitrogen and phosphorus co-limitation in the reservoir.

Goldstream River (Figure 3.2)

Data from 2009 to 2016 for the Goldstream River are shown in Figure 3.2. Flow in the Goldstream River (Figure 3.2a) shows a similar pattern to the Columbia at Donald with spring freshet from early June to mid-July, followed by gradually declining flow into August. Notable is a peak in late September 2015, due to an autumn rainstorm.

Compared to the Columbia River at Donald, the Goldstream River was cooler, with July temperatures of only 7 - 12 ºC with the exception of 14 °C measured on 28 July 2009 (Figure 3.2b).

The conductivity (C25) in Goldstream River declined to approximately half of its spring value by mid-summer (Figure 3.2c). Unlike in 2015 and 2016, when data were available from mid-April, in most years data began after C25 had already begun to decline. From September to December, C25 gradually increased, and, by December, it had reached pre-freshet levels.

Turbidity was generally below 50 NTU, except for one outlier of 198 NTU on 28 July 2009 (Figure 3.2d). The pH remained slightly alkaline, varying from about 8 pH units in winter to a range of 7.2 to 7.8 pH units during summer (Figure 3.2e).

Similar to the Columbia River at Donald, the Goldstream River experienced a peak in nitrate (NN) concentration during the start of freshet (Figure 3.2f). The highest observed nitrate was 565 µg/L on 8 May 2013. In 2016, the high was 408 µg/L on 25 April 2016 which declined by a factor of 6 to a low of 69 µg/L on 9 August 2016.

In 2016, soluble reactive phosphorus (SRP) was similar to previous years with the exception of a few slightly higher values in the spring (Figure 3.2g). Total dissolved phosphorus (TDP) concentrations for 2016 were relatively constant around the detection level of 2.0 µg/L (Figure 3.2h). In 2016, the maximum concentration of TDP was 4.1 µg/L on 26 July 2016.

As in previous years, total phosphorus (TP) concentrations for 2016 showed high variability, and ranged from < 2 µg/L to 183 µg/L (Figure 3.2i). The NN:TDP ratios in

Goldstream River were generally greater than 10, suggesting phosphorus limitation (Figure 3.2j).

Beaver River (Figure 3.3)

Similar to Goldstream River and the Columbia River at Donald, flow in Beaver River was dominated by spring freshet (Figure 3.3a). However, compared to Goldstream and the Columbia at Donald, the temperature in Beaver River was cooler, with a maximum of 9 °C in 2016 (Figure 3.3b).

The conductivity (C25) in 2016 declined from 213 µS/cm on 15 March 2016 to 71 µS/cm on 25 July 2016 (Figure 3.3c). This decline during freshet was similar to that observed in other years. As in previous years, the turbidity in Beaver River varied considerably in 2016 ranging from 0.5 NTU to 12 NTU, with one value of 35 NTU on 6 July 2016 (Figure 3.3d).

The pH in Beaver River for 2016 remained slightly alkaline (Figure 3.3e). Note that samples collected by BC Hydro near confluence (marked +) were slightly less alkaline in summer compared to samples collected further upstream near East Park Gate by Environment Canada. The average pH in 2016 was approximately 7.8 pH units, similar to previous years.

Data for nitrate (NN) in 2016 followed the pattern of previous years (Figure 3.3f). Values of nitrate were moderate in winter (e.g. 160 µg/L on 22 February 2016) and increased rapidly at the start of freshet (to 356 µg/L on 26 April 2016). This large increase in nitrate then declined dramatically after the start of freshet, to a low in summer (48 µg/L on 26 July 2016). Finally, nitrate gradually increased through summer and fall to winter levels of about 180 µg/L by December.

For the most part, the concentrations of soluble reactive phosphorus (SRP) were low, and near the detection level (1 ug/L), though occasional higher values were observed (Figure 3.3g). The data for 2016 also followed this pattern. A few slightly higher values were observed in 2014 (up to 5.6 ug/L). Note the absence, with two exceptions, of SRP value above detection in the Environment Canada data.

Total dissolved phosphorus (TDP) was low and close to the detection limit of 2 ug/L (Figure 3.3i). In 2016, Environment Canada began to also analyze for TDP for all the samples. The Environment Canada data for 2016 (*) were lower than those collected by BC Hydro (+). In the Environment Canada data the detection limit appears to be 0.5 ug/L, and most values were at detection, with the highest value being 1.2 ug/L.

Total phosphorus (TP) was variable in Beaver River ranging between the detection limit (2 ug/L BC Hydro and 0.5 ug/L Environment Canada) and 29 ug/L (Figure 3.3i). The NN:TDP ratio also remained high in Beaver River, with all but two value values greater than ten (Figure 3.3j).

Kinbasket and Revelstoke Outflows (Figures 3.4 and 3.5)

Note that the location at which Kinbasket outflow was sampled is referred to as the "Columbia at Mica Outflow" in Appendix 3.1, and the location at which Revelstoke outflow was sampled is referred to as the "Columbia above Jordan". It should also be noted that the Revelstoke Reservoir backs all the way to the foot of Mica Dam (Kinbasket Reservoir); as a result, samples of Kinbasket outflow taken from the riverine section below the dam can be influenced by Revelstoke Reservoir when outflow from Kinbasket is low, which typically occurs from late spring to early summer (Figure 3.4a).

As in previous years, the temperature of the outflows from the dams were cold (≤11 ºC) as a result of the deep intakes (Figures 3.4b and 3.5b). Unlike other years, there were no exceptions for the Kinbasket (Mica Dam) outflow in 2016; at low flow, the temperature below Mica Dam has in the past been noticeably influenced by Revelstoke Reservoir.

The conductivity of the outflow from the Kinbasket and Revelstoke Reservoirs was relatively steady in 2016, with the occasional lower value during low outflow from Mica Dam as in previous years (Figures 3.4c and 3.5c). The turbidity of the outflow from both Mica and Revelstoke was very low, generally < 2 NTU (Figures 3.4d and 3.5d). The average turbidity for the Kinbasket outflow was 0.7 NTU in 2016 (maximum 2 NTU), and for Revelstoke outflow was 0.5 NTU in 2016 (maximum 0.9 NTU), similar to previous years. Like the tributaries, the pH was relatively constant and slightly alkaline (Figures 3.4e and 3.5e). There were some lower values of pH below Mica Dam from mid-May to mid-June, again corresponding to low outflow conditions.

Nitrate and nitrite concentrations (NN) in the Kinbasket outflow were generally constant throughout the year at approximately 100 µg/L (Figure 3.4f). The exceptions occurred mainly during spring when outflow was low. Exceptions include 322 µg/L on 25 April 2016. In the outflow from Revelstoke, nitrate was also relatively constant throughout the year, varying from 70 to 170 µg/L (Figures 3.5f). There was one exception of 288 µg/L on 7 November 2016; the cause of this exception is not known.

For both Kinbasket and Revelstoke outflows, SRP concentrations were close to the detection limit and generally below 5 µg/L (Figures 3.4g and 3.5g), with the exception of one value of 7.2 µg/L in the Kinbasket outflow on 5 October 2015. Both TDP (Figures 3.4h and 3.5h) and TP (Figures 3.4i and 3.5i) were low and relatively constant in the outflow of both dams (ranging from about 2 to 5 µg/L). The NN:TDP ratio for the Kinbasket and Revelstoke outflows exceeded 10 throughout 2016, suggesting nutrients from these sources were phosphorus limited (Figures 3.4j and 3.5j).

Downie Creek (Figure 3.6)

Because Downie Creek has a large influence on the lower half of Revelstoke Reservoir, it was decided to add Downie Creek as another reference tributary beginning in 2016. The first year of data are shown in Figure 3.6, which generally follow the pattern of the other natural tributaries.

4. Discussion

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. As a result, intensive sampling of a set of reference tributaries has been undertaken to provide an indicator of seasonal variability.

Another example of seasonal variability is given by the long record of water quality data available for the Illecillewaet River, which is located just south of the Revelstoke Reservoir (Figures 3.7 and 3.8). The Illecillewaet is the largest local inflow to the Arrow Reservoir, with a drainage area of 1170 km^2, and including flow of glacial origin. Water quality data from 1997 to 2001 are shown in Figure 3.7. Also shown in grey is the flow from the Illecillewaet at Greeley (WSC Station 08ND013). 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 (Figures 3.7a and 3.7d). In late August, the values begin to increase again. Also shown for reference are water temperature, pH, NH_3, SRP, TDP, and TP (Figures 3.7).

Figure 3.8 compares the seasonal evolution of the flow, C25 and nitrate (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 3.8b). The decline in nitrate occurs more gradually through May and June to very low values in July and August (Figure 3.8c). Overall, nitrate declined from 420-480 µg/L in May to 50-100 µg/L in mid-summer. A similar decline in nitrate is seen in other tributaries to the Arrow Reservoir (e.g. Pieters *et al.,* 2003).

5. Conclusions

Based on these data, and those of previous years, the tributaries to both Kinbasket and Revelstoke Reservoirs are low in nutrients. Soluble reactive phosphorus (SRP) was very low in both basins, generally close to the detection limit. Total dissolved phosphorus (TDP) was also low, at ~ 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 approximately 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 greater than 10 (by weight), phosphorus is expected to limit phytoplankton productivity (Horne and Goldman, 1994). The N:P ratio, based on nitrate and TDP, is greater than 10 for the reference tributaries, which suggests phosphorus limitation, with the notable exception of Columbia River at Donald in some summers, 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.

Acknowledgements

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Figure 3.1 Columbia R. at Donald: 09, 10, 11, 12, 13, 14 15 & 16

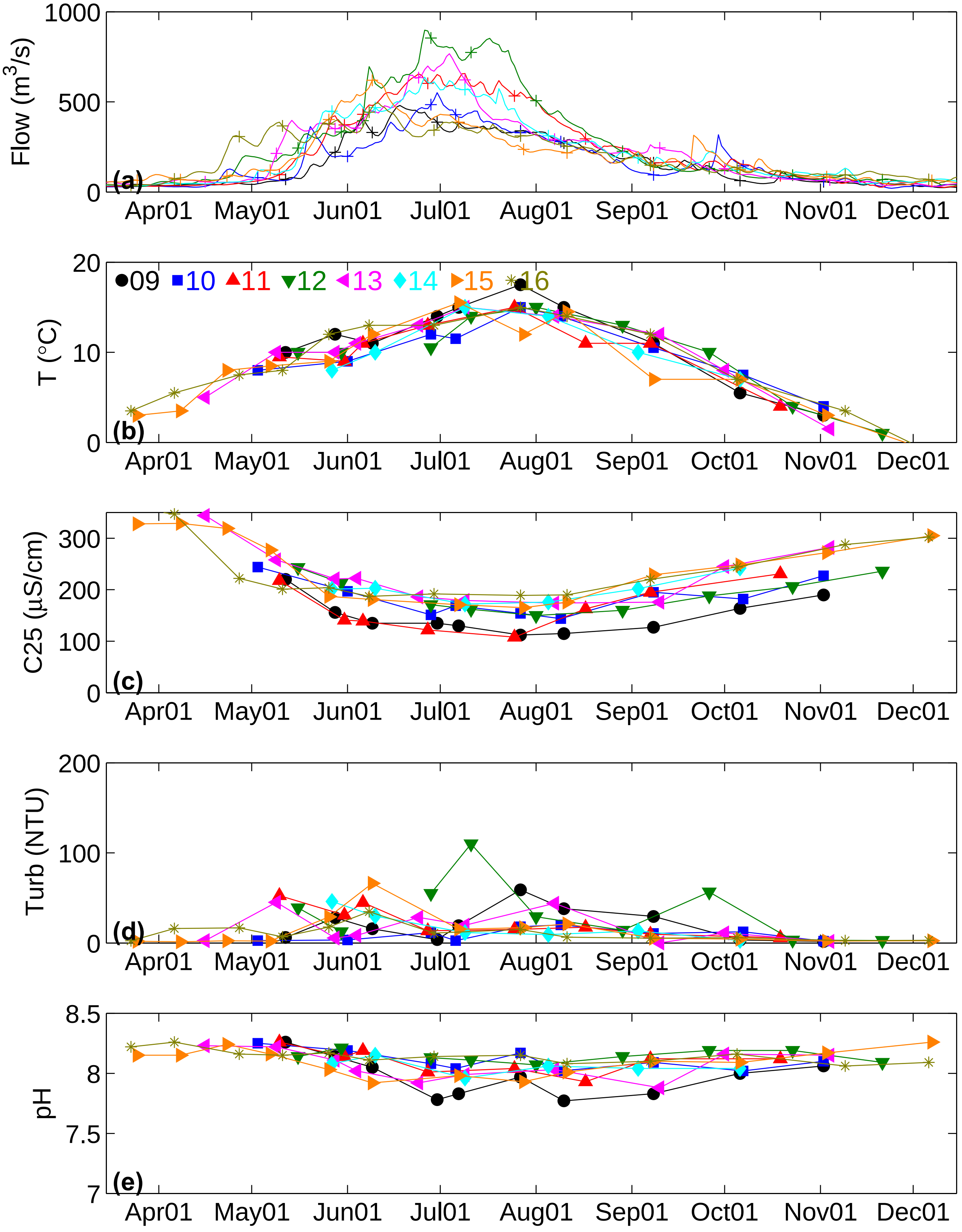

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Figure 3.1 con't Columbia R. at Donald: 09, 10, 11, 12, 13, 14 15 & 16

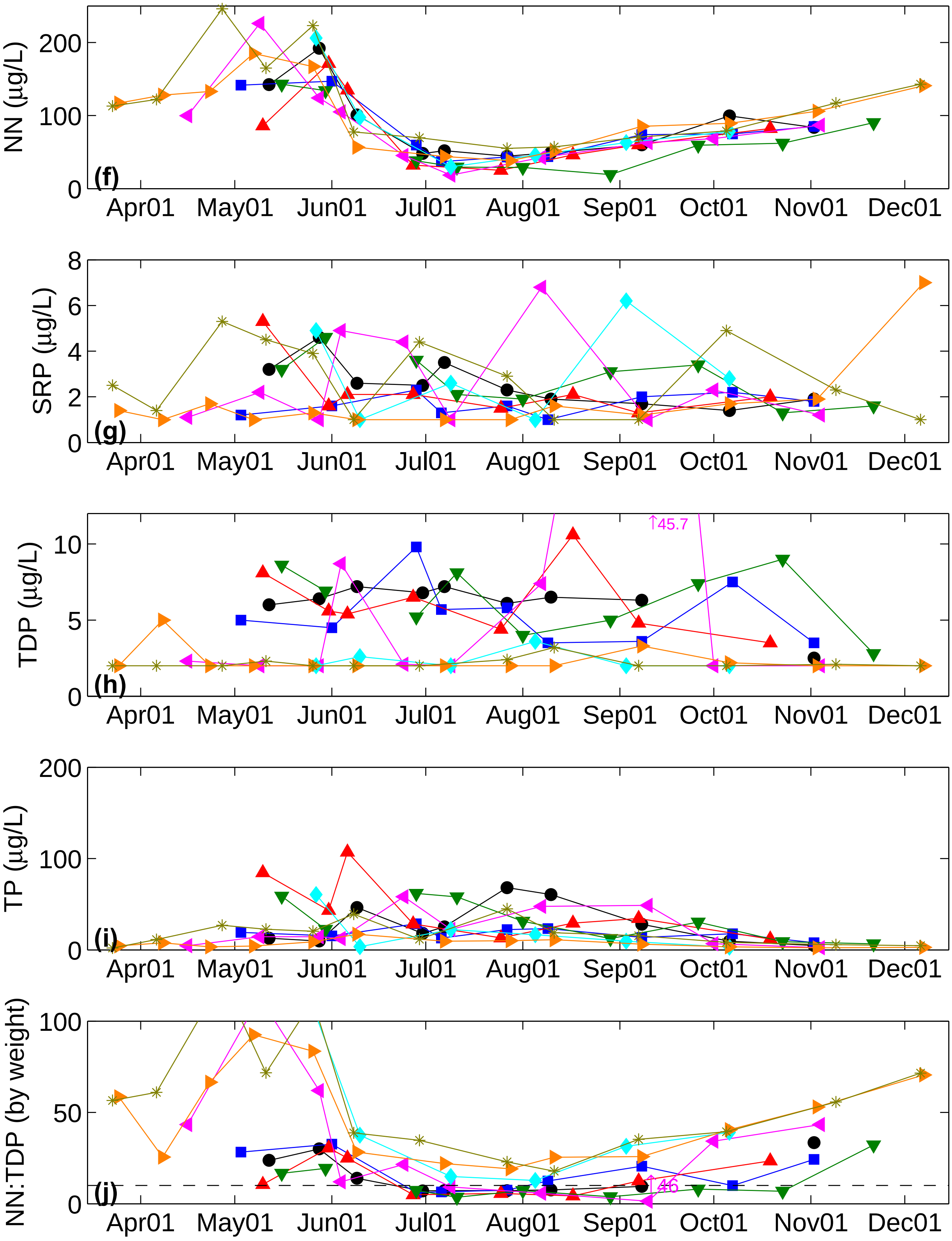

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Figure 3.2 Goldstream River: 09, 10, 11, 12, 13, 14 15 & 16

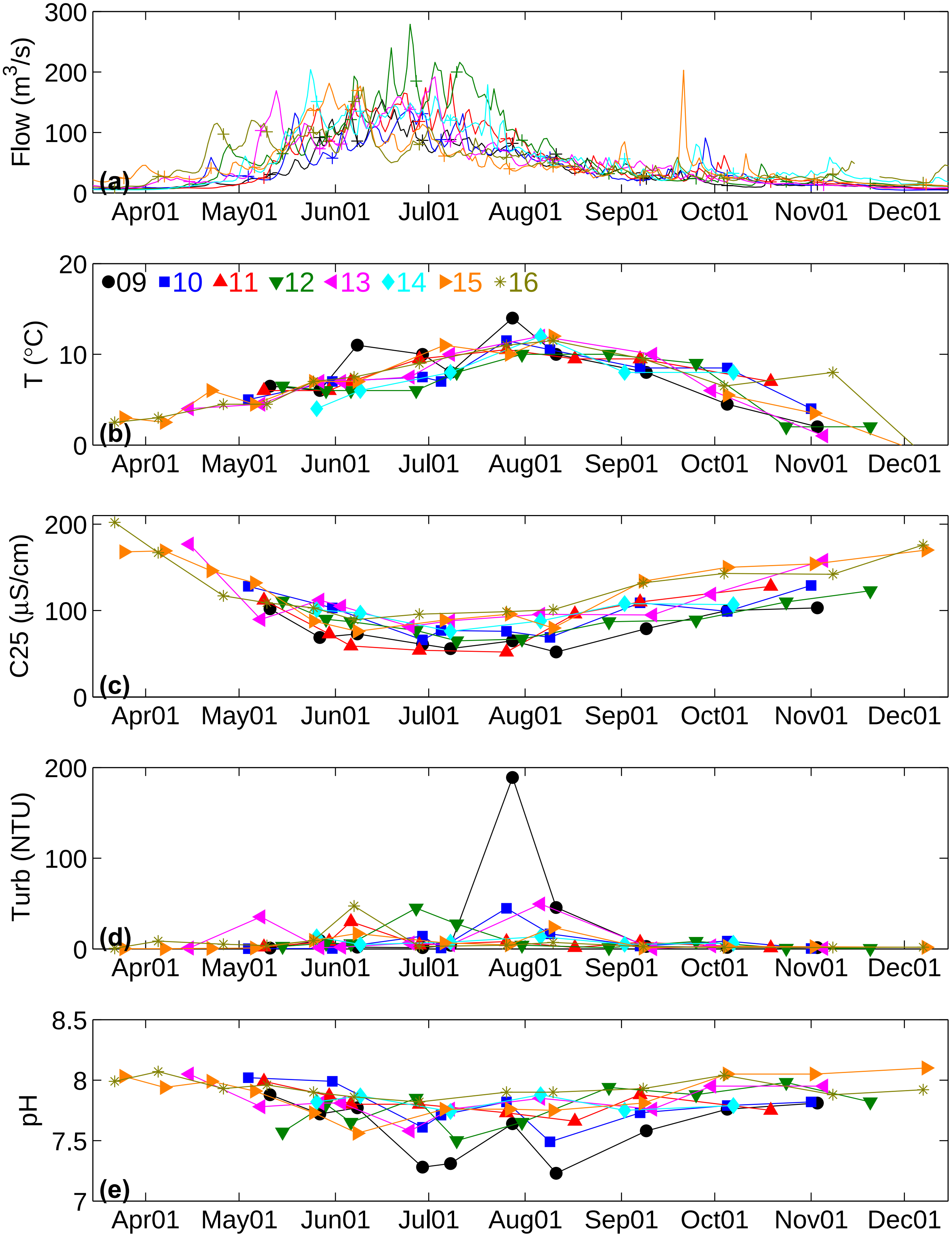

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Figure 3.2 con't Goldstream River: 09, 10, 11, 12, 13, 14 15 & 16

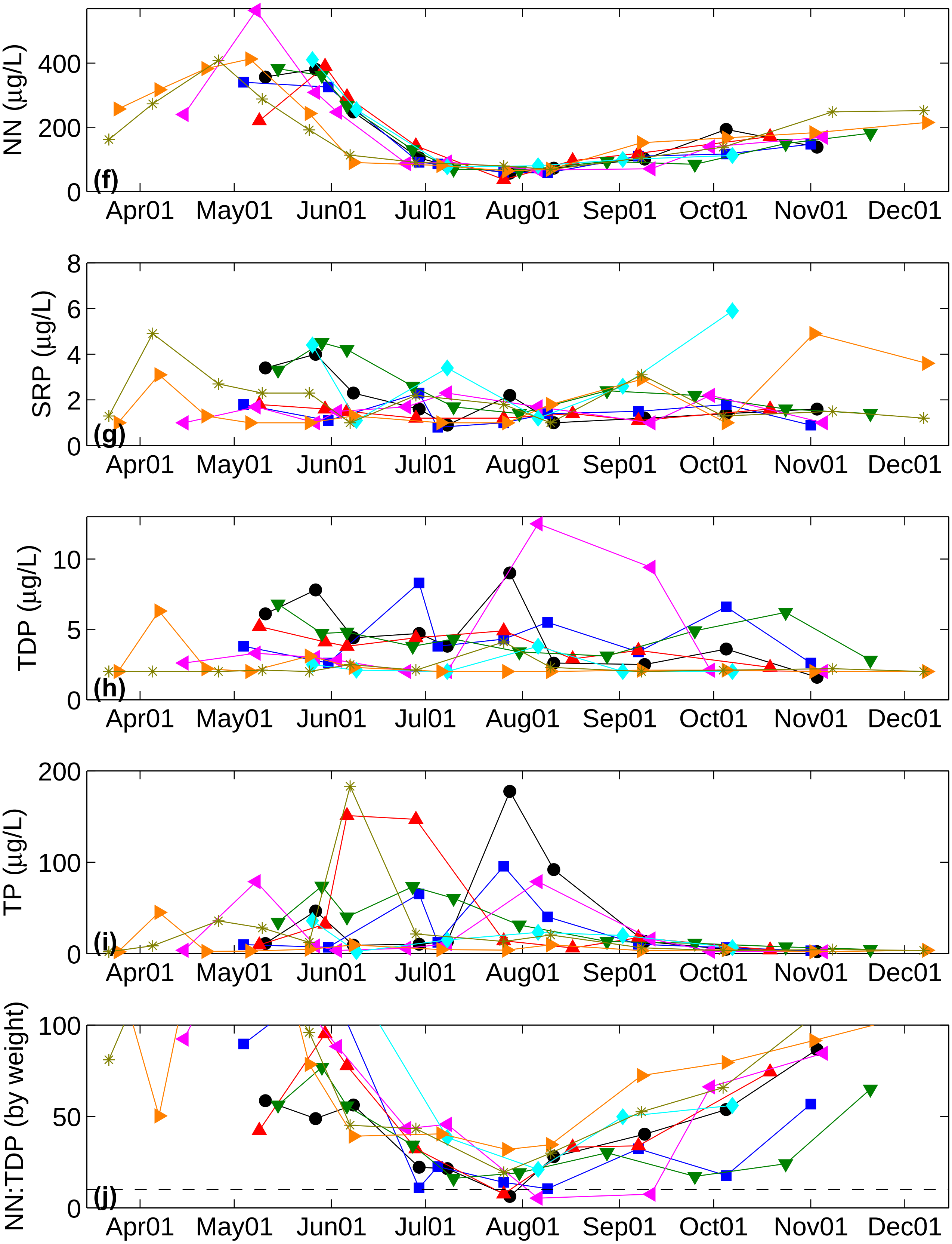

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Figure 3.3 Beaver River: 09, 10, 11, 12, 13, 14 15 & 16

all near East Park Gate except (+) near confluence

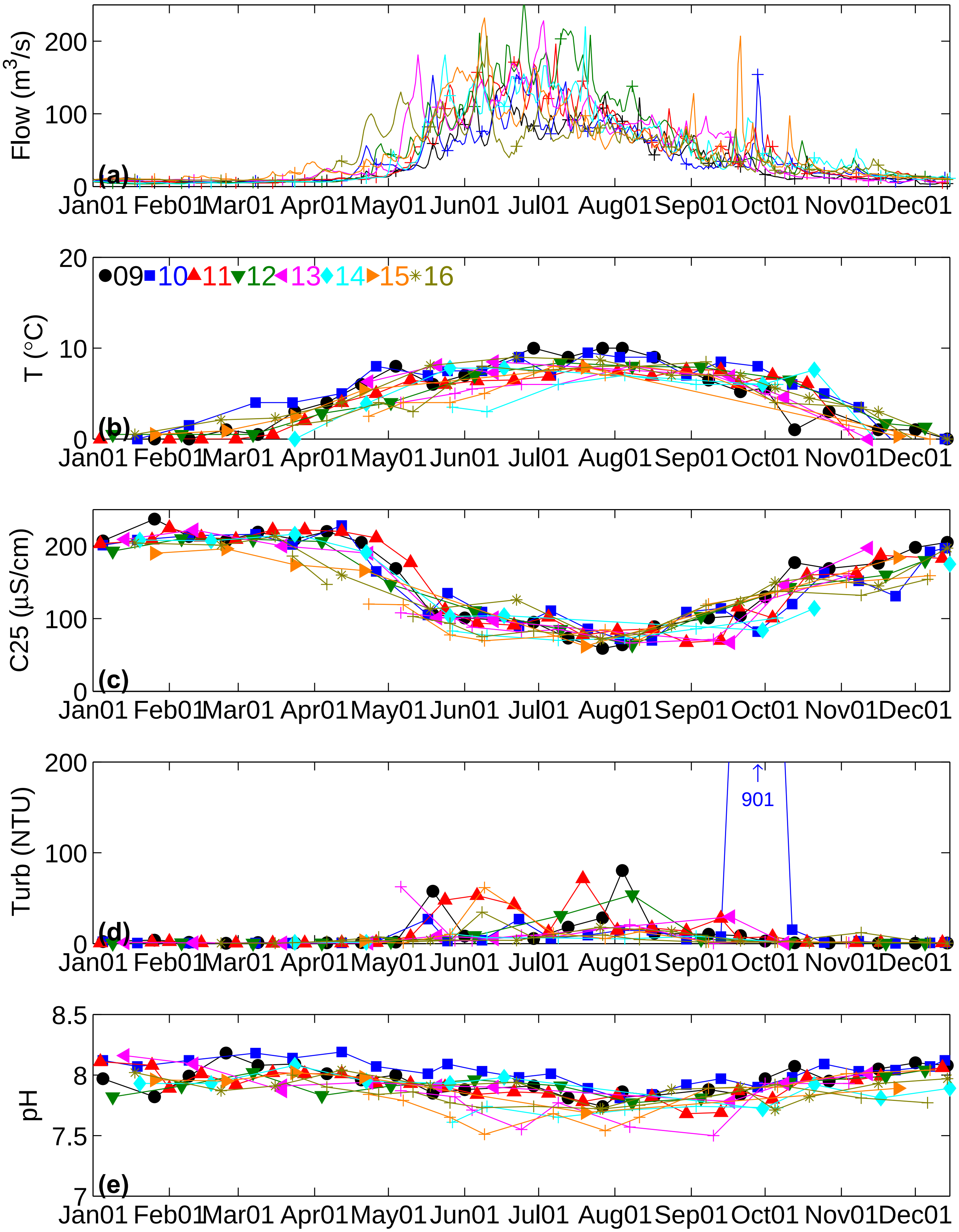

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Figure 3.3 con't Beaver River: 09, 10, 11, 12, 13, 14 15 & 16
all near East Park Gate except (+) near confluence

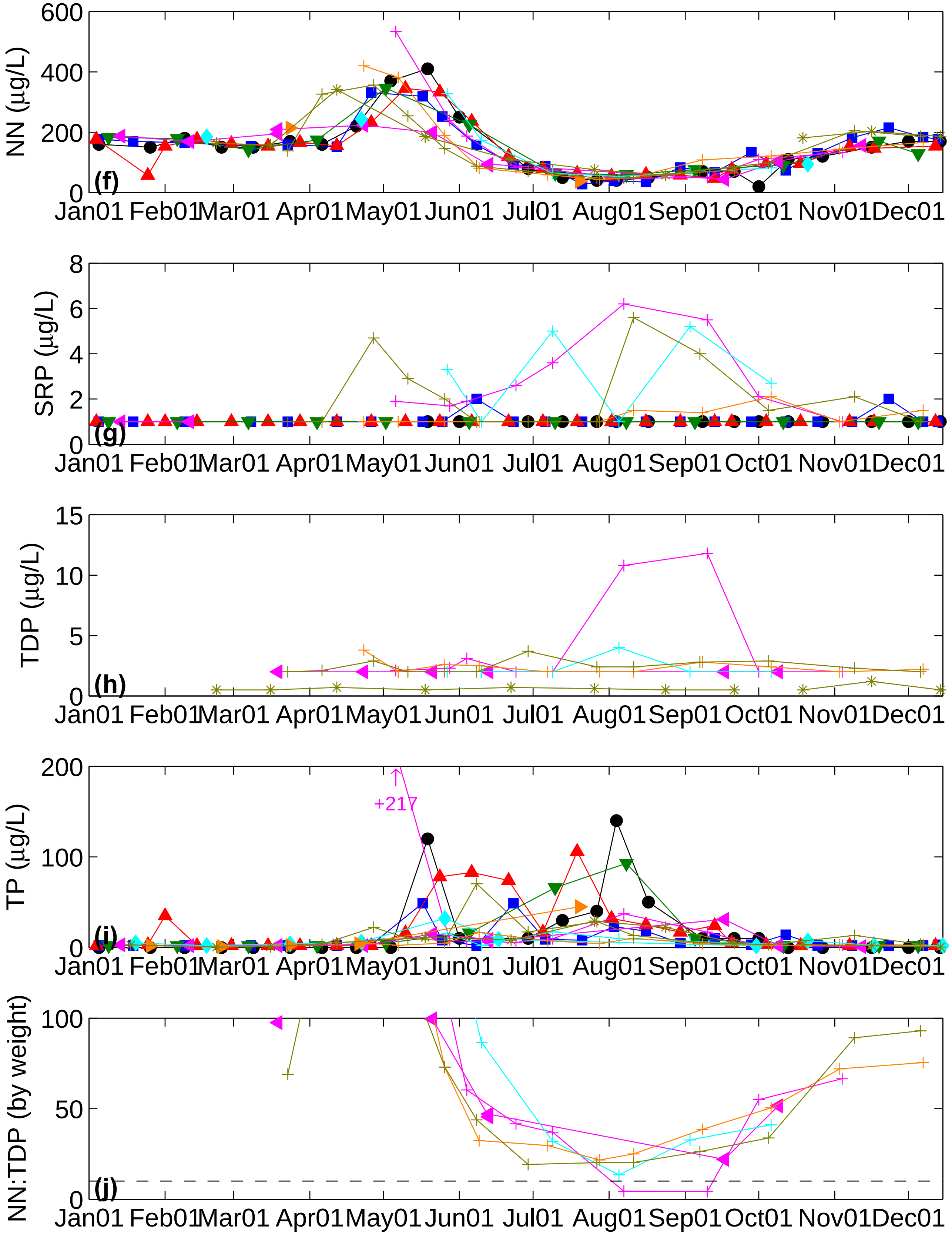

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Figure 3.4 Kinbasket Outflow: 09, 10, 11, 12, 13, 14 15 & 16

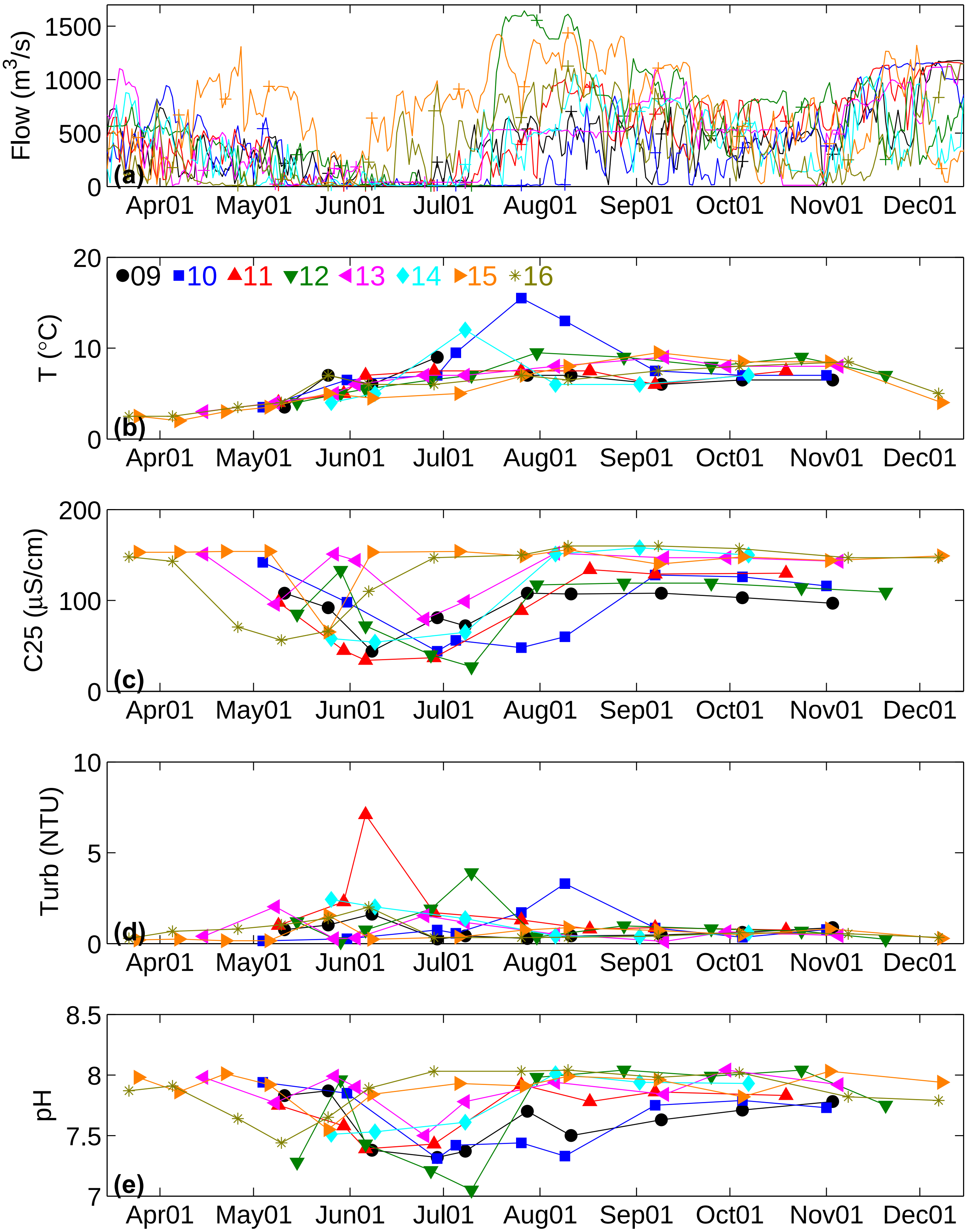

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Figure 3.4 con't Kinbasket Outflow: 09, 10, 11, 12, 13, 14 15 & 16

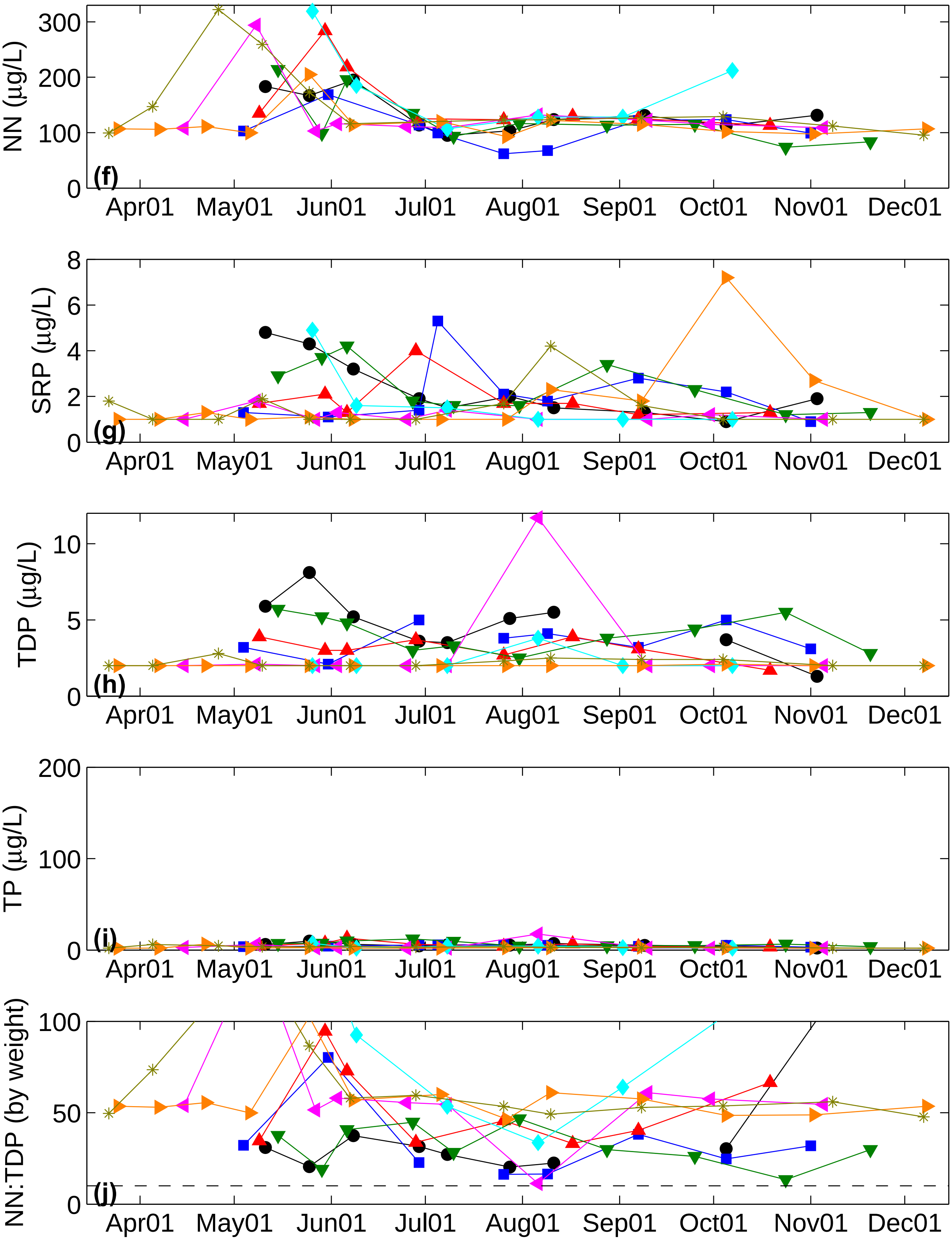

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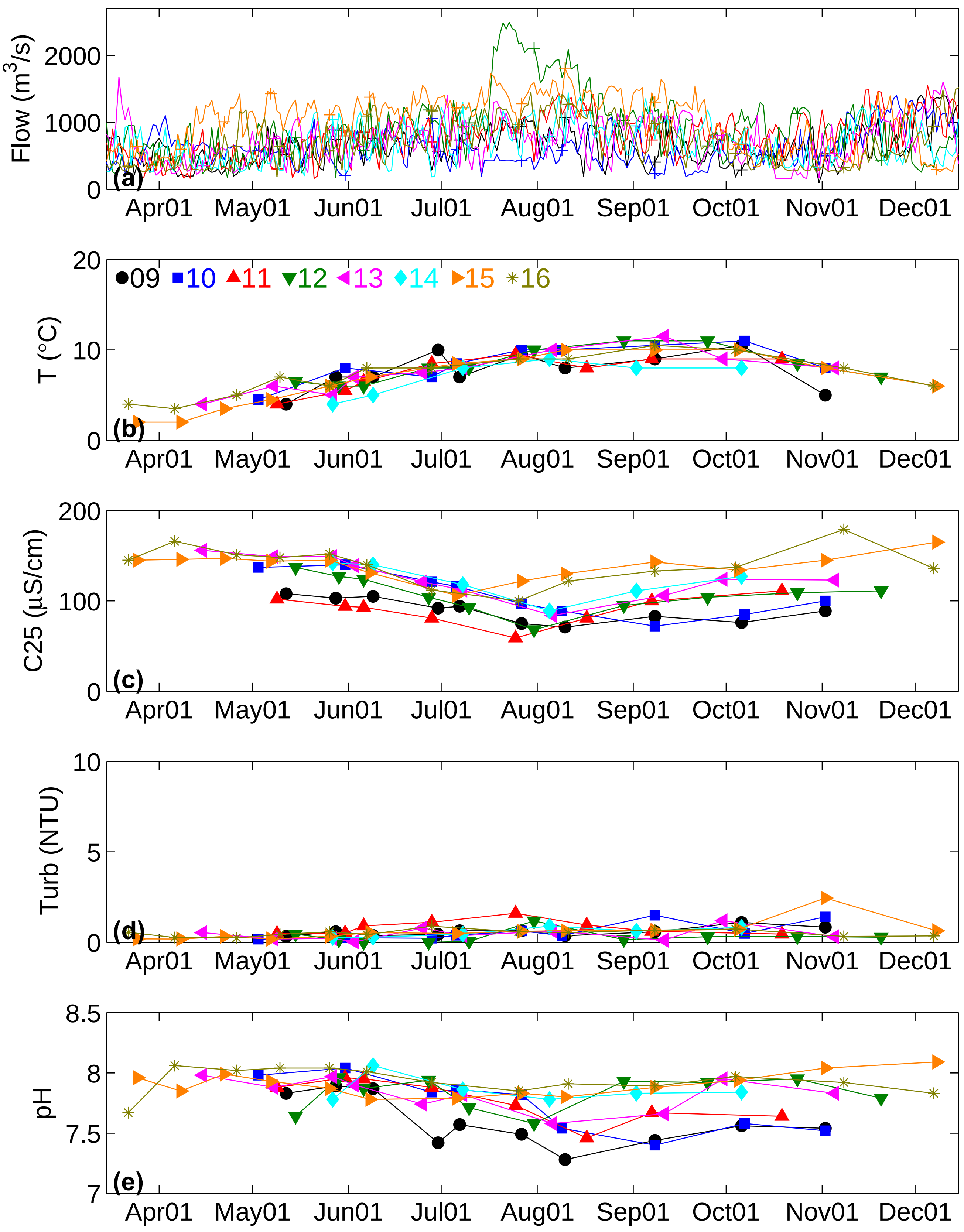
Figure 3.5 Revelstoke Outflow: 09, 10, 11, 12, 13, 14 15 & 16



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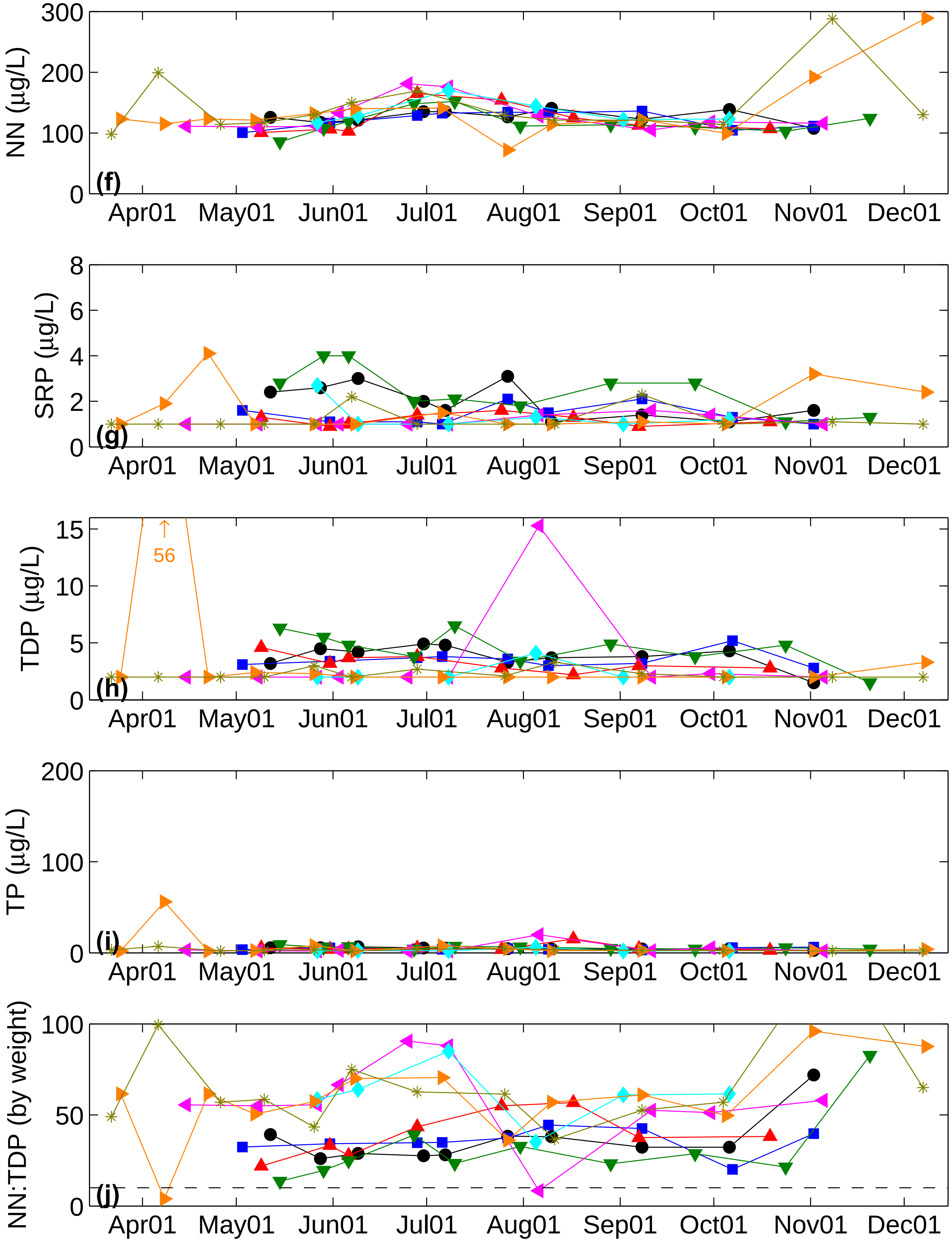

Figure 3.5 con't Revelstoke Outflow: 09, 10, 11, 12, 13, 14 15 & 16

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Figure 3.6 Downie Creek: 09, 10, 11, 12, 13, 14 15 & 16

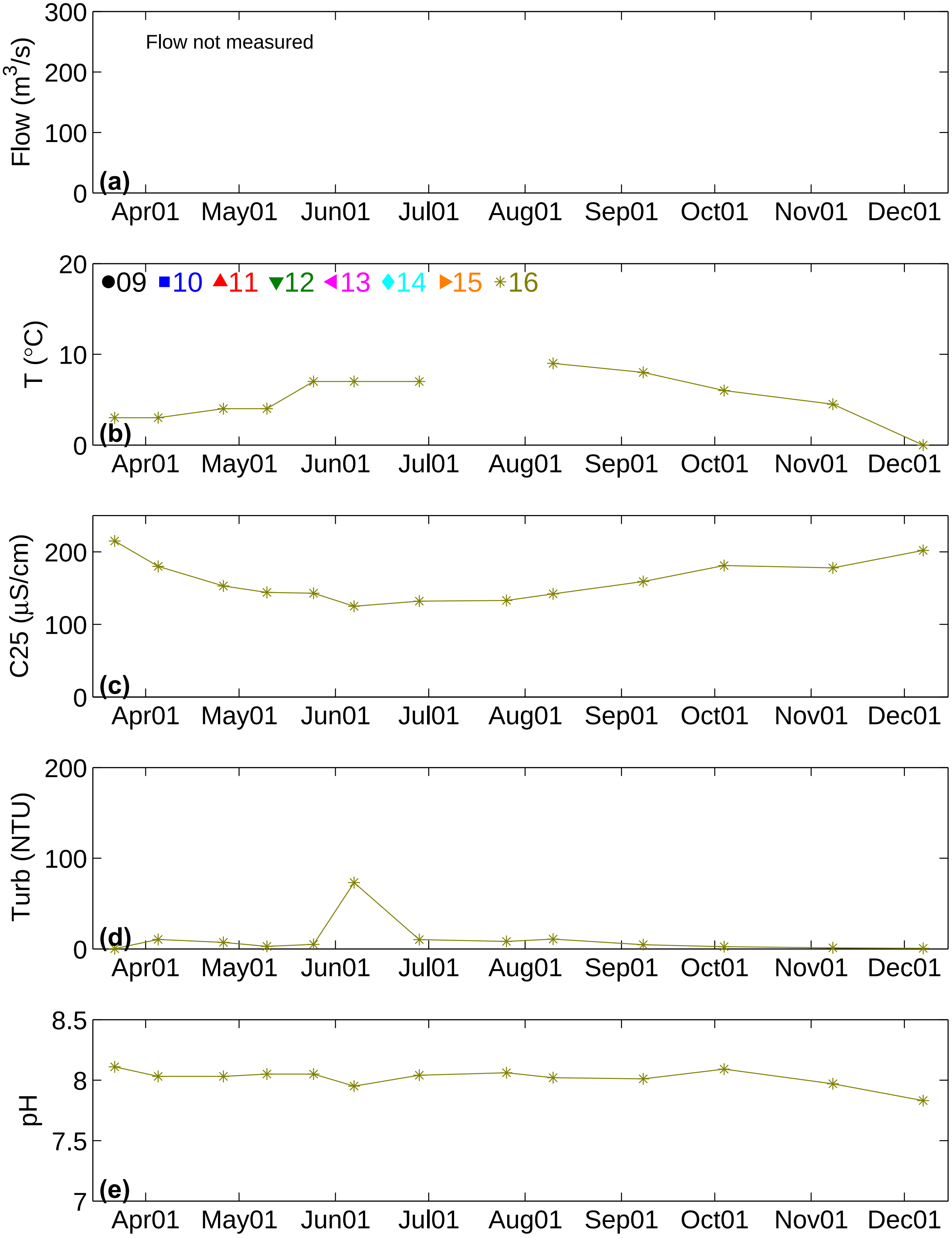

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Figure 3.6 con't Downie Creek: 09, 10, 11, 12, 13, 14 15 & 16

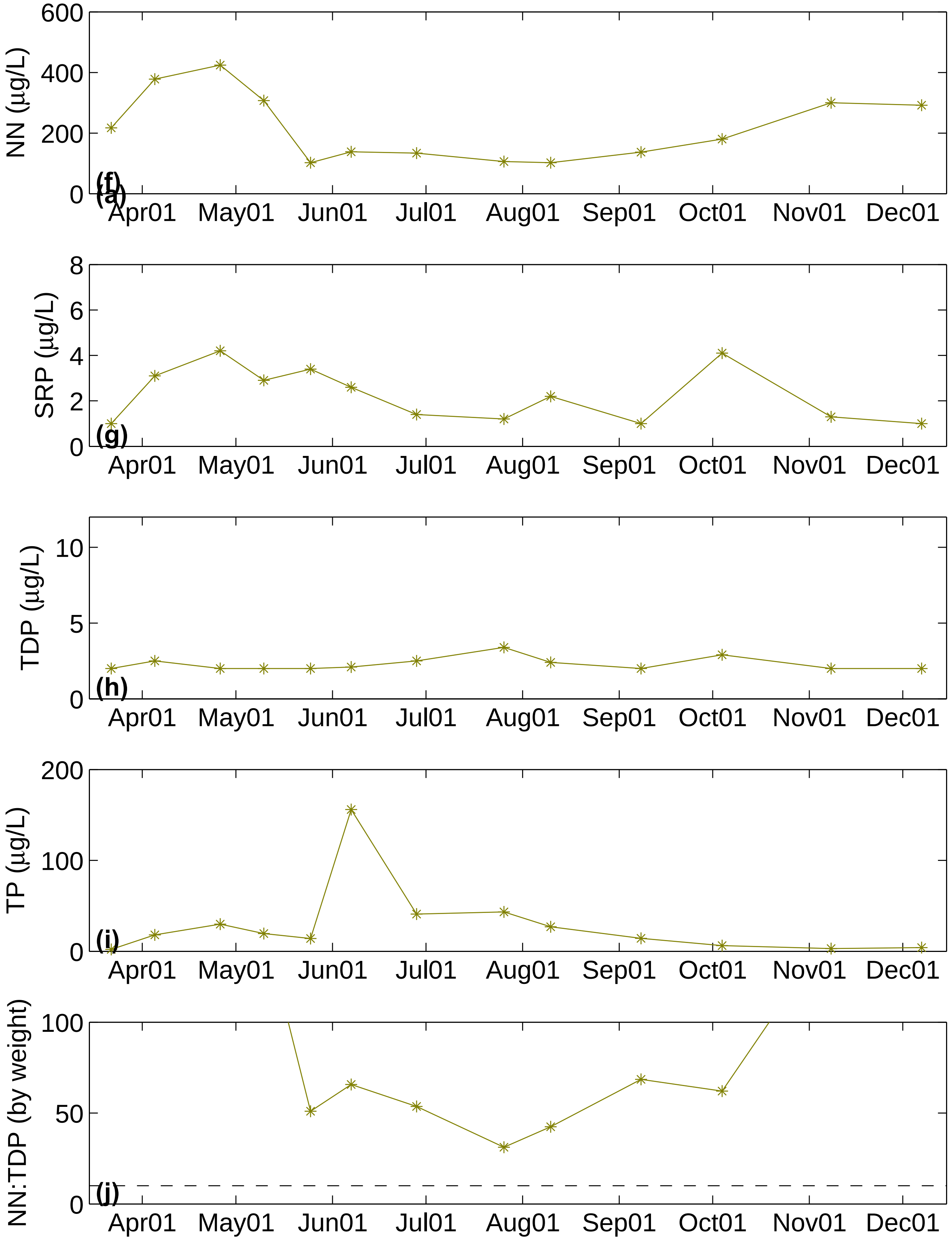

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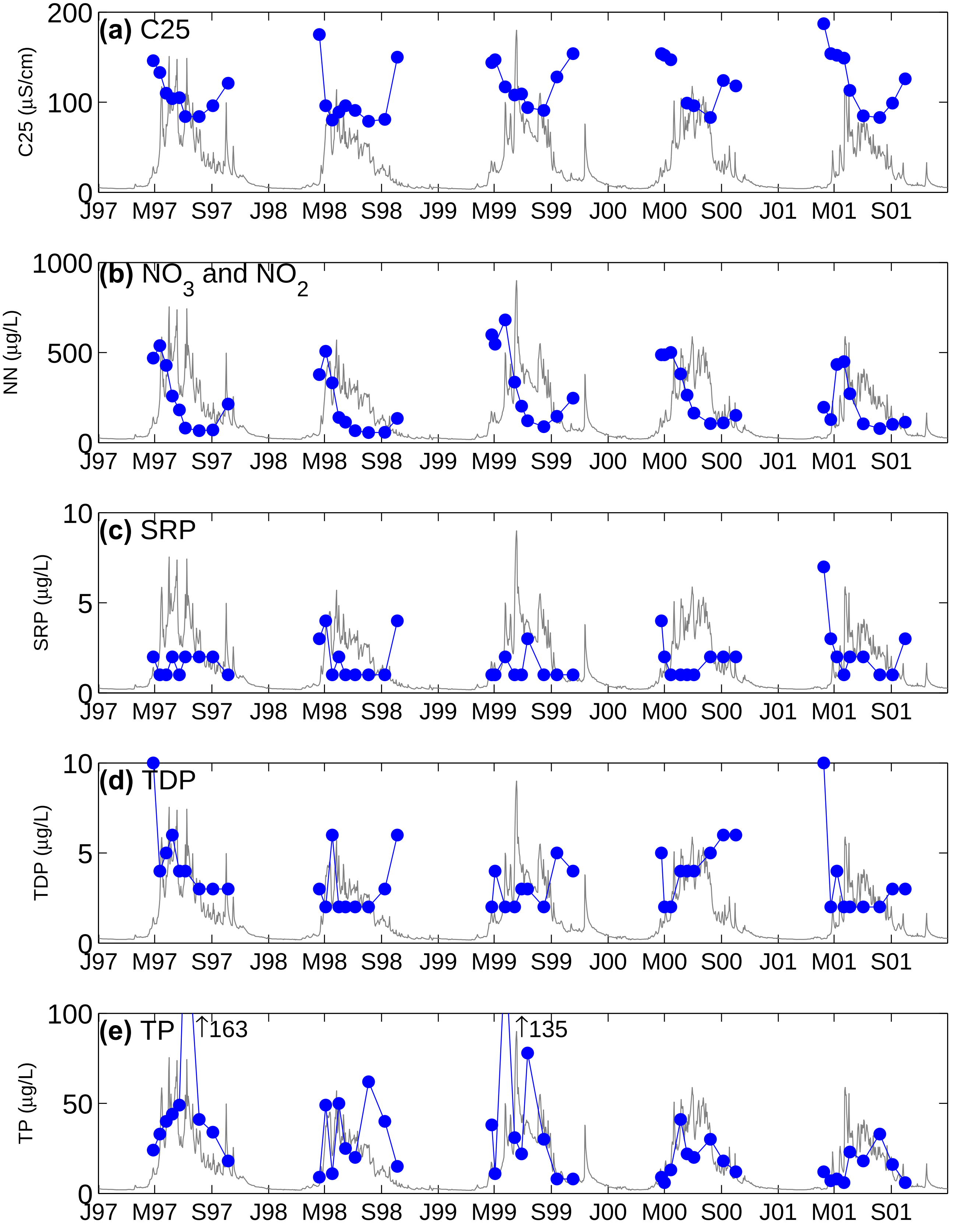
Figure 3.7 Water quality of Illecillewaet River, 1997−2001



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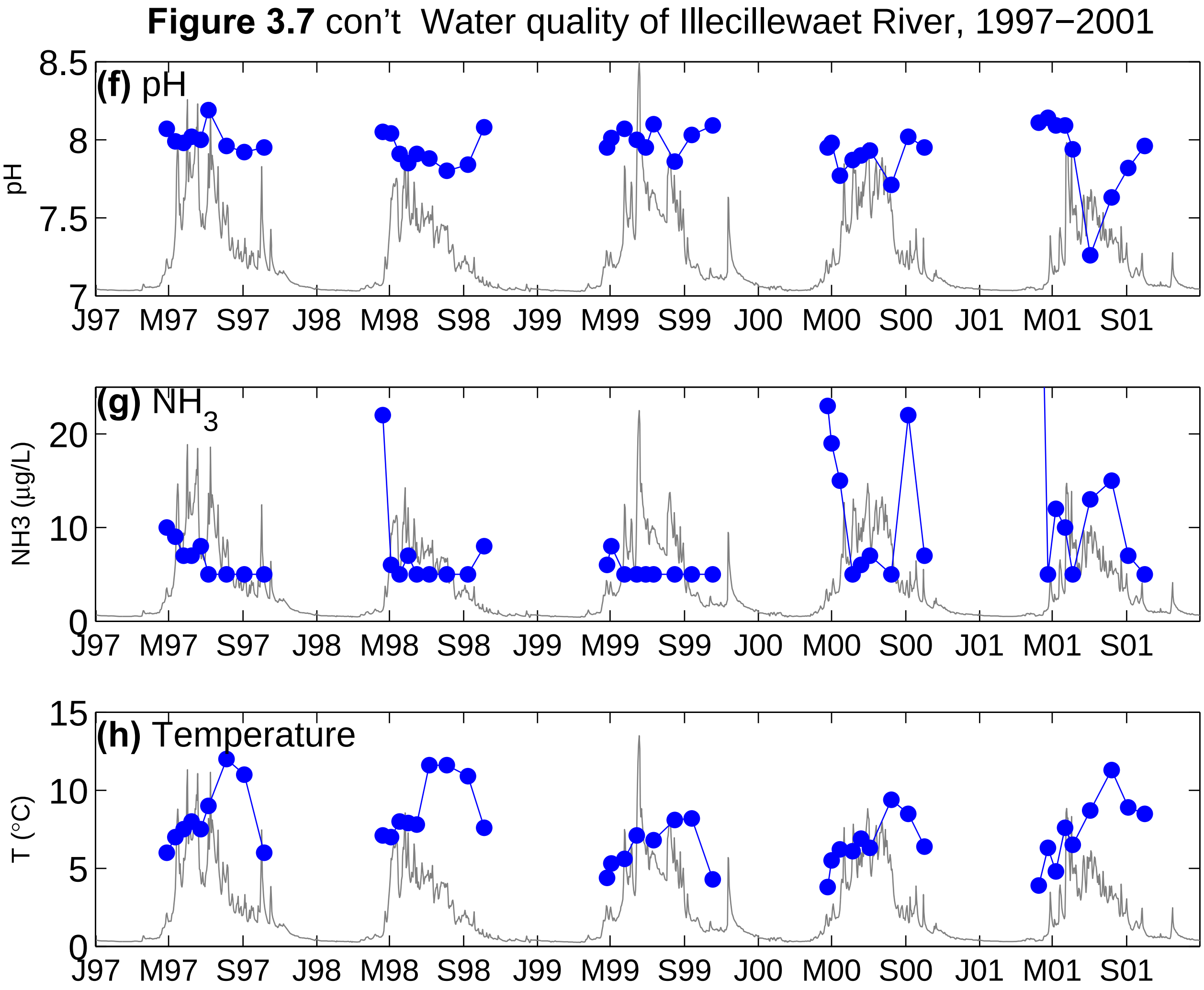
Figure 3.7 con't Water quality of Illecillewaet River, 1997−2001

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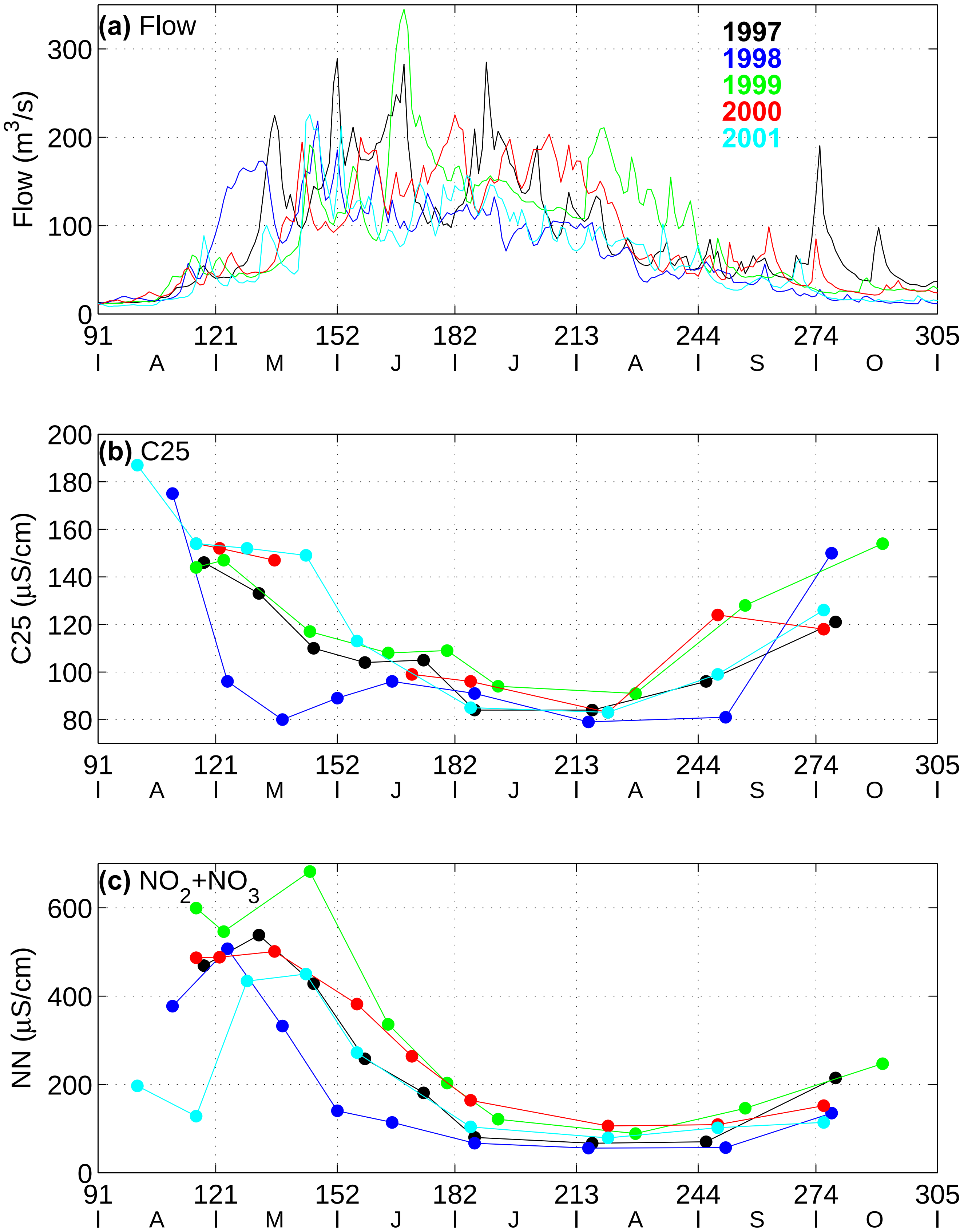
Figure 3.8 Flow, C25 and NN in the Illecillewaet River, 1997−2001



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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° 29.0 117° 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° 30.58 117° 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° 41.5 117° 42.5	542
Bush Arm		
Bush River	51° 47.5 117° 22.4	1032
Prattle Creek	51 ° 47.3 117 ° 25.4	199
Chatter Creek	51 ° 47.1 117 ° 26.3	102
Succour Creek (new in 2013)	51°45.014 117°35.631	*~50*
Columbia Reach		
Windy Creek	51° 52.5 118° 01.2	243
Sullivan River	51° 57.2 117° 51.4	593
Kinbasket River	51° 58.5 117° 57.5	*160*
Cummins	52° 03.1 118° 09.5	268
Wood Arm		
Wood River	52° 12.2 118° 10.3	451
Canoe Reach		
Canoe River	52° 46.4 119° 09.6	611

Dave Henry Creek	52° 44.4 119° 05.6	96
Yellowjacket Creek	52° 42.1 119° 03.1	104
Bulldog Creek	52° 38.4 118° 58.5	107
Ptarmigan Creek	52° 35.0 118° 39.5	295
Hugh Allan Creek	52° 26.4 118° 39.5	626
Foster Creek	52° 15.2 118° 38.1	187
Dawson Creek	52° 15.6 118° 29.5	108
Molson Creek	52° 10.4 118° 21.8	77

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

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

Table A2-2 Tributaries to Revelstoke Reservoir

Name	**Lat Long**	**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	TN	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)	(ug/L)	(NTU)	(mgCaCO3/L)	(°C)	
Columbia at Donald	1	06/24/2008	8.06	160	63.2	NaN	2.7	10.7	43.0	25.5	17.5	19.2	83	11.5	B
Columbia at Donald	1	05/12/2009	8.26	220	142.3	NaN	3.2	6	12.8	3.1	9.7	6.08	132	10.0	TM
Columbia at Donald	1	05/28/2009	8.14	156	191.9	NaN	4.6	6.4	9.7	3.7	6	28	100	12.0	TB
Columbia at Donald	1	06/09/2009	8.05	135	100.6	NaN	2.6	7.2	46.5	NaN	NaN	15.8	83	11.0	TB
Columbia at Donald	1	06/30/2009	7.78	135	48	NaN	2.5	6.8	18	3.4	14.6	3.8	79.2	14.0	TB
Columbia at Donald	1	07/07/2009	7.83	130	51.8	NaN	3.5	7.2	25.4	5.8	19.6	19.2	77	15.0	MB
Columbia at Donald	1	07/27/2009	7.97	112	44.3	NaN	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	NaN	1.9	6.5	60.6	33.8	26.8	38.1	73	15.0	TM
Columbia at Donald	1	09/08/2009	7.83	127	60	NaN	1.7	6.3	28	17	11	29.6	78.4	11.0	MB
Columbia at Donald	1	10/06/2009	8	164	99.6	NaN	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	NaN	1.9	2.5	4.8	1.9	2.9	1.7	114.2	3.0	C
Columbia at Donald	1	05/03/2010	8.25	244	141.5	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	2.1	6.5	28.5	3.5	25.1	13.5	86	13.0	TB
Columbia at Donald	1	07/25/2011	8.04	108	25.0	NaN	1.5	4.4	13.1	3.5	9.6	15.0	78.6	15.0	TB
Columbia at Donald	1	08/17/2011	7.93	163	46.2	NaN	2.1	10.6	29.4	9.7	19.7	17.5	79.5	11.0	TB
Columbia at Donald	1	09/07/2011	8.12	195	60.0	NaN	1.3	4.8	34.4	8.7	25.6	9.8	95.5	11.0	TB
Columbia at Donald	1	10/19/2011	8.12	231	82.3	NaN	2.0	3.5	11.9	**	NaN	5.9	108.5	4.0	TB
Columbia at Donald	1	05/15/2012	8.14	243	143.0	NaN	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	NaN	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	NaN	n/a
Columbia at Donald	1	06/27/2012	8.13	171	38.0	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	1.1	2.3	4.7	NaN	NaN	2.6	145	5.0	GC
Columbia at Donald	1	05/09/2013	8.22	258	226	NaN	2.2	<2.00	14.4	NaN	NaN	45.2	114	10.0	B
Columbia at Donald	1	05/28/2013	8.11	221	124	NaN	1.0	<2.00	14.4	NaN	NaN	5.46	94	10.0	MG
Columbia at Donald	1	06/04/2013	8.02	222	105	NaN	4.9	8.7	12.4	NaN	NaN	8.49	95.8	11.0	GB
Columbia at Donald	1	06/24/2013	7.92	186	45.3	NaN	4.4	2.1	58.3	NaN	NaN	28.4	79.7	13.0	B
Columbia at Donald	1	07/09/2013	7.99	179	18.5	NaN	<1.00	<2.00	22.5	NaN	NaN	19.7	77.8	15.0	B
Columbia at Donald	1	08/07/2013	8.03	174	42.5	NaN	6.8	7.4	47.6	NaN	NaN	44	74.6	14.0	MB
Columbia at Donald	1	09/10/2013	7.88	176	62.9	NaN	<1.00	45.7	48.8	NaN	NaN	0.13	71.1	12.0	B
Columbia at Donald	1	10/01/2013	8.16	245	68.5	NaN	2.3	<2.00	6.9	NaN	NaN	11.1	97.8	8.0	B
Columbia at Donald	1	11/04/2013	8.15	282	86.8	NaN	1.2	<2.00	2.4	NaN	NaN	1.74	112	1.5	C
Columbia at Donald	1	05/27/2014	8.08	201	206.0	NaN	4.9	<2.00	60.5	NaN	NaN	46.1	87.9	8.0	B
Columbia at Donald	1	06/10/2014	8.15	203	97.6	NaN	<1.00	3.5*	2.6	NaN	NaN	29.8	87.3	10.0	B
Columbia at Donald	1	07/09/2014	7.96	172	29.9	NaN	2.6	<2.00	22.3	NaN	NaN	11.6	72.0	15.0	B
Columbia at Donald	1	08/05/2014	8.06	176	45.8	NaN	<1.00	3.6	16.7	NaN	NaN	9.3	72.0	14.0	B
Columbia at Donald	1	09/03/2014	8.04	202	62.9	NaN	6.2	<2.00	9.5	NaN	NaN	13.4	78.5	10.0	MG
Columbia at Donald	1	10/06/2014	8.04	242	78.2	NaN	2.8	<2.00	3.0	NaN	NaN	2.89	93.8	7.0	GC

		Date	pH	Cond	NN	TN	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)	(ug/L)	(NTU)	(mgCaCO3/L)	(°C)	
Columbia at Donald	1	03/25/2015	8.15	328	117.0	NaN	1.4	<2.00	4.4	NaN	NaN	1.91	136.0	3.0	MG
Columbia at Donald	1	04/08/2015	8.15	329	128.0	NaN	<1.00	5.0	7.7	NaN	NaN	1.33	131.0	3.5	GC
Columbia at Donald	1	04/23/2015	8.24	319	133.0	NaN	1.7	<2.00	3.4	NaN	NaN	2.43	135.0	8.0	GC
Columbia at Donald	1	05/07/2015	8.16	277	185.0	NaN	<1.00	<2.00	4.2	NaN	NaN	2.01	112.0	8.5	GB
Columbia at Donald	1	05/26/2015	8.03	187	167.0	NaN	1.3	<2.00	8.8	NaN	NaN	28.9	80.9	9.0	B
Columbia at Donald	1	06/09/2015	7.92	181	56.6	NaN	<1.00	<2.00	17.1	NaN	NaN	66.2	76.1	12.0	B
Columbia at Donald	1	07/07/2015	7.98	171	44.0	NaN	<1.00	2.0	9.5	NaN	NaN	15.4	68.7	15.5	B
Columbia at Donald	1	07/28/2015	7.93	165	38.3	NaN	<1.00	<2.00	10.0	NaN	NaN	16.9	66.6	12.0	GB
Columbia at Donald	1	08/11/2015	8.01	176	50.9	NaN	1.6	<2.00	11.2	NaN	NaN	21.1	72.0	14.5	GB
Columbia at Donald	1	09/08/2015	8.10	229	85.2	NaN	1.2	3.3	6.3	NaN	NaN	5.39	87.9	7.0	MG
Columbia at Donald	1	10/06/2015	8.09	248	89.3	NaN	1.7	2.2	3.4	NaN	NaN	4.35	93.9	7.0	M
Columbia at Donald	1	11/03/2015	8.17	272	106.0	NaN	1.9	<2.00	2.3	NaN	NaN	2.05	108.0	3.0	GC
Columbia at Donald	1	12/07/2015	8.26	305	141.0	NaN	7.0	<2.00	2.9	NaN	NaN	2.37	128.0	-1.0	C 3/4F
Columbia at Donald	1	03/22/2016	8.22	359	113	NaN	2.5	<2.0	<2.0	NaN	NaN	2.52	146.0	3.5	C
Columbia at Donald	1	04/05/2016	8.26	347	122	NaN	1.4	2.0	11.4	NaN	NaN	16.10	108.0	5.5	MG
Columbia at Donald	1	04/26/2016	8.16	222	246	342	5.3	<2.0	26.9	NaN	NaN	16.80	99.6	7.5	8i
Columbia at Donald	1	05/10/2016	8.15	201	165	258	4.5	2.3	22.7	NaN	NaN	6.87	86.7	8	TB
Columbia at Donald	1	05/25/2016	8.17	204	223	246	3.9	<2.0	20.5	NaN	NaN	17.80	87.2	12	GB
Columbia at Donald	1	06/07/2016	8.11	187	77.6	167	<1.0	<2.0	39.1	NaN	NaN	34.80	80.4	13	MB
Columbia at Donald	1	06/28/2016	8.14	192	69.5	121	4.4	<2.0	11.7	NaN	NaN	11.00	77.7	13	MG
Columbia at Donald	1	07/26/2016	8.15	189	55.1	108	2.9	2.4	44.9	NaN	NaN	14.90	73.3	15	TB
Columbia at Donald	1	08/10/2016	8.08	190	57	228	<1.0	3.2	18.8	NaN	NaN	6.48	74.0	14	MG
Columbia at Donald	1	09/06/2016	8.10	220	70.6	232	<1.0	<2.0	15.6	NaN	NaN	5.30	83.4	12	M
Columbia at Donald	1	10/04/2016	8.16	244	78.9	201	4.9	<2.0	8.2	NaN	NaN	5.83	91.8	7	M
Columbia at Donald	1	11/08/2016	8.06	288	117	244	2.3	2.1	5.7	NaN	NaN	2.66	116.0	3.5	C
Columbia at Donald	1	12/05/2016	8.09	302	143	249	<1.0	<2.0	4.7	NaN	NaN	3.05	127.0	-1	C/I
Columbia at Mica Outflow	2	06/24/2008	7.80	108	114.0	NaN	2.9	5.8	8.7	0.9	7.8	0.74	52	7.0	n/a
Columbia at Mica Outflow	2	05/11/2009	7.83	108	183.2	NaN	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	NaN	4.3	8.1	9.8	0.1	9.8	1.02	55	7.0	C
Columbia at Mica Outflow	2	06/08/2009	7.38	44	194.6	NaN	3.2	5.2	6.2	0.1	6.2	1.62	22	6.0	TB
Columbia at Mica Outflow	2	06/29/2009	7.32	81	113.6	NaN	1.9	3.6	4.5	0.1	4.5	0.25	48.1	9.0	C
Columbia at Mica Outflow	2	07/08/2009	7.37	72	95.1	NaN	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	NaN	2	5.1	5.4	0.1	5.4	0.29	71	7.0	C
Columbia at Mica Outflow	2	08/11/2009	7.5	107	123.6	NaN	1.5	5.5	7.1	0.1	7.1	0.42	70	7.0	C
Columbia at Mica Outflow	2	09/09/2009	7.63	108	130.7	NaN	1.3	NaN	5.1	0.1	5.1	0.48	70	6.0	C
Columbia at Mica Outflow	2	10/05/2009	7.71	103	112.5	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	2.9	5.7	7.2	1.1	6.1	1.20	37.3	4.0	C

		Date	pH	Cond	NN	TN	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)	(ug/L)	(NTU)	(mgCaCO3/L)	(°C)	
Columbia at Mica Outflow	2	05/28/2012	7.96	133	98.9	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	<1.00	2.0	2.9	NaN	NaN	0.4	66	3.0	C
Columbia at Mica Outflow	2	05/08/2013	7.77	95.9	294	NaN	1.8	2.1	6.1	NaN	NaN	2.03	40.2	4.0	LB
Columbia at Mica Outflow	2	05/27/2013	7.99	151	103	NaN	<1.00	2.4*	<2.00	NaN	NaN	0.27	62.9	5.0	C
Columbia at Mica Outflow	2	06/03/2013	7.9	144	116	NaN	1.3	<2.00	2.6	NaN	NaN	0.3	59.6	6.0	C
Columbia at Mica Outflow	2	06/25/2013	7.5	79.4	111	NaN	<1.00	<2.00	<2.00	NaN	NaN	1.54	29	7.0	C
Columbia at Mica Outflow	2	07/08/2013	7.78	99	109	NaN	1.4	<2.00	<2.00	NaN	NaN	1.17	39.4	7.0	C
Columbia at Mica Outflow	2	08/06/2013	7.94	152	132	NaN	1.0	11.7	17.5	NaN	NaN	0.51	66.4	8.0	C
Columbia at Mica Outflow	2	09/10/2013	7.84	147	122	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.12	62.8	9.0	C
Columbia at Mica Outflow	2	09/30/2013	8.04	147	115	NaN	1.2	<2.00	<2.00	NaN	NaN	0.65	62.8	8.0	C
Columbia at Mica Outflow	2	11/05/2013	7.92	143	109	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.44	58.9	8.0	C
Columbia at Mica Outflow	2	05/26/2014	7.51	58	319.0	NaN	4.9	<2.00	7.4	NaN	NaN	2.43	17.2	4.0	C
Columbia at Mica Outflow	2	06/09/2014	7.53	54	185.0	NaN	1.6	<2.00	<2.00	NaN	NaN	2.02	16.7	5.0	LB
Columbia at Mica Outflow	2	07/08/2014	7.61	65	107.0	NaN	1.5	<2.00	4.2	NaN	NaN	1.38	25.5	12.0	C
Columbia at Mica Outflow	2	08/06/2014	8.01	151	128.0	NaN	<1.00	3.8	4.2	NaN	NaN	0.42	63.8	6.0	C
Columbia at Mica Outflow	2	09/02/2014	7.94	158	128.0	NaN	<1.00	<2.00	2.6	NaN	NaN	0.38	64.0	6.0	C
Columbia at Mica Outflow	2	10/07/2014	7.93	150	212.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.59	63.1	7.0	C
Columbia at Mica Outflow	2	03/25/2015	7.98	153.0	107.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.20	63.0	2.5	C
Columbia at Mica Outflow	2	04/07/2015	7.86	153.0	106.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.25	60.9	2.0	C
Columbia at Mica Outflow	2	04/22/2015	8.01	154.0	111.0	NaN	1.3	<2.00	6.4	NaN	NaN	0.16	63.7	3.0	C
Columbia at Mica Outflow	2	05/06/2015	7.92	154.0	99.8	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.16	63.1	3.5	C
Columbia at Mica Outflow	2	05/25/2015	7.55	65.3	205.0	NaN	1.1	2.0	2.7	NaN	NaN	1.56	22.5	5.0	C
Columbia at Mica Outflow	2	06/08/2015	7.84	153	114.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.24	63.3	4.5	LB
Columbia at Mica Outflow	2	07/06/2015	7.93	154	120.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.36	64.1	5.0	C
Columbia at Mica Outflow	2	07/27/2015	7.91	149	92.9	NaN	<1.00	<2.00	2.5	NaN	NaN	0.75	60.9	7.0	C
Columbia at Mica Outflow	2	08/10/2015	7.99	156	122.0	NaN	2.3	<2.00	2.5	NaN	NaN	0.88	67.1	8.0	C
Columbia at Mica Outflow	2	09/08/2015	7.96	140	115.0	NaN	1.8	2.0	3.1	NaN	NaN	0.72	57.4	9.5	C
Columbia at Mica Outflow	2	10/05/2015	7.82	148	102.0	NaN	7.2	2.1	2.3	NaN	NaN	0.49	58.0	8.5	C
Columbia at Mica Outflow	2	11/02/2015	8.03	144	97.6	NaN	2.7	<2.00	<2.00	NaN	NaN	0.81	59.6	8.5	C
Columbia at Mica Outflow	2	12/08/2015	7.94	149	107.0	NaN	<1.00	<2.00	2.1	NaN	NaN	0.29	62.6	4.0	C
Columbia at Mica Outflow	2	03/21/2016	7.87	148	99.3	NaN	1.8	<2.0	<2.0	NaN	NaN	0.29	62.5	2.5	C
Columbia at Mica Outflow	2	04/04/2016	7.91	143	147	NaN	<1.0	<2.0	6.0	NaN	NaN	0.68	59.3	2.5	C
Columbia at Mica Outflow	2	04/25/2016	7.64	70.7	322	344	<1.0	4.6	2.8	NaN	NaN	0.80	25.7	3.5	C
Columbia at Mica Outflow	2	05/09/2016	7.44	56.2	259	297	1.9	<2.0	3.8	NaN	NaN	1.03	16.7	4	C
Columbia at Mica Outflow	2	05/24/2016	7.65	66.2	173	268	<1.0	<2.0	3.5	NaN	NaN	1.39	24.0	7	C
Columbia at Mica Outflow	2	06/06/2016	7.89	110	116	154	<1.0	<2.0	4.0	NaN	NaN	2.01	45.1	6	C
Columbia at Mica Outflow	2	06/27/2016	8.03	147	119	156	<1.0	<2.0	3.1	NaN	NaN	0.33	61.5	6	C
Columbia at Mica Outflow	2	07/25/2016	8.03	150	123	176	1.7	2.3	3.8	NaN	NaN	0.33	59.9	7	C
Columbia at Mica Outflow	2	08/09/2016	8.04	160	123	201	4.2	2.5	3.0	NaN	NaN	0.35	66.5	6.5	C
Columbia at Mica Outflow	2	09/07/2016	7.98	160	127	535	1.6	2.4	2.4	NaN	NaN	0.41	63.9	7.5	C
Columbia at Mica Outflow	2	10/03/2016	8.02	157	129	280	<1.0	2.4	3.4	NaN	NaN	0.60	62.8	8	C
Columbia at Mica Outflow	2	11/07/2016	7.82	147	112	178	<1.0	2.2	<2.0	NaN	NaN	0.54	61.3	8.5	C
Columbia at Mica Outflow	2	12/06/2016	7.79	147	95.4	167	<1.0	<2.0	<2.0	NaN	NaN	0.34	61.8	5	C
Goldstream River	3	06/24/2008	7.73	75	1172.5	NaN	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	NaN	2.1	0.0	20.8	7.5	13.3	2.71	41	13.0	n/a
Goldstream River	3	05/11/2009	7.88	102	357.1	NaN	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	NaN	4	7.8	46.6	3.1	43.5	9.26	45	6.0	TB

		Date	pH	Cond	NN	TN	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)	(ug/L)	(NTU)	(mgCaCO3 /L)	(°C)	
Goldstream River	3	06/08/2009	7.77	73	247.7	NaN	2.3	4.4	9.1	0.6	8.5	1.86	46	11.0	TB
Goldstream River	3	06/29/2009	7.28	61	104.2	NaN	1.6	4.7	10.4	0.8	9.6	1.38	40	10.0	TB
Goldstream River	3	07/08/2009	7.31	56	81.2	NaN	0.9	3.8	13.1	1.6	11.5	4.11	37.5	8.0	C
Goldstream River	3	07/28/2009	7.64	65	57.2	NaN	2.2	9	177.3	116	61.3	189	40.5	14.0	TB
Goldstream River	3	08/11/2009	7.23	52	72.5	NaN	1	2.6	91.9	33	58.9	45.6	35	10.0	TB
Goldstream River	3	09/09/2009	7.58	79	100.8	NaN	1.2	2.5	13.3	3.7	9.6	2.55	51	8.0	C
Goldstream River	3	10/05/2009	7.76	100	193.4	NaN	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	NaN	1.6	1.6	2.2	0.1	2.2	1.35	67	2.0	C
Goldstream River	3	05/04/2010	8.02	128	340.4	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	1.4	3.4	31.3	5.9	25.4	4.04	37.2	10.0	TLB
Goldstream River	3	08/27/2012	7.94	87	93.3	NaN	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	NaN	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	NaN	1.6	6.2	7.4	<0.1	7.3	0.63	65	2.0	C
Goldstream River	3	11/19/2012	7.82	123	181.7	NaN	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	NaN	<1.00	2.6	3.7	NaN	NaN	1.07	80.8	4.0	GC
Goldstream River	3	05/08/2013	7.78	89.7	564	NaN	1.7	3.3	78.7	NaN	NaN	35.3	37.5	4.5	B
Goldstream River	3	05/27/2013	7.81	112	309	NaN	<1.00	3.0	8.5	NaN	NaN	1.3	50.2	7.0	GC
Goldstream River	3	06/03/2013	7.81	105	247	NaN	1.5	2.8	3.6	NaN	NaN	1.85	46.7	7.0	GC
Goldstream River	3	06/25/2013	7.58	81.5	86.7	NaN	1.7	<2.00	5.9	NaN	NaN	6.4	33.9	7.5	BG
Goldstream River	3	07/08/2013	7.76	88.2	91.2	NaN	2.3	<2.00	10.9	NaN	NaN	4.57	37.8	10.0	MG
Goldstream River	3	08/06/2013	7.85	95.7	66.9	NaN	1.7	12.5	78.7	NaN	NaN	49.5	43.7	12.0	MB
Goldstream River	3	09/11/2013	7.76	94.9	70.5	NaN	<1.00	9.4	16.0	NaN	NaN	0.24	39.8	10.0	B
Goldstream River	3	09/30/2013	7.95	119	139	NaN	2.2	2.1	2.7	NaN	NaN	3.4	51.2	6.0	GC
Goldstream River	3	11/05/2013	7.95	158	169	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.61	68.7	1.0	C
Goldstream River	3	05/26/2014	7.82	101	411.0	NaN	4.4	2.5	36.0	NaN	NaN	13.40	42.1	4.0	B
Goldstream River	3	06/09/2014	7.87	97	255.0	NaN	1.1	2.1	2.2	NaN	NaN	4.85	41.3	6.0	B
Goldstream River	3	07/08/2014	7.74	76	76.9	NaN	3.4	<2.00	14.9	NaN	NaN	7.48	33.3	8.0	MG
Goldstream River	3	08/06/2014	7.88	88	79.8	NaN	1.2	3.8	23.4	NaN	NaN	13.60	40.4	12.0	MG
Goldstream River	3	09/02/2014	7.75	108	99.7	NaN	2.6	<2.00	19.9	NaN	NaN	5.20	41.6	8.0	MG
Goldstream River	3	10/07/2014	7.79	107	112.0	NaN	5.9	2.0	6.7	NaN	NaN	6.22	41.6	8.0	MG
Goldstream River	3	03/25/2015	8.03	168	257.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.36	75.2	3.0	VC
Goldstream River	3	04/07/2015	7.94	169	317.0	NaN	3.1	6.3	45.1	NaN	NaN	0.33	73.7	2.5	C
Goldstream River	3	04/22/2015	7.99	146	383.0	NaN	1.3	2.5*	2.2	NaN	NaN	0.66	65.0	6.0	GC
Goldstream River	3	05/06/2015	7.91	132	413.0	NaN	<1.00	<2.00	2.8	NaN	NaN	0.91	56.8	4.5	MG

		Date	pH	Cond	NN	TN	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)	(ug/L)	(NTU)	(mgCaCO3/L)	(°C)	
Goldstream River	3	05/25/2015	7.73	87.8	243.0	NaN	<1.00	3.1	4.8	NaN	NaN	9.33	36.5	7.0	B
Goldstream River	3	06/08/2015	7.56	76.0	90.2	NaN	1.3	2.3	9.6	NaN	NaN	17.00	32.7	7.0	B
Goldstream River	3	07/06/2015	7.76	89.0	81.0	NaN	<1.00	<2.00	4.5	NaN	NaN	6.58	36.3	11.0	MG
Goldstream River	3	07/27/2015	7.76	95.8	63.8	NaN	<1.00	<2.00	3.9	NaN	NaN	4.44	38.2	10.0	MG
Goldstream River	3	08/10/2015	7.75	79.8	69.1	NaN	1.8	<2.00	9.8	NaN	NaN	23.70	34.1	12.0	GB
Goldstream River	3	09/08/2015	7.81	134	152.0	NaN	2.9	2.1	3.3	NaN	NaN	0.96	52.5	Not Taken	C
Goldstream River	3	10/05/2015	8.05	150	167.0	NaN	<1.00	2.1	4.3	NaN	NaN	2.89	62.8	5.5	GC
Goldstream River	3	11/02/2015	8.05	154	183.0	NaN	4.9	<2.00	2.0	NaN	NaN	2.37	66.6	3.5	C
Goldstream River	3	12/08/2015	8.10	170	215.0	NaN	3.6	2.0	3.7	NaN	NaN	1.77	76.8	-1.0	C 1/2F
Goldstream River	3	03/21/2016	7.99	202	162	NaN	1.3	<2.0	<2.0	NaN	NaN	0.69	90.7	2.5	C
Goldstream River	3	04/04/2016	8.07	167	273	NaN	4.9	<2.0	8.6	NaN	NaN	8.65	77.1	3	MGB
Goldstream River	3	04/25/2016	7.93	117	408	483	2.7	<2.0	35.9	NaN	NaN	5.12	52.8	4.5	TB
Goldstream River	3	05/09/2016	7.96	109	288	332	2.3	2.1	28.0	NaN	NaN	3.81	47.4	4.5	GB
Goldstream River	3	05/24/2016	7.90	103	192	273	2.3	<2.0	12.5	NaN	NaN	9.15	44.9	7	T
Goldstream River	3	06/06/2016	7.86	89.3	113	310	<1.0	2.5	183.0	NaN	NaN	47.40	42.1	7.5	TB
Goldstream River	3	06/27/2016	7.82	95.9	90.8	144	2.2	2.1	21.6	NaN	NaN	2.71	40.1	9	G
Goldstream River	3	07/25/2016	7.90	98.7	79.5	121	1.8	4.1	13.3	NaN	NaN	4.08	41.0	11	M
Goldstream River	3	08/09/2016	7.90	101	68.8	145	<1.0	2.3	20.5	NaN	NaN	7.21	42.2	11.5	TB
Goldstream River	3	09/07/2016	7.93	132	105	253	3.1	<2.0	6.5	NaN	NaN	2.37	52.4	9.5	C
Goldstream River	3	10/03/2016	8.04	143	138	286	1.3	2.1	3.4	NaN	NaN	1.55	59.2	6.5	C
Goldstream River	3	11/07/2016	7.88	142	248	404	1.5	2.2	4.4	NaN	NaN	1.58	63.1	8	C
Goldstream River	3	12/06/2016	7.92	176	252	330	1.2	<2.0	3.5	NaN	NaN	1.87	80.5	-1	C/I
Columbia above Jordan [4]	4	06/24/2008	7.94	118	144.3	NaN	2.7	6.7	8.2	1.0	7.2	0.16	50	10.0	n/a
Columbia above Jordan	4	05/12/2009	7.83	108	125.7	NaN	2.4	5.6*	3.2	0.1	3.2	0.32	64	4.0	C
Columbia above Jordan	4	05/28/2009	7.89	103	117.3	NaN	2.6	4.5	5.6	0.1	5.6	0.59	63	7.0	C
Columbia above Jordan	4	06/09/2009	7.87	105	121.2	NaN	3	6.7*	4.2	0.1	4.2	0.37	64	7.0	C
Columbia above Jordan	4	06/30/2009	7.42	92	134.9	NaN	2	5.3*	4.9	0.1	4.9	0.43	56	10.0	C
Columbia above Jordan	4	07/07/2009	7.57	94	134.9	NaN	1.6	4.8	5.2	0.1	5.2	0.63	58.4	7.0	C
Columbia above Jordan	4	07/27/2009	7.49	75	126.7	NaN	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	NaN	1.1	3.7	4.3	0.1	4.3	0.36	45.4	8.0	C
Columbia above Jordan	4	09/08/2009	7.44	83	122.8	NaN	1.4	4.2*	3.8	0.7	3.1	0.58	52.6	9.0	C
Columbia above Jordan	4	10/06/2009	7.56	76	138.9	NaN	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	NaN	1.6	1.5	2.7	0.1	2.7	0.83	55.2	5.0	C
Columbia above Jordan	4	05/03/2010	7.98	137	100.5	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	2.0	4.0	3.8	0.7	3.1	0.00	52.6	8.0	C
Columbia above Jordan	4	07/09/2012	7.71	93	151.8	NaN	2.1	6.5	7.1	0.8	6.3	0.05	48.2	8.0	C

		Date	pH	Cond	NN	TN	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)	(ug/L)	(NTU)	(mgCaCO3/L)	(°C)	
Columbia above Jordan	4	07/30/2012	7.58	68	111.4	NaN	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	NaN	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	NaN	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	NaN	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	NaN	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	NaN	<1.00	<2.00	3.2	NaN	NaN	0.53	67.7	4.0	C
Columbia above Jordan	4	05/08/2013	7.88	149	110	NaN	<1.00	<2.00	2.1	NaN	NaN	0.18	64.1	6.0	C
Columbia above Jordan	4	05/27/2013	7.97	149	111	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.21	64.4	5.0	C
Columbia above Jordan	4	06/03/2013	7.9	139	133	NaN	<1.00	<2.00	2.9	NaN	NaN	0.024	59.3	7.0	C
Columbia above Jordan	4	06/25/2013	7.74	121	181	NaN	<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	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.37	48.2	8.0	C
Columbia above Jordan	4	08/06/2013	7.58	83.9	128	NaN	1.4	15.3	19.9	NaN	NaN	0.62	35.2	10.0	C
Columbia above Jordan	4	09/11/2013	7.66	106	105	NaN	1.6	2.0	2.3	NaN	NaN	0.11	42.6	11.5	C
Columbia above Jordan	4	09/30/2013	7.95	124	118	NaN	1.4	2.3	5.5	NaN	NaN	1.19	51.6	9.0	C
Columbia above Jordan	4	11/05/2013	7.83	123	116	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.3	50.3	8.0	C
Columbia above Jordan	4	05/27/2014	7.78	142	117.0	NaN	2.7	<2.00	<2.00	NaN	NaN	0.27	56.2	4.0	C
Columbia above Jordan	4	06/09/2014	8.06	140	128.0	NaN	<1.00	<2.00	2.7	NaN	NaN	0.28	59.3	5.0	C
Columbia above Jordan	4	07/08/2014	7.86	118	170.0	NaN	<1.00	<2.00	2.2	NaN	NaN	0.45	50.0	8.0	C
Columbia above Jordan	4	08/05/2014	7.78	89	144.0	NaN	1.3	4.1	6.1	NaN	NaN	0.89	35.7	9.0	C
Columbia above Jordan	4	09/02/2014	7.83	111	122.0	NaN	1.0	<2.00	<2.00	NaN	NaN	0.61	45.6	8.0	C
Columbia above Jordan	4	10/06/2014	7.84	127	123.0	NaN	1.2	<2.00	<2.00	NaN	NaN	0.82	52.0	8.0	C
Columbia above Jordan	4	03/25/2015	7.96	145	123.0	NaN	<1.00	<2.00	<2.00	NaN	NaN	0.19	61.5	2.0	C
Columbia above Jordan	4	04/08/2015	7.85	146	115.0	NaN	1.9	29.3	56.0	NaN	NaN	0.18	60.3	2.0	C
Columbia above Jordan	4	04/22/2015	7.99	147	123.0	NaN	4.1	<2.00	<2.00	NaN	NaN	0.32	63.0	3.5	C
Columbia above Jordan	4	05/07/2015	7.93	144	121.0	NaN	<1.00	2.5*	2.4	NaN	NaN	0.18	58.7	4.5	C
Columbia above Jordan	4	05/26/2015	7.87	145	132.0	NaN	<1.00	2.3	7.9	NaN	NaN	0.33	60.7	6.0	C
Columbia above Jordan	4	06/08/2015	7.78	131	140.0	NaN	<1.00	<2.0	<2.00	NaN	NaN	0.53	54.4	7.0	C
Columbia above Jordan	4	07/06/2015	7.79	106	141.0	NaN	1.5	7.8*	<2.00	NaN	NaN	0.49	41.6	8.5	C
Columbia above Jordan	4	07/27/2015	7.83	122	72.2	NaN	<1.00	2.0	4.4	NaN	NaN	0.60	50.2	9.0	C
Columbia above Jordan	4	08/10/2015	7.80	130	114.0	NaN	<1.00	<2.00	2.2	NaN	NaN	0.64	55.1	10.0	C
Columbia above Jordan	4	09/08/2015	7.88	143	122.0	NaN	1.1	<2.00	2.7	NaN	NaN	0.63	55.0	10.0	C
Columbia above Jordan	4	10/05/2015	7.94	134	99.2	NaN	<1.00	<2.00	2.3	NaN	NaN	0.72	54.7	10.0	C
Columbia above Jordan	4	11/02/2015	8.04	145	192.0	NaN	3.2	<2.00	2.4	NaN	NaN	2.45	60.2	8.0	C
Columbia above Jordan	4	12/08/2015	8.09	165	289.0	NaN	2.4	3.9*	3.3	NaN	NaN	0.63	72.8	6.0	C
Columbia above Jordan	4	03/21/2016	7.67	145	98	NaN	<1.0	3.2	<2.00	NaN	NaN	0.55	63.0	4.0	C
Columbia above Jordan	4	04/05/2016	8.06	166	199	NaN	1.0	<2.0	7.2	NaN	NaN	0.26	72.5	3.5	C
Columbia above Jordan	4	04/25/2016	8.02	151	114	166	<1.0	<2.0	<2.0	NaN	NaN	0.24	63.5	5.0	C
Columbia above Jordan	4	05/09/2016	8.04	148	117	186	<1.0	<2.0	<2.0	NaN	NaN	0.43	63.3	7.0	C
Columbia above Jordan	4	05/25/2016	8.04	152	130	229	<1.0	3.3	<2.0	NaN	NaN	0.58	63.9	6.0	C
Columbia above Jordan	4	06/06/2016	8.01	140	150	221	2.2	<2.0	2.1	NaN	NaN	0.42	60.3	8.0	C
Columbia above Jordan	4	06/27/2016	7.92	112	169	209	1.0	2.7	3.9	NaN	NaN	0.89	49.5	8.0	C
Columbia above Jordan	4	07/25/2016	7.85	100	129	191	<1.0	4.6	2.1	NaN	NaN	0.58	39.4	9.0	C
Columbia above Jordan	4	08/10/2016	7.91	122	121	232	<1.0	3.5	3.3	NaN	NaN	0.53	48.8	9.0	C
Columbia above Jordan	4	09/07/2016	7.89	133	121	162	2.3	2.3	2.9	NaN	NaN	0.67	50.8	10.5	C
Columbia above Jordan	4	10/03/2016	7.97	137	114	319	<1.0	2.0	2.7	NaN	NaN	0.73	56.3	10.0	C
Columbia above Jordan	4	11/07/2016	7.92	179	288	325	1.1	<2.0	<2.00	NaN	NaN	0.32	76.0	8.0	C
Columbia above Jordan	4	12/06/2016	7.83	136	130	211	<1.0	<2.0	<2.00	NaN	NaN	0.35	57.0	6.0	C
Beaver River	6	05/06/2013	7.87	108	533	NaN	1.9	2.1	217.0	NaN	NaN	62.6	44.9	4.0	B
Beaver River	6	05/28/2013	7.82	100	239	NaN	1.7	2.3	8.1	NaN	NaN	3.33	39.5	5.0	C
Beaver River	6	06/04/2013	7.71	88.2	187	NaN	1.9	3.1	6.4	NaN	NaN	3.16	36.2	5.5	C
Beaver River	6	06/24/2013	7.55	81.7	83.2	NaN	2.6	<2.00	5.8	NaN	NaN	9.14	30.7	6.0	TG
Beaver River	6	07/09/2013	7.77	85.1	74.1	NaN	3.6	<2.00	9.7	NaN	NaN	8.03	34.1	6.0	C
Beaver River	6	08/07/2013	7.57	66.4	47.2	NaN	6.2	10.8	37.1	NaN	NaN	20.8	28	8.0	M
Beaver River	6	09/10/2013	7.5	71.4	49.7	NaN	5.5	11.8	17.0	NaN	NaN	0.23	28.5	7.0	M
Beaver River	6	10/01/2013	7.93	125	110	NaN	2.1	<2.00	<2.00	NaN	NaN	2.33	50.9	5.0	C

		Date	pH	Cond (µS/cm)	NN (ug/L)	TN (ug/L)	SRP (ug/L)	TDP (ug/L)	TP (ug/L)	TP Turb (ug/L)	TPc[1] (ug/L)	Turb (NTU)	Alk [2] (mgCaCO3/L)	T (°C)	Color [3]
Beaver River	6	11/04/2013	7.93	159	133	NaN	<1.00	<2.00	2.5	NaN	NaN	0.74	64	1.0	C
Beaver River	6	05/27/2014	7.61	83	327.0	NaN	3.3	<2.00	15.2	NaN	NaN	10.70	31.6	3.5	GB
Beaver River	6	06/10/2014	7.74	77	173.0	NaN	<1.00	<2.00	2.2	NaN	NaN	6.53	29.7	3.0	MG
Beaver River	6	07/09/2014	7.65	70	64.1	NaN	5.0	<2.00	17.4	NaN	NaN	6.25	28.7	6.0	MG
Beaver River	6	08/05/2014	7.71	73	53.9	NaN	<1.00	4.0	9.7	NaN	NaN	5.14	28.8	7.0	MG
Beaver River	6	09/03/2014	7.74	86	65.5	NaN	5.2	<2.00	6.9	NaN	NaN	8.12	34.2	6.0	MG
Beaver River	6	10/06/2014	7.73	101	82.2	NaN	2.7	<2.00	3.8	NaN	NaN	2.02	38.7	6.0	C
Beaver River	6	04/23/2015	7.84	120	420.0	NaN	<1.00	4.9*	3.8	NaN	NaN	1.39	49.1	2.5	B
Beaver River	6	05/07/2015	7.79	119	381.0	NaN	<1.00	<2.00	2.5	NaN	NaN	0.77	46.7	4.0	C
Beaver River	6	05/26/2015	7.65	77.6	189.0	NaN	<1.00	2.6	4.8	NaN	NaN	10.20	30.0	4.0	B
Beaver River	6	06/09/2015	7.51	69.7	81.0	NaN	<1.00	2.5	16.6	NaN	NaN	61.60	27.4	5.0	B
Beaver River	6	07/07/2015	7.68	75.8	59.4	NaN	<1.00	<2.00	7.4	NaN	NaN	11.60	31.6	8.0	MG
Beaver River	6	07/28/2015	7.54	84.5	43.3	NaN	<1.00	<2.00	4.2	NaN	NaN	5.63	31.1	7.0	M
Beaver River	6	08/11/2015	7.65	70.7	50.0	NaN	1.5	<2.00	10.2	NaN	NaN	12.90	30.1	8.0	M
Beaver River	6	09/08/2015	7.89	120	108.0	NaN	1.4	2.8	4.0	NaN	NaN	1.84	45.6	7.0	C
Beaver River	6	10/06/2015	7.90	137	121.0	NaN	2.1	2.4	2.5	NaN	NaN	1.83	51.9	4.0	C
Beaver River	6	11/03/2015	8.01	150	144.0	NaN	<1.00	2.7*	<2.00	NaN	NaN	1.74	58.7	2.0	C
Beaver River	6	12/07/2015	8.04	159	166.0	NaN	1.5	2.2	2.7	NaN	NaN	1.07	65.8	0.0	C
Beaver River	6	03/22/2016	8.00	186	138	NaN	<1.0	<2.0	<2.00	NaN	NaN	1.07	78.8	1.5	C
Beaver River	6	04/05/2016	7.90	147	326	NaN	<1.0	2.1	3.5	NaN	NaN	2.37	59.4	2	LB
Beaver River	6	04/26/2016	7.84	NaN	356	420	4.7	2.9	22.2	NaN	NaN	7.22	40.7	4	TB
Beaver River	6	05/10/2016	7.86	103	254	330	2.9	<2.0	10.1	NaN	NaN	2.10	40.2	3	G
Beaver River	6	05/25/2016	7.77	93.5	146	225	2.0	<2.0	7.5	NaN	NaN	3.56	37.5	6	C
Beaver River	6	06/07/2016	7.73	75.1	87.6	195	<1.0	2.0	70.4	NaN	NaN	34.60	31.6	8	C
Beaver River	6	06/28/2016	7.74	83	71.1	110	<1.0	3.7	17.1	NaN	NaN	6.46	33.8	7.5	MG
Beaver River	6	07/26/2016	7.72	72.9	48.6	107	<1.0	2.4	28.7	NaN	NaN	9.45	27.7	8	MG
Beaver River	6	08/10/2016	7.75	78.7	48.8	102	5.6	2.4	13.4	NaN	NaN	4.44	30.7	8	M
Beaver River	6	09/06/2016	7.82	118	73.5	181	4.0	2.8	5.6	NaN	NaN	1.55	42.1	8.5	C
Beaver River	6	10/04/2016	7.92	138	98.2	269	1.5	2.9	3.2	NaN	NaN	1.51	50.4	4	C
Beaver River	6	11/08/2016	7.81	132	205	324	2.1	2.3	13.3	NaN	NaN	12.10	53.4	3.5	TB
Beaver River	6	12/05/2016	7.77	154	186	272	<1.0	<2.0	3.6	NaN	NaN	1.44	63.8	-1	C/I
Downie Creek	7	03/21/2016	8.11	215	217	NaN	<1.0	<2.0	<2.0	NaN	NaN	0.36	99.1	3	C
Downie Creek	7	04/04/2016	8.03	180	378	NaN	3.1	2.5	18.1	NaN	NaN	10.40	85.1	3	GB
Downie Creek	7	04/25/2016	8.03	153	424	455	4.2	<2.0	29.8	NaN	NaN	7.20	70.1	4	M
Downie Creek	7	05/09/2016	8.05	144	307	369	2.9	<2.0	19.5	NaN	NaN	2.78	64.2	4	M
Downie Creek	7	05/24/2016	8.05	143	102	279	3.4	<2.0	14.1	NaN	NaN	5.03	63.0	7	T
Downie Creek	7	06/06/2016	7.95	125	138	243	2.6	2.1	156.0	NaN	NaN	73.20	56.7	7	TB
Downie Creek	7	06/27/2016	8.04	132	134	186	1.4	2.5	40.9	NaN	NaN	10.20	55.4	7	M
Downie Creek	7	07/25/2016	8.06	133	106	141	1.2	3.4	43.4	NaN	NaN	8.20	57.6	NaN	MB
Downie Creek	7	08/09/2016	8.02	142	102	146	2.2	2.4	26.9	NaN	NaN	10.80	61.1	9	M
Downie Creek	7	09/07/2016	8.01	159	137	201	<1.0	<2.0	14.2	NaN	NaN	4.64	65.0	8	LT
Downie Creek	7	10/03/2016	8.09	181	180	336	4.1	2.9	6.3	NaN	NaN	2.38	74.6	6	C
Downie Creek	7	11/07/2016	7.97	178	300	395	1.3	<2.0	3.0	NaN	NaN	1.11	79.3	4.5	C
Downie Creek	7	12/06/2016	7.83	202	292	359	<1.0	<2.0	4.1	NaN	NaN	0.64	92.2	0	C/I

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, (V)ery, (F)rozen
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

	ALK-T	Ca*	Cl-D	K*	Mg*	Na*	NH3	NO2	NO3	pH	OP	TP	SO4	COND	T	TURB	TN	TND	TDP	
	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	USIE/CM	DEG C	NTU	MG/L	MG/L	MG/L	
18/01/2016 10:50	86.6	25.9	0.86	0.4	8.2	1.7	NaN	NaN	NaN	8.02	NaN	0.0029	18.7	204	0.5	NaN	0.16	0.16	NaN	
22/02/2016 11:10	90.9	29	0.83	0.4	9	2	NaN	0.005	0.159	7.87	NaN	5.00E-04	17.2	201	2.1	0.41	0.19	0.14	5.00E-04	
15/03/2016 10:55	90	30.1	1.39	0.4	8.7	2.1	NaN	0.005	0.152	7.91	NaN	8.00E-04	18.8	213	2.3	0.39	0.15	0.15	5.00E-04	
11/04/2016 10:39	65.1	21	2.81	0.4	6	2.4	NaN	0.005	0.336	8.04	NaN	0.0054	13.7	160	4	2.68	0.38	0.37	7.00E-04	
17/05/2016 11:43	47.8	15.1	0.43	0.3	4.2	0.9	NaN	0.012	0.173	7.91	NaN	0.0112	9.16	113	8.1	4.16	0.28	0.22	5.00E-04	
21/06/2016 10:05	50	15.6	0.3	0.3	5.1	0.7	NaN	0.016	0.093	7.94	NaN	0.008	13	126	9	3.59	0.14	0.11	7.00E-04	
25/07/2016 10:57	29.9	10	0.11	0.3	2.8	0.5	NaN	0.036	0.04	7.72	NaN	0.0291	8.04	71.4	8.7	18	0.07	0.06	6.00E-04	
23/08/2016 9:40	36.5	12.1	0.19	0.3	3.2	0.4	NaN	0.005	0.053	7.88	NaN	0.0222	8.8	90.5	7	13.6	0.07	0.06	5.00E-04	
20/09/2016 10:40	46.8	18.5	0.29	0.3	5.3	0.8	NaN	0.005	0.071	7.9	NaN	0.0052	14.9	123	7	3.1	0.11	0.11	5.00E-04	
04/10/2016 14:20	0.5	0.1	0.05	0.1	0.1	0.2	NaN	0.005	0.002	5.77	NaN	5.00E-04	0.1	2	5.6	0.06	0.02	0.02	5.00E-04	Note (1)
04/10/2016 14:20	148	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	7.71	NaN	NaN	NaN	150	5.6	NaN	NaN	NaN	0.1	Note (2)
18/10/2016 9:35	62.8	21.3	0.64	0.4	6.4	1.3	NaN	0.005	0.176	7.82	NaN	0.0033	18.1	156	4.5	1.01	0.19	0.19	5.00E-04	
15/11/2016 9:42	62	19.1	0.67	0.4	5.6	1.3	NaN	0.005	0.198	7.93	NaN	0.0019	13.7	145	3	1.11	0.23	0.22	0.0012	
13/12/2016 9:20	82.8	25.3	0.85	0.4	7.9	1.6	NaN	0.005	0.181	7.97	NaN	5.00E-04	18.5	197	0	0.44	0.2	0.21	5.00E-04	

* Jan-Apr, Extractable; May to December, Dissolved.

(1) This row is measurement of a blank

(2) TheTDP of 0.1 mg/L is judged erronous and was not used in the analysis.

Appendix 3

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2016

Roger Pieters and Greg Lawrence
University of British Columbia

CTD Surveys
Kinbasket and Revelstoke Reservoirs, 2016

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Upper Revelstoke Reservoir, 19 August 2016

Prepared for

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1200 Powerhouse Road
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January 8, 2018

Contents

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Appendix 4

1. Introduction

This report examines CTD (conductivity-temperature-depth) profiles collected from Kinbasket and Revelstoke Reservoirs in 2016. These data were collected as part of year nine of 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.

Sampling was conducted in both reservoirs monthly from April to October 2016. A list of the profiles collected in 2016 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 6 April 2016.

In 2016, intensive CTD surveys were not undertaken in Kinbasket Reservoir. In Revelstoke Reservoir, intensive surveys focused on the reach between Revelstoke Dam and Downie Arm. The surveys were conducted on 30 May, 14 July, and 3, 5 and 7 October 2016. Additional casts were collected during measurement of primary production, and these data are shown in Appendix 4. In 2016, two additional casts were collected near Kinbasket and Revelstoke Dams on 12 and 14 July, respectively, in conjunction with a study of total gas pressure (TGP).

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[*] Data collected prior to this program 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).

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

Pump problems From 2009 to 2011, the pump on the profiler did not turn on due to a problem with the setting of the parameter for 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 the descent of the instrument forced water through the plumbing.

From 2012-2016, 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 is lowered, beginning the descent.

The pump comes on half way through the soak at 105 sec (420 scans). However, in 2013, the descent had 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 2013 plots, and as a result most plots in 2013 began 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. From 2014 to 2016, this problem did not occur as all casts were in the water before scan 420, and descent did not begin until after scan 420.

Problem transmissometer data The transmissometer assesses the clarity of the water, returning a higher voltage when light transmission is higher (clearer water), and returning a lower voltage when less light is transmitted through the water (the water is more turbid). Other than lenses of turbidity, the readings in Kinbasket and Revelstoke Reservoir are generally fairly high (Figure F1e).

In 2016, the transmissometer data was observed to intermittently drop suddenly to very low readings (low voltage), or to have a low reading for the first part of the profile. This problem began in 2015, and service of the transmissometer in early 2016 did not resolve the problem. This intermittent change is likely the result of a mechanical fault in the cable between the transmissometer and the profiler. Line and contour plots of this data should be disregarded.

Table 2.1 Kinbasket surveys, 2016

Date	**FB** **K1**	**K1.5**	**MI** **K2**	**CO** **K3**	**CA** **Kcal**	**WO** **Kwol**	**TGP**
11-12 April	✓		✓	✓	✓	✓	
16-17 May	✓		✓	✓	✓	✓	
13, 23 June	✓	✓*			✓		
11-12 July	✓✓		✓	✓	✓	✓	✓
21 July		✓*					
8 August	✓			✓	✓	✓	
24 August		✓*					
12-13 September	✓		✓	✓	✓	✓	
22 September		✓*					
11-12 October	✓		✓	✓	✓	✓	

* Collected during measurement of primary production (See Appendix 3)

Table 2.2 Revelstoke surveys, 2016

Date	FB	MI	UP	Downie	
				Rd0	Rd1
6, 18-19 April	✓+2	✓	✓	✓	✓
24-25 May	✓	✓	✓	✓	✓
30 May	✓+12				
21-22 June	✓*	✓*			
14 July	✓+11				
18-20 July	✓*	✓✓*	✓	✓	✓
15-17 August	✓*	✓✓*	✓	✓	✓
19-21 September	✓*	✓✓*	✓	✓	✓
3 October	✓+7				
5 October	✓+15	✓✓			
7 October	✓+15	✓✓			
17-18 October	✓	✓	✓	✓	✓

* Collected during measurement of primary production (See Appendix 3)

3. Results

We first look at the water levels and flows during 2016, shown in Figure A2, respectively. The first survey in Kinbasket Reservoir was undertaken on 11-12 April 2016 shortly after the time of minimum water level (1 Apr 2016, Figure A2a). The last survey was on 11-12 October 2016, when the water level was high. 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 April 2016 the water level experienced a brief (6 day) drawdown 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. 2018b). This seasonal change in the conductivity of the inflow will assist in identifying water masses as discussed below.

3.1 Kinbasket Reservoir

***11-12 April 2016* (Figure B1)** Line plots for the surveys of Kinbasket Reservoir are shown in Figures B. In April 2016, the reservoir was unstratified with temperature ranging between 3 to 4 ºC, with the exception of Wood Arm where there was slight stratification with the surface reaching 6 °C (Figure B1b). During this time, the outlet from Kinbasket Reservoir was 40 m below the surface, as marked with the dotted lines in Figure B1.

The temperature stratification in April 2016 was slightly unstable, namely water close to 4 °C near the surface was slightly denser than the water near 3 °C at depth. However, the small conductivity gradient was sufficient to stabilize the temperature profile. For example, at K3co the conductivity increased by ~30 µS/cm from ~190 µS/cm at the surface to ~220 µS/cm at the bottom (black, Figure B1c).

A slight increase in conductivity with depth was observed throughout the reservoir (Figure B1c). Note the Columbia Reach, K3co, had a higher conductivity of 190-220 µS/cm (black, Figure B1c). The station at K3co is located at the former Kinbasket Lake, and the conductivity of the water below 80 m remained distinctly different (Figures B1c to B7c) and relatively unchanged (Figure B10c) throughout the summer, as also observed in previous years.

In April 2016, the reservoir was generally clear (high light transmission) with somewhat reduced transmission at the bottom of Wood Arm (cyan, Figure B1d). Dissolved oxygen was high (>10 mg/L) throughout the reservoir (Figure B1e). The nominal concentration of chlorophyll was relatively low and uniform, not unexpected for this time of year (Figure B1g). The 1% light level determined from PAR is marked with dashed lines; the 1% light level varied between 25 and 30 m.

16-17 May 2016 **(Figure B2)** The temperature shows the start of seasonal stratification, with surface temperature ranging from 8 to 12 ºC (Figure B2b). During this time, the outlet from Kinbasket Reservoir was 47 m below the surface, as marked with the dotted lines in Figure B2.

The conductivity in the top 50 m shows some reduction due to freshet inflow, and this is particularly noticeable between 20 and 40 m at K3co in the Columbia Reach (black Figure B2c). Light transmission is beginning to decrease in the top 30 m, particularly in Wood Arm (Figure B2d). Distinct peaks in nominal chlorophyll are observed at all sites, with peaks above 1 µg/L at 5 to 20 m depth, near the 1% light level (Figure B2g).

13, 23 June 2016 **(Figure B3)** Only one cast was collected from Kinbasket Reservoir on 13 June 2016 due to problems with the electronic metered block. A profile in the forebay, K1fb, was collected during measurement of primary production on 23 June 2016. Also, the cast from the station at which primary production was measured, K1.5, is shown in place of the cast at the mid station, K2mi. As a result, profiles from Wood Arm (Kwo1) and the Columbia Reach (K3co) are missing in June 2016.

In June 2016, the surface temperature varied from 12 to 14 ºC (Figure B3b), showing the beginnings of a broad thermocline extending from the surface to 50 m depth. The conductivity in the top 60 m continued to decline, most noticeably in the Canoe Reach (green, Figure B3c). Two of the three casts were affected by an intermittent problem with the transmissometer described in the methods (Figure B3d).

The solubility of oxygen is sensitive to temperature, and decreases as temperature increases. As the surface water warms, it can hold less oxygen, and this is reflected in the slight decline in dissolved oxygen concentrations in the top 60 m (Figure B3e). To remove the effect of temperature, dissolved oxygen is also plotted as percent saturation (Figure B3f). The dissolved oxygen was close to 100% saturation near the surface and decreased to ~80% at depth, indicating that the water was well oxygenated as would be expected for an oligotrophic system (Figure B3f). Peaks in chlorophyll remain (Figure B3g), though they were slightly smaller than in May (Figure B2g).

11-12 July 2016 **(Figure B4)** In July, surface temperature varied from 14 to 17 ºC (Figure B4b). As in June, there was a broad thermocline, now extending from the surface to 60 m depth. In the conductivity plot, the most notable feature is again the decline in the conductivity in the top 60 m, especially in the Canoe and Columbia Reaches (Figure B4c).

The turbidity showed layers of very high turbidity (low light transmission) in Wood Arm (blue), Canoe Reach (green) and the Columbia Reach (black, Figure B4d). In July, the chlorophyll layer was between 10 and 20 m depth, and similar in magnitude to that observed in previous months (Figure B4g).

8 August 2016 **(Figure B5)** The temperature at the surface was 16 - 17 ºC at all stations, and the broad thermocline extended to about 60 m (Figure B5b). The stratification is slightly reduced in the top 10 m in several of the casts, suggesting some surface mixing. The conductivity of the surface layer continued to decline in the Columbia Reach (Figure B5c). All but the forebay showed layers of turbidity between 20 and 50 m, with the highest turbidity in Wood Arm (cyan, Figure B5d).

Fall 2016 **(Figures B6 and B7)** By mid-September the surface had cooled to 15 ºC and deepened to between 20 and 30 m depth (Figure B6b). By mid-October the surface had cooled to 12 ºC, and a distinct surface mixed layer was observed to 30 to 50 m depth (Figure B7b).

Seasonal changes Seasonal changes at the Forebay (K1fb), Middle (K2mi), Columbia (K3co), Canoe (Kca1) and Wood (Kwo1) stations, are shown respectively in Figures B8 to B12. 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 to C7. Each contour shows Canoe Reach (Kca1), the main pool (K2mi) and Columbia Arm (K3co). The exceptions were June 2016 where data were not available for K2mi and K3co (Figure C3), and August 2016 when data at the forebay, K1fb, was shown to replace the missing data at K2mi (Figure C5).

Contour plots highlight variations along the reservoir; however, care must be taken when interpreting features between the stations marked. Note, the black line does not give the bathymetry along the thalweg, but simply connects the maximum depth from the sounder at each station. The approximate depth of the outlet is marked with a white circle. The 1% light level is given by black bars in the last panel of each figure.

After the reservoir stratified (May onward), the temperature was relatively uniform along the reservoir during each survey (Figure C2a to C7a). As the summer progressed, the conductivity was lowest in Canoe Reach (e.g. July 2016 Figure C4b), but a distinct layer of low conductivity also appeared in the top 60 m in the Columbia Reach. Light transmission was generally high (turbidity low) in the deep (> 60 m) water. Lenses of turbidity can be observed in the thermocline at different times and locations along the reservoir (Figures C1c to C7c); blocks of bad transmissometer data should be ignored. Oxygen is generally high (e.g. Figures C1d to C7d). 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, e.g. Figures C1e to C7e).

3.2 Revelstoke Reservoir

In spring 2015, the outflow from Kinbasket Reservoir had been higher than usual (Figure 4.2.2g, Pieters et al. 2018a). In 2016, the outflow saw a return to a pattern that was more typical of the previous study years, and the outflow from Kinbasket Reservoir was very low from mid-April to early June, 2016 (Figure A2d).

April to June 2016 On 6 April 2016, Revelstoke Reservoir was unstratified with relative uniform temperature from top to bottom of about 4 °C (Figure D1b). By 18 - 19 April 2016, the top 30 m was already stratified with surface temperature ranging from 6 to 9.5 °C. The conductivity was also relatively uniform in April (150 µS/cm), light transmission and dissolved oxygen were both uniform and high (Figure D1d,e,f), and chlorophyll levels were generally low, though by 18 – 19 April 2017 there were small peaks in the top 30 m (Figure D1g).

Thermal stratification was observed in mid-May, with surface temperature reaching 13 °C (Figure D2b). By this time, the conductivity of the near surface of the reservoir had declined significantly, especially in the upper reaches of the reservoir (Figure D2c). There were decreases in light transmission (increases in turbidity) consistent with the beginning of freshet inflow (Figure D2d). In addition, there were also small peaks in chlorophyll (~ 1 µg/L) suggesting an increase in biological activity (Figure D2g).

On 30 May 2016, an intensive survey was conducted of the lower fourth of the reservoir to examine variability in the stratification along the length of the reservoir (Figure D3).

By late June, thermal stratification continued to develop with surface temperature reaching 19 °C (Figure D2.4b). The conductivity of the top 50 m of the reservoir continued to decline due to freshet inflow (Figure D2.4c). Chlorophyll fluorescence was surprisingly low with only a small increase above the depth of the one percent light level (Figure D2.4g).

July to October 2016 By the end of June 2016, the top 50 m of Revelstoke Reservoir was dominated by local inflow, as indicated by the reduced conductivity from the surface to about 50 m depth (Figure D4c). Beginning in mid-June, the outflow from Kinbasket Reservoir increased, and an interflow of (1) cooler, (2) higher conductivity and (3) less turbid water from Kinbasket Reservoir can be observed passing through Revelstoke Reservoir at 20 to 40 m depth. This interflow was first observed at the stations closer to Kinbasket Reservoir (Figures D5c and D6c). By the middle of August, the effect of the interflow was clearly visible at Revelstoke Forebay (Figure D7c).

The effect of the Kinbasket interflow can be also be seen in the temperature data. While there remains a gradient in temperature through the depth of the interflow (from 8-11 °C), this gradient was small compared to the gradients above and below the interflow (Figures D5b to D11b). By mid-October, the interflow had almost reached the surface (Figure D12b).

Comparison of casts in the forebay (e.g. Figure D13) indicate slight changes to the deep water (> 60 m) throughout 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 ultraoligotrophic;
- 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 high inflow, short residence time (< 1 yr), and deep outlets (in 2016 ranging from 40 to 62 m in Kinbasket and at 29 m in Revelstoke) may also be important.

The variation in the conductivity of the tributary inflows provides a tracer that can be used to identify water masses. Both Kinbasket and Revelstoke Reservoirs had a surface layer of reduced conductivity, which suggests surface waters contain a significant fraction 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. (2018a), 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 - for example, from mid-September to mid-October 2012 (Pieters and Lawrence 2014b) - suggests that internal wave motions can bring the interflow into the photic zone for significant periods of time. Internal motions can also be seen on, for example, 5 October 2016 when the stratification was weak, the internal deflections were large, and part of the interflow (Figure E10b) was in the photic zone (Figure E10e).

Acknowledgements

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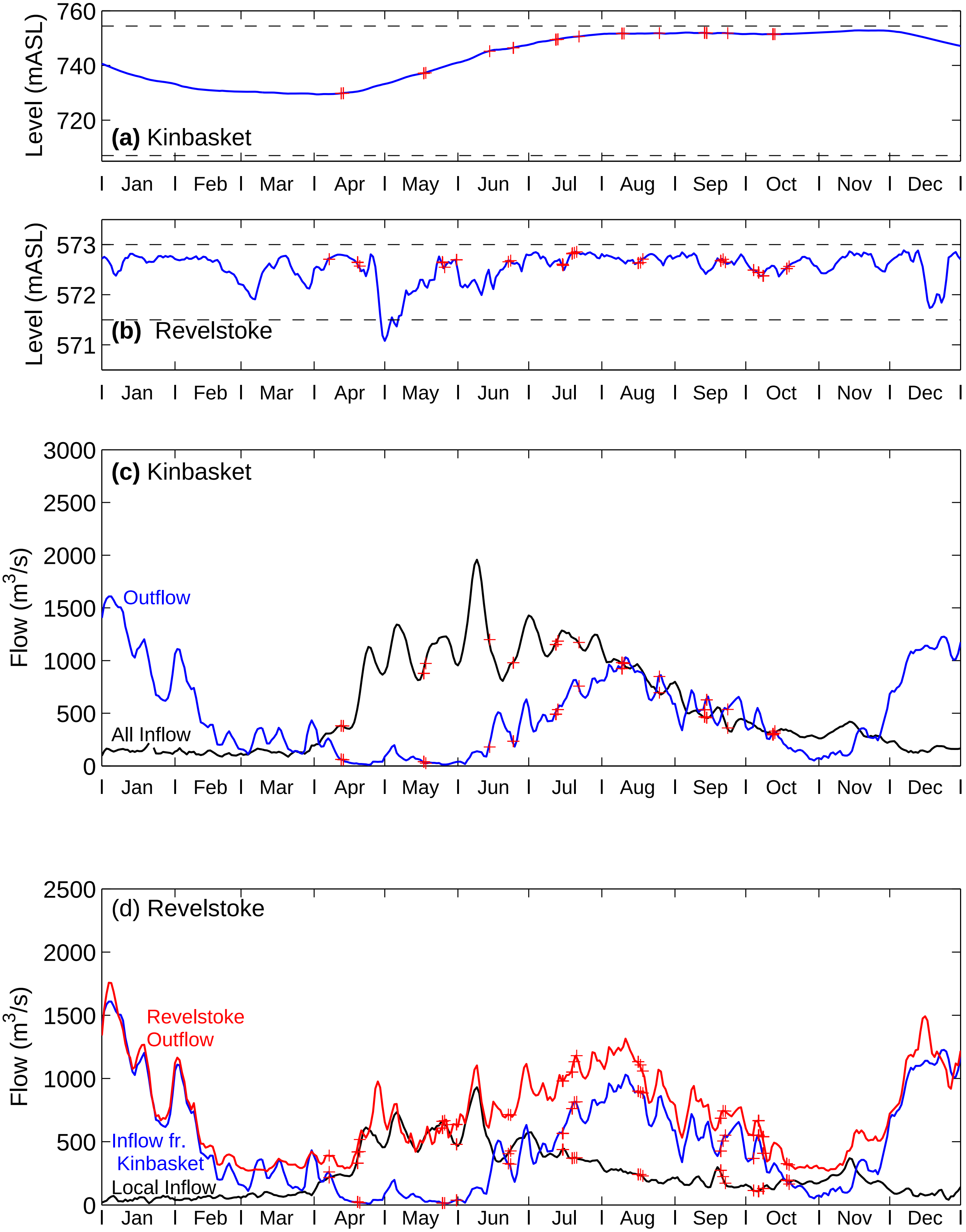
Figure A1 Map showning approximate location of profile stations

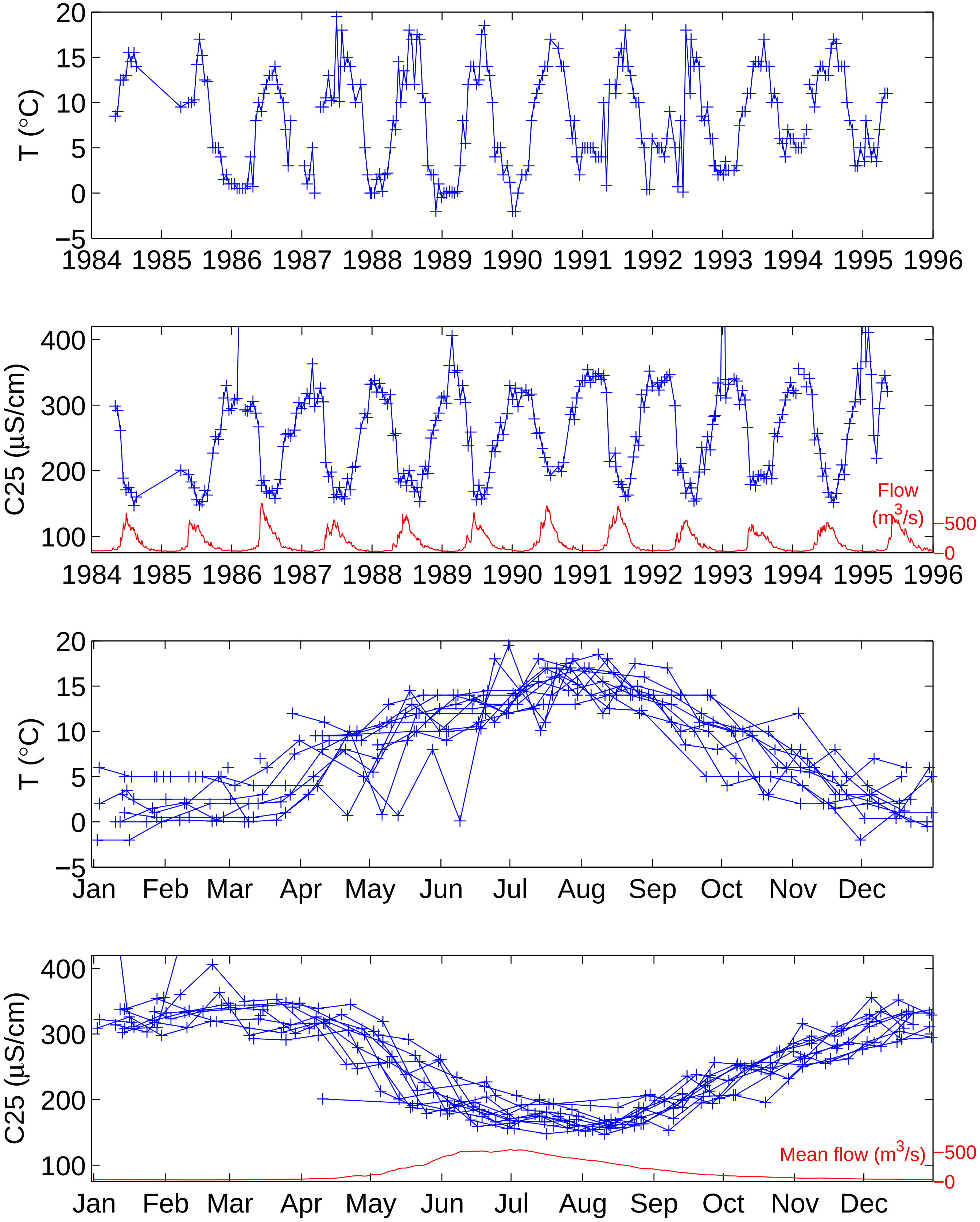
/ocean/rpieters/kr/bathy/map/map1REP09.m fig= 1 2011−Jan−26

Figure A2 Water level and flow, Kinbasket and Revelstoke Reservoirs, 2016



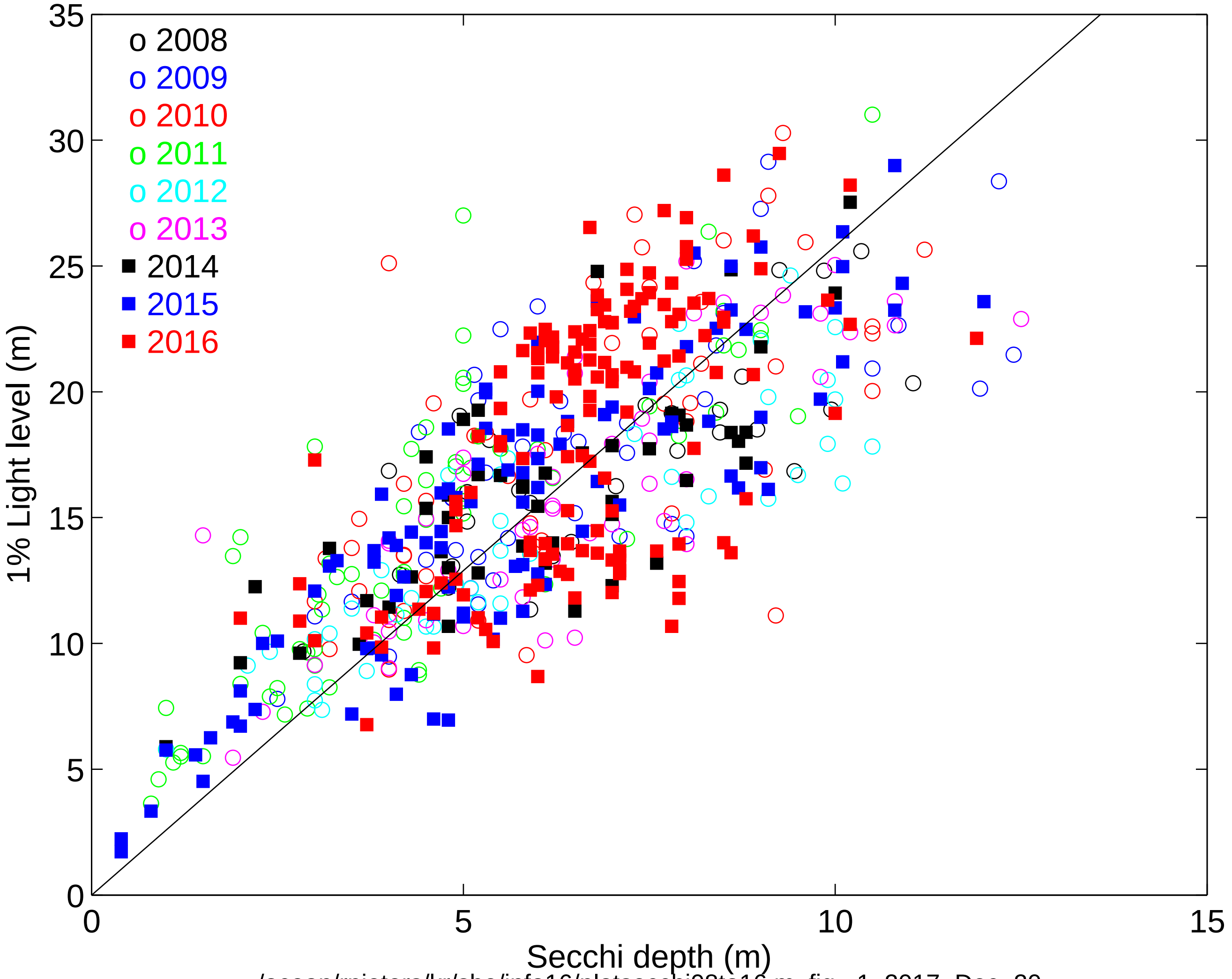
/ocean/rpieters/kr/flow/plot/localflow2016.m fig= 1 2017−Dec−20

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



/ocean/rpieters/kr/sbe/info16/plotsecchi08to16.m fig= 1 2017−Dec−20

Figure B1 Kinbasket Reservoir, 11−12 Apr 2016

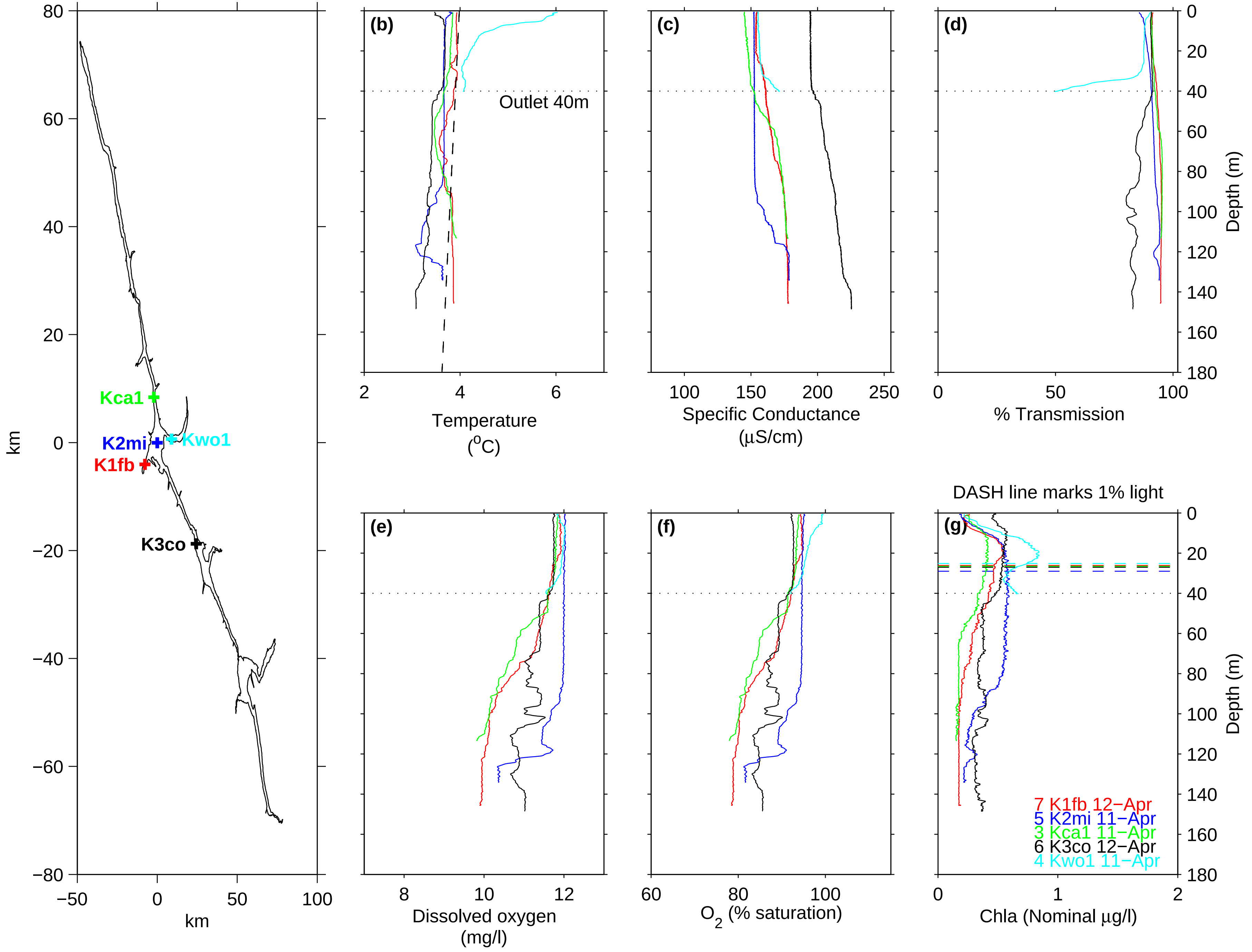


Figure B2 Kinbasket Reservoir, 16−17 May 2016

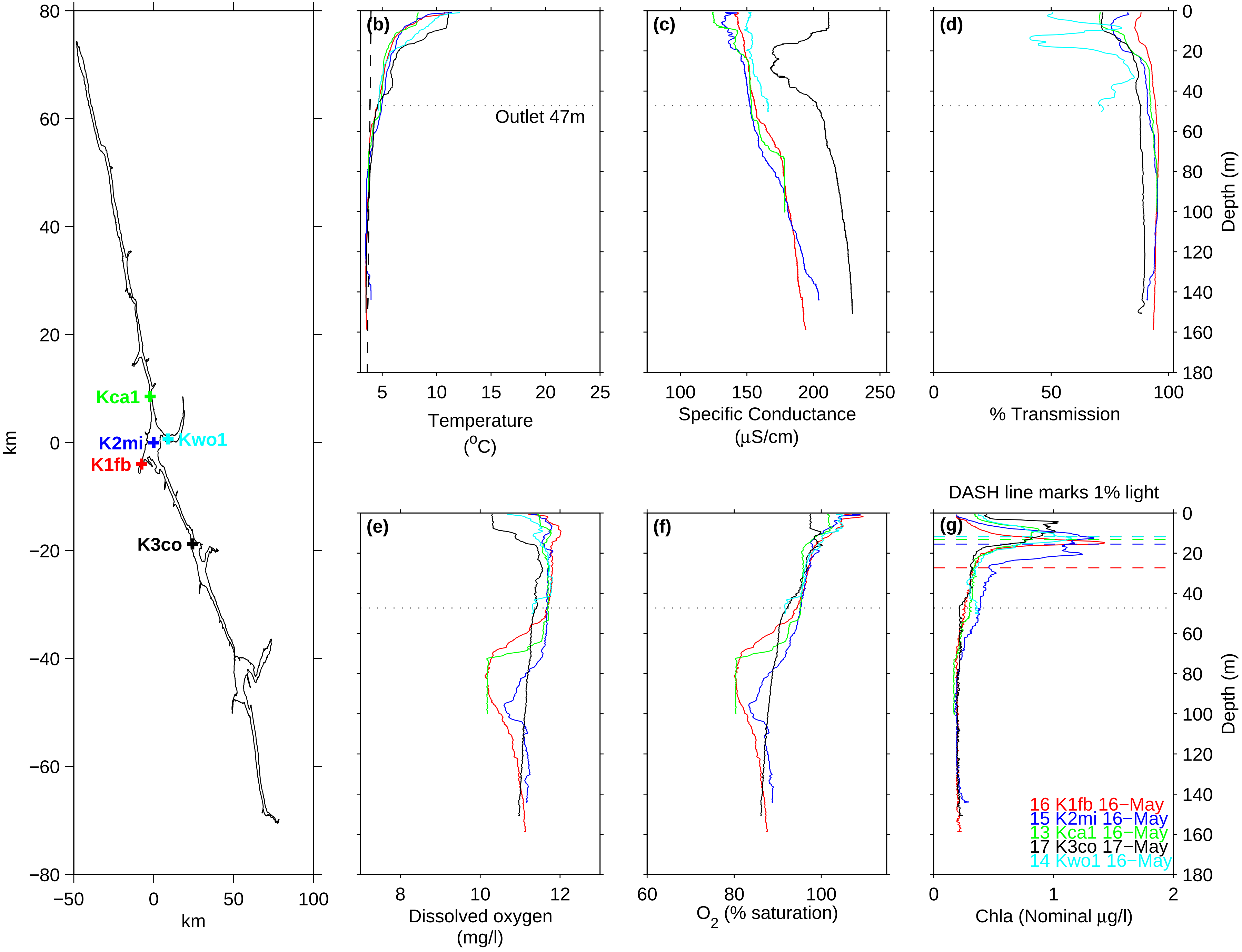


Figure B3 Kinbasket Reservoir, 13, 23 Jun 2016

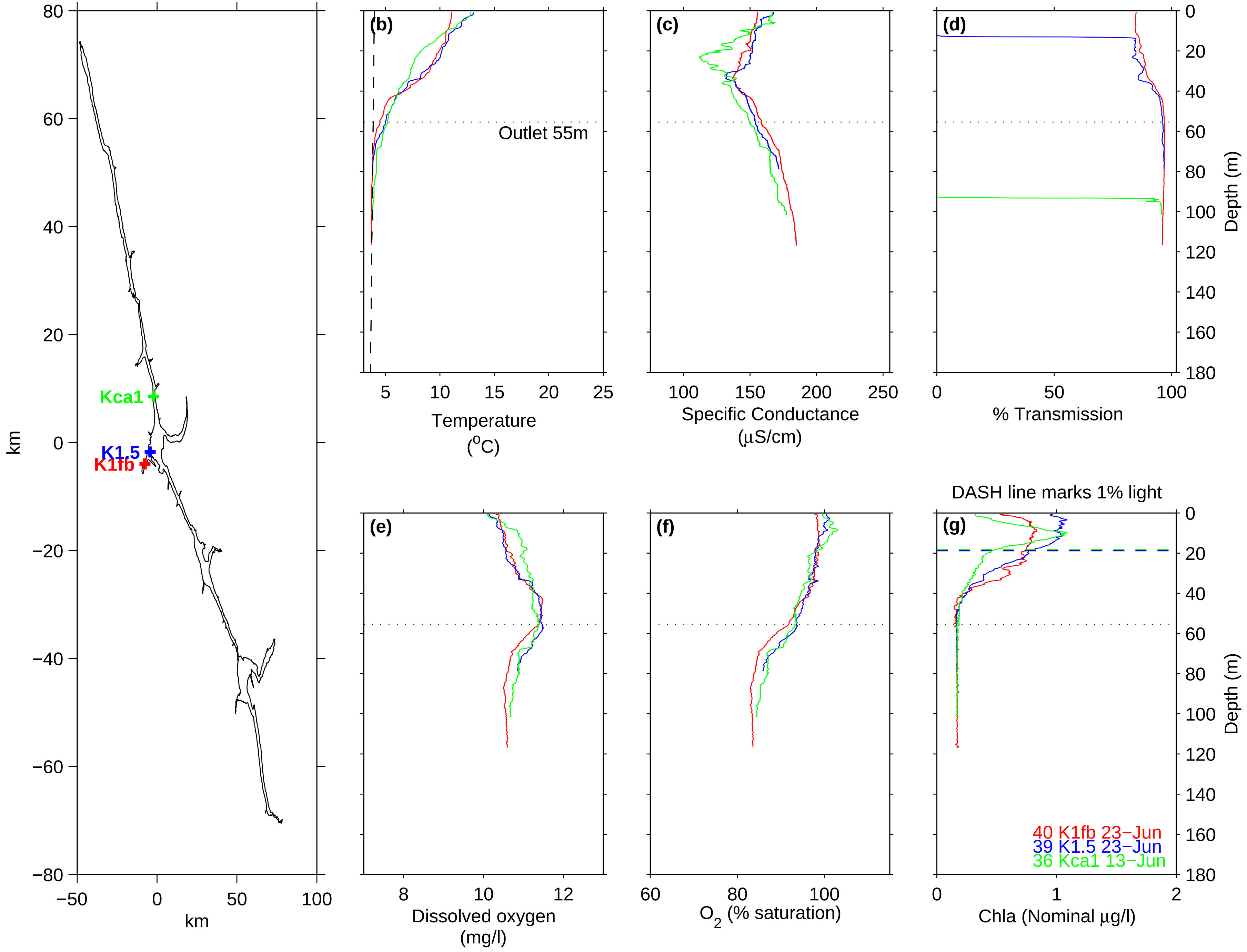


Figure B4 Kinbasket Reservoir, 11−12 Jul 2016

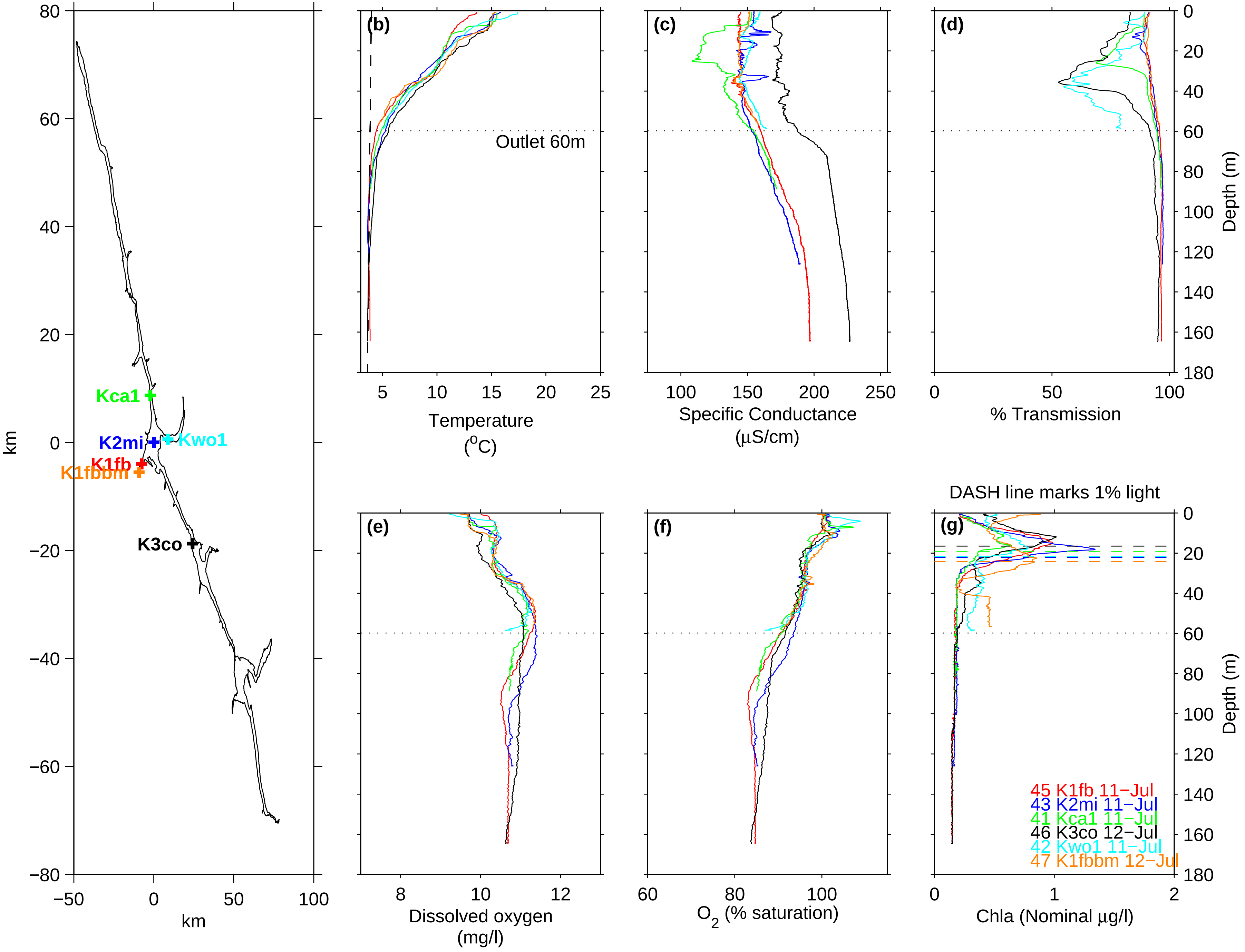


Figure B5 Kinbasket Reservoir, 8 Aug 2016

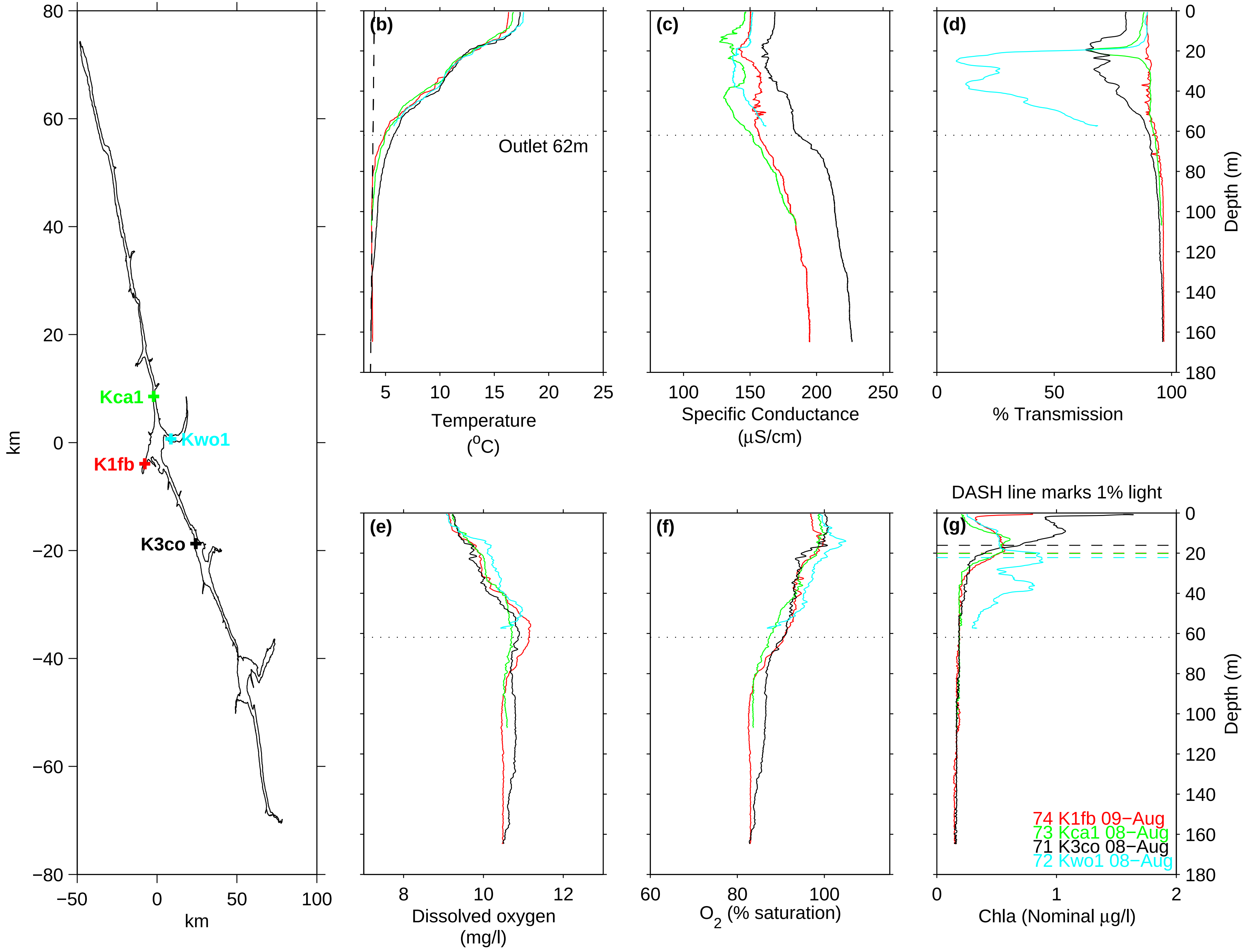


Figure B6 Kinbasket Reservoir, 12−13 Sep 2016

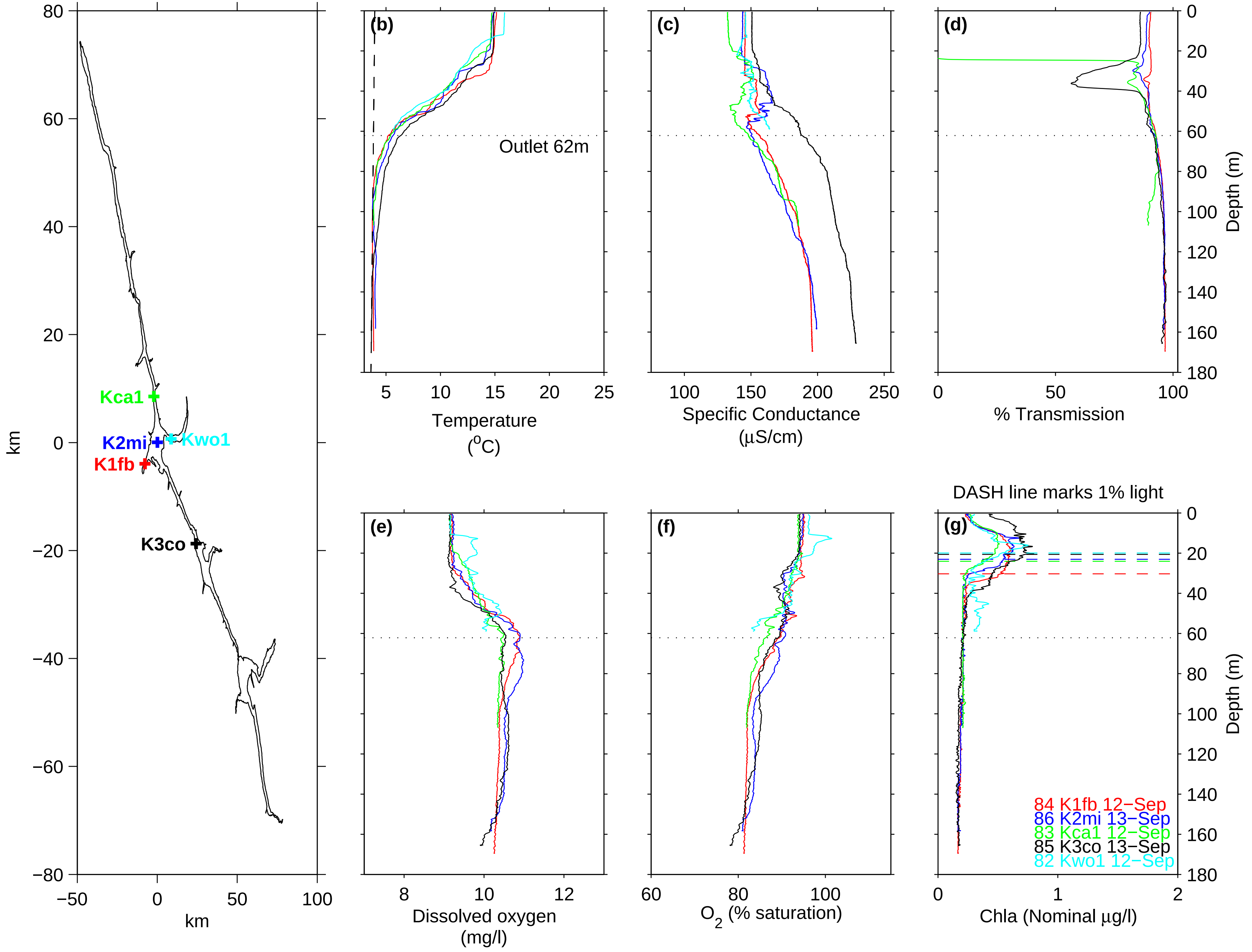


Figure B7 Kinbasket Reservoir, 11−12 Oct 2016

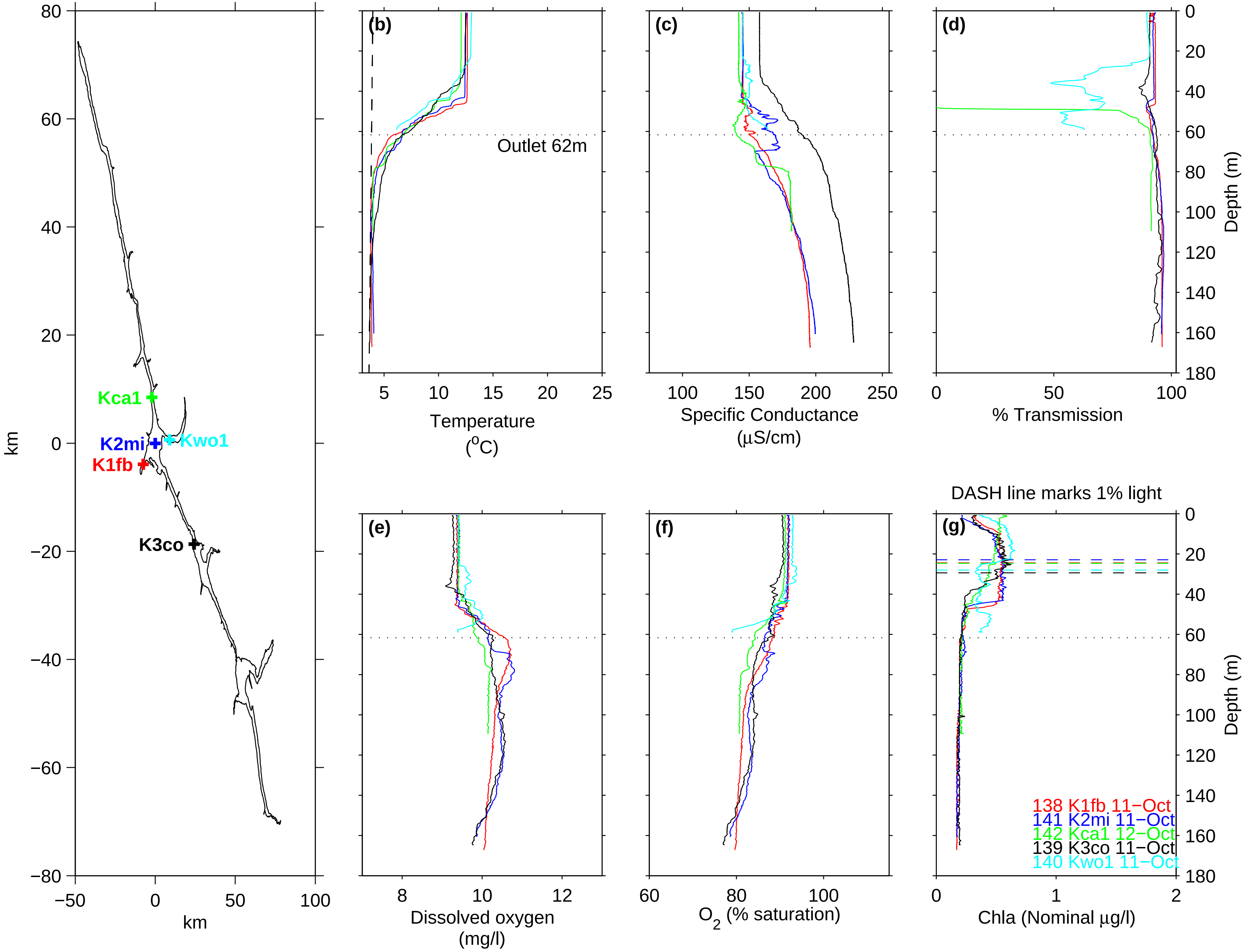


Figure B8 Kinbasket Reservoir, Forebay, K1fb, 2016

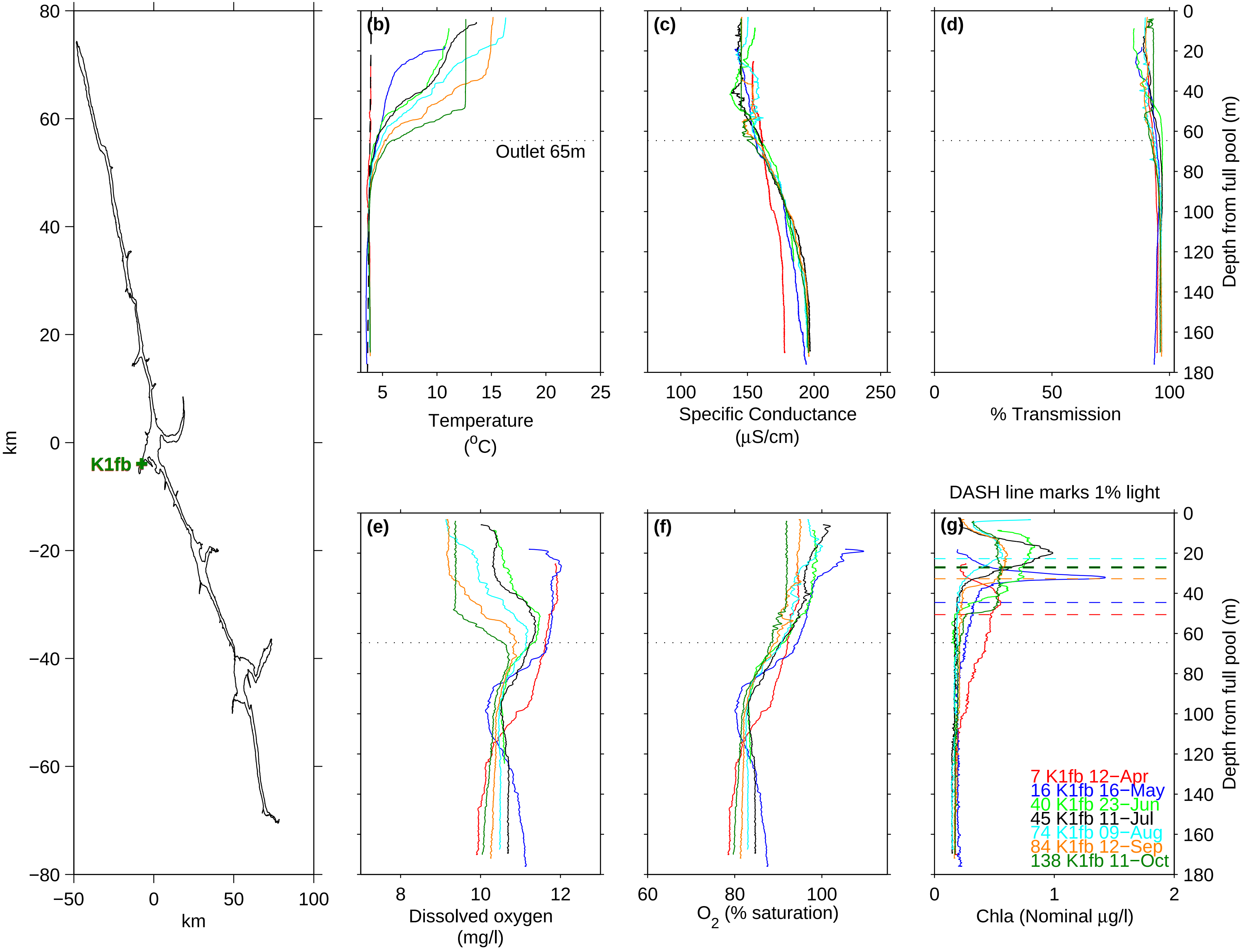


Figure B9 Kinbasket Reservoir, Middle, K2mi, 2016

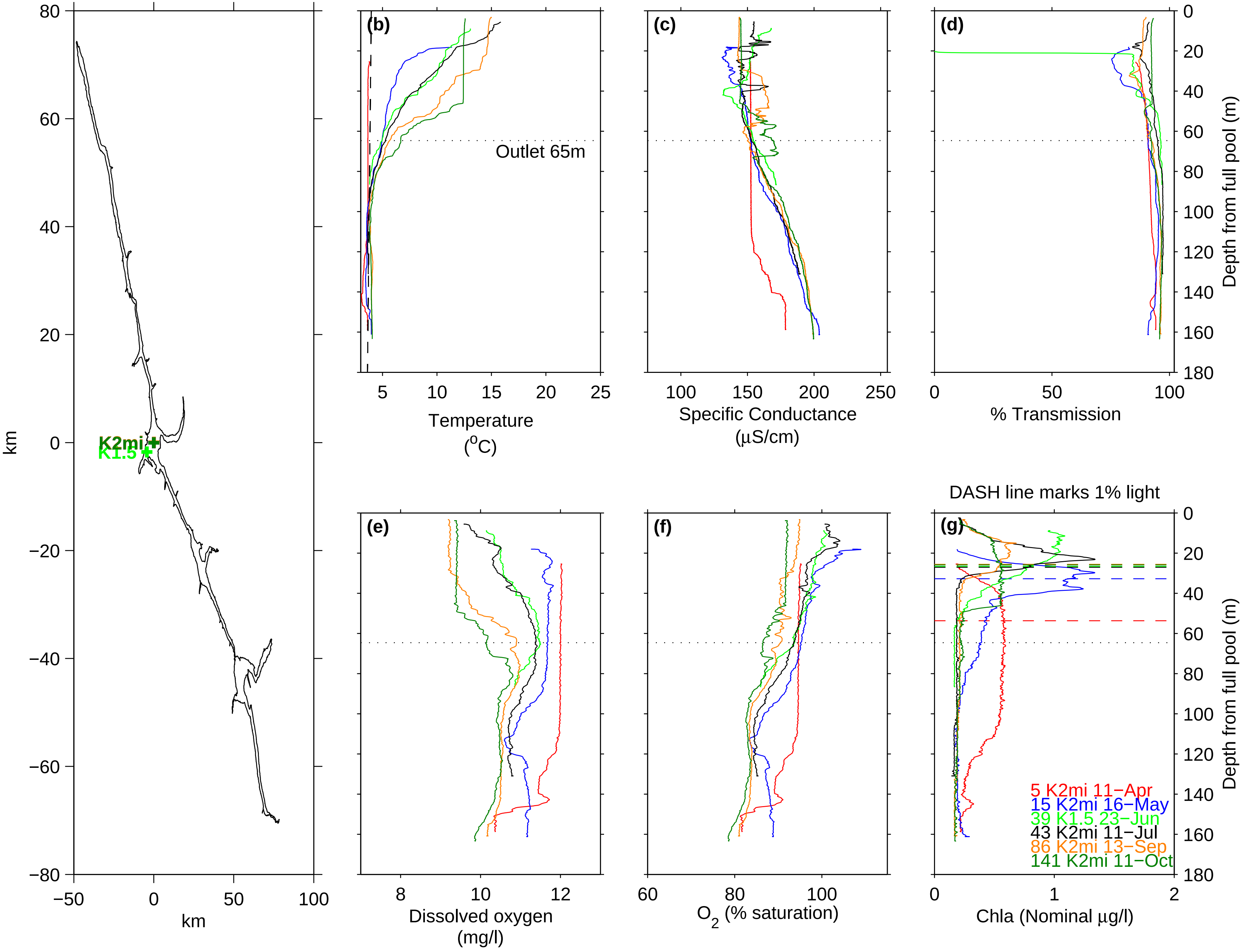


Figure B10 Kinbasket Reservoir, Columbia, K3co, 2016

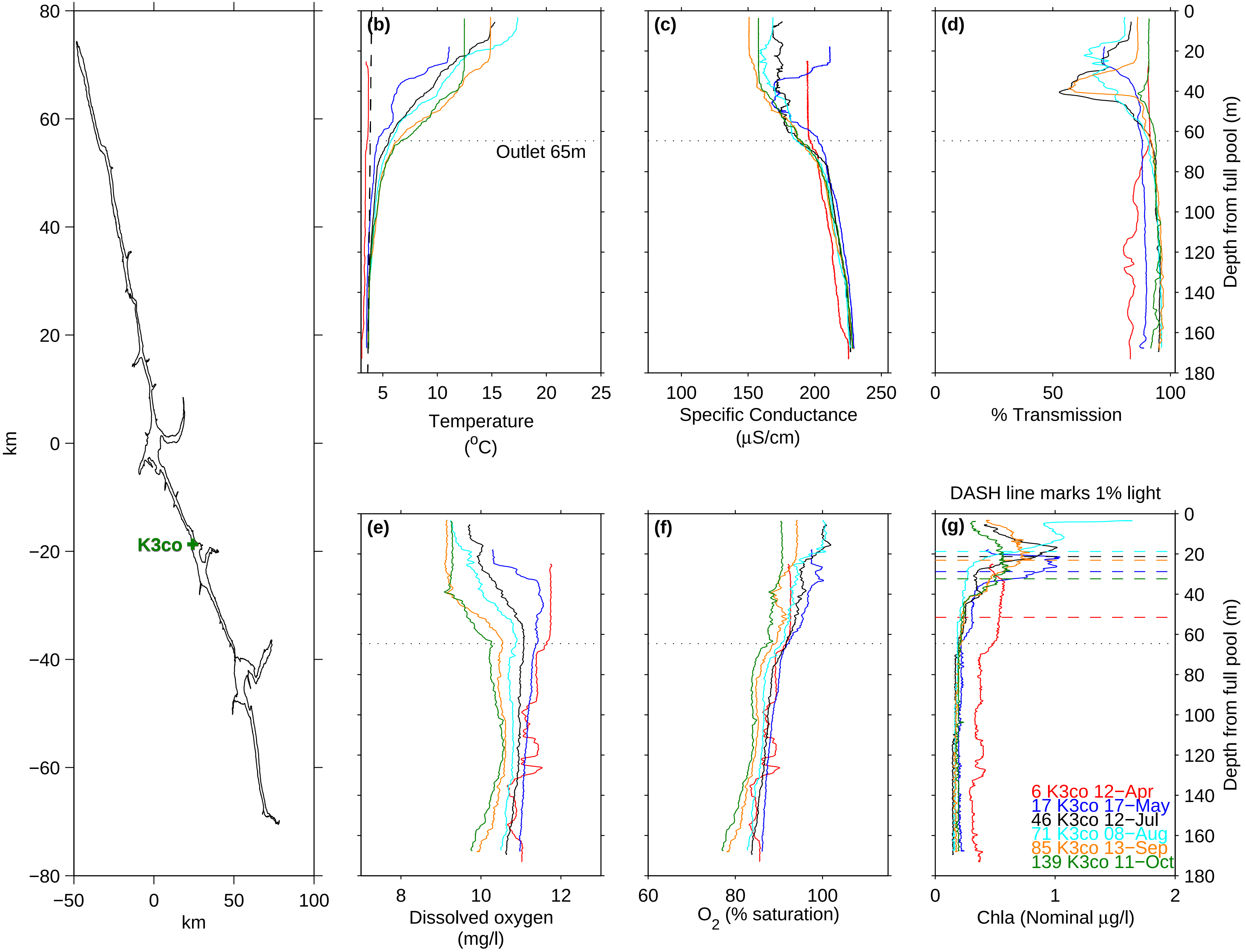


Figure B11 Kinbasket Reservoir, Canoe, Kca1, 2016

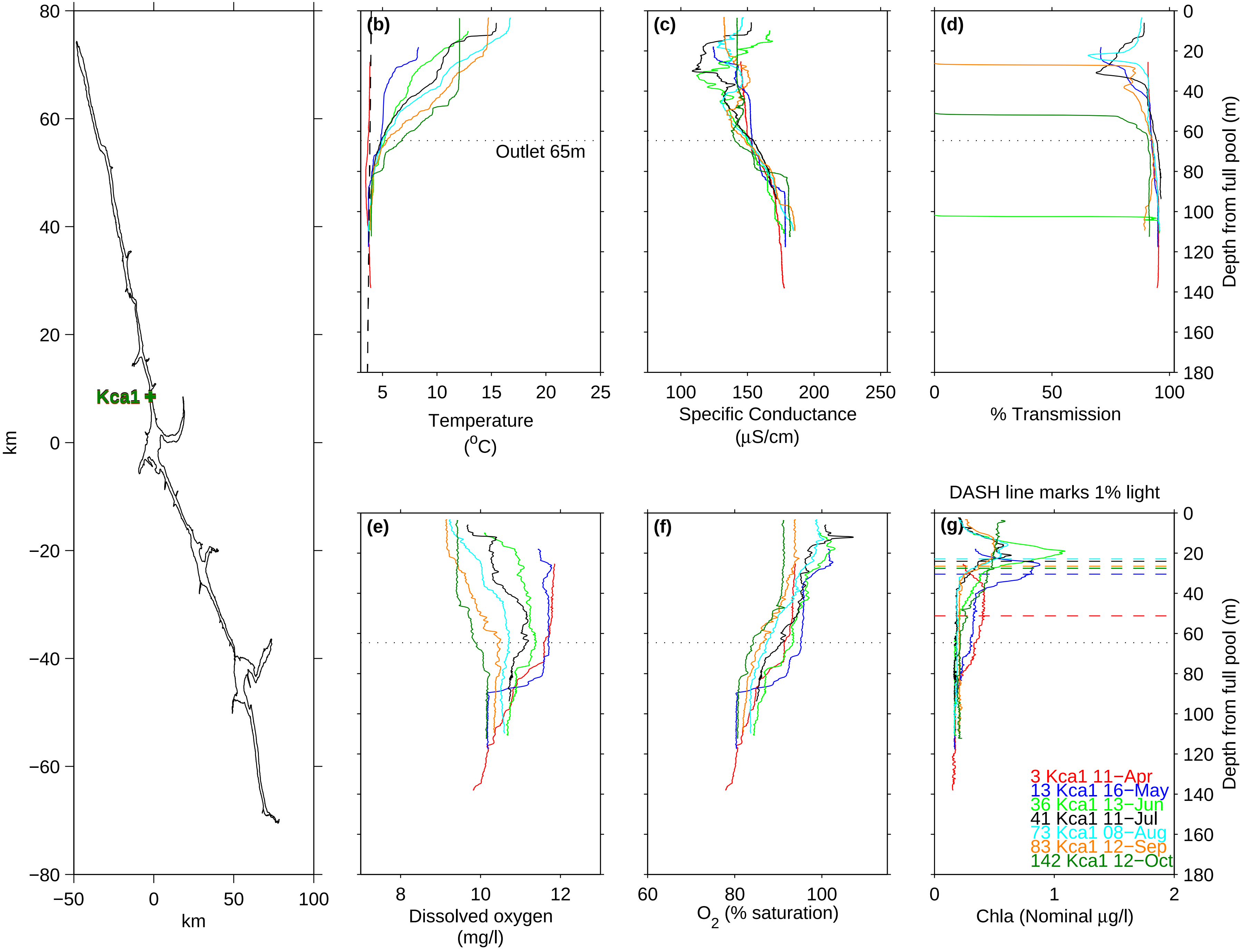


Figure B12 Kinbasket Reservoir, Wood, Kwo1, 2016

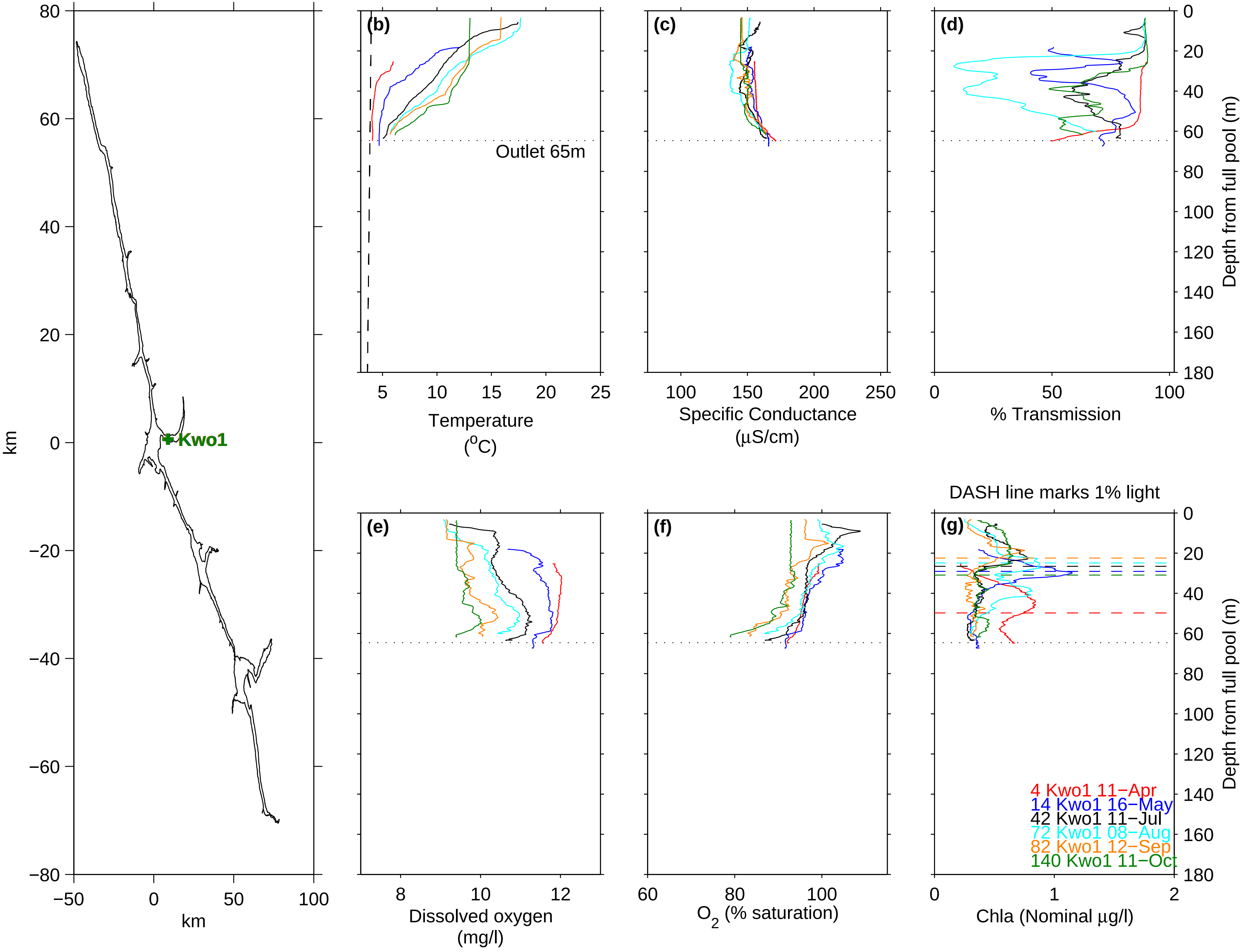


Figure C1 Kinbasket Reservoir 11−12 Apr 2016

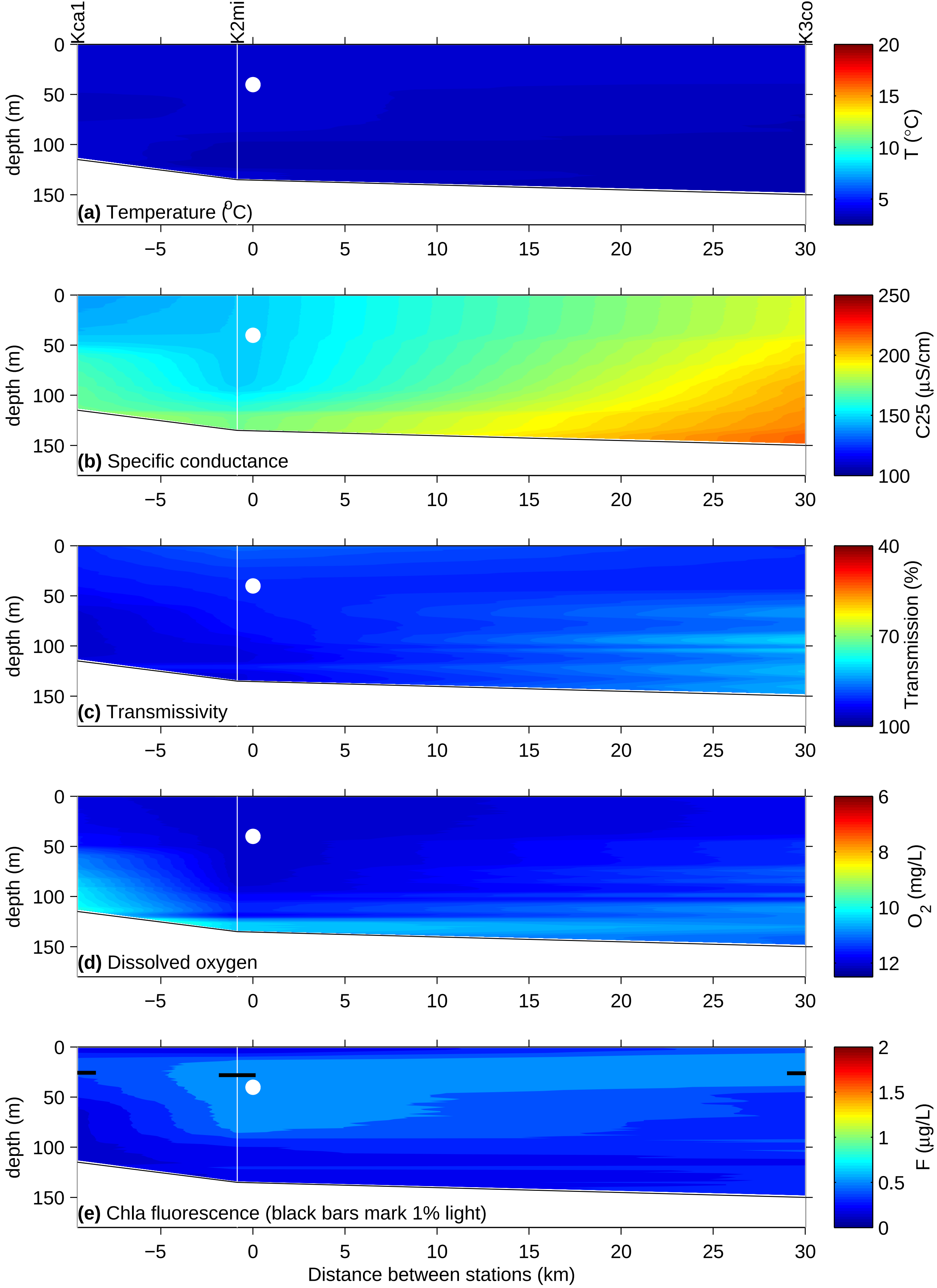


Figure C2 Kinbasket Reservoir 16−17 May 2016

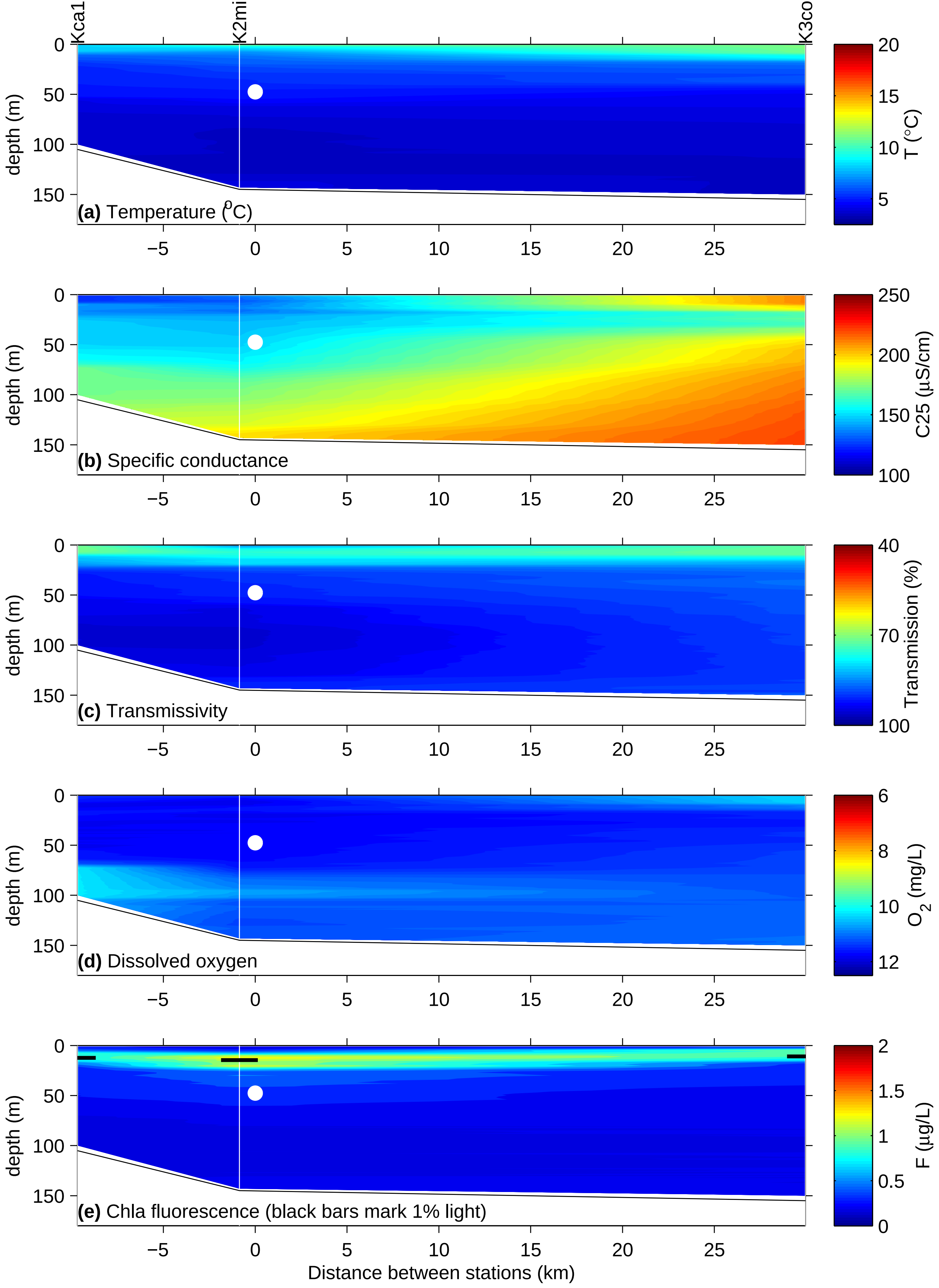


Figure C3 Kinbasket Reservoir 13, 23 Jun 2016

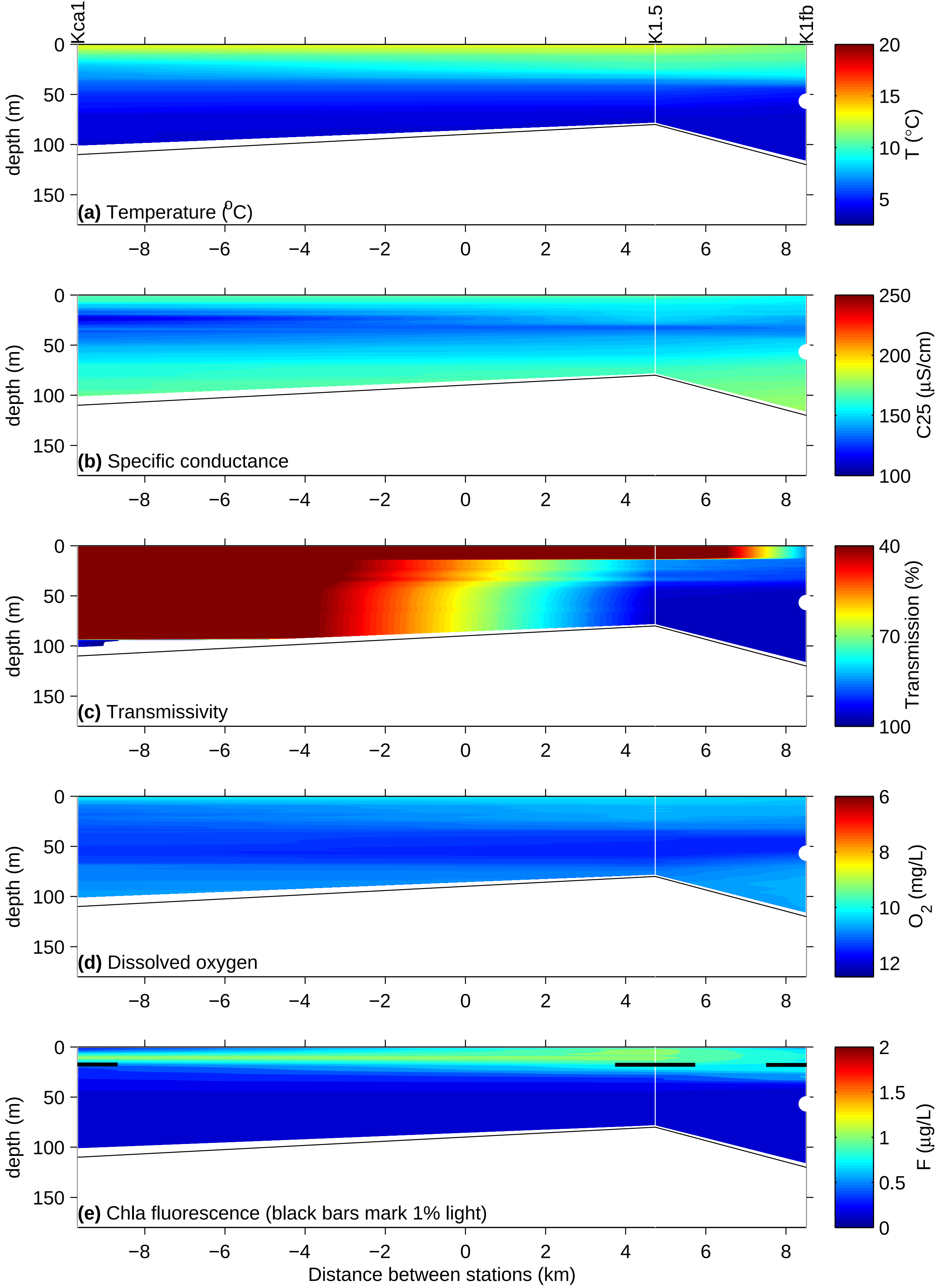


Figure C4 Kinbasket Reservoir 11−12 Jul 2016

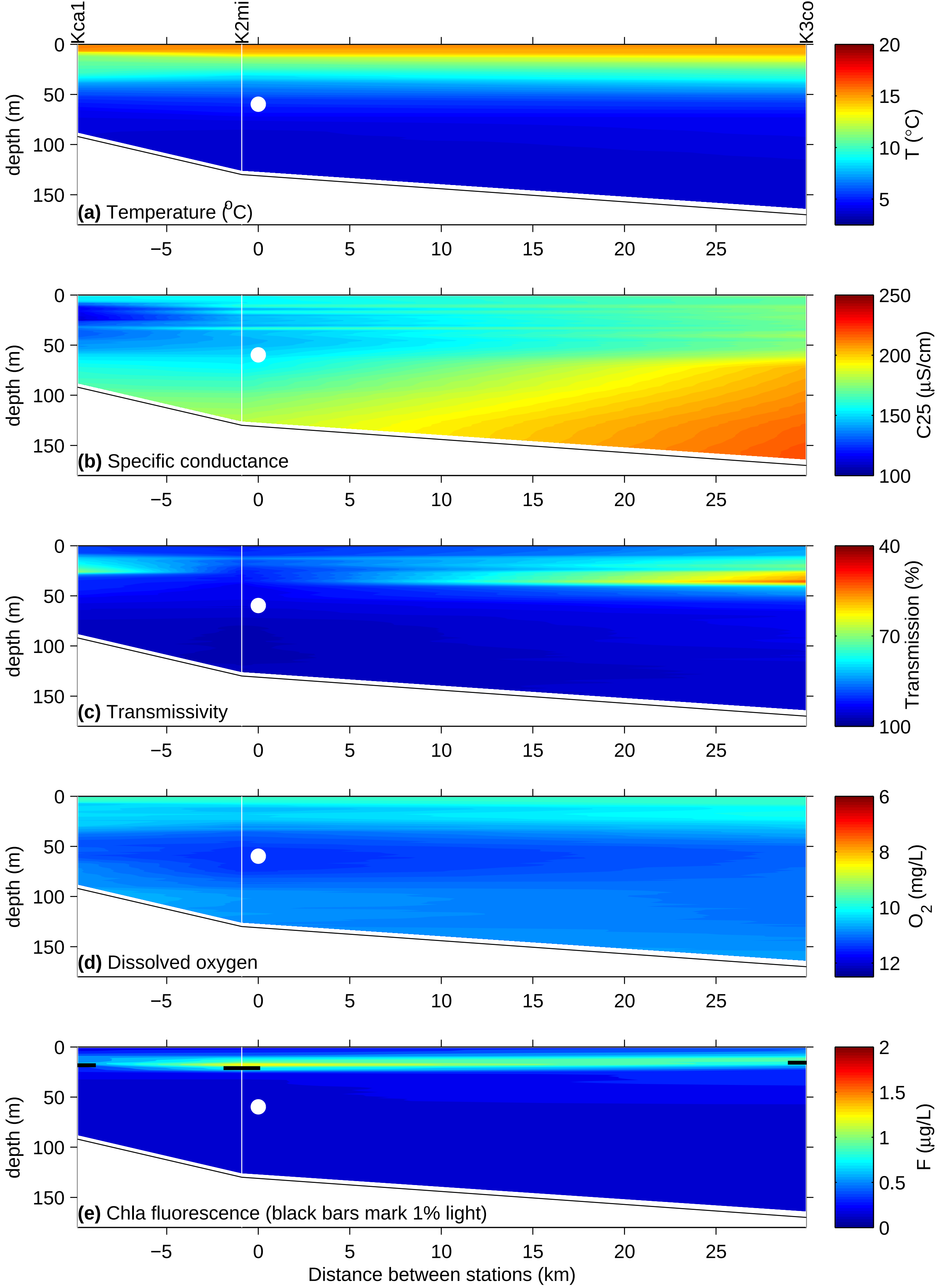


Figure C5 Kinbasket Reservoir 8 Aug 2016

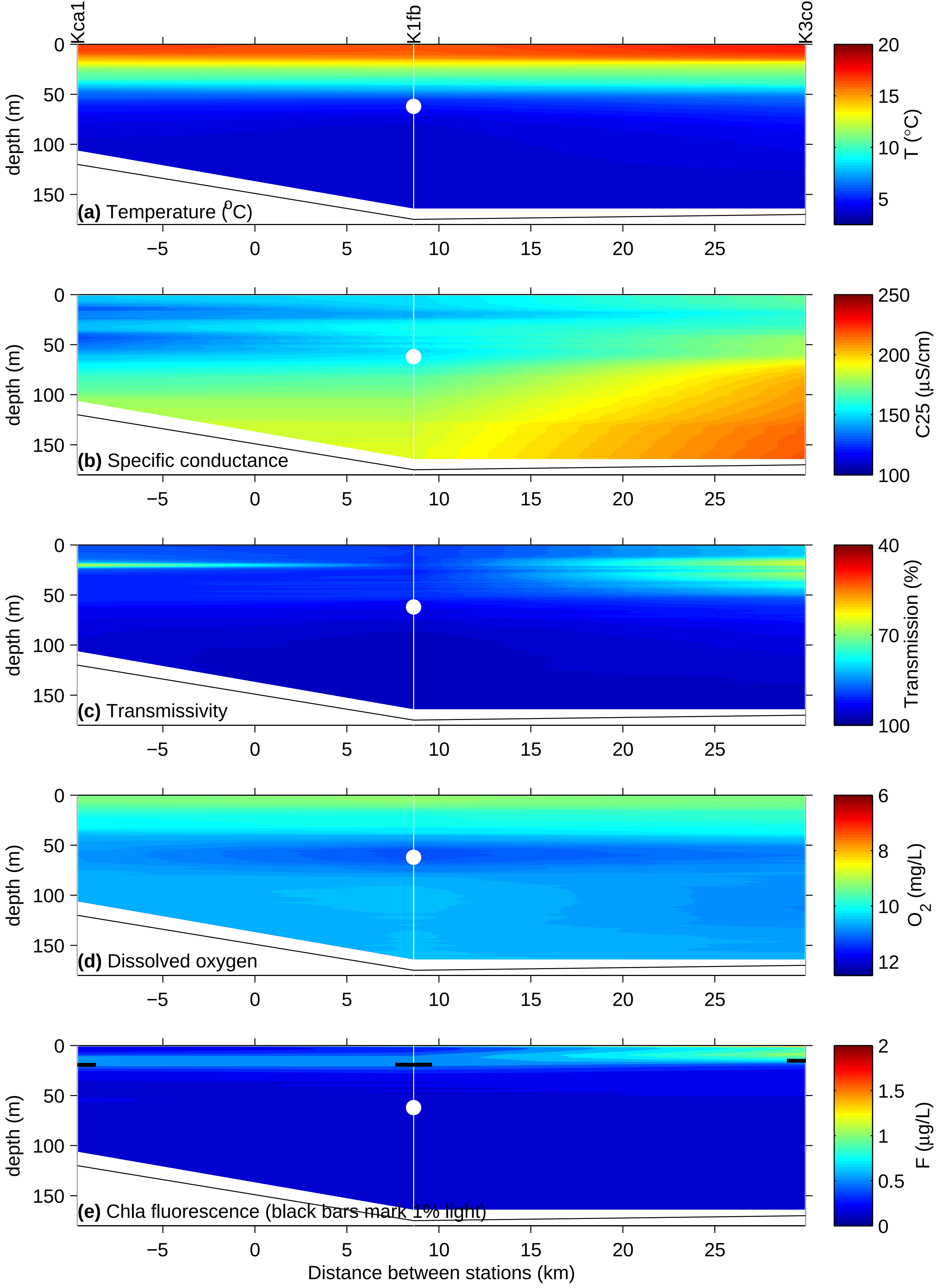
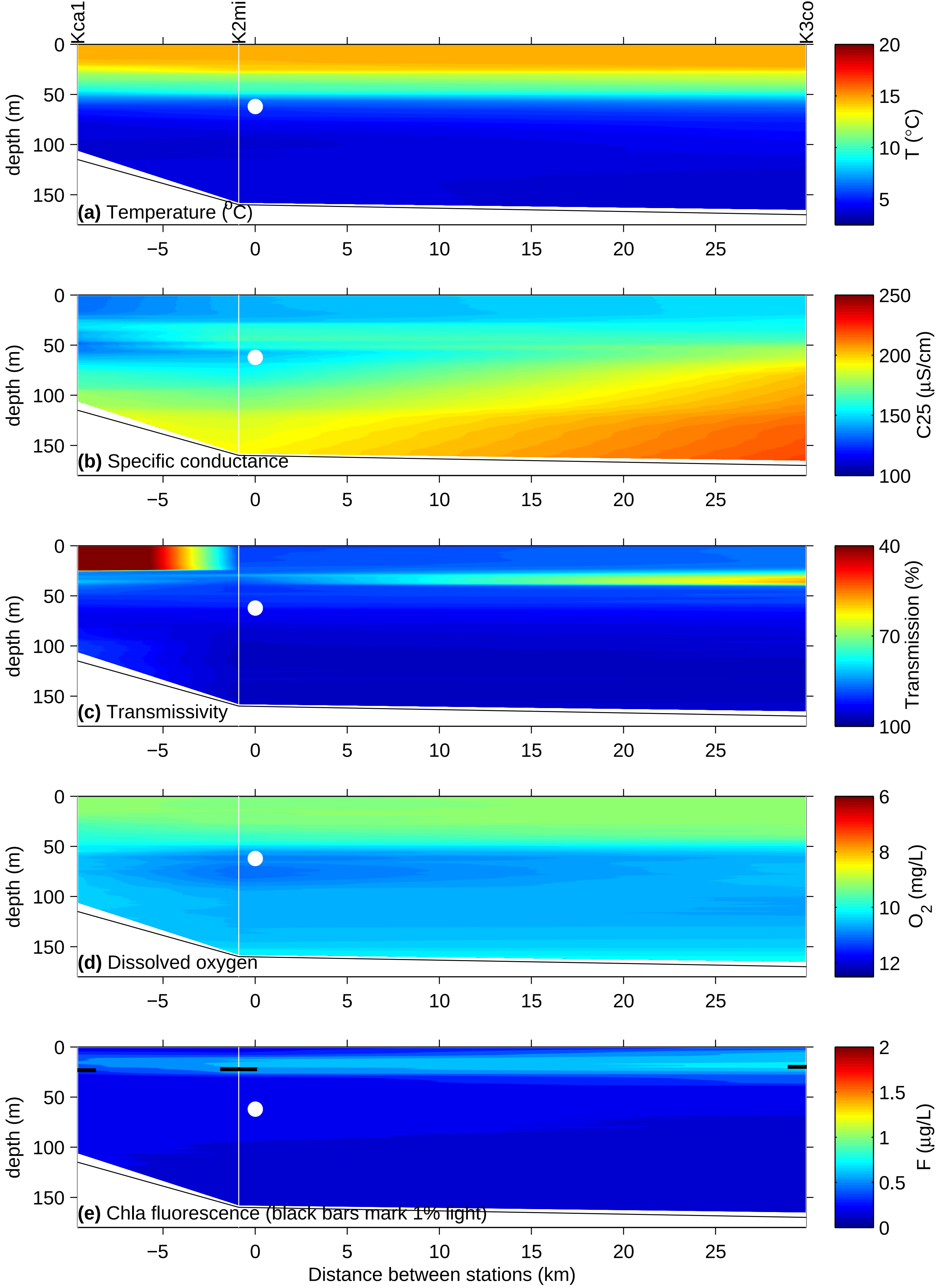


Figure C6 Kinbasket Reservoir 12−13 Sep 2016



(a) Temperature (°C)

(b) Specific conductance

(c) Transmissivity

(d) Dissolved oxygen

(e) Chla fluorescence (black bars mark 1% light)

Figure C7 Kinbasket Reservoir 11−12 Oct 2016

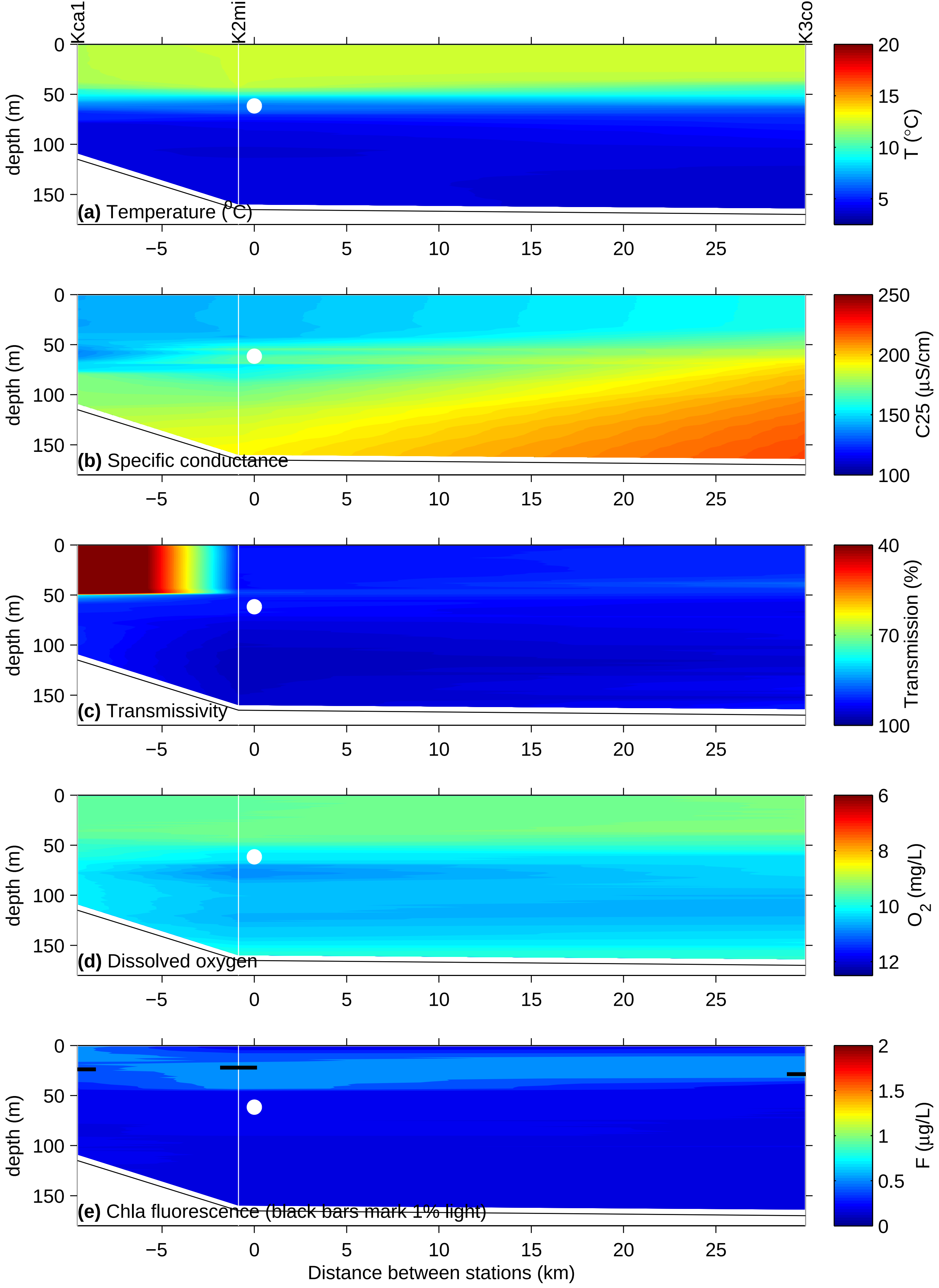


Figure D1 Revelstoke Reservoir, 6, 18−19 Apr 2016

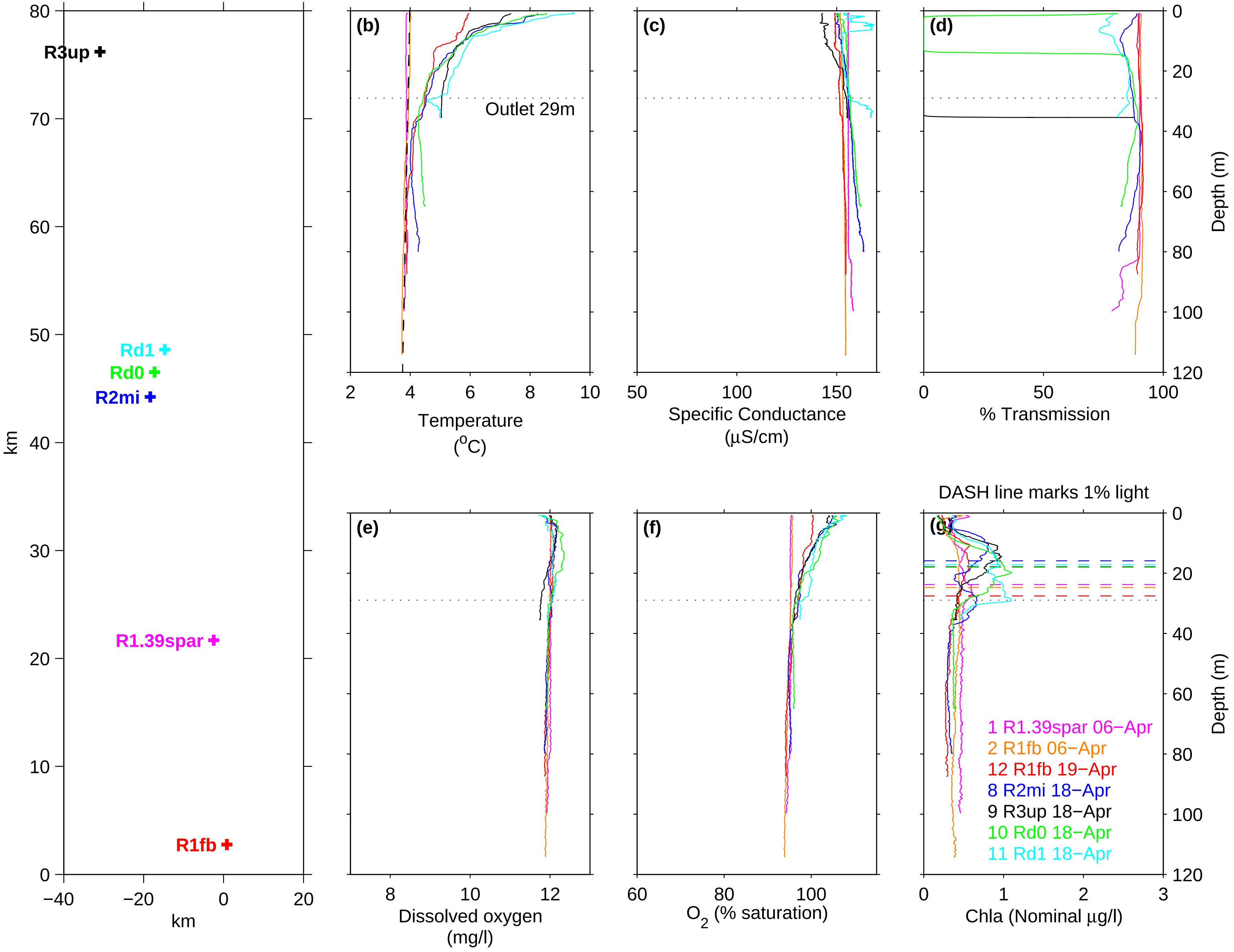


Figure D2 Revelstoke Reservoir, 24−25 May 2016

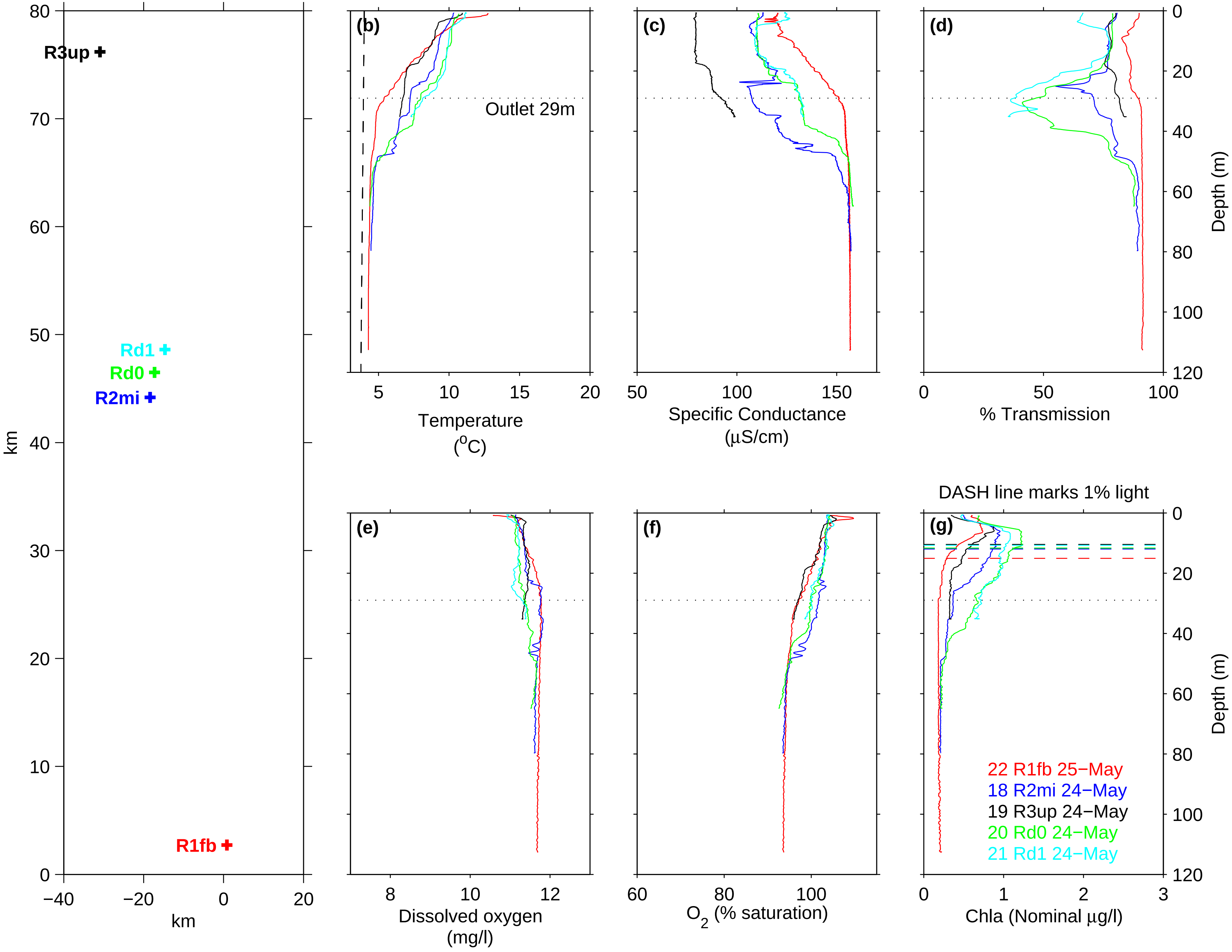


Figure D3 Revelstoke Reservoir, 30 May 2016

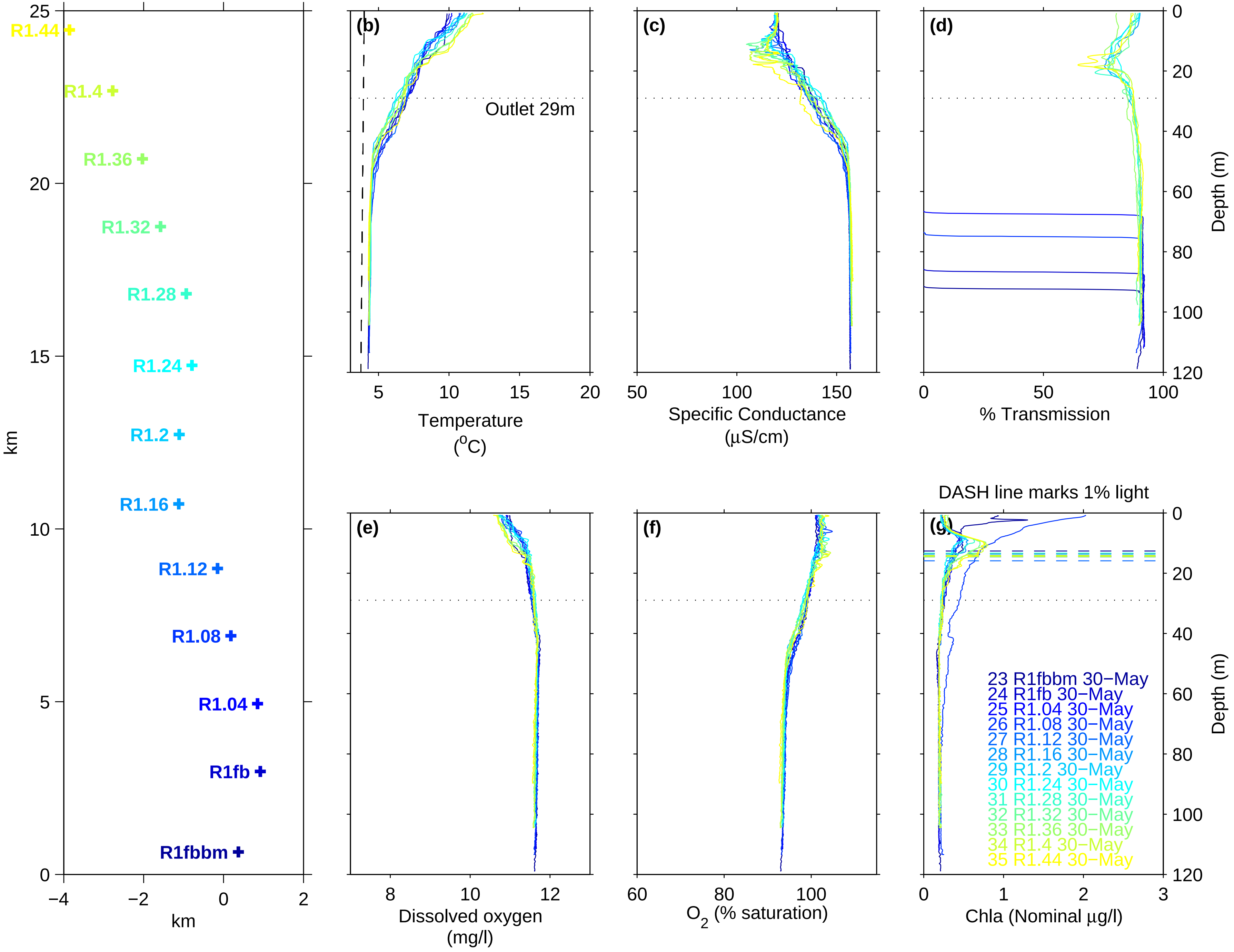


Figure D4 Revelstoke Reservoir, 21−22 Jun 2016

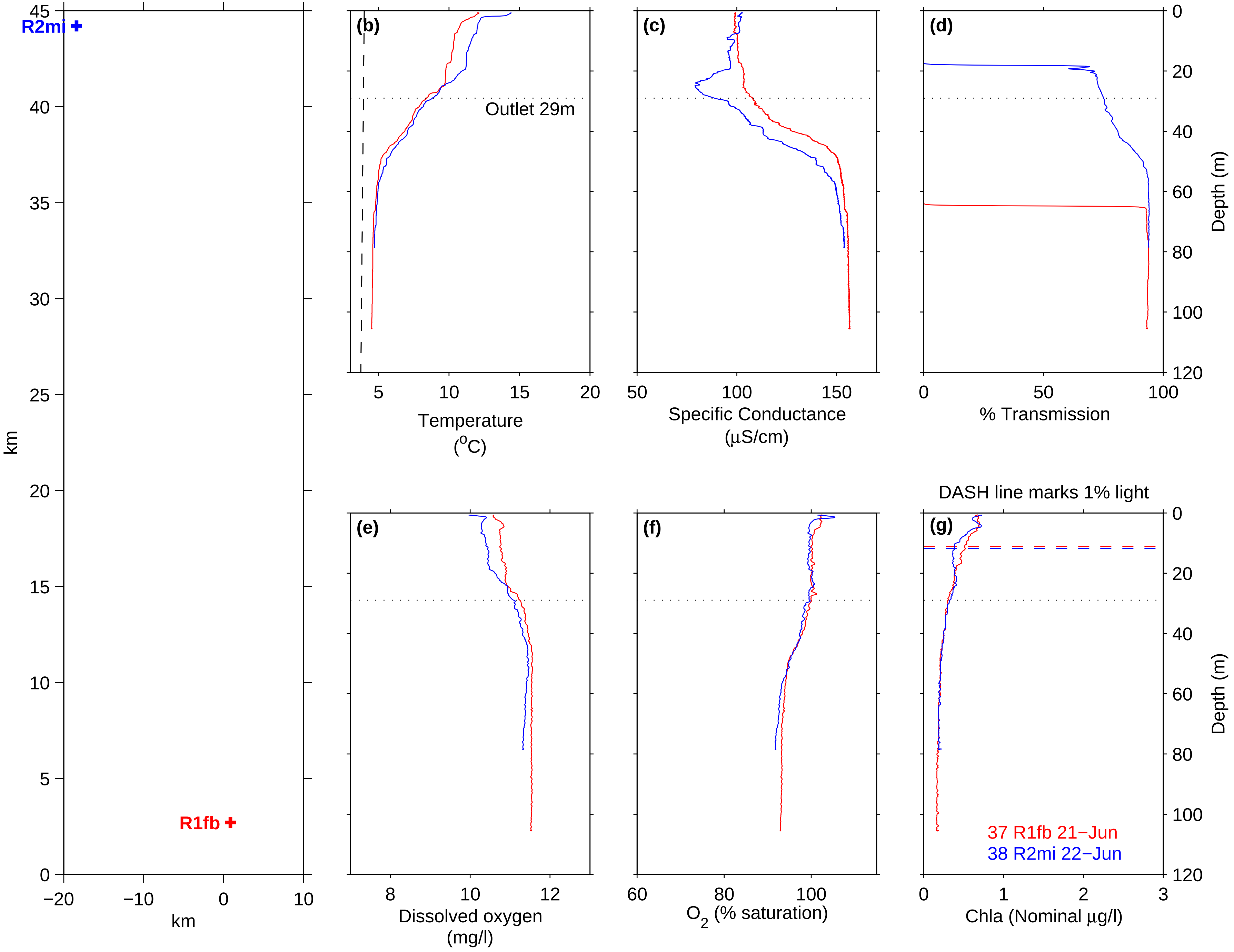


Figure D5 Revelstoke Reservoir, 14 Jul 2016

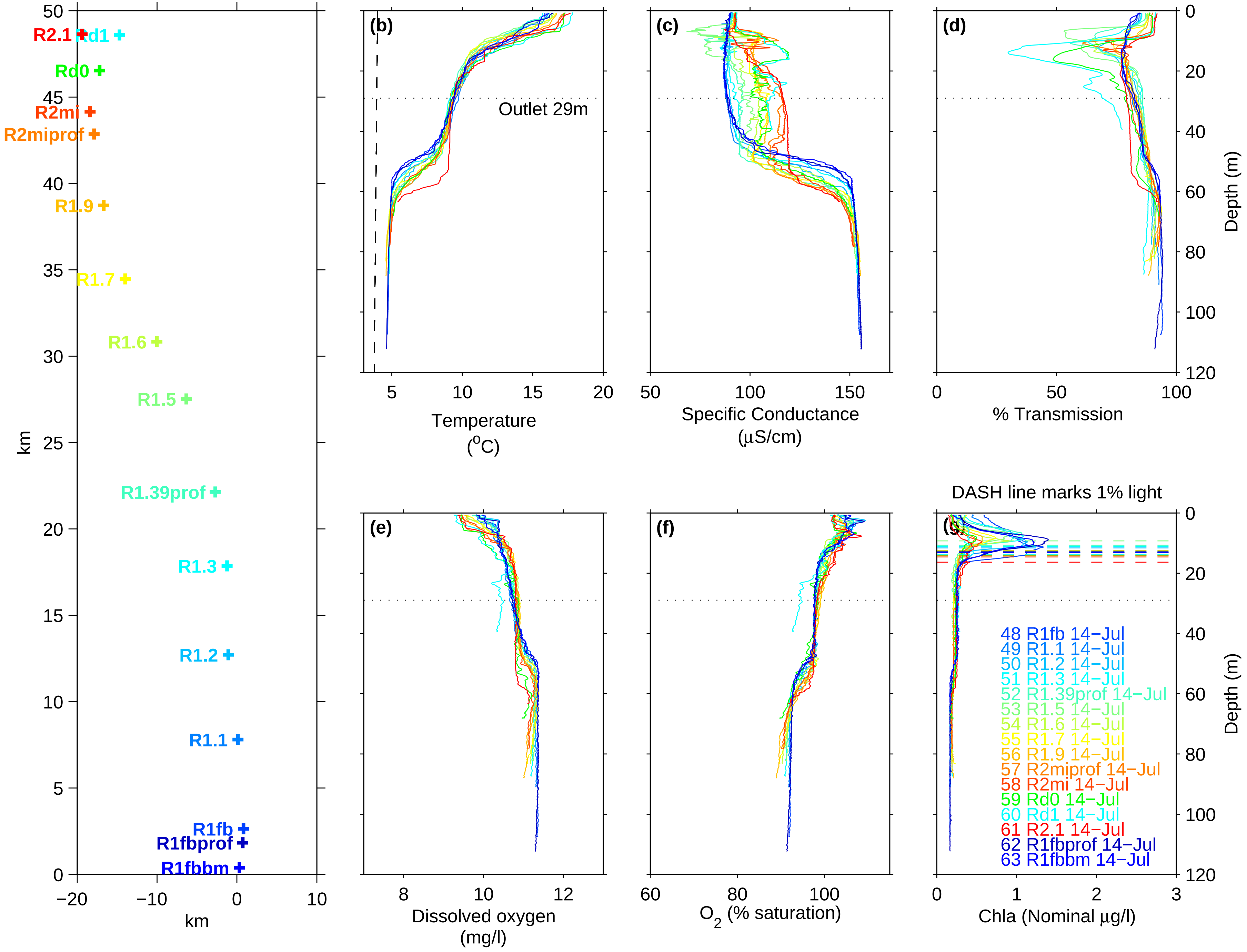


Figure D6 Revelstoke Reservoir, 18−20 Jul 2016

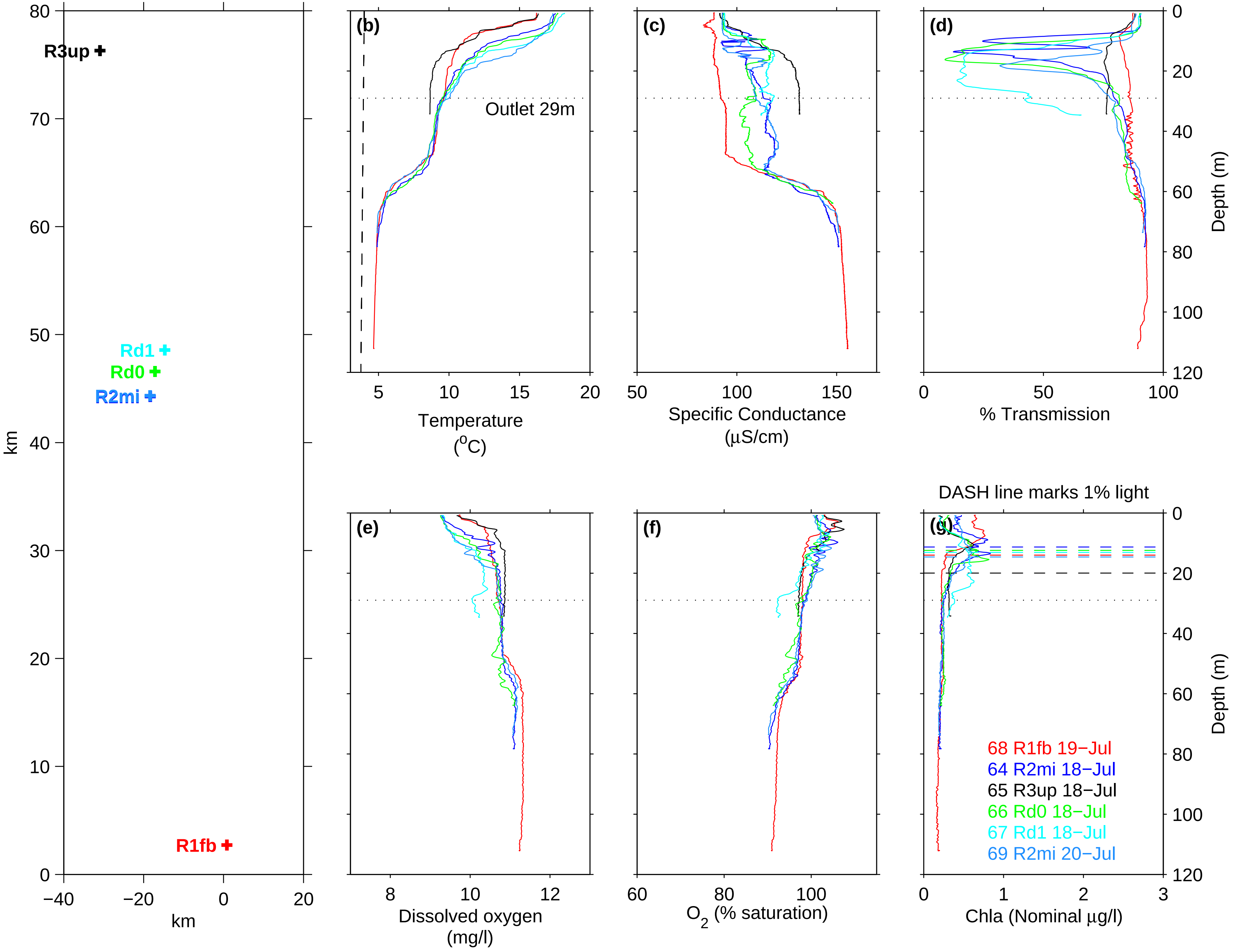


Figure D7 Revelstoke Reservoir, 15−17 Aug 2016

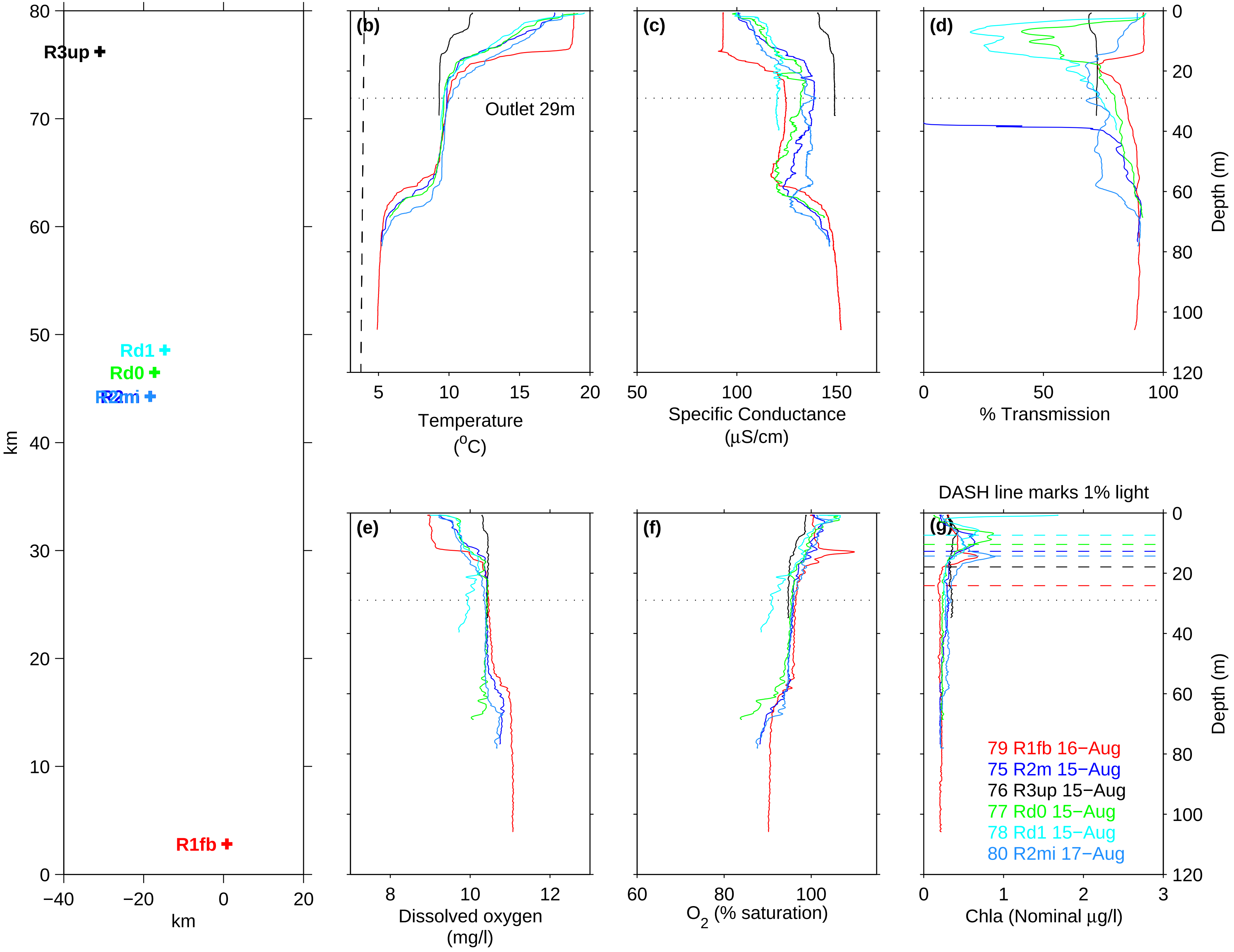


Figure D8 Revelstoke Reservoir, 19−21 Sep 2016

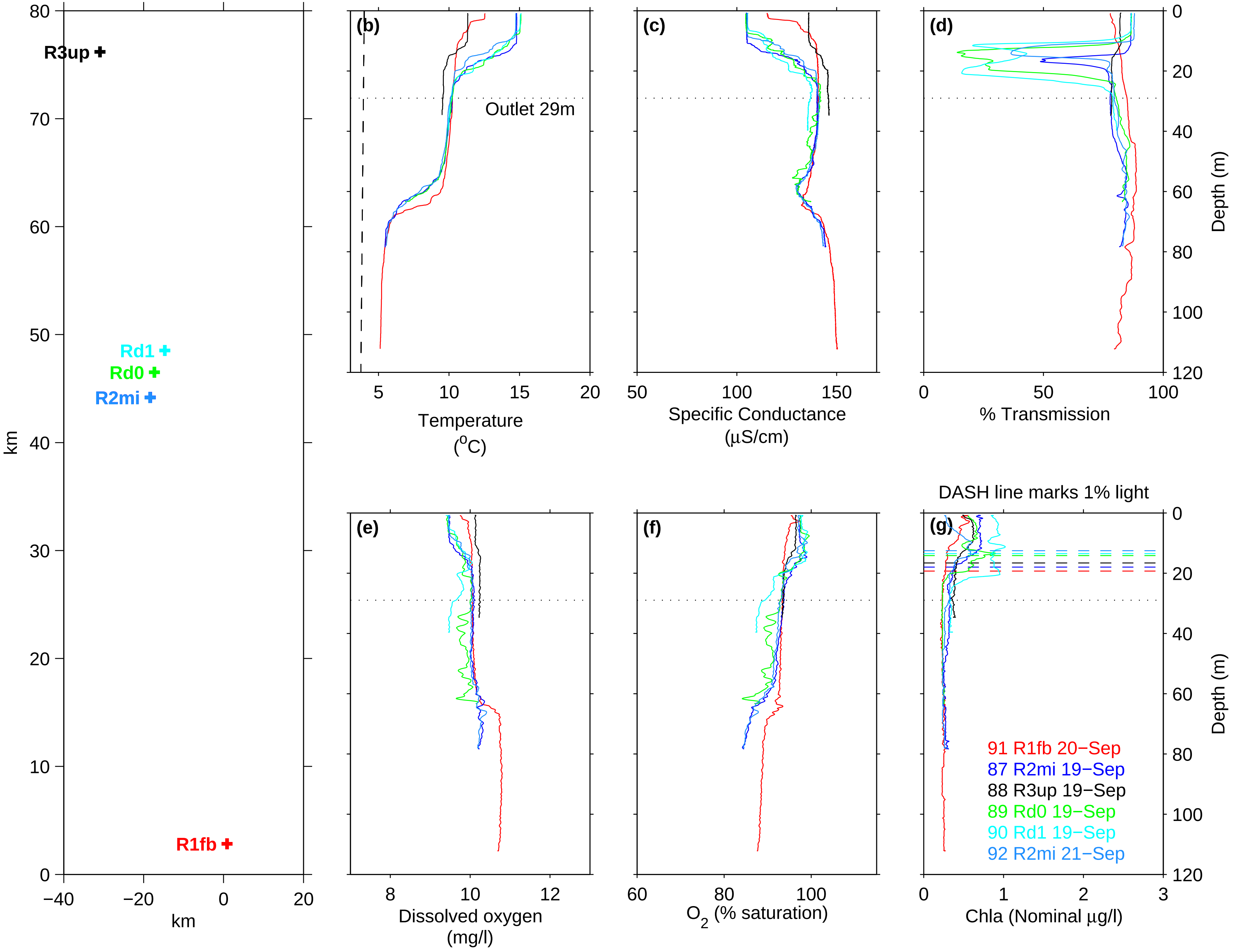


Figure D9 Revelstoke Reservoir, 3 Oct 2016

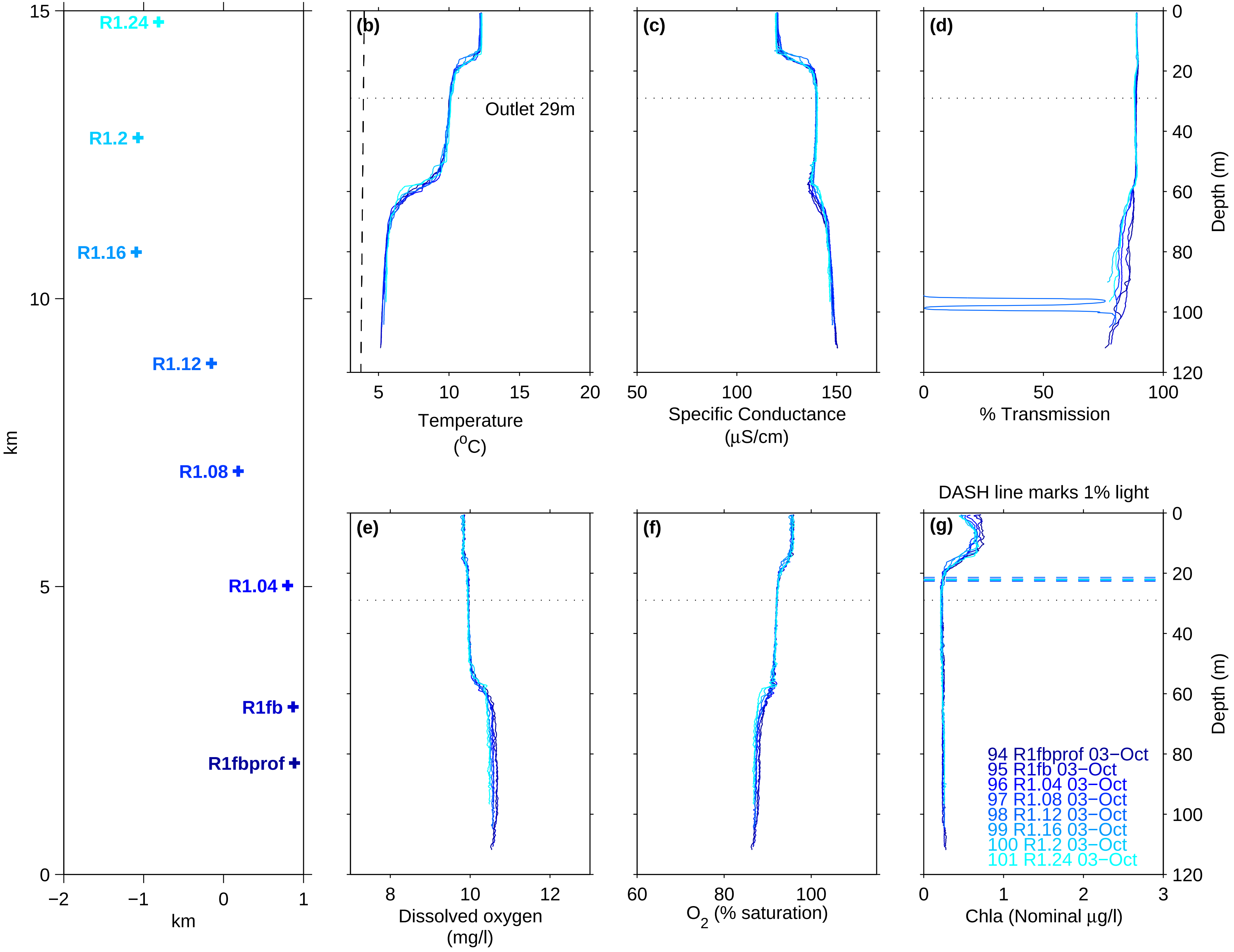


Figure D10 Revelstoke Reservoir, 5 Oct 2016

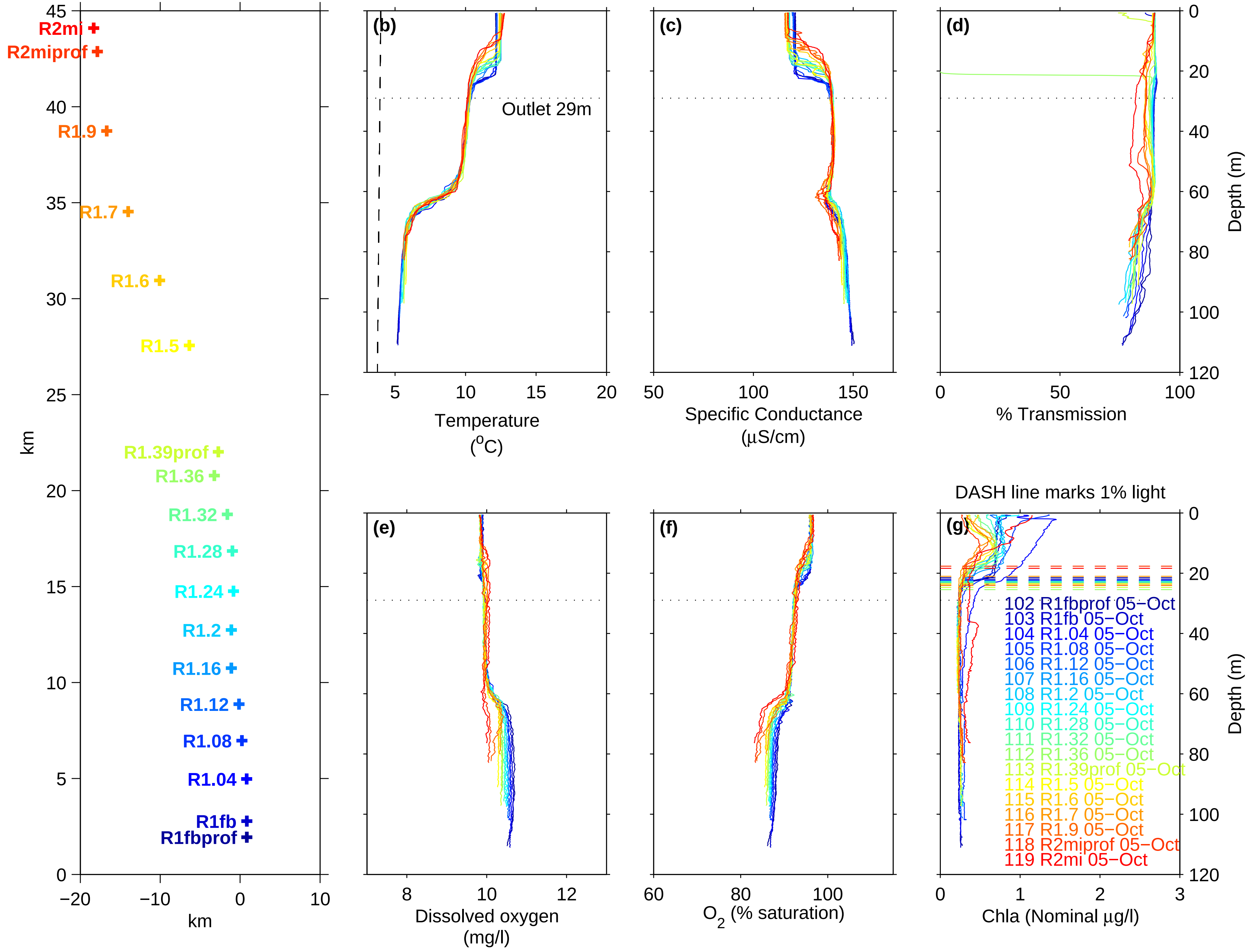


Figure D11 Revelstoke Reservoir, 7 Oct 2016

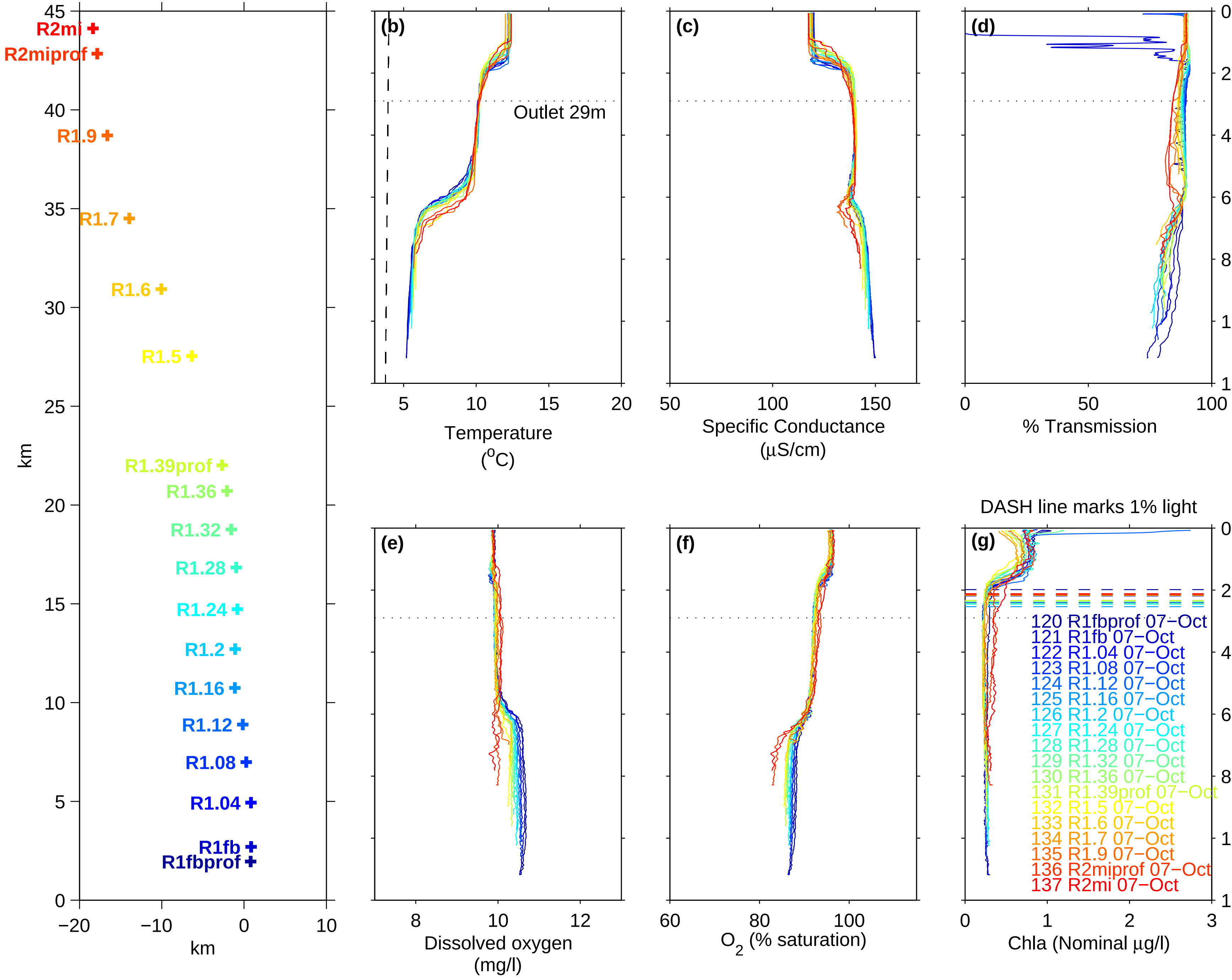


Figure D12 Revelstoke Reservoir, 17−18 Oct 2016

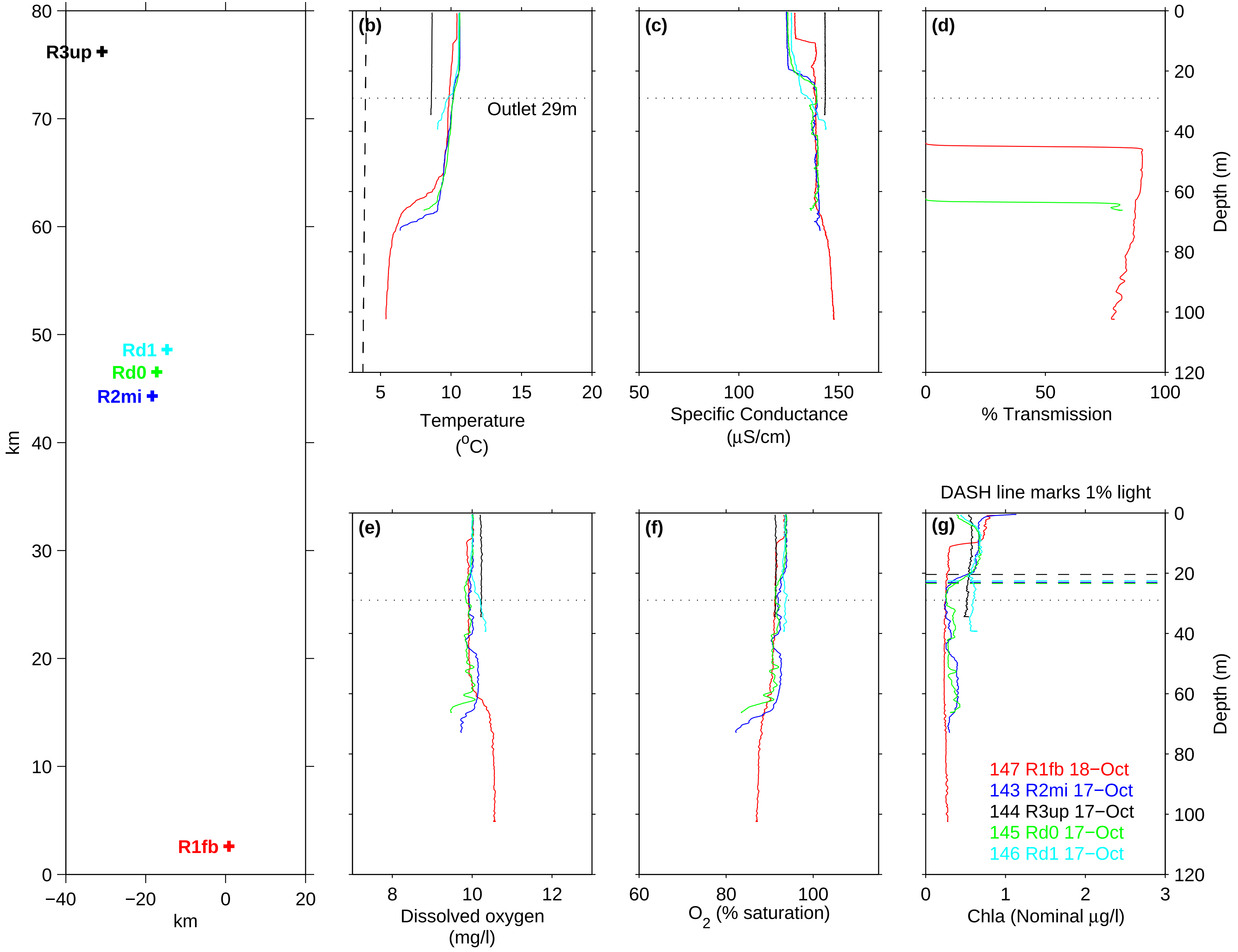


Figure D13 Revelstoke Reservoir, Forebay 2016

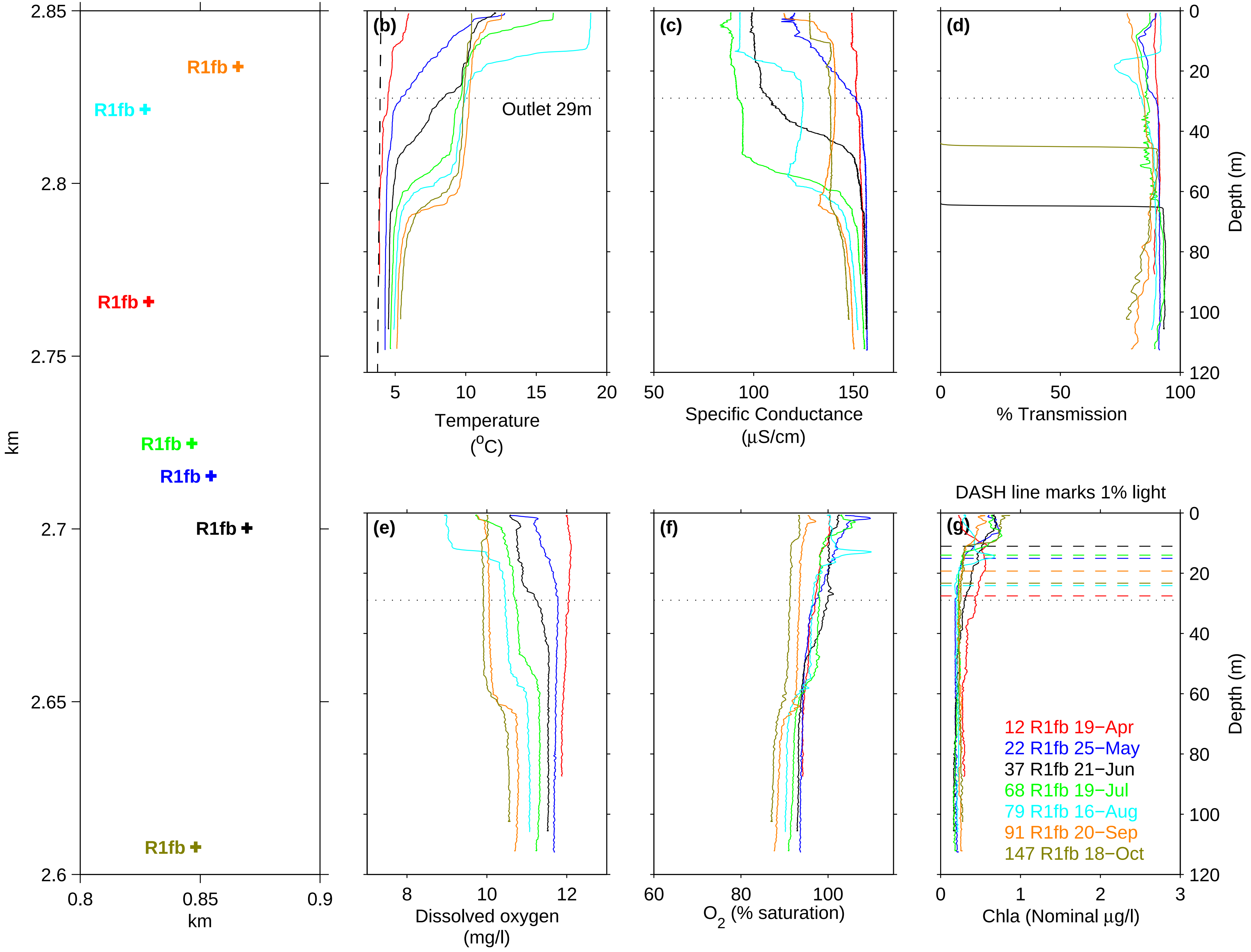


Figure D14 Revelstoke Reservoir, Middle 2016

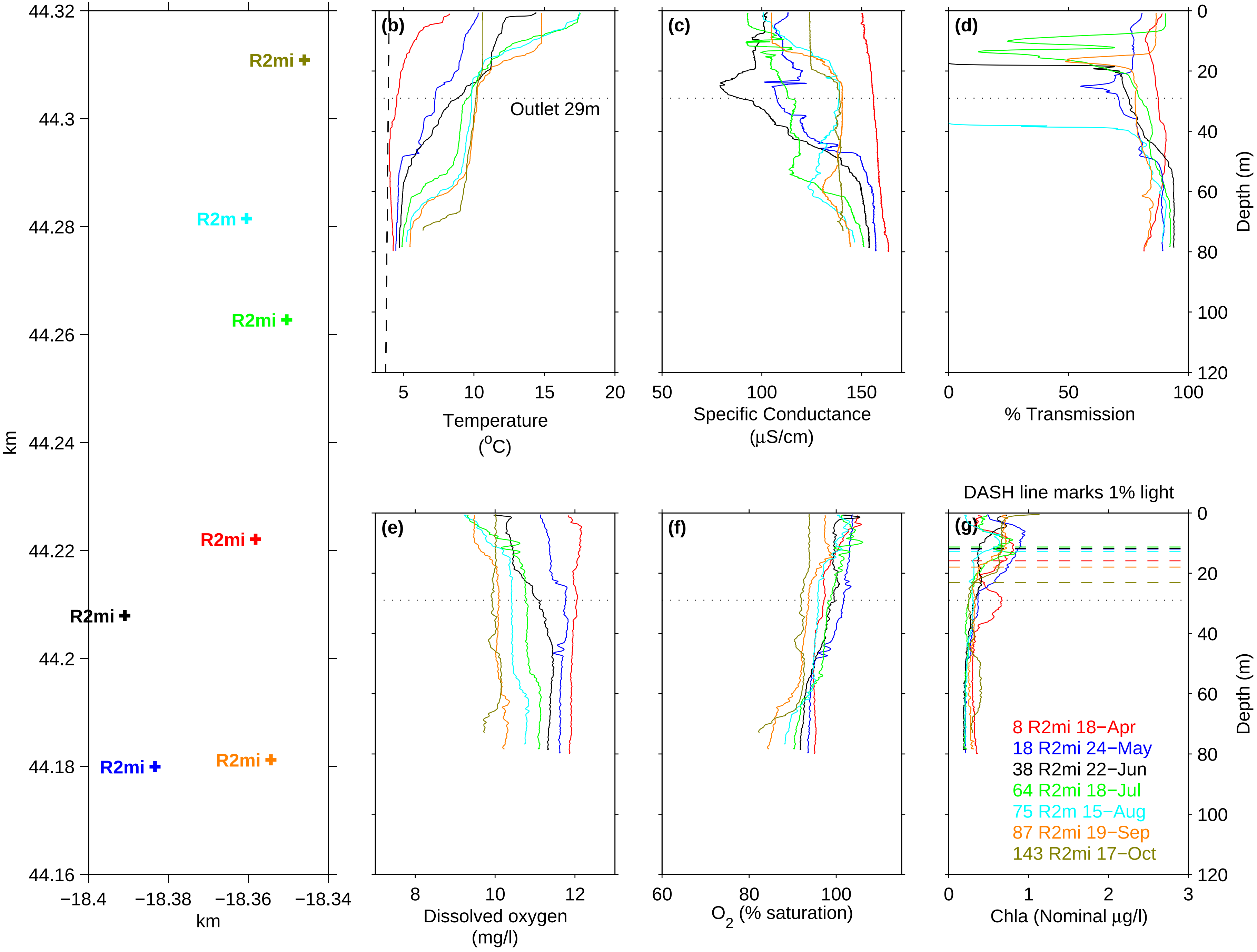


Figure D15 Revelstoke Reservoir, Upper 2016

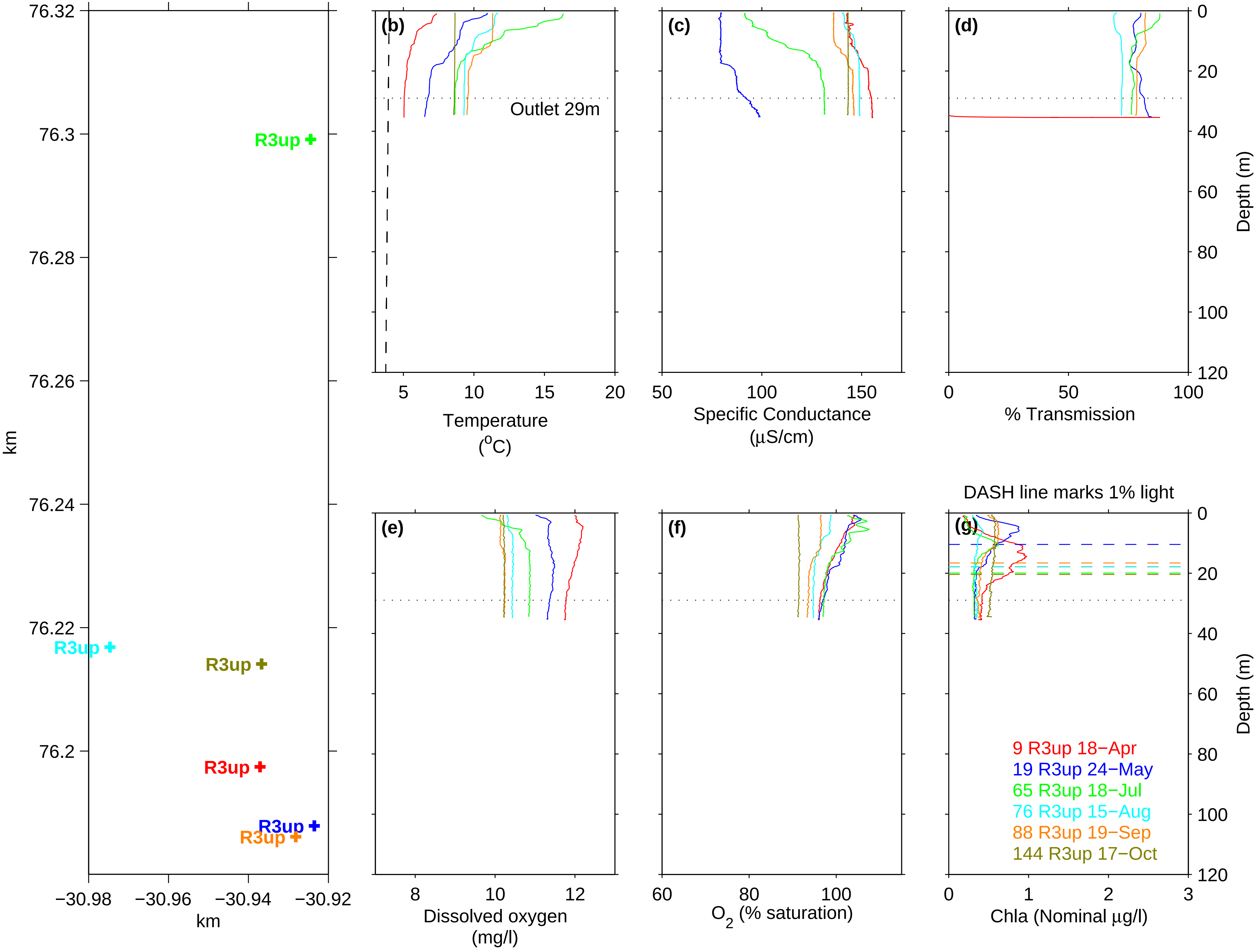


Figure D16 Revelstoke Reservoir, Downie Arm 2016

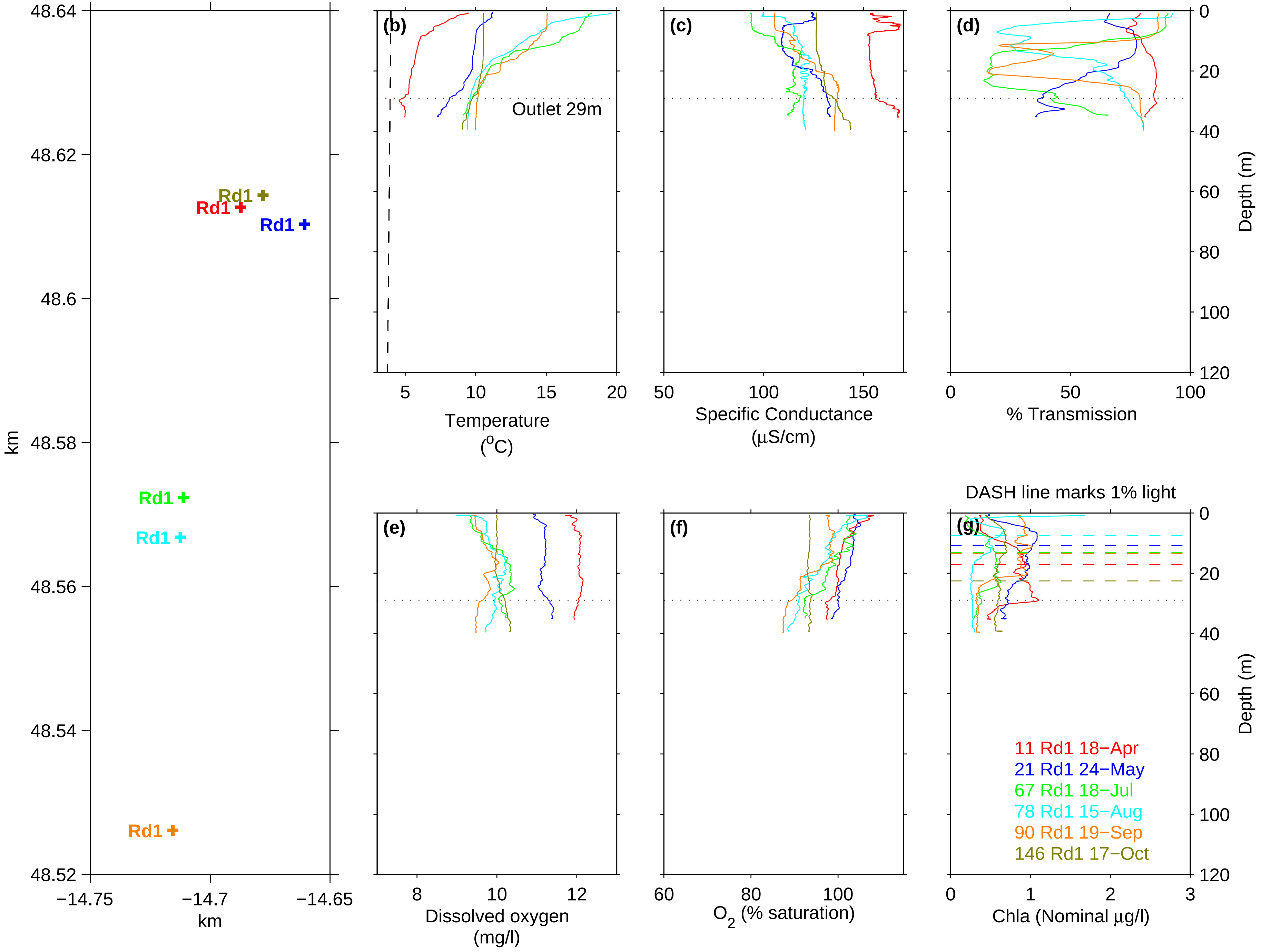


Figure E1 Revelstoke Reservoir 18−19 Apr 2016

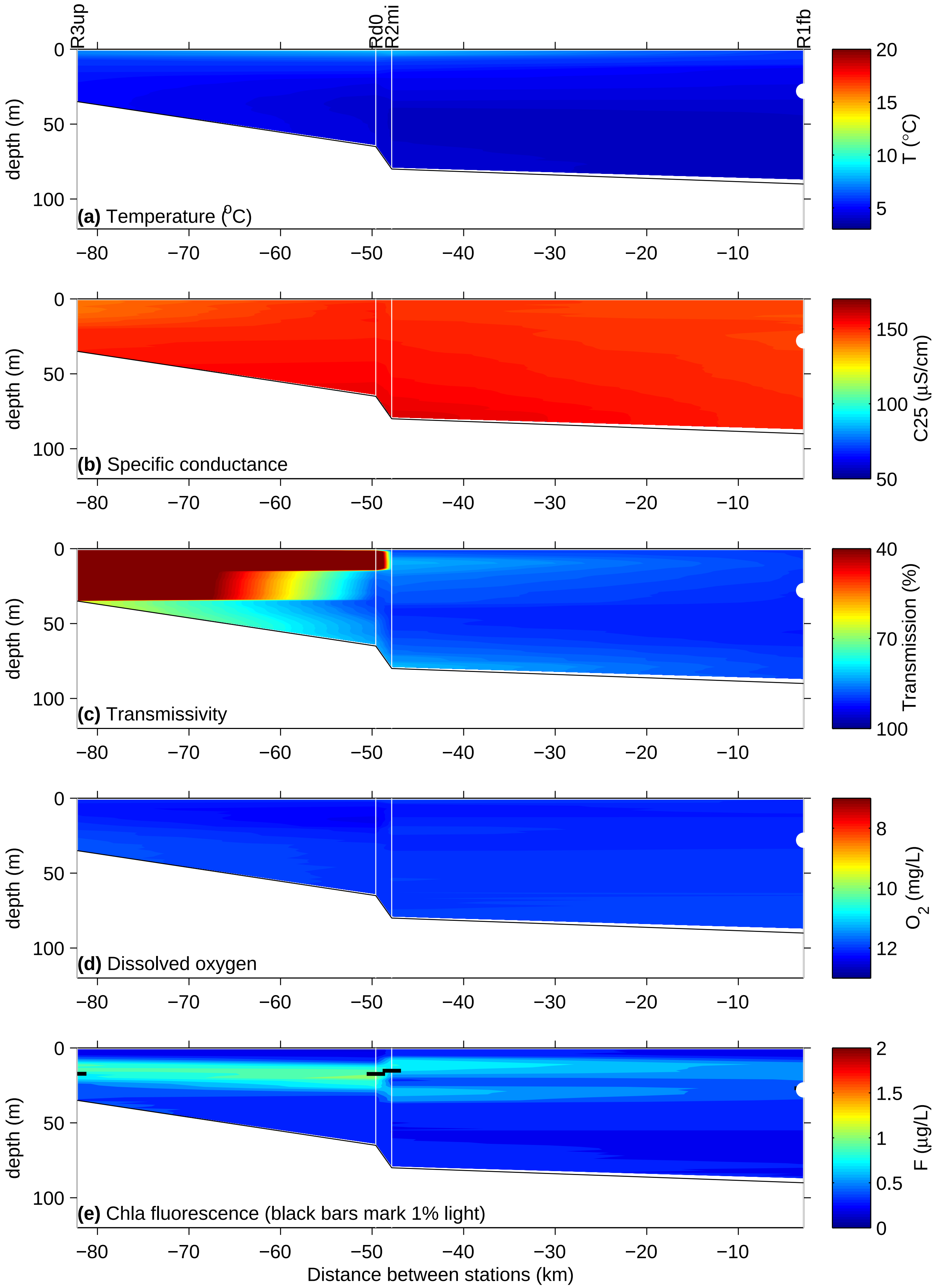


Figure E2 Revelstoke Reservoir 24−25 May 2016

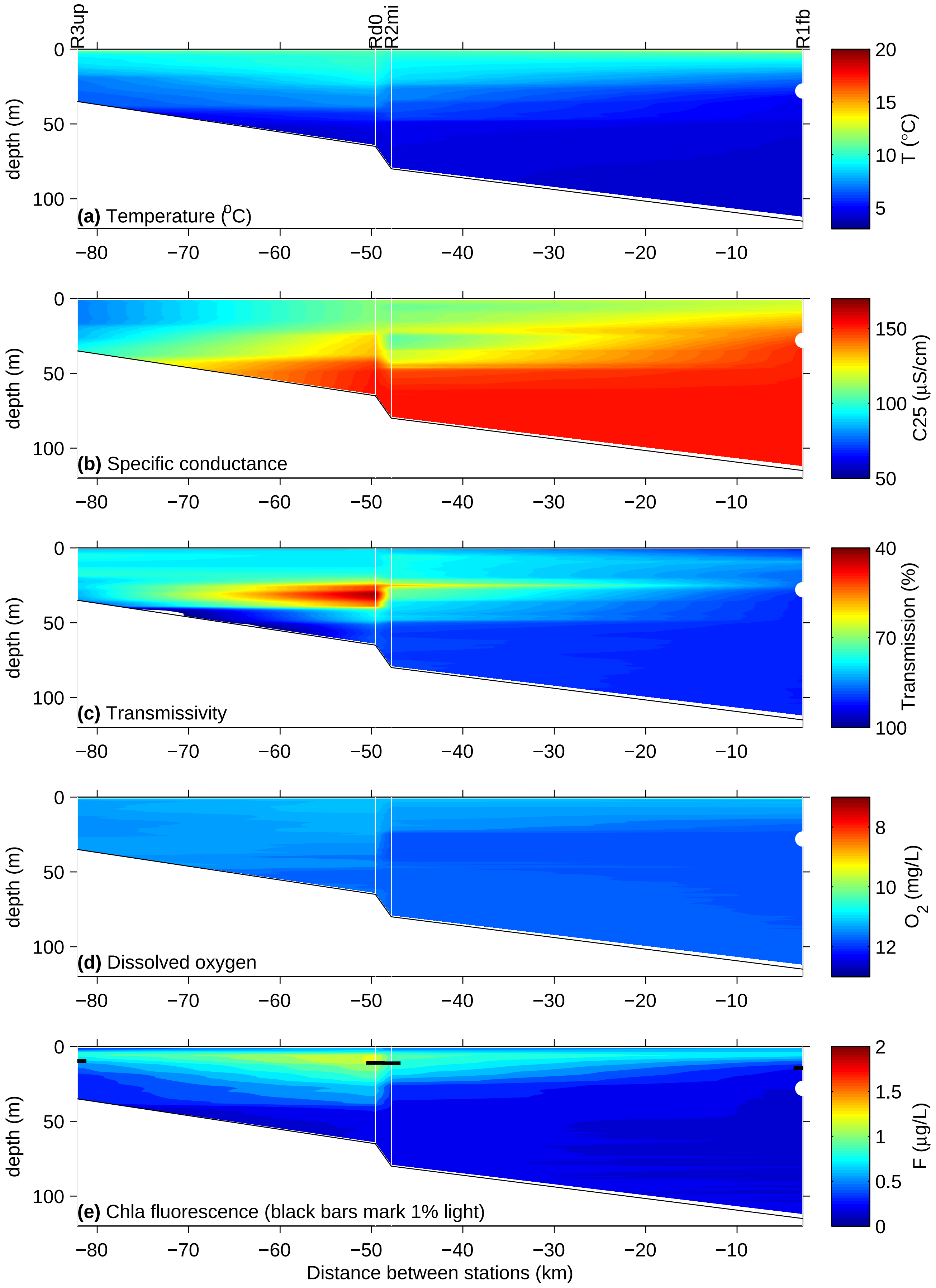


Figure E3 Revelstoke Reservoir 30 May 2016

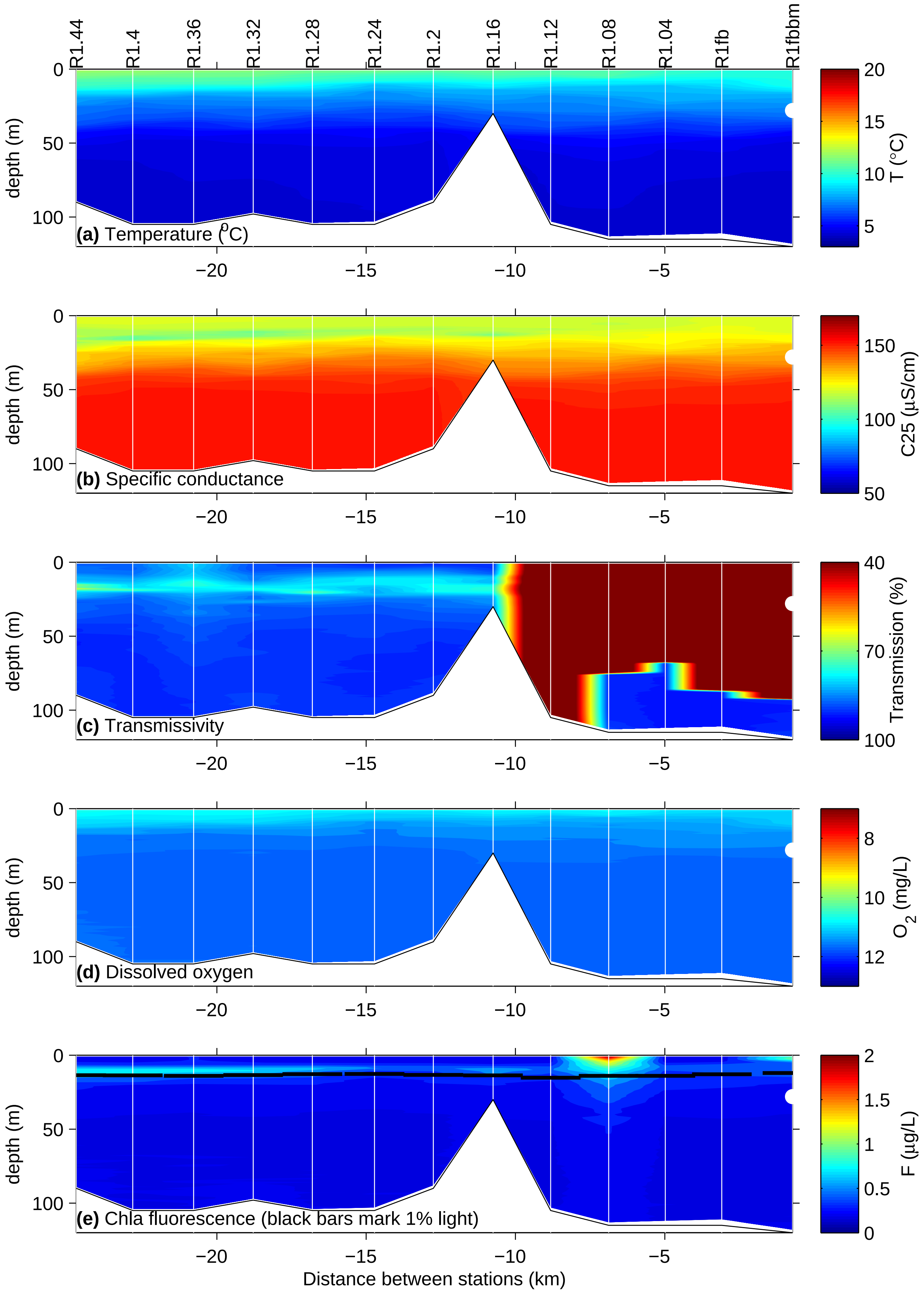


Figure E4 Revelstoke Reservoir 21−22 Jun 2016

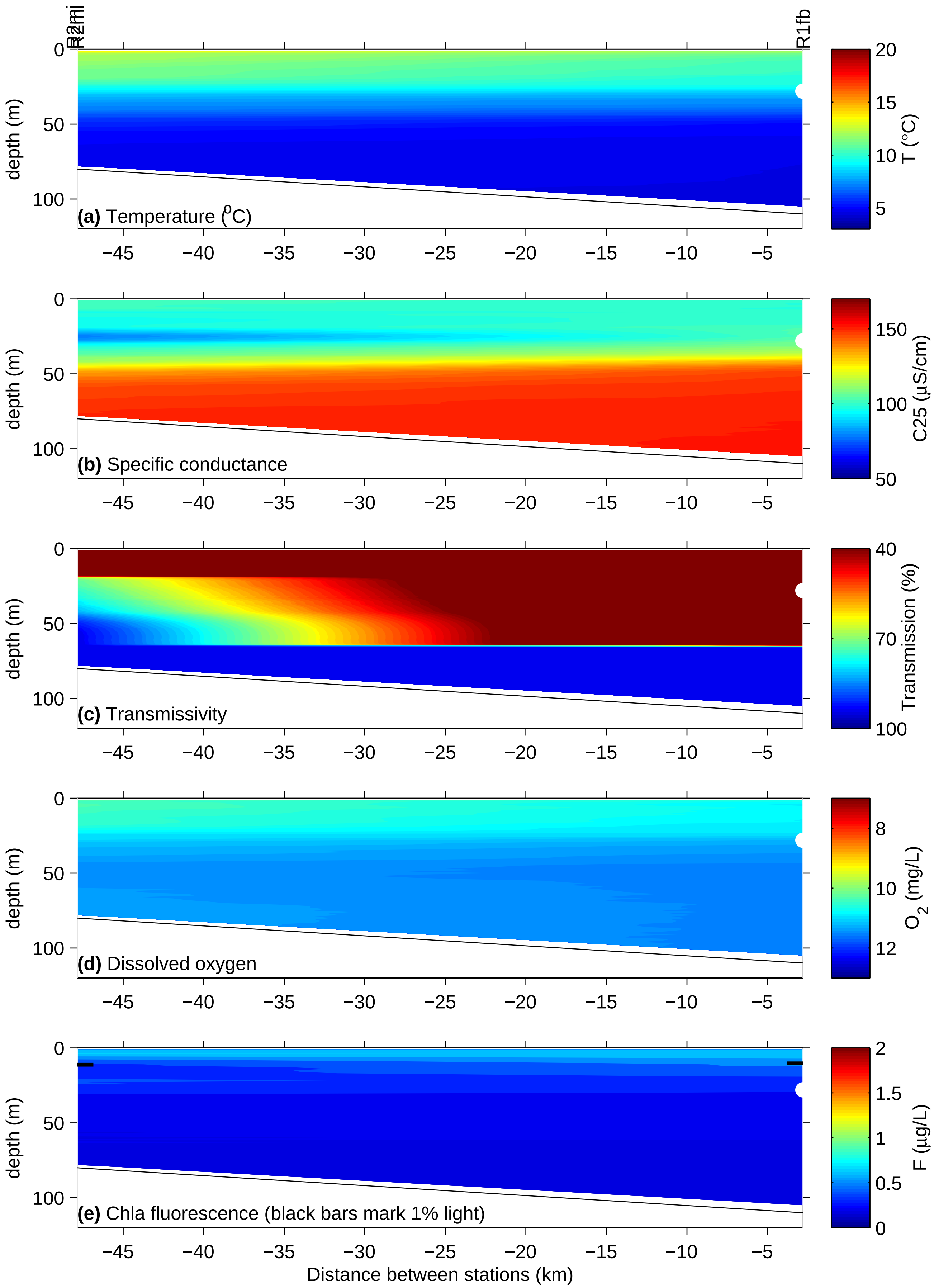


Figure E5 Revelstoke Reservoir 14 Jul 2016

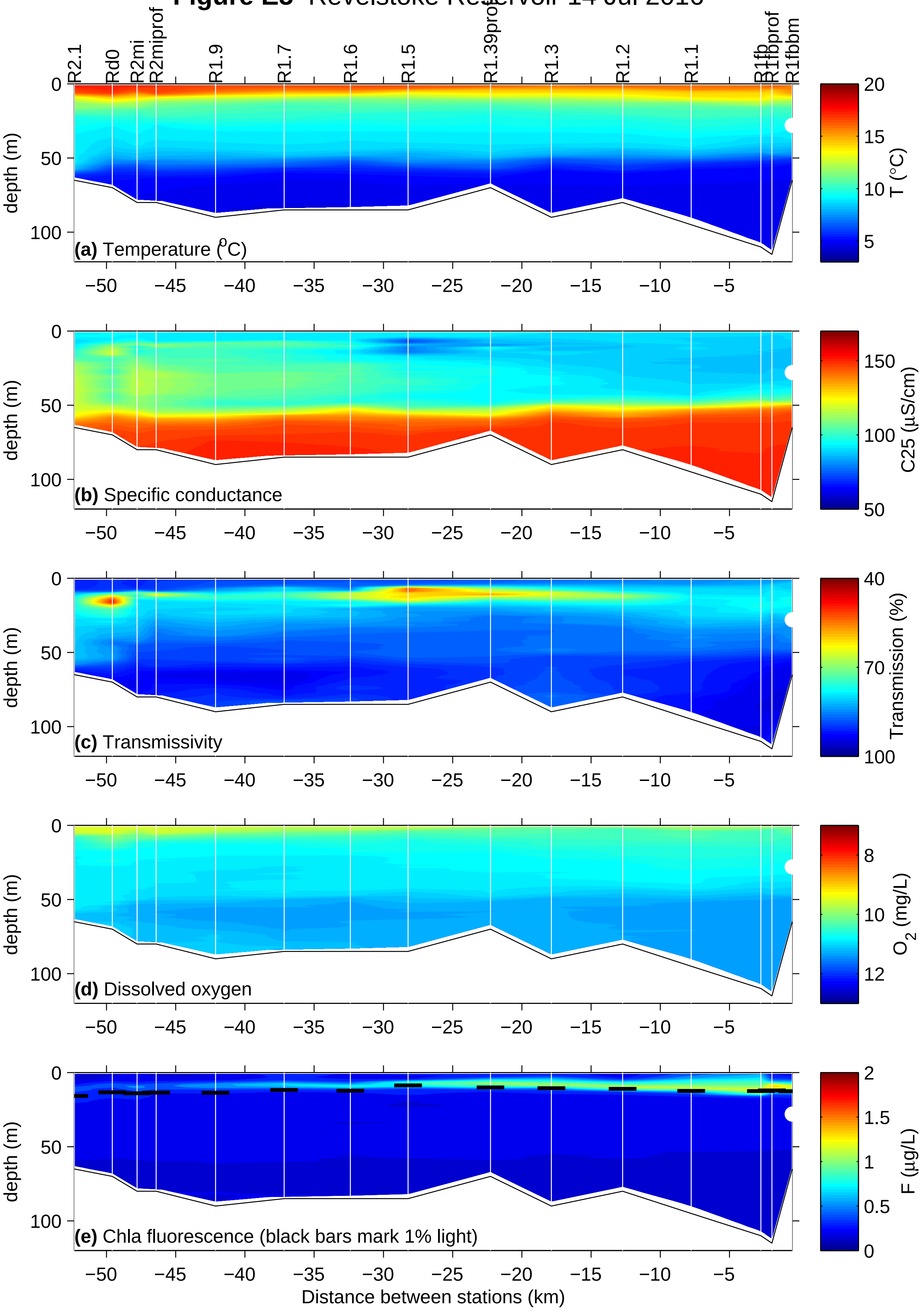


Figure E6 Revelstoke Reservoir 18−20 Jul 2016

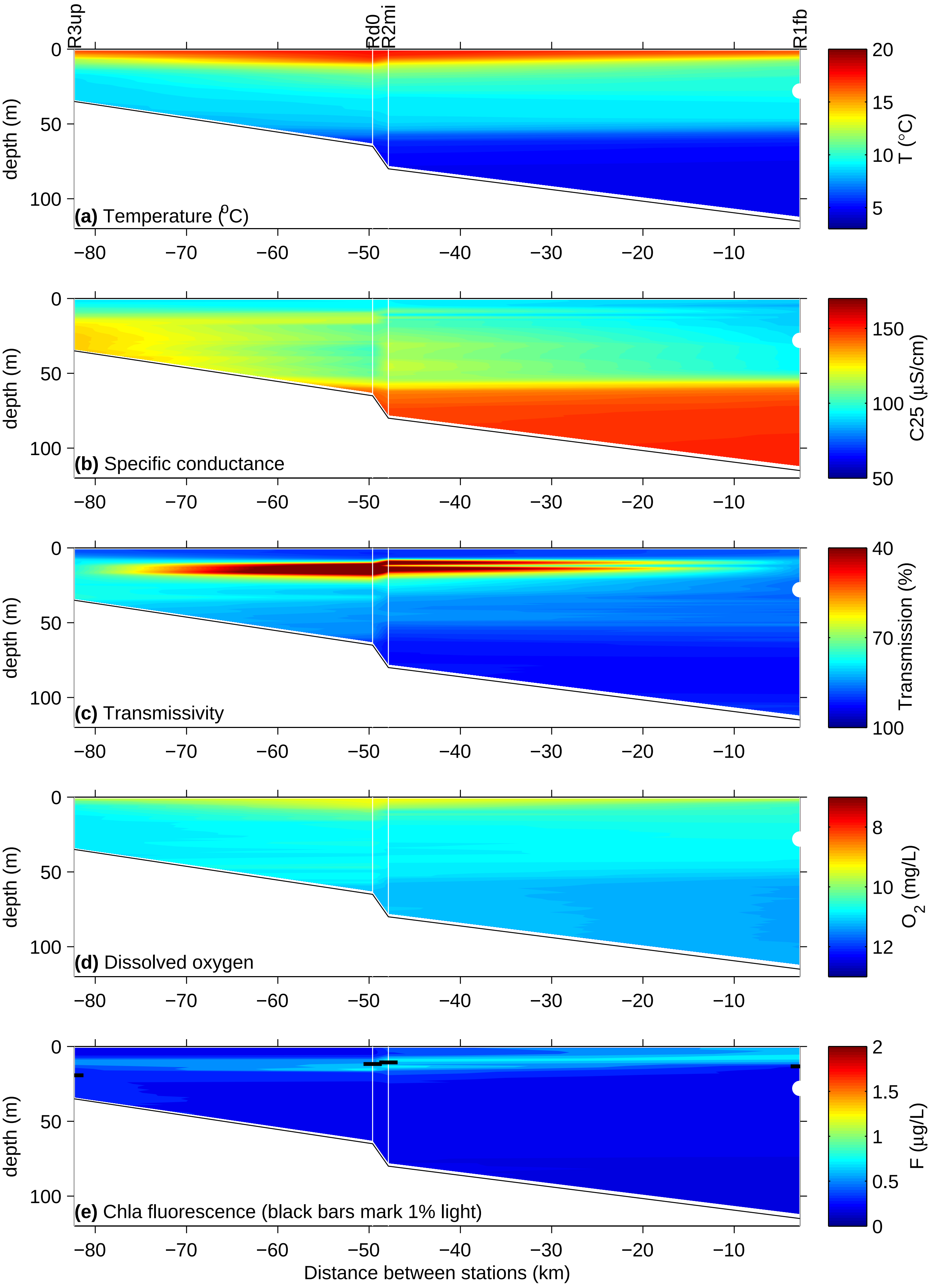


Figure E7 Revelstoke Reservoir 15−17 Aug 2016

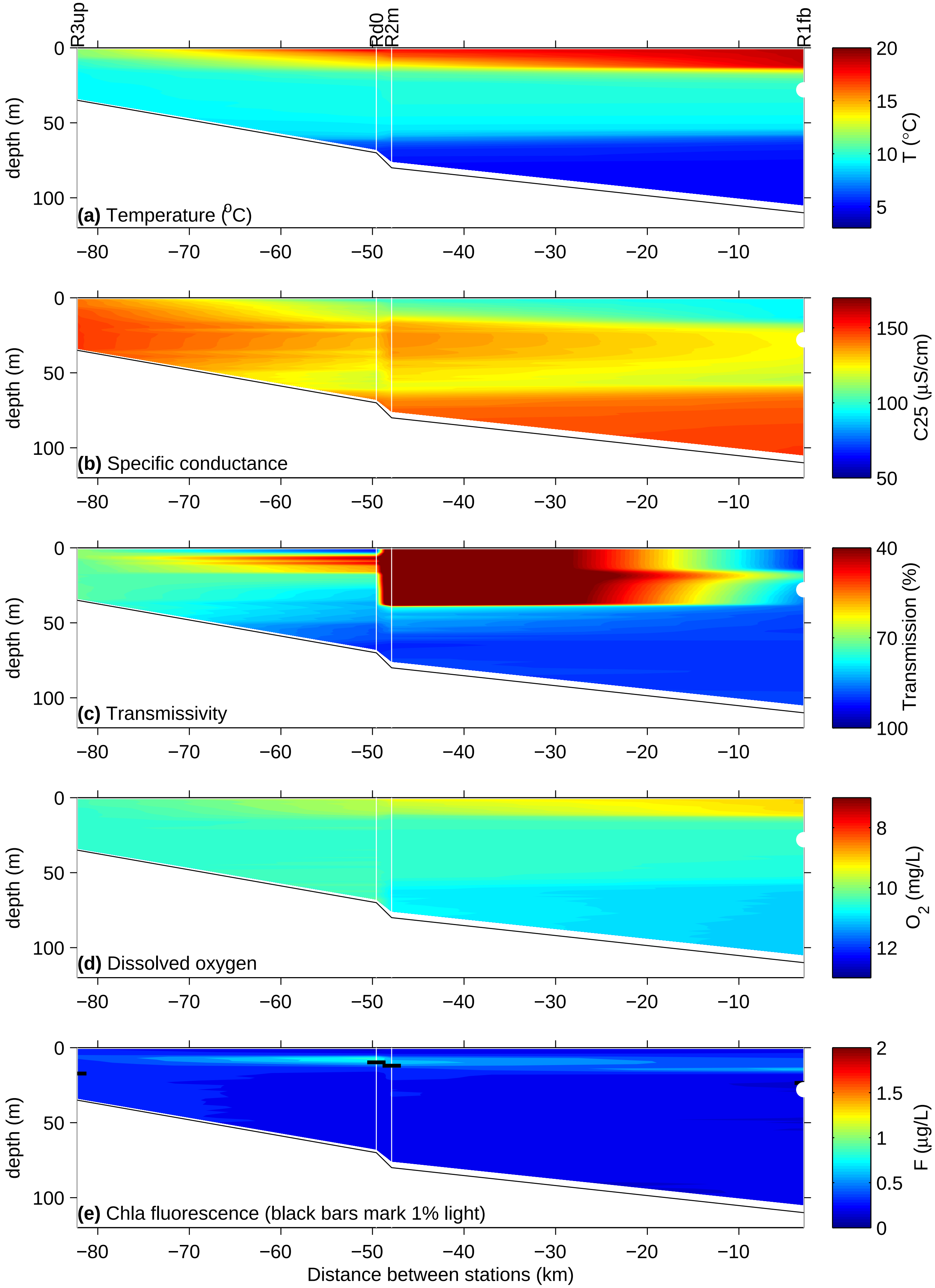


Figure E8 Revelstoke Reservoir 19−21 Sep 2016

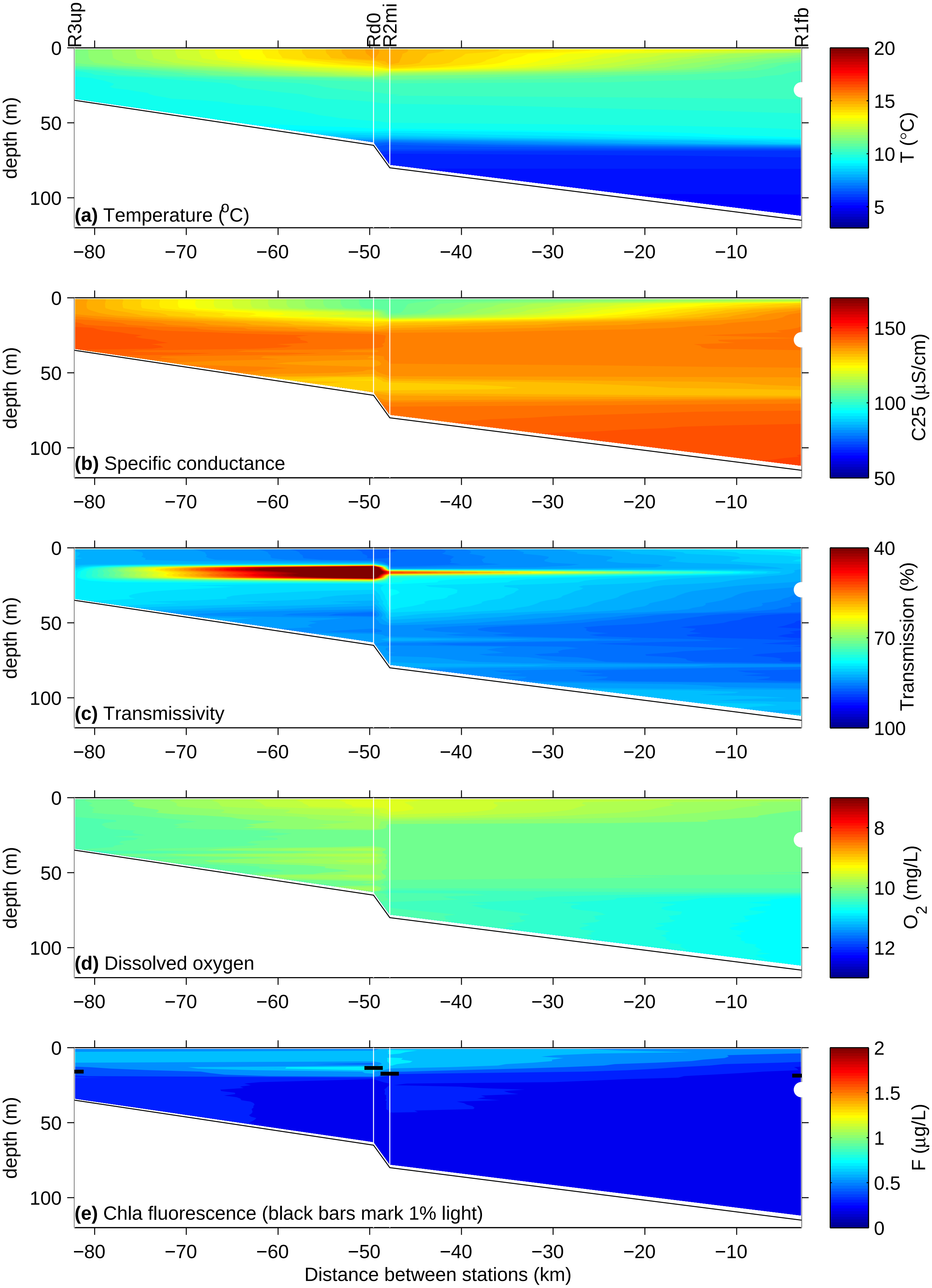


Figure E9 Revelstoke Reservoir 3 Oct 2016

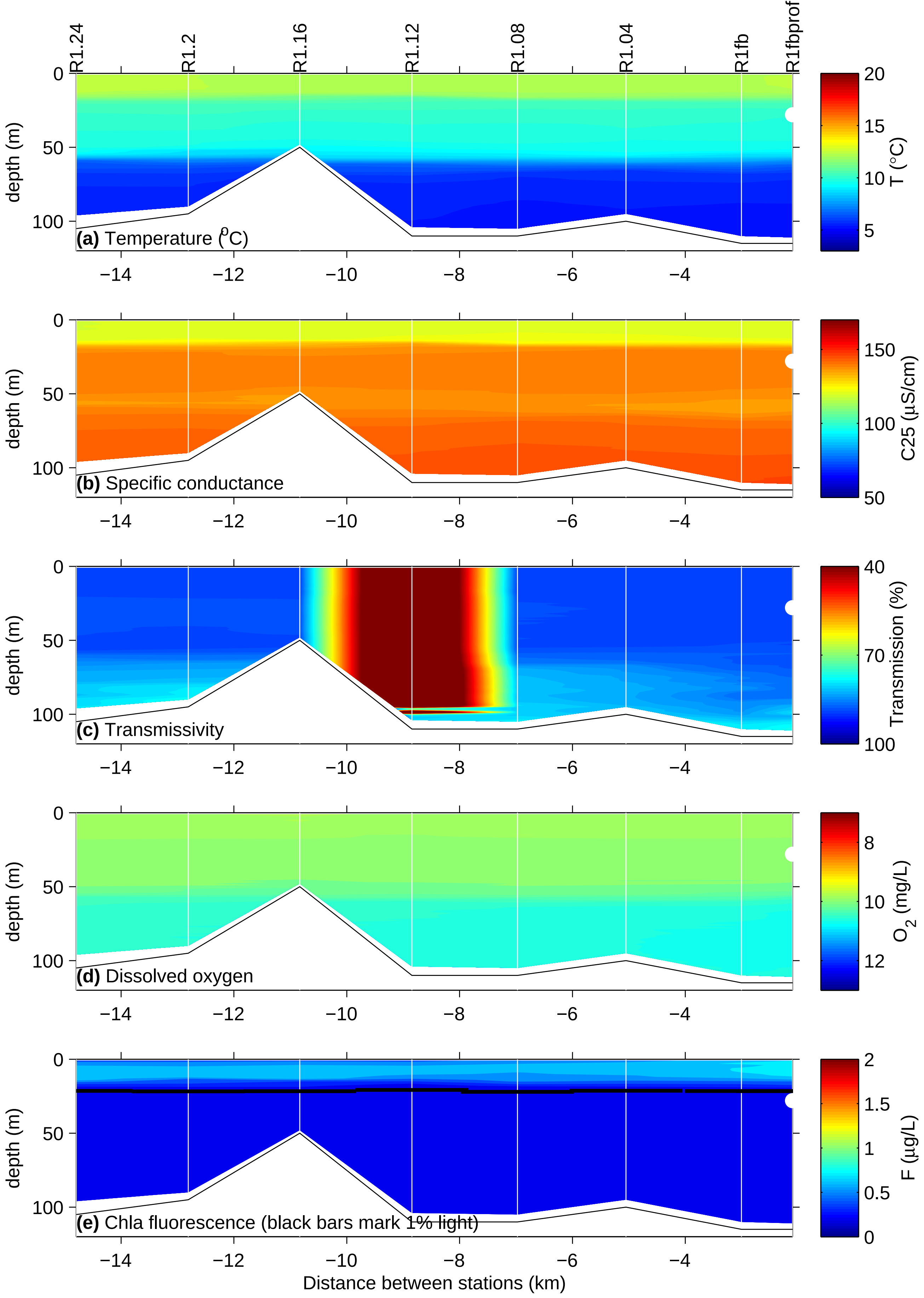


Figure E10 Revelstoke Reservoir 5 Oct 2016

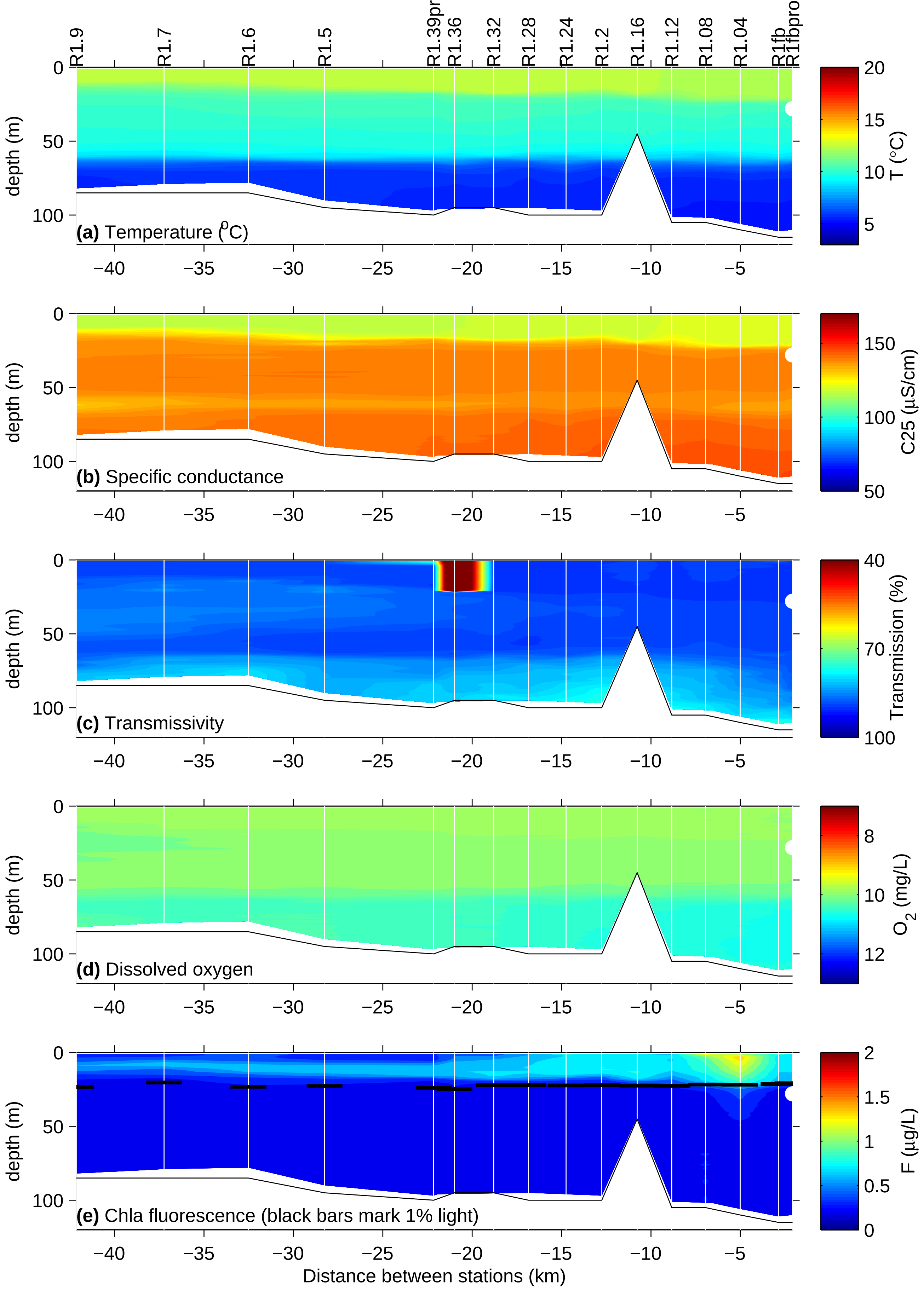


Figure E11 Revelstoke Reservoir 7 Oct 2016

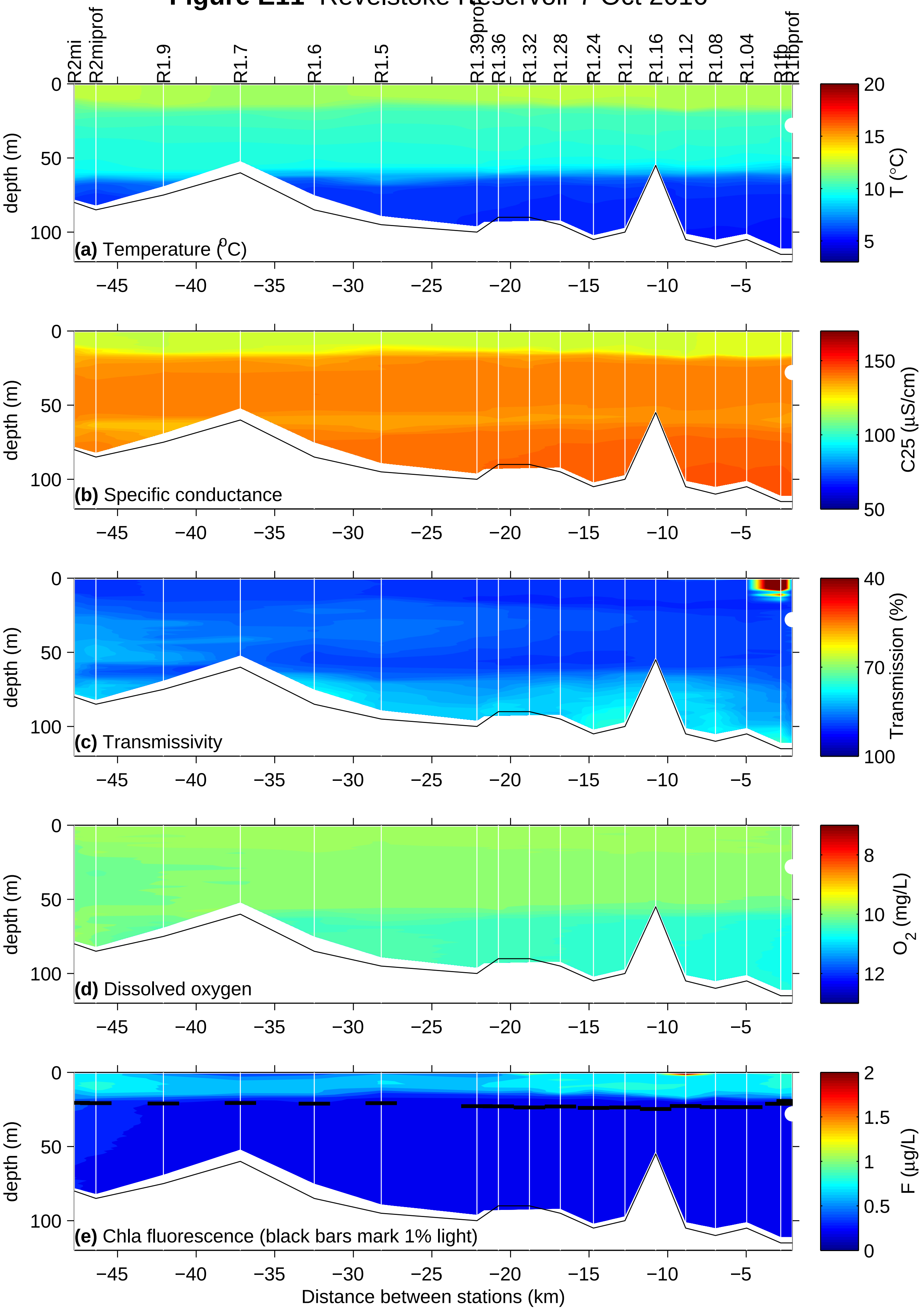


Figure E12 Revelstoke Reservoir 17−18 Oct 2016

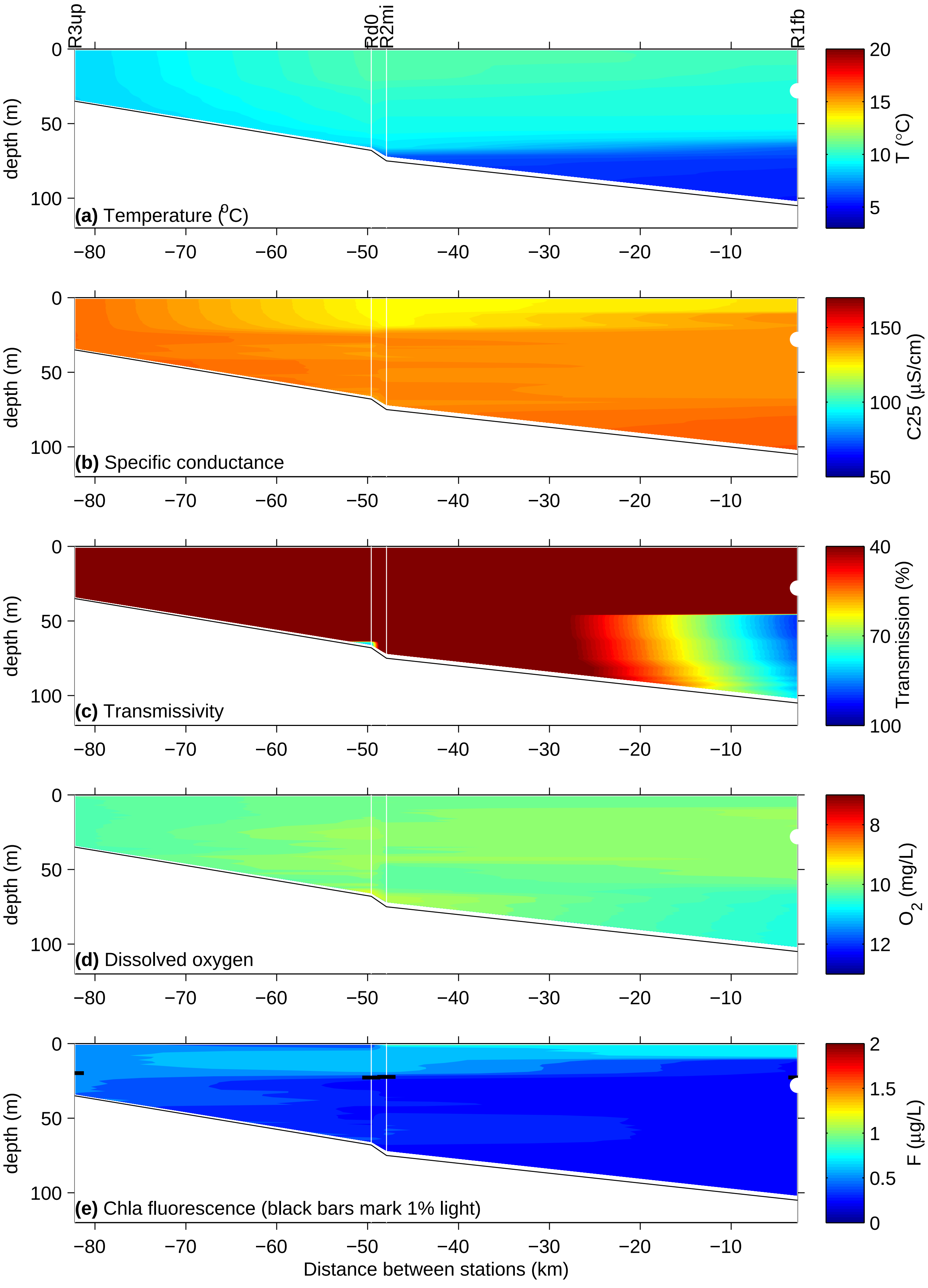
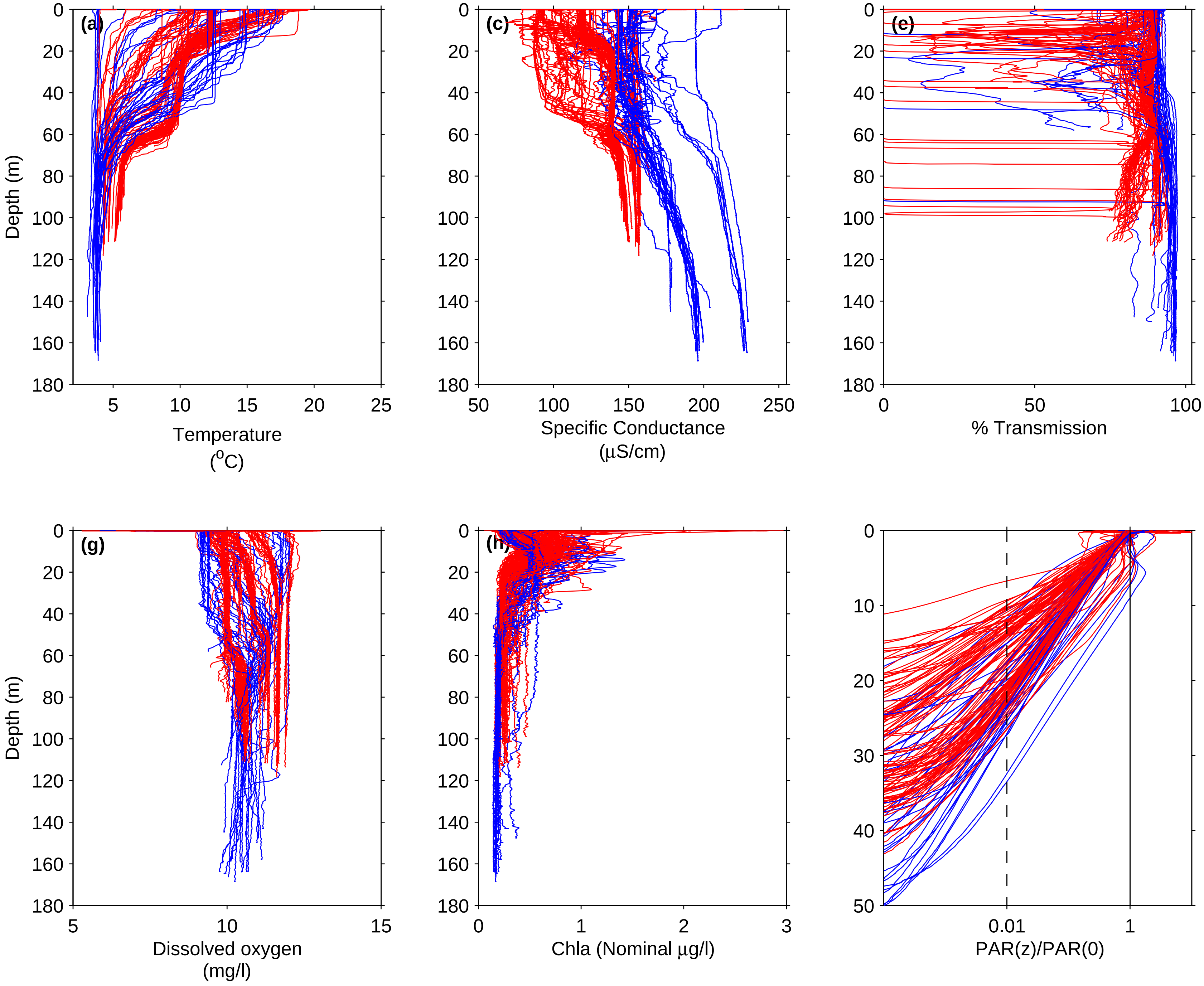


Figure F1 All Kinbasket (BLU) and Revesltoke (RED) Data, 2017



Appendix 1
Station Names
Kinbasket Reservoir

Name*	Description	Approximate Location
Kinbasket-Columbia Arm		
K1fbbm	Next to Mica Dam (2016 only)	52º04.780 118º34.398
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

Appendix 1
Station Names
Revelstoke Reservoir

Name*	Description	Approximate Location
Revelstoke		
R1fbbm	Rev-Forebay by log boom mooring	51°03.222 118°11.383
R1prof	Rev-Forebay by profiler mooring	51°04.037 118°10.937
R1sub	Rev-Forebay by subsurface mooring	51°04.272 118°10.919
R1fb	**Rev-Forebay**	51°04.584 118°10.929
R1.04	Rev-2 km from Forebay	51°05.670 118°11.000
R1.08	Rev-4 km from Forebay	51°06.743 118°11.544
R1.12	Rev-6km from Forebay	51°07.756 118°11.886
R1.16	Rev-8km from Forebay	51°08.774 118°12.730
R1.2	Rev-10 km from Forebay	51°09.988 118°12.677
R1.24	Rev-12 km from Forebay	51°10.934 118°12.533
R1.28	Rev-14 km from Forebay	51°12.052 118°12.682
R1.32	Rev-16 km from Forebay	51°13.085 118°13.249
R1.36	Rev-18 km from Forebay	51°14.142 118°13.685
R1.39spar	Rev-Laforme spar	51°14.667 118°14.054
R1.39prof	Rev-Laforme profiler	51°14.832 118°14.258
R1.4	Rev-20 km from Forebay	51°15.179 118°14.332
R1.44	Rev-22 km from Forebay	51°16.131 118°15.288
R1.5	Rev-25 km from Forebay	51°17.785 118°17.476
R1.6	Rev-30 km from Forebay	51°19.593 118°20.842
R1.7	Rev-35 km from Forebay	51°21.467 118°24.153
R1.9	Rev-40 km from Forebay	51°23.852 118°26.552
R2miprof	Rev-Middle Profiler	51°25.931 118°26.597
R2misub	Rev-Mid sub	51°25.981 118°27.675
R2mi	**Rev-Mid**	51°26.612 118°27.939
Rd0	Rev-Downie loop across from boat launch	51°27.929 118°27.109
Rd1	Rev-Downie Loop 3.35 km from BL site	51°29.063 118°25.003
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	06/Apr/2016	Laforme Spar (boat test run)	09:43	09:53	51˚14.662 118˚14.045	100	R1.39spar
2	06/Apr/2016	Rev - Forebay	10:21	10:32	51˚04.490 118˚10.940	115	R1fb
3	11/Apr/2016	Kin - Canoe	10:30	10:42	52˚12.353 118˚28.452	115	Kca1
4	11/Apr/2016	Kin - Wood	12:10	12:15	52˚08.280 118˚18.635	40	Kwo1
5	11/Apr/2016	Kin - Center	13:16	13:29	52˚07.833 118˚26.430	135	K2mi
6	12/Apr/2016	Kin - Columbia	08:15	08:29	51˚57.956 118˚04.809	150	K3co
7	12/Apr/2016	Kin - Forebay	10:22	10:36	52˚05.586 118˚33.083	155	K1fb
8	18/Apr/2016	Rev - Middle	08:40	08:49	51˚26.655 118˚28.097	80	R2mi
9	18/Apr/2016	Rev - Upper	10:24	10:29	51˚43.754 118˚39.579	35	R3up
10	18/Apr/2016	Rev - Downie Loop Across from Boat Launch	11:54	12:02	51˚27.907 118˚27.199	65	Rd0
11	18/Apr/2016	Rev - 3.35km from Downie BL Site	12:08	12:14	51˚29.062 118˚25.002	35	Rd1
12	19/Apr/2016	Rev - Forebay	08:50	08:59	51˚04.481 118˚10.960	90	R1fb
13	16/May/2016	Kin - Canoe	10:09	10:20	52˚12.435 118˚28.470	105	Kca1
14	16/May/2016	Kin - Wood	11:35	11:41	52˚08.302 118˚18.492	50	Kwo1
15	16/May/2016	Kin - Center	12:58	13:12	52˚07.835 118˚26.444	145	K2mi
16	16/May/2016	Kin - Forebay	13:25	13:41	52˚05.618 118˚32.978	160	K1fb
17	17/May/2016	Kin - Columbia	07:51	08:06	51˚57.950 118˚04.879	155	K3co
18	24/May/2016	Rev - Middle	08:39	08:48	51˚26.632 118˚28.118	80	R2mi
19	24/May/2016	Rev - Upper	10:19	10:24	51˚43.749 118˚39.567	35	R3up
20	24/May/2016	Rev - Downie Loop Across from Boat Launch	11:48	11:55	51˚27.897 118˚27.181	65	Rd0
21	24/May/2016	Rev - 3.35km from Downie BL Site	12:03	12:09	51˚29.061 118˚24.979	35	Rd1
22	25/May/2016	Rev - Forebay	07:45	07:57	51˚04.454 118˚10.937	115	R1fb
23	30/May/2016	Rev - By log boom	07:53	08:05	51˚03.336 118˚11.322	120	R1fbbm
24	30/May/2016	Rev - Forebay	08:12	08:23	51˚04.597 118˚10.886	115	R1fb
25	30/May/2016	Rev - 2km from FB	08:32	08:44	51˚05.654 118˚10.970	115	R1.04
26	30/May/2016	Rev - 4km from FB	08:50	09:01	51˚06.710 118˚11.569	115	R1.08
27	30/May/2016	Rev - 6km from FB	09:09	09:19	51˚07.756 118˚11.882	105	R1.12
28	30/May/2016	Rev - 8km from FB	09:33	09:38	51˚08.757 118˚12.740	30	R1.16
29	30/May/2016	Rev - 10km from FB	09:43	09:52	51˚09.841 118˚12.759	90	R1.2
30	30/May/2016	Rev - 12km from FB	10:00	10:10	51˚10.922 118˚12.515	105	R1.24
31	30/May/2016	Rev - 14km from FB	10:17	10:27	51˚12.040 118˚12.665	105	R1.28
32	30/May/2016	Rev - 16km from FB	10:35	10:46	51˚13.082 118˚13.247	98	R1.32
33	30/May/2016	Rev - 18km from FB	10:53	11:04	51˚14.135 118˚13.665	105	R1.36
34	30/May/2016	Rev - 20km from FB	11:10	11:21	51˚15.192 118˚14.331	105	R1.4
35	30/May/2016	Rev - 22km from FB	11:27	11:37	51˚16.131 118˚15.288	90	R1.44
36	13/Jun/2016	Kin - Canoe	10:10	10:23	52˚12.435 118˚28.473	110	Kca1
37	21/Jun/2016	Rev - Forebay & PP	08:06	08:19	51˚04.446 118˚10.924	110	R1fb
38	22/Jun/2016	Rev - Middle & PP	08:56	09:06	51˚26.647 118˚28.125	80	R2mi
39	23/Jun/2016	Kin - PP	08:49	08:58	52˚06.864 118˚30.157	80	K1.5
40	23/Jun/2016	Kin - Forebay	12:20	12:33	52˚05.628 118˚32.965	120	K1fb
41	11/Jul/2016	Kin - Canoe	10:32	10:46	52˚12.539 118˚28.500	92	Kca1
42	11/Jul/2016	Kin - Wood	12:20	12:28	52˚08.271 118˚18.712	60	Kwo1
43	11/Jul/2016	Kin - Center	13:38	13:50	52˚07.878 118˚26.367	130	K2mi
44	11/Jul/2016	Kin - Forebay Garbage	14:32	14:32	52˚05.628 118˚32.965	120	K1fb
45	11/Jul/2016	Kin - Forebay	14:35	14:51	52˚05.637 118˚32.964	170	K1fb
46	12/Jul/2016	Kin - Columbia	08:02	08:18	51˚57.973 118˚04.880	170	K3co
47	12/Jul/2016	Kin - TGP	10:11	10:18	52˚04.780 118˚34.398	58	KTP
48	14/Jul/2016	Rev - Forebay	07:41	07:52	51˚04.415 118˚10.958	110	R1fb
49	14/Jul/2016	Rev - 5km from FB	08:01	08:11	51˚07.191 118˚11.631	95	R1.1
50	14/Jul/2016	Rev - 10km from FB	08:19	08:28	51˚09.828 118˚12.725	80	R1.2
51	14/Jul/2016	Rev - 15km from FB	08:37	08:46	51˚12.604 118˚12.938	90	R1.3
52	14/Jul/2016	Rev - Laforme Profiler & 20km from FB	08:54	09:02	51˚14.898 118˚14.268	70	R1.39prof
53	14/Jul/2016	Rev - 25km from FB	09:12	09:21	51˚17.773 118˚17.461	85	R1.5
54	14/Jul/2016	Rev - 30km from FB	09:29	09:39	51˚19.519 118˚20.679	85	R1.6
55	14/Jul/2016	Rev - 35km from FB	09:50	09:59	51˚21.443 118˚24.163	85	R1.7
56	14/Jul/2016	Rev - 40km from FB	10:07	10:17	51˚23.706 118˚26.540	90	R1.9

57	14/Jul/2016	Rev - Downie Profiler	10:25	10:34	51˚25.928 118˚27.663	80	R2miprof
58	14/Jul/2016	Rev - Middle	10:39	10:48	51˚26.612 118˚28.116	80	R2mi
59	14/Jul/2016	Rev - Downie Loop Across from Boat Launch	10:53	11:01	51˚27.913 118˚27.131	70	Rd0
60	14/Jul/2016	Rev - 3.35km from Downie BL Site	11:09	11:15	51˚29.053 118˚25.015	40	Rd1
61	14/Jul/2016	Rev - 50km from FB	11:26	11:34	51˚29.026 118˚29.053	65	R2.1
62	14/Jul/2016	Rev - Forebay Profiler	12:37	12:47	51˚03.975 118˚11.037	115	R1fbprof
63	14/Jul/2016	Rev - TGP	12:52	13:00	51˚03.195 118˚11.365	65	R1fbbm
64	18/Jul/2016	Rev - Middle	08:45	08:54	51˚26.677 118˚28.091	80	R2mi
65	18/Jul/2016	Rev - Upper	10:30	10:35	51˚43.809 118˚39.570	35	R3up
66	18/Jul/2016	Rev - Downie Loop Across from Boat Launch	12:04	12:12	51˚27.940 118˚27.112	65	Rd0
67	18/Jul/2016	Rev - 3.35km from Downie BL Site	12:18	12:24	51˚29.040 118˚25.022	35	Rd1
68	19/Jul/2016	Rev - Forebay & PP	07:43	07:55	51˚04.459 118˚10.944	115	R1fb
69	20/Jul/2016	Rev - Middle PP	08:28	08:37	51˚26.719 118˚28.127	75	R2mi
70	21/Jul/2016	Kin - PP	07:07	07:23	52˚06.826 118˚30.183	165	K1.5
71	08/Aug/2016	Kin - Columbia	10:51	11:06	51˚57.977 118˚04.881	170	K3co
72	08/Aug/2016	Kin- Wood	12:56	13:03	52˚08.299 118˚18.821	60	Kwo1
73	08/Aug/2016	Kin - Canoe	14:09	14:21	52˚12.422 118˚28.448	120	Kca1
74	09/Aug/2016	Kin - Forebay	08:47	09:02	52˚05.637 118˚33.089	175	K1fb
75	15/Aug/2016	Rev - Middle	08:40	08:49	51˚26.687 118˚28.100	80	R2mi
76	15/Aug/2016	Rev - Upper	10:28	10:33	51˚43.764 118˚39.612	35	R3up
77	15/Aug/2016	Rev - Downie Loop Across from Boat Launch	12:00	12:08	51˚27.896 118˚27.209	70	Rd0
78	15/Aug/2016	Rev - 3.35km from Downie BL Site	12:15	12:21	51˚29.037 118˚25.023	40	Rd1
79	16/Aug/2016	Rev - Forebay & PP	09:31	09:42	51˚04.511 118˚10.962	110	R1fb
80	17/Aug/2016	Rev - Middle PP	08:43	08:52	51˚26.681 118˚28.105	80	R2mi
81	24/Aug/2016	Kin - PP	09:21	09:36	52˚06.838 118˚30.178	165	K1.5
82	12/Sep/2016	Kin - Wood	10:45	10:52	52˚08.299 118˚18.821	65	Kwo1
83	12/Sep/2016	Kin - Canoe	12:29	12:50	52˚12.422 118˚28.448	115	Kca1
84	12/Sep/2016	Kin - Forebay	14:25	14:41	52˚05.637 118˚33.089	175	K1fb
85	13/Sep/2016	Kin - Columbia	09:14	09:30	51˚57.977 118˚04.881	170	K3co
86	13/Sep/2016	Kin - Center	11:50	12:06	52˚07.878 118˚26.367	160	K2mi
87	19/Sep/2016	Rev - Middle	08:45	08:55	51˚26.633 118˚28.093	80	R2mi
88	19/Sep/2016	Rev - Upper	10:24	10:29	51˚43.748 118˚39.571	35	R3up
89	19/Sep/2016	Rev - Downie Loop Across from Boat Launch	11:58	12:05	51˚27.897 118˚27.216	65	Rd0
90	19/Sep/2016	Rev - 3.35km from Downie BL Site	12:11	12:17	51˚29.015 118˚25.025	40	Rd1
91	20/Sep/2016	Rev - Forebay & PP	08:37	08:50	51˚04.518 118˚10.929	115	R1fb
92	21/Sep/2016	Rev - Middle PP	09:46	09:55	51˚26.625 118˚28.105	80	R2mi
93	22/Sep/2016	Kin - PP	09:11	09:25	52˚06.857 118˚30.134	165	K1.5
94	03/Oct/2016	Rev - Forebay Profiler	07:42	07:52	51˚04.033 118˚10.897	115	R1fbprof
95	03/Oct/2016	Rev - Forebay	07:58	08:10	51˚04.558 118˚10.926	115	R1fb
96	03/Oct/2016	Rev - 2km from FB	08:16	08:26	51˚05.696 118˚11.014	100	R1.04
97	03/Oct/2016	Rev - 4km from FB	08:33	08:43	51˚06.761 118˚11.571	110	R1.08
98	03/Oct/2016	Rev - 6km from FB	08:49	08:59	51˚07.768 118˚11.885	110	R1.12
99	03/Oct/2016	Rev - 8km from FB	09:07	09:13	51˚08.803 118˚12.718	50	R1.16
100	03/Oct/2016	Rev - 10km from FB	09:21	09:30	51˚09.874 118˚12.727	95	R1.2
101	03/Oct/2016	Rev - 12km from FB	09:37	09:47	51˚10.960 118˚12.536	105	R1.24
102	05/Oct/2016	Rev - Forebay Profiler	07:39	07:50	51˚04.035 118˚10.934	115	R1fbprof
103	05/Oct/2016	Rev - Forebay	07:57	08:08	51˚04.486 118˚10.947	115	R1fb
104	05/Oct/2016	Rev - 2km from FB	08:14	08:24	51˚05.673 118˚10.995	110	R1.04
105	05/Oct/2016	Rev - 4km from FB	08:29	08:39	51˚06.745 118˚11.533	105	R1.08
106	05/Oct/2016	Rev - 6km from FB	08:44	08:54	51˚07.763 118˚11.880	105	R1.12
107	05/Oct/2016	Rev - 8km from FB	09:00	09:05	51˚08.770 118˚12.729	45	R1.16
108	05/Oct/2016	Rev - 10km from FB	09:11	09:21	51˚09.840 118˚12.753	100	R1.2
109	05/Oct/2016	Rev - 12km from FB	09:26	09:35	51˚10.934 118˚12.547	100	R1.24
110	05/Oct/2016	Rev - 14km from FB	09:40	09:50	51˚12.063 118˚12.692	100	R1.28
111	05/Oct/2016	Rev - 16km from FB	09:56	10:05	51˚13.085 118˚13.262	95	R1.32
112	05/Oct/2016	Rev - 18km from FB	10:16	10:25	51˚14.160 118˚14.694	95	R1.36
113	05/Oct/2016	Rev - Laforme Profiler	10:31	10:40	51˚14.834 118˚14.277	100	R1.39prof
114	05/Oct/2016	Rev - 25km from FB	10:51	11:00	51˚17.791 118˚17.479	95	R1.5
115	05/Oct/2016	Rev - 30km from FB	11:10	11:18	51˚19.581 118˚20.740	85	R1.6

116	05/Oct/2016	Rev - 35km from FB	11:27	11:35	51˚21.475 118˚24.174	85	R1.7
117	05/Oct/2016	Rev - 40km from FB	11:44	11:52	51˚23.711 118˚26.562	85	R1.9
118	05/Oct/2016	Rev - Middle Profiler	12:00	12:09	51˚25.931 118˚27.640	85	R2miprof
119	05/Oct/2016	Rev - Middle	12:13	12:23	51˚26.588 118˚28.071	78	R2mi
120	07/Oct/2016	Rev - Forebay Profiler	07:41	07:52	51˚04.043 118˚10.979	115	R1fbprof
121	07/Oct/2016	Rev - Forebay	07:55	08:06	51˚04.445 118˚10.931	115	R1fb
122	07/Oct/2016	Rev - 2km from FB	08:10	08:20	51˚05.651 118˚10.979	105	R1.04
123	07/Oct/2016	Rev - 4km from FB	08:27	08:37	51˚06.754 118˚11.501	110	R1.08
124	07/Oct/2016	Rev - 6km from FB	08:41	08:51	51˚07.774 118˚11.896	105	R1.12
125	07/Oct/2016	Rev - 8km from FB	08:56	09:02	51˚08.765 118˚12.733	55	R1.16
126	07/Oct/2016	Rev - 10km from FB	09:06	09:15	51˚09.824 118˚12.738	100	R1.2
127	07/Oct/2016	Rev - 12km from FB	09:20	09:29	51˚10.919 118˚12.533	105	R1.24
128	07/Oct/2016	Rev - 14km from FB	09:35	09:43	51˚12.052 118˚12.689	95	R1.28
129	07/Oct/2016	Rev - 16km from FB	09:48	09:57	51˚13.088 118˚13.237	90	R1.32
130	07/Oct/2016	Rev - 18km from FB	10:01	10:09	51˚14.131 118˚13.696	90	R1.36
131	07/Oct/2016	Rev - Laforme Profiler	10:13	10:22	51˚14.829 118˚14.239	100	R1.39prof
132	07/Oct/2016	Rev - 25km from FB	10:30	10:39	51˚17.778 118˚17.473	95	R1.5
133	07/Oct/2016	Rev - 30km from FB	10:46	10:54	51˚19.566 118˚20.721	85	R1.6
134	07/Oct/2016	Rev - 35km from FB	11:02	11:09	51˚21.459 118˚24.132	60	R1.7
135	07/Oct/2016	Rev - 40km from FB	11:17	11:24	51˚23.695 118˚26.492	75	R1.9
136	07/Oct/2016	Rev - Middle Profiler	11:31	11:40	51˚25.916 118˚27.632	85	R2miprof
137	07/Oct/2016	Rev - Middle	11:44	11:52	51˚26.600 118˚28.093	80	R2mi
138	11/Oct/2016	Kin - Forebay	09:45	10:00	52˚05.659 118˚32.905	175	K1fb
139	11/Oct/2016	Kin - Columbia	11:49	12:04	51˚58.006 118˚04.928	170	K3co
140	11/Oct/2016	Kin - Wood	13:48	13:56	52˚08.274 118˚18.633	60	Kwo1
141	11/Oct/2016	Kin - Center	15:01	15:16	52˚07.832 118˚26.453	165	K2mi
142	12/Oct/2016	Kin - Canoe	07:41	07:51	52˚12.391 118˚28.424	115	Kca1
143	17/Oct/2016	Rev - Middle	08:29	08:37	51˚26.703 118˚28.088	75	R2mi
144	17/Oct/2016	Rev - Upper	10:06	10:11	51˚43.763 118˚39.579	35	R3up
145	17/Oct/2016	Rev - Downie Loop Across from Boat Launch	11:32	11:40	51˚27.915 118˚27.175	68	Rd0
146	17/Oct/2016	Rev - 3.35km from Downie BL Site	11:46	11:52	51˚29.063 118˚24.994	40	Rd1
147	18/Oct/2016	Rev - Forebay	08:34	08:45	51˚04.396 118˚10.941	105	R1fb

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 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, 2016

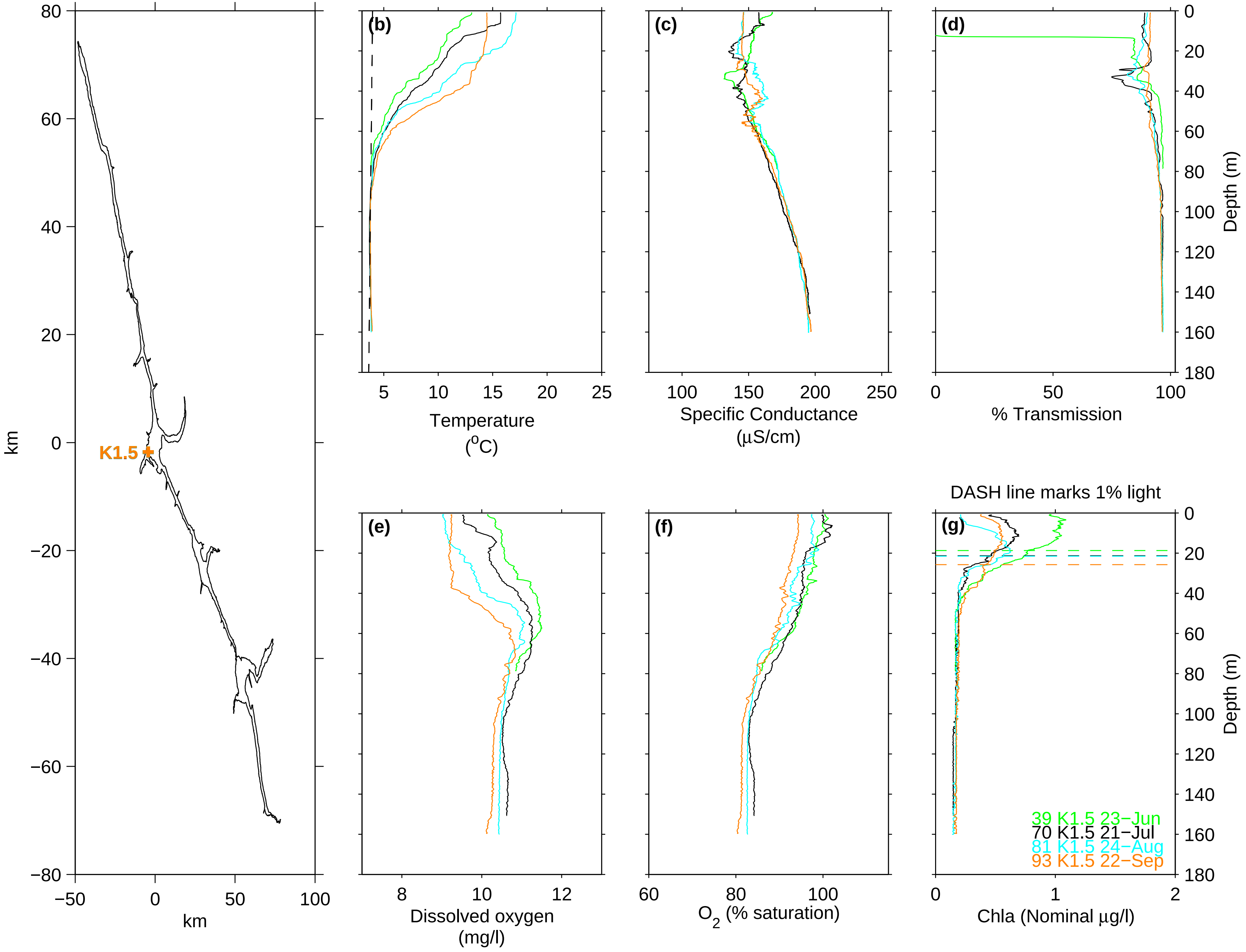


Figure A4−2 Revelstoke Reservoir, Forebay PP 2016

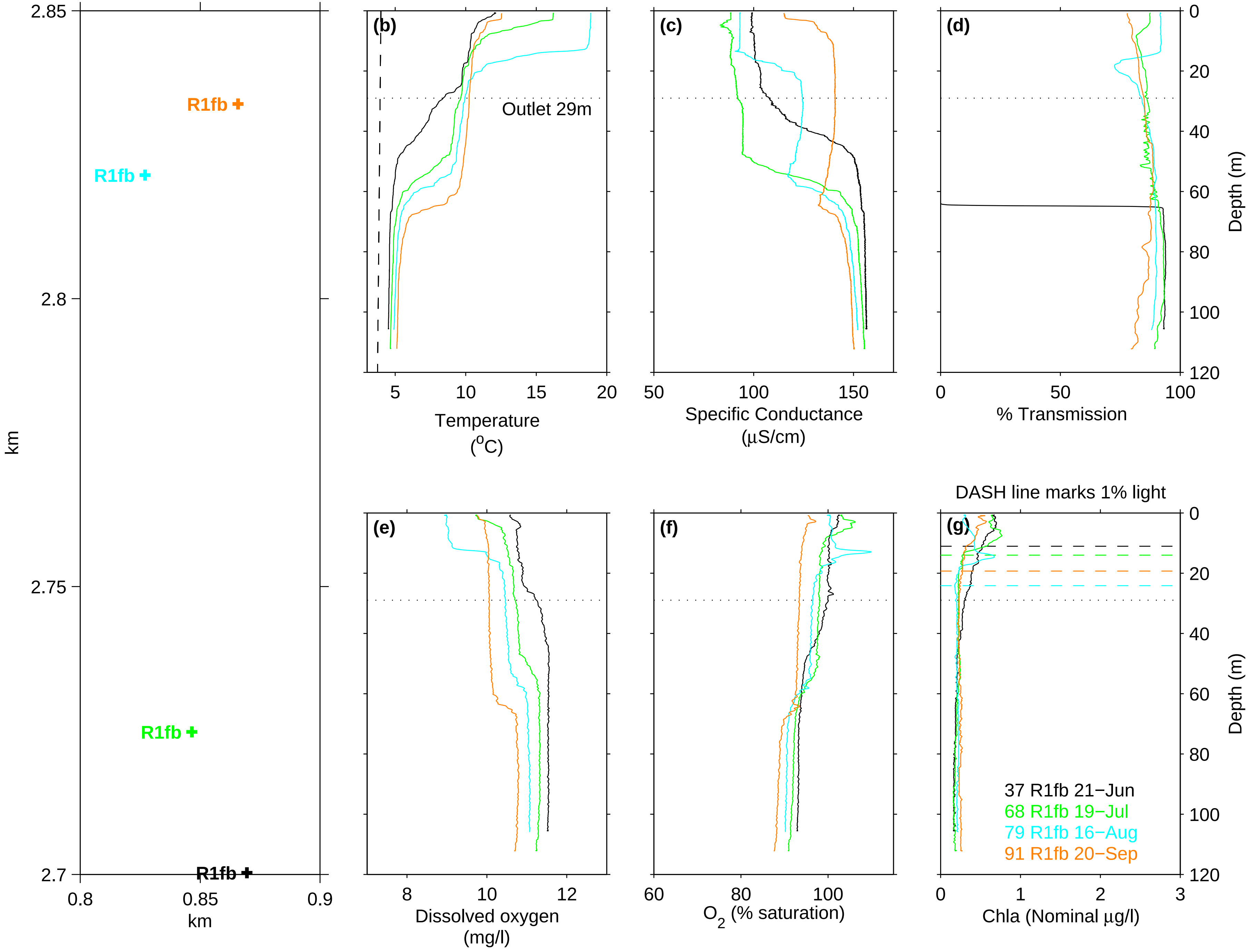
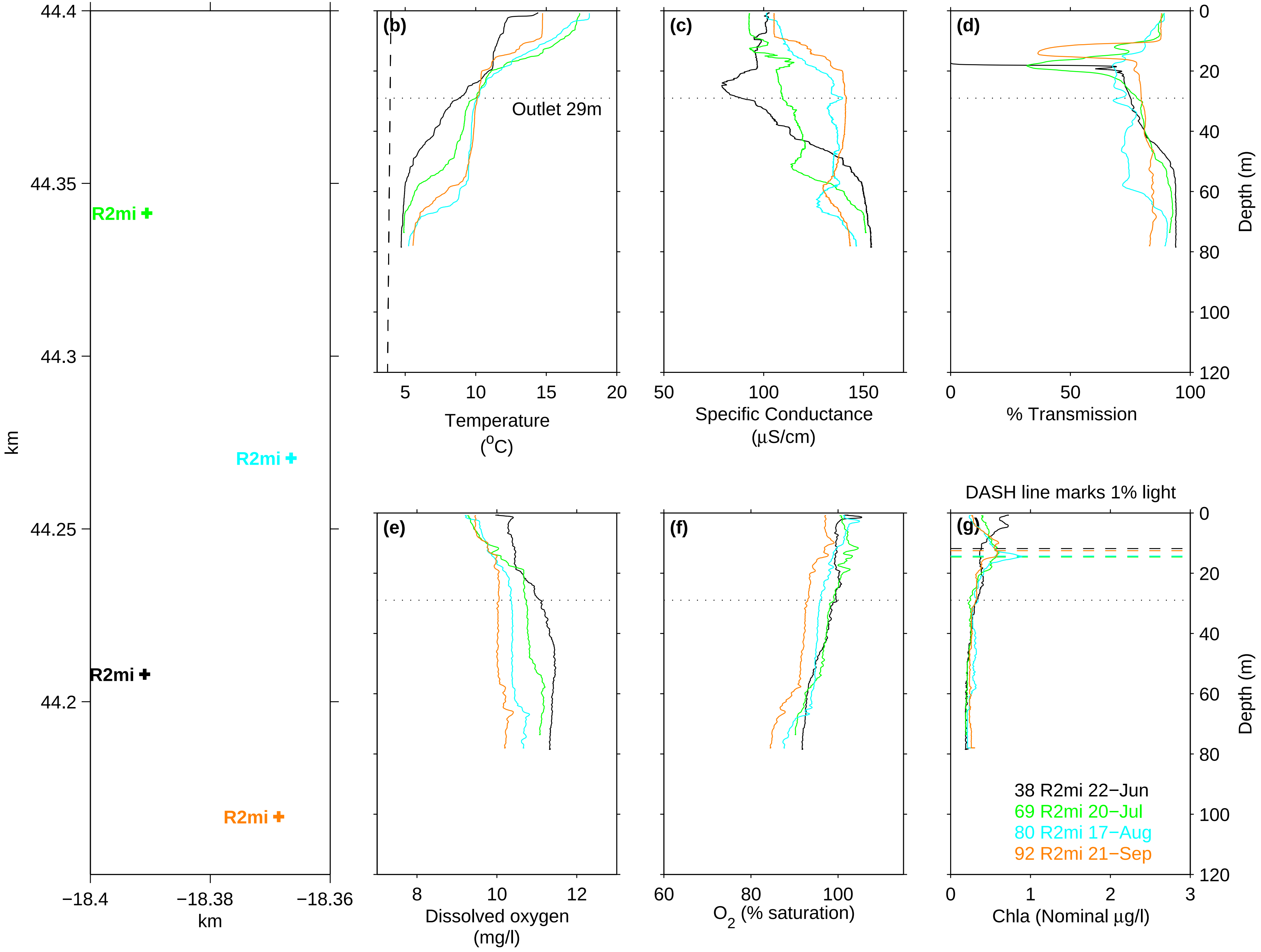


Figure A4−3 Revelstoke Reservoir, Middle PP 2016



Appendix 4

Reservoir Water Chemistry Kinbasket and Revelstoke Reservoirs, 2016

Karen Bray
BC Hydro

Reservoir Water Chemistry
Kinbasket and Revelstoke Reservoirs, 2016

Kinbasket Reservoir, September 2016

Prepared By:
Karen Bray
Revelstoke, B.C.

November 2017

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1. Introduction

This report summarises Year 9 (2016) 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 and three stations in Revelstoke reservoir (Table 2, Figure 1). In 2016, sampling began in April and concluded in October at all stations. June sampling at Kinbasket stations Canoe, Wood, and Columbia and REV Upper was not completed and sampling to only 20m was conducted at the KIN Forebay, REV Forebay, and REV Middle stations due to a malfunction in the wire counter that rendered the depth measurements inaccurate for lowering bottles and the Seabird Profiler.

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, NN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), alkalinity, conductivity, pH, and turbidity. Integrated tube samples were analysed for soluble reactive silica. In 2016, total nitrogen (TN) was added to the suite of parameters for discrete depths to evaluate the relative contribution of NN. A summary of sample preparation, analytical methods, and laboratory detection limits can be found in Appendix 2 (Tributary Water Chemistry) and 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, 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 are 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, 2016.

Station	Coordinates	Max Depth Sampled (m)	Dates Sampled in 2015
KIN Forebay	52°05.611 118°32.932	175	April 12, May 16, June 23, July 11, Aug 9, Sep 12, Oct 11
KIN Canoe Reach	52°12.400 118°28.417	120	April 11, May 16, July 11, Aug 8, Sep 12, Oct 12
KIN Wood Arm	52°08.314 118°18.637	60	April 11, May 16, July 11, Aug 8, Sep 12, Oct 11
KIN Columbia Reach	51°58.448 118°05.061	170	April 12, May 17, July 12, Aug 8, Sep 13, Oct 11
REV Forebay	51°04.504 118°10.981	115	April 19, May 25, June 21, July 10, Aug 16, Sep 20, Oct 18
REV Middle	51°26.495 118°28.116	80	April 18, May 24, June 22, July 18, Aug 15, Sep 19, Oct 17
REV Upper	51°43.797 118°39.579	35	April 18, May 24, July 18, Aug 15, Sep 19, Oct 17

3. Results

Stations were sampled at Kinbasket reservoir forebay elevations between 729.8 m and 751.5 m; full pool is 754.4m and minimum level is 707.1 m (cf. Figure 2 of main report). The reservoir reached its daily minimum level (729.4 m) for the year on April 1, 2016, and its daily maximum level (752.8 m) on November 16, 2016. The total range of elevation in 2016 was 23.4 m whereas the maximum licenced range is 47 m without surcharge. From 1977 and 2016, the average reservoir elevation range was 25.4 m. See Appendix 1 – Hydrology for more information on operations in 2016.

In 2016, Revelstoke reservoir daily average elevations ranged by 1.8 m between 571.1 m and 572.9 m. Full pool is 573 m and the normal operating range is within 1.5 m (to 571.5 m), although the water licence allowable minimum level is much lower.

Nitrite and Nitrate* (**NO_2**+**NO_3 ***or NN) – NN is a measure predominantly of nitrate, nitrite being almost negligible. This is typical in oligotrophic waters where oxygen is not limiting (Wetzel 2001). Average NN was similar across stations in Kinbasket reservoir (106-114 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 (129-136 µg/L), with the greatest seasonal variation at REV Upper station (Table 2, Figures 3 and 6).

Overall NN tends to peak in spring (late May/early June) and decline into the summer and fall, a trend that remains consistent across reservoirs and years (Figures 2 and 3). Early season peaks in NN were evident in surface waters (Figure 6) particularly at KIN Columbia and REV Upper and Middle stations.

Total Nitrogen (TN) – Average total nitrogen ranged from 155 – 174 µg/L in Kinbasket and was higher in Revelstoke reservoir at 191 – 198 µg/L (Table 2). October analyses were not completed due to a lab error. Highest TN values occurred in May at REV Middle and Upper stations and in the upper 10m of KIN Columbia, which was in contrast to May having the lowest TN at all other stations.

Phosphorus (TP/TDP/SRP) – Average Total Phosphorus (TP) in Kinbasket ranged from 2.5–2.9 µg/L with the greatest range at KIN Canoe station (Table 2). In Revelstoke reservoir, average TP ranged from 2.3–3.6 µg/L with the highest seasonal average at REV Middle station (Table 2). This high average is a result of three unusually high TP (>10 µg/L) results at 15 m in June and 2 and 10 m in July at REV Middle (12.8, 10.4, and 15.3 µg/L respectively). Similar spikes in TP at REV Middle occurred in 2015.

Average Total Dissolved Phosphorus (TDP) in Kinbasket and Revelstoke reservoirs was at or close to the detection limit (2.1–2.2 µg/L and 2.1–2.5 µg/L, respectively) (Table 2) with a maximum of 6.8 µg/L at KIN Forebay in October at 175 m and 9.4 µg/L at REV Middle in June at 10 m (Table 2). High TDP values can be errors as TP from the same samples can be lower, as was the case in both these samples. Occasionally TP values returned are lower than TDP which can happen in systems that have particularly low phosphorus levels or can occur through lab or field contamination. For the purpose of analysis, all values returned at <2.0 µg/L (DL) are transformed to 2.0 µg/L. A substantial portion of samples from both reservoirs were below the 2.0 µg/L detection: 77% in Kinbasket reservoir and 71% in Revelstoke reservoir.

Soluble Reactive Phosphorus (SRP) values across Kinbasket and Revelstoke reservoir stations were on average 1.1 to 1.7 µg/L with 71% of values below the detection limit of 1.0 µg/L in Kinbasket and 55% in Revelstoke reservoir. Highest values in Kinbasket occurred at KIN Columbia (5.2 µg/L in October at 10 m) and at REV Forebay (4.7 µg/L in July at 5 m) (Table 2) As with TDP, these high values could be anomalies or errors as they are often isolated peaks and higher than TDP or even TP from the same sample. These is little seasonal or depth trend evident in SRP values and the high values are not usually mirrored in the TP or TDP data (Figures 2, 3,and 7).

Alkalinity and Conductivity – Alkalinity was higher in Kinbasket reservoir, average seasonal values ranging from 62 to 79 mg$CaCO_3$/L in Kinbasket and from 53 to 55 mg$CaCO_3$/L in Revelstoke reservoir (Table 2). Average seasonal conductivity is also higher in Kinbasket (152-187 µS/cm) than in Revelstoke (127-132 µS/cm) (Table 2; Figures 4, 5).

pH and Turbidity - pH varies little and is always slightly alkaline. Average turbidity was similar across most stations (0.3 – 1.6 NTUs) (Table 2) although KIN Wood and REV Middle stations had the highest point sample turbidity levels (17 and 3.4 NTUs, respectively). Spikes in turbidity are often seen in an interflow depth, e.g. at 40 m in KIN Wood in August and at 10 m in REV Middle in July.

Silica (Si) – Silica concentrations were similar across stations in each reservoir with a small decline through the sampling season following a spring peak (Figure 8). Reservoir silica averages ranged from 2.1 to 3.5 mg/L. Other than at Revelstoke Upper station, Revelstoke reservoir silica values were slightly higher than at Kinbasket reservoir stations (Table 2; Figure 8).

Secchi – Secchi depths averaged from 6.0 – 7.6 m across the four Kinbasket reservoir stations in 2016 and from 5.2 – 6.6 m in Revelstoke (Table 2; Figure 9). Secchi values were generally lowest in May at Kinbasket stations with increasing depth into the fall. In Revelstoke reservoir, Secchi depths were lowest in June with greatest variability in August. Forebay stations in both reservoirs generally have the greatest transparency (Figure 9).

Table 2**.** Average water chemistry values for all depths combined at Kinbasket (Apr-Oct) and Revelstoke (Apr-Oct) reservoir stations, sampled monthly, 2016. Range of values in parentheses.

Parameter	**Units**	**STATIONS**						
		KIN Forebay	***KIN Canoe***	***KIN Wood***	***KIN Columbia***	***REV Forebay***	***REV Middle***	***REV Upper***
NO_2+NO_3 (NN)	µg/L	111 (73.4-155)	111 (80.4-141)	106 (70.8-162)	114 (58.0-213)	129 (90.5-172)	129 (70.4-209)	136 (84.0-242)
TN	µg/L	162 (99.0-247)	160 (124-199)	155 (119-227)	174 (117-302)	191 (119-324)	193 (112-350)	198 (124-361)
TP*	µg/L	2.5 (2.0-7.1)	2.8 (2.0-17.3)	2.9 (2.0 – 8.4)	2.6 (2.0-4.4)	2.6 (2.0 – 5.4)	3.6 (2.0 – 15.3)	2.3 (2.0 – 3.5)
TDP*	µg/L	2.2 (2.0 – 6.8)	2.1 (2.0 – 3.2)	2.1 (2.0 – 3.1)	2.1 (2.0 –4.9)	2.3 (2.0 – 7.3)	2.5 (2.0 – 9.4)	2.1 (2.0 – 3.2)
SRP*	µg/L	1.1 (1.0 – 2.3)	1.3 (1.0 – 4.4)	1.7 (1.0 – 4.8)	1.7 (1.0 – 5.2)	1.5 (1.0 – 4.7)	1.6 (1.0 – 4.2)	1.4 (1.0 – 3.9)
Alkalinity	mg $CaCO_3$/L	65 (59–84)	62 (45-79)	65 (58-73)	79 (63-97)	55 (37-76)	53 (41–72)	53 (34–69)
pH		8.0 (7.9 – 8.1)	8.0 (7.8 – 8.1)	8.0 (7.9 – 8.1)	8.1 (8.0 – 8.2)	7.9 (7.7 – 8.1)	7.9 (7.7 – 8.1)	7.9 (7.8 – 8.1)
Conductivity	µS/cm	158 (146-199)	152 (122 - 185)	155 (140 - 171)	187 (152 - 228)	132 (90.2 - 161)	127 (95.1 - 166)	131 (84.7-168)
Turbidity	NTU	0.3 (0.1 – 0.6)	0.5 (0.1 – 1.9)	1.6 (0.3 – 17)	0.7 (0.2 – 2.6)	0.6 (0.2 – 1.6)	0.9 (0.3 – 3.4)	0.8 (0.3 – 1.3)
Silica**	mg/L	3.2 (2.3 – 3.4)	3.0 (2.3 – 3.3)	2.8 (2.2 – 3.2)	3.0 (2.1 – 3.9)	3.5 (3.2 – 4.0)	3.5 (3.1 – 4.3)	2.1 (3.2 – 5.0)
Secchi	m	7.6 (5.5 – 9.9)	6.0 (2.8 – 8.0)	6.8 (2.0 - 10)	6.0 (2.8 - 8.9)	6.6 (3.7 – 8.1)	6.0 (4.4 – 7.4)	5.2 (3.0 – 6.7)

*Laboratory detection limit for SRP=1.0 µg/L, for TP/TDP=2.0 µg/L
**Silica values are from a single 0-20 integrated sample per month.

4. Discussion

The 2016 results represent the ninth 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. Phosphorus fraction results from different laboratories continue to be complicated and under discussion. Total nitrogen analyses will likely continue in the 2017 field year to provide more comparison. Seasonal and spatial comparisons and trends will be the subject of analysis in the final synthesis report following the 2019 monitoring year.

5. References

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Figure 1. Location of sampling stations on Kinbasket and Revelstoke reservoirs, 2016.

Figure 2. Seasonal average NN, TN,TP, TDP, and SRP (µg/L) at Kinbasket Reservoir stations, 2009-2016. Note change in laboratory in 2013.

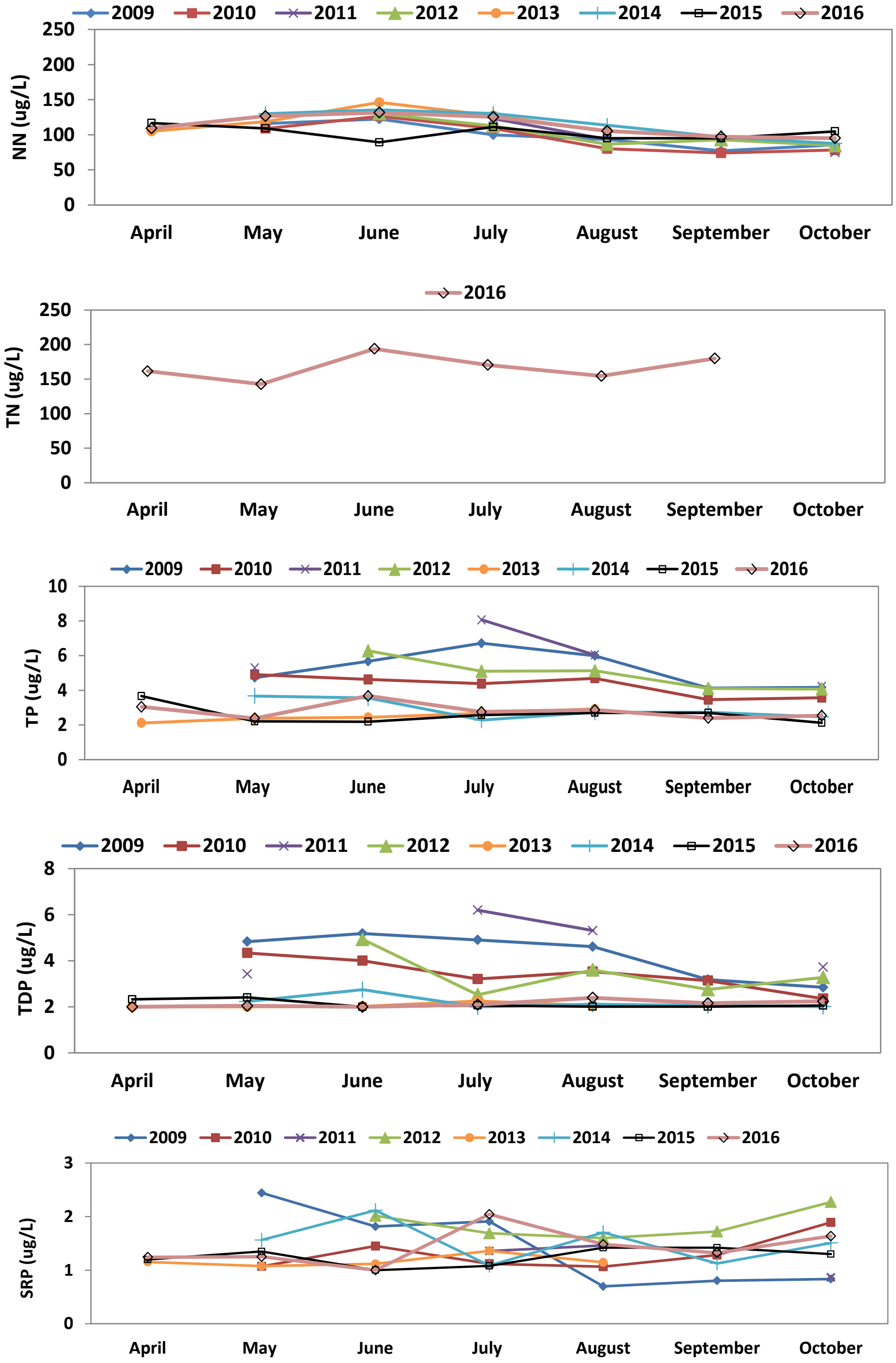


Figure 3. Seasonal average NN, TN, TP, TDP, and SRP (µg/L) at Revelstoke Reservoir stations, 2009-2016. Note change in laboratory in 2013.

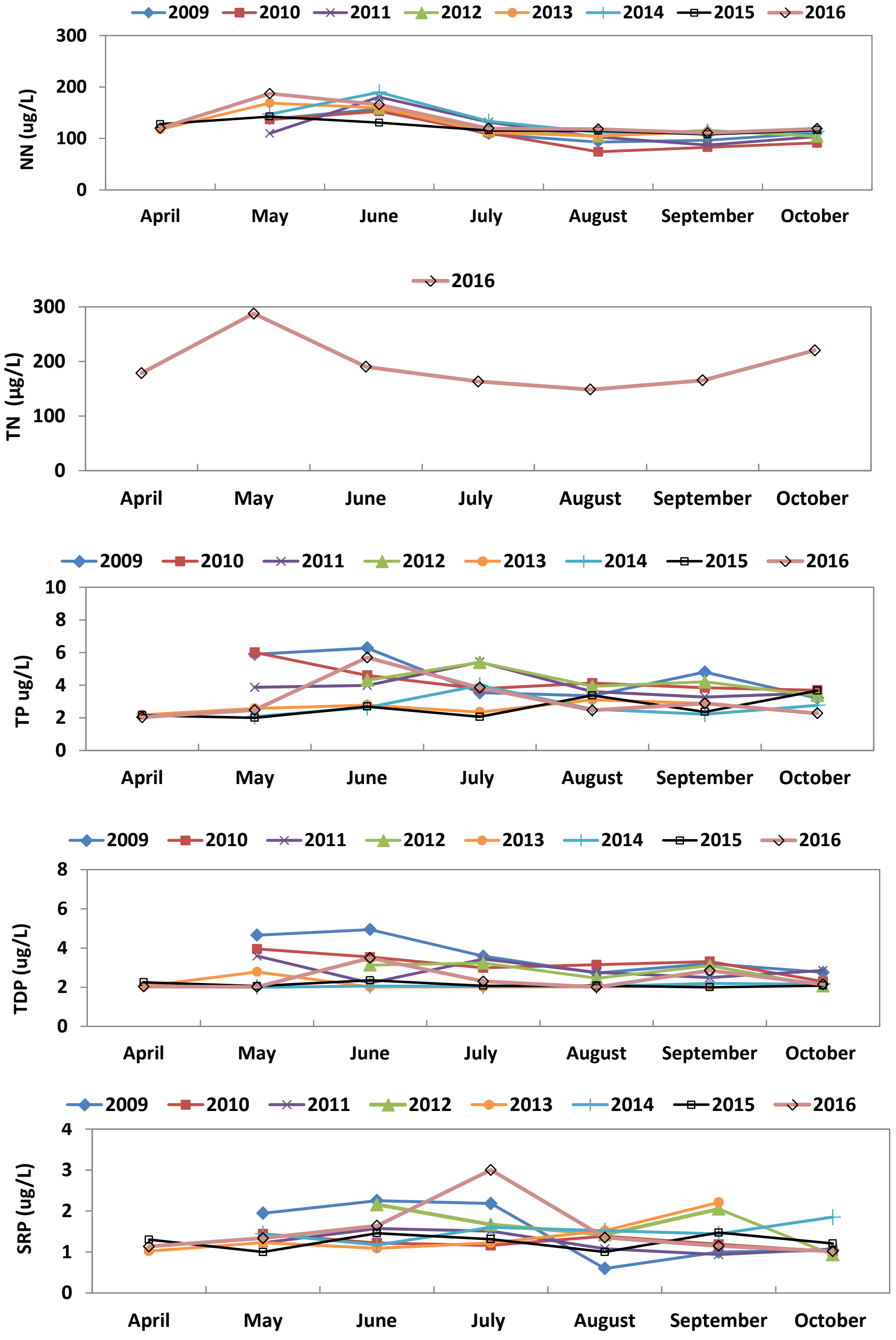
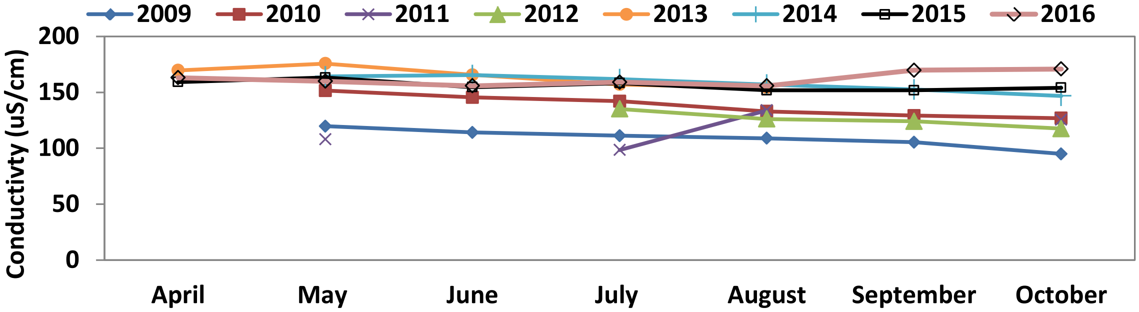


Figure 4. Seasonal average (a) conductivity (µS/cm) and (b) alkalinity (mgCaCO$_3$/L) at Kinbasket Reservoir stations, 2009-2016. Note change in laboratory in 2013.

(a)



(b)

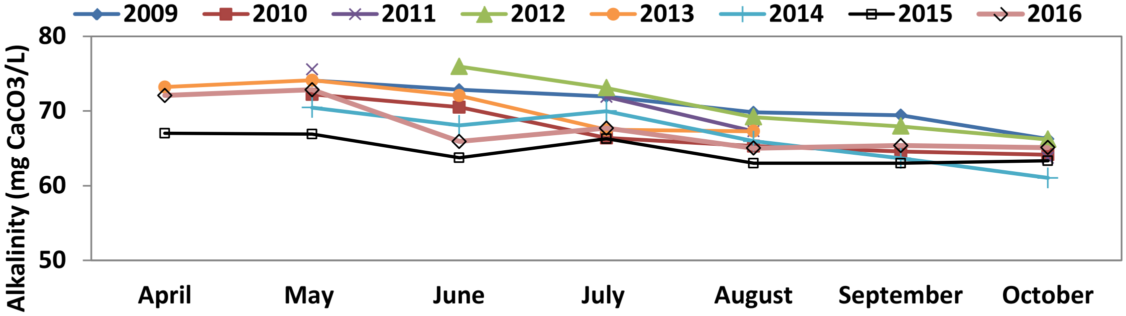


Figure 5. Seasonal average (a) conductivity (µS/cm) and (b) alkalinity (mg$CaCO_3$/L) at Revelstoke Reservoir stations, 2009-2016. Note change in laboratory in 2013.

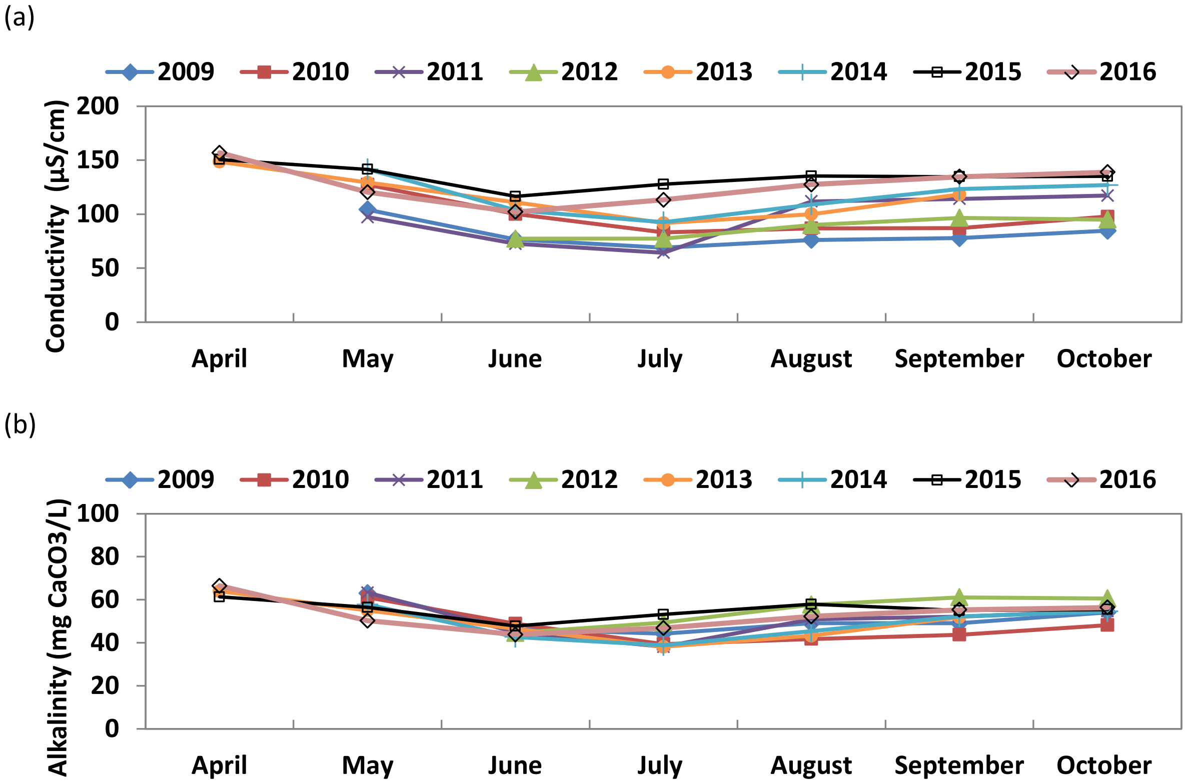
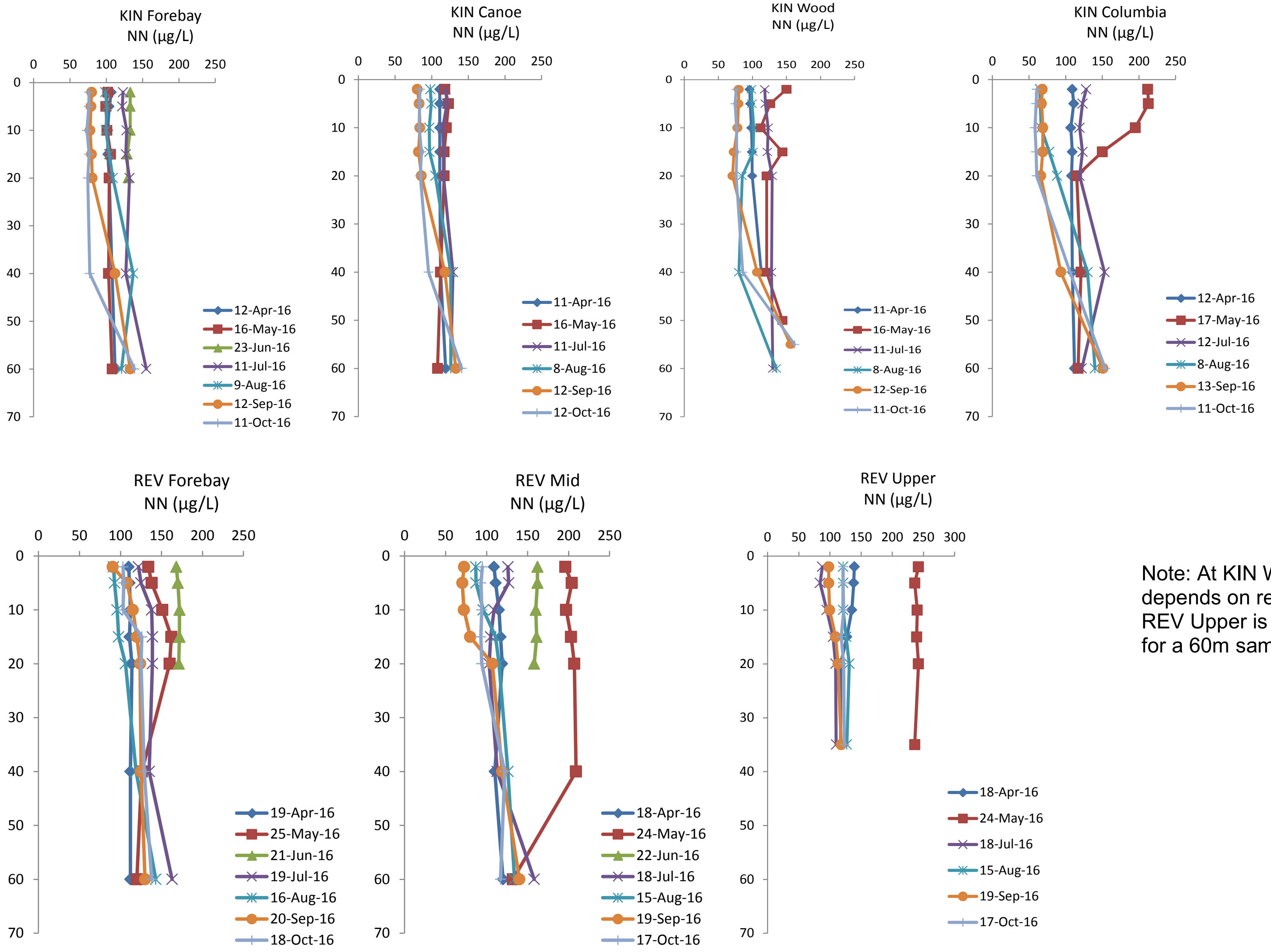


Figure 6. NN (µg/L) depth profiles (0-60m) for Kinbasket and Revelstoke Reservoir stations, 2016.



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, 2016.

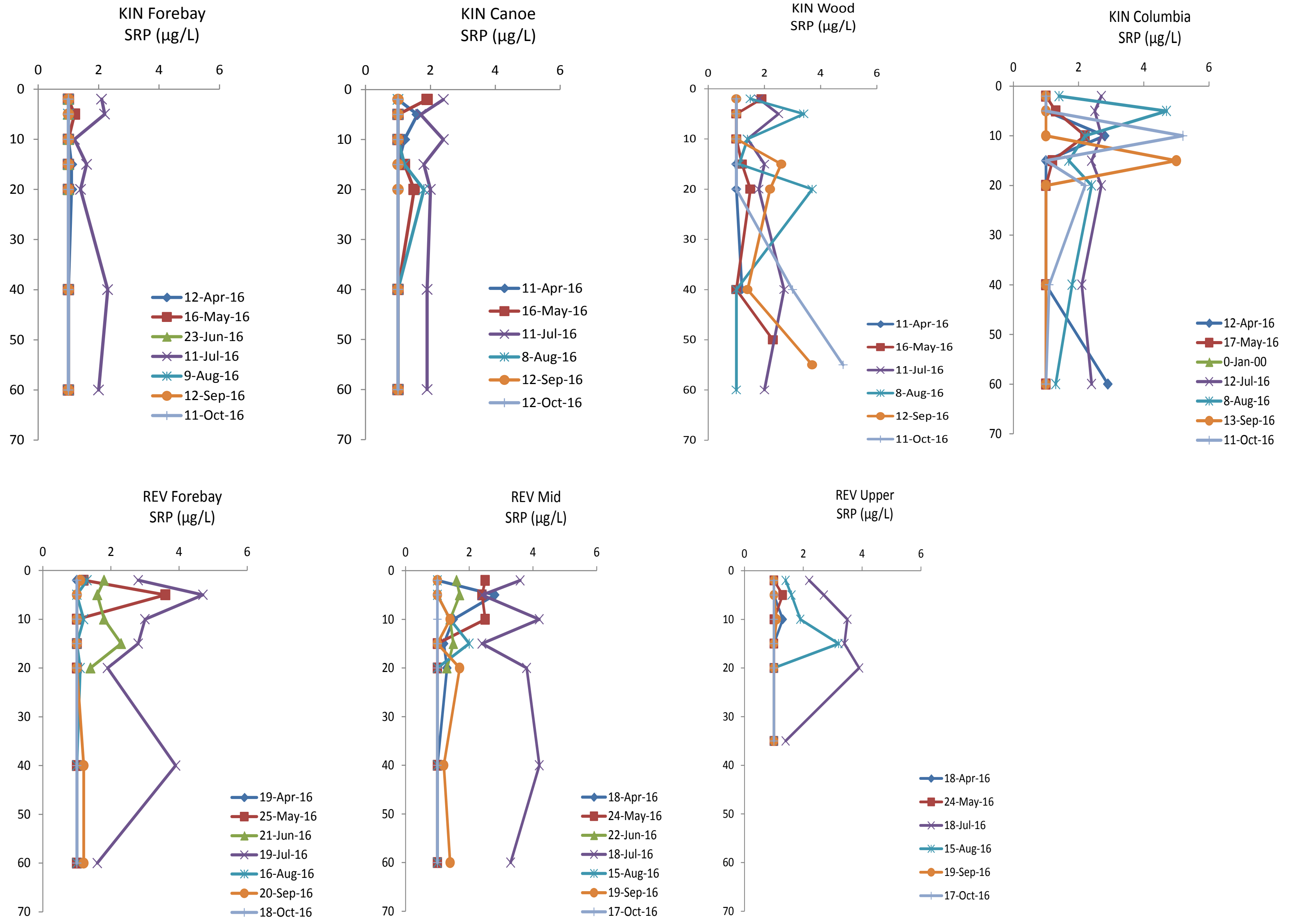


Figure 8. Seasonal silica (mg/L) from a 0-20m integrated tube sample at (a) Kinbasket and (b) Revelstoke stations, 2016.

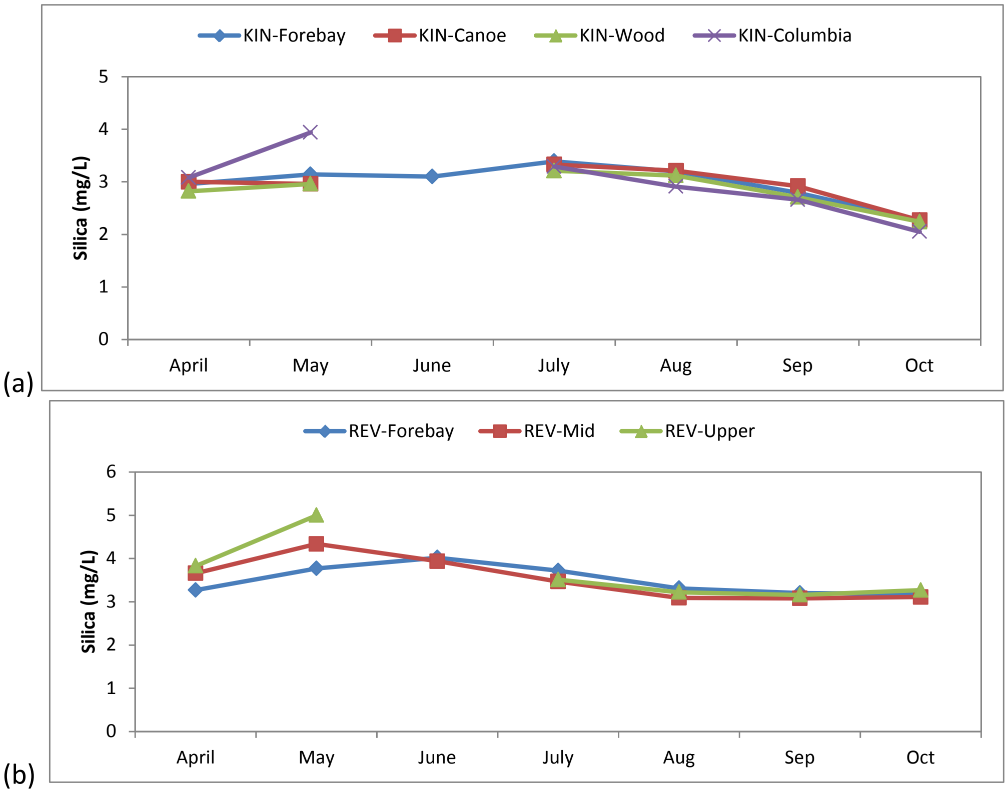
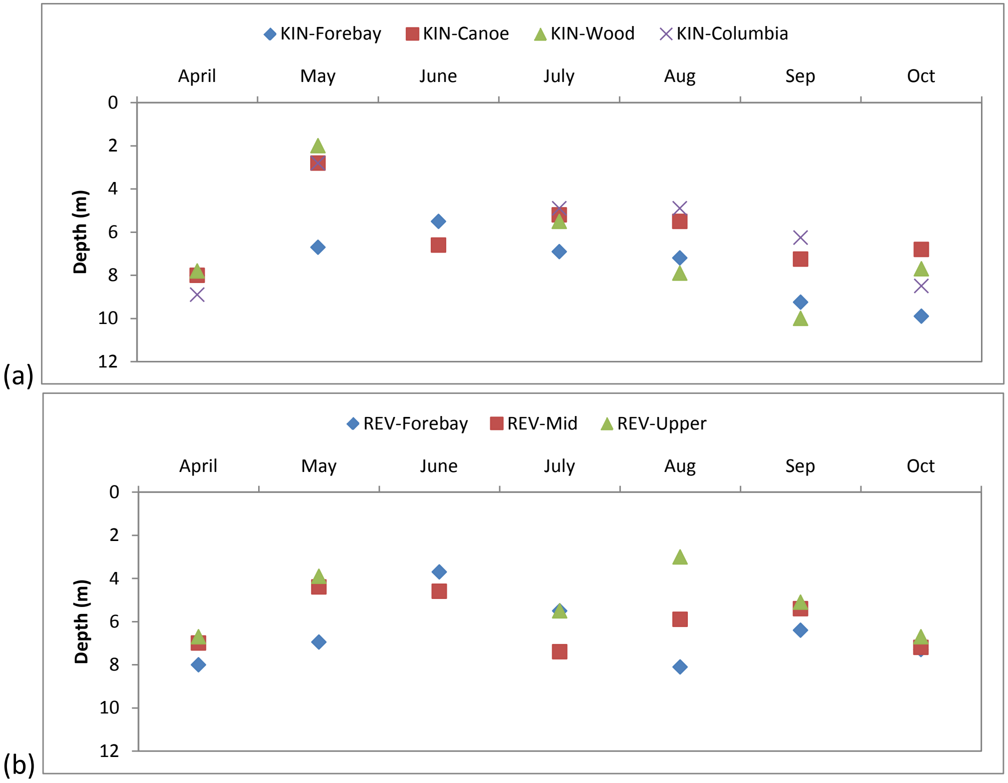


Figure 9. Seasonal Secchi depth (m) at (a) Kinbasket and (b) Revelstoke stations, 2016.



Appendix 1 – Data

Site	Depth	Date	NN	SRP	TP	TDP	SRS	TN	Alkalinity	pH	Turbidity	Cond
	m		ug/L	ug/L	ug/L	ug/L	mgSi/L	ug/L	mg$CaCO_3$/L		(NTU)	µS/cm
KIN FB	2	12-Apr-16	107	1.0	2.0	2.0		175	64.2	8.00	0.25	156
	5	12-Apr-16	104	1.0	2.1	2.0		154	66.1	8.01	0.24	156
	10	12-Apr-16	102	1.0	2.1	2.0		162	66.0	8.02	0.25	155
	15	12-Apr-16	102	1.1	2.0	2.0		149	65.1	8.05	0.29	156
	20	12-Apr-16	104	1.1	2.0	2.0		143	65.3	8.05	0.28	157
	40	12-Apr-16	108	1.0	2.1	2.0			67.6	8.03	0.26	164
	60	12-Apr-16	112	1.0	2.2	2.0			70.0	8.05	0.24	166
	80	12-Apr-16	118	1.3	2.3	2.0			72.6	8.06	0.24	170
	155	12-Apr-16	129	1.0	2.0	2.0			77.1	8.07	0.23	180
	2	16-May-16	102	1.0	2.0	2.0		117	62.6	8.05	0.26	147
	5	16-May-16	99	1.2	2.0	2.0		104	60.9	8.06	0.28	146
	10	16-May-16	101	1.0	2.6	2.0		113	61.6	8.00	0.27	147
	15	16-May-16	106	1.0	2.0	2.0		113	63.1	8.01	0.25	150
	20	16-May-16	104	1.0	2.0	2.0		99	60.6	7.92	0.22	150
	40	16-May-16	103	1.0	2.0	2.0		111	66.2	8.05	0.15	155
	60	16-May-16	108	1.0	2.0	2.0		113	70.3	8.03	0.13	163
	80	16-May-16	124	1.0	2.0	2.0		110	76.6	8.02	0.14	177
	160	16-May-16	116	1.0	2.0	2.0		108	83.1	8.07	0.19	192
	2	23-Jun-16	133	1.0	5.7	2.0		177	66.4	8.10	0.47	158
	5	23-Jun-16	133	1.0	3.4	2.0		187	67.2	8.09	0.53	158
	10	23-Jun-16	133	1.0	3.5	2.0		214	66.7	8.07	0.51	157
	15	23-Jun-16	129	1.0	3.4	2.0		209	65.3	8.07	0.53	154
	20	23-Jun-16	130	1.0	2.4	2.0		182	64.0	8.03	0.50	152
	2	11-Jul-16	123	2.1	2.0	2.0		170	60.7	8.02	0.31	149
	5	11-Jul-16	122	2.2	3.9	2.0		176	60.0	7.99	0.37	146
	10	11-Jul-16	128	1.2	2.5	2.0		173	60.1	8.00	0.37	149
	15	11-Jul-16	127	1.6	2.4	2.0		177	59.4	8.01	0.39	150
	20	11-Jul-16	132	1.4	2.0	2.0		184	60.1	8.01	0.34	150
	40	11-Jul-16	127	2.3	2.0	2.0		163	59.6	7.96	0.21	147
	60	11-Jul-16	155	2.0	2.0	2.0		146	65.4	7.99	0.27	157
	80	11-Jul-16	121	1.3	3.3	2.0		162	69.7	8.02	0.13	168
	170	11-Jul-16	126	2.0	7.1	3.7		151	84.1	8.04	0.13	199
	2	9-Aug-16	99	1.0	2.0	2.2		153	59.6	8.04	0.44	152
	5	9-Aug-16	101	1.0	3.0	2.0		150	62.2	8.05	0.48	153
	10	9-Aug-16	100	1.0	2.4	2.7		155	60.2	8.06	0.53	152
	15	9-Aug-16	104	1.0	2.2	2.4		153	58.9	8.04	0.46	150
	20	9-Aug-16	109	1.0	3.5	2.0		179	59.2	8.02	0.51	147
	40	9-Aug-16	137	1.0	2.4	2.8		169	66.0	8.04	0.63	160
	60	9-Aug-16	121	1.0	2.0	2.9		154	63.5	8.02	0.35	157
	80	9-Aug-16	116	1.0	3.1	2.1		153	68.5	8.01	0.28	169
	175	9-Aug-16	123	1.0	2.0	2.0		160	80.6	8.08	0.17	195
	2	12-Sep-16	80	1.0	2.0	2.0		210	60.1	8.04	0.39	147
	5	12-Sep-16	79	1.0	2.0	2.0		247	61.1	8.06	0.38	148
	10	12-Sep-16	78	1.0	2.0	2.0		158	60.1	8.06	0.43	147
	15	12-Sep-16	80	1.0	2.0	2.0		194	58.5	8.05	0.40	147
	20	12-Sep-16	81	1.0	2.0	2.0		154	60.2	8.04	0.38	147
	40	12-Sep-16	112	1.0	2.0	2.0		230	65.1	8.02	0.40	156
	60	12-Sep-16	133	1.0	2.0	2.0		196	62.6	7.96	0.25	151
	80	12-Sep-16	123	1.0	2.0	2.0		237	70.2	8.02	0.21	168
	175	12-Sep-16	130	1.0	2.0	2.0		170	82.4	8.04	0.24	194
	2	11-Oct-16	76	1.0	3.5	4.6			60.2	7.94	0.27	148
	5	11-Oct-16	76	1.0	2.0	2.0			60.2	7.94	0.23	149
	10	11-Oct-16	73	1.0	2.7	2.1			61.7	7.93	0.26	147
	15	11-Oct-16	76	1.0	3.3	2.0			60.5	7.96	0.26	149
	20	11-Oct-16	75	1.0	2.2	2.0			61.0	7.92	0.33	148
	40	11-Oct-16	77	1.0	2.3	2.0			60.0	7.93	0.27	146
	60	11-Oct-16	139	1.0	2.0	2.0			59.2	7.94	0.26	151
	80	11-Oct-16	125	1.0	2.0	2.0			69.5	7.99	0.17	166
	175	11-Oct-16	135	1.0	2.1	6.8			81.5	8.03	0.18	195
	0 - 20	12-Apr-16					2.96					
	0 - 20	16-May-16					3.14					
	0 - 20	23-Jun-16					3.1					
	0 - 20	11-Jul-16					3.39					
	0 - 20	9-Aug-16					3.2					
	0 - 20	12-Sep-16					2.79					
	0 - 20	11-Oct-16					2.27					
KIN Canoe	2	11-Apr-16	111	1.0	17.3	2.0		170	62.4	8.03	0.35	149
	5	11-Apr-16	111	1.6	2.1	2.0		157	62.1	8.02	0.28	149
	10	11-Apr-16	111	1.2	3.2	2.0		164	61.7	8.02	0.29	149
	15	11-Apr-16	111	1.0	2.5	2.0		164	63.2	8.04	0.26	151
	20	11-Apr-16	111	1.0	2.1	2.0		166	62.1	8.05	0.28	151
	40	11-Apr-16	112	1.0	9.0	2.0			64.0	8.02	0.24	153
	60	11-Apr-16	119	1.0	2.0	2.0			72.5	8.08	0.21	170
	80	11-Apr-16	122	1.0	2.9	2.0			74.3	8.10	0.16	174
	115	11-Apr-16	131	4.4	2.0	2.0			75.9	7.98	0.22	179
	2	16-May-16	118	1.9	2.1	2.2		143	67.8	8.10	1.90	156
	5	16-May-16	123	1.0	2.6	2.0		137	65.5	8.09	1.19	155
	10	16-May-16	120	1.0	2.0	2.3		124	65.0	8.08	0.69	154
	15	16-May-16	117	1.2	4.2	2.2		142	68.9	8.10	1.59	157
	20	16-May-16	117	1.5	2.0	2.0		142	66.6	8.10	0.81	156
	40	16-May-16	112	1.0	2.0	2.0		126	69.5	8.05	0.66	162
	60	16-May-16	108	1.0	2.0	2.0		151	65.2	8.07	0.20	153
	80	16-May-16	112	1.0	2.2	2.0		171	69.1	8.11	0.17	162
	105	16-May-16	122	2.3	2.0	2.0		142	71.7	8.10	1.21	169

	2	11-Jul-16	119	2.4	2.0	2.0		199	65.8	8.06	0.37	159
	5	11-Jul-16	121	1.7	3.4	2.0		172	65.7	8.05	0.37	159
	10	11-Jul-16	115	2.4	2.0	2.0		164	54.9	7.97	0.55	140
	15	11-Jul-16	116	1.8	2.9	2.0		171	47.5	7.89	0.59	124
	20	11-Jul-16	116	2.0	2.0	2.0		192	45.3	7.89	0.66	122
	40	11-Jul-16	129	1.9	6.9	2.0		164	56.2	7.95	0.29	137
	60	11-Jul-16	126	1.9	2.1	2.0		183	61.3	7.99	0.19	150
	80	11-Jul-16	122	2.0	2.1	2.0		169	69.5	8.02	0.16	167
	115	11-Jul-16	122	2.2	2.1	2.0		167	77.4	8.07	0.13	185
	2	8-Aug-16	98	1.0	3.2	2.5		147	60.4	8.04	0.63	148
	5	8-Aug-16	100	1.0	3.0	2.2		161	58.5	8.04	0.52	147
	10	8-Aug-16	97	1.0	2.4	2.4		151	54.3	8.01	0.56	143
	15	8-Aug-16	97	1.2	2.6	2.6		143	51.0	7.97	0.64	132
	20	8-Aug-16	105	1.8	4.5	2.0		186	56.1	7.97	1.26	138
	40	8-Aug-16	126	1.0	2.0	2.7		172	58.0	8.02	0.31	150
	60	8-Aug-16	126	1.0	2.2	3.2		156	54.0	7.92	0.28	137
	80	8-Aug-16	122	1.0	2.9	2.6		166	60.7	7.96	0.20	157
	120	8-Aug-16	117	1.0	2.0	2.8		155	75.4	8.05	0.19	183
	2	12-Sep-16	80	1.0	2.0	2.0		133	54.0	7.99	1.33	136
	5	12-Sep-16	83	1.0	2.0	2.0		157	53.3	7.95	0.70	134
	10	12-Sep-16	84	1.0	2.5	2.0		146	52.4	7.99	0.67	135
	15	12-Sep-16	82	1.0	2.0	2.0		156	55.2	7.98	0.64	137
	20	12-Sep-16	86	1.0	2.0	2.0		157	56.1	8.02	0.69	138
	40	12-Sep-16	118	1.0	2.0	2.0		161	61.5	8.05	0.68	147
	60	12-Sep-16	133	1.0	2.0	2.0		188	56.4	7.97	0.33	140
	80	12-Sep-16	127	1.0	2.0	2.0		170	69.8	8.02	0.35	166
	115	12-Sep-16	123	1.0	2.0	2.0		170	78.7	8.06	0.46	185
	2	12-Oct-16	84	1.0	2.4	2.2			57.4	7.96	0.39	145
	5	12-Oct-16	84	1.0	2.2	2.0			60.1	7.95	0.39	145
	10	12-Oct-16	83	1.0	2.0	2.1			58.0	7.95	0.41	145
	15	12-Oct-16	86	1.0	2.6	2.0			59.3	7.95	0.43	145
	20	12-Oct-16	84	1.0	2.5	2.0			57.7	7.84	0.39	145
	40	12-Oct-16	96	1.0	3.4	2.0			59.4	7.96	0.59	148
	60	12-Oct-16	141	1.0	2.2	2.0			58.2	7.93	0.49	144
	80	12-Oct-16	137	1.0	2.0	2.0			63.2	7.97	0.37	157
	115	12-Oct-16	127	1.0	2.5	2.0			76.0	8.03	0.43	182
	0 - 20	11-Apr-16					3.00					
	0 - 20	16-May-16					2.96					
	0 - 20	11-Jul-16					3.33					
	0 - 20	8-Aug-16					3.21					
	0 - 20	12-Sep-16					2.92					
	0 - 20	12-Oct-16					2.27					
KIN	2	11-Apr-16	96	1.0	2.0	2.0		162	66.2	7.99	0.28	158
Wood	5	11-Apr-16	97	1.0	2.0	2.0		155	66.2	8.04	0.28	158
	10	11-Apr-16	98	1.0	2.9	2.0		156	67.0	8.04	0.27	159
	15	11-Apr-16	99	1.0	2.6	2.0		161	67.0	8.07	0.28	160
	20	11-Apr-16	100	1.0	2.1	2.0		152	67.0	8.07	0.33	160
	40	11-Apr-16	113	1.2	3.6	2.0			72.5	8.09	1.68	171
	2	16-May-16	150	1.9	2.1	2.2		143	67.8	8.10	1.90	156
	5	16-May-16	126	1.0	2.6	2.0		137	65.5	8.09	1.19	155
	10	16-May-16	112	1.0	2.0	2.3		124	65.0	8.08	0.69	154
	15	16-May-16	144	1.2	4.2	2.2		142	68.9	8.10	1.59	157
	20	16-May-16	121	1.5	2.0	2.0		142	66.6	8.10	0.81	156
	40	16-May-16	121	1.0	2.0	2.0		126	69.5	8.05	0.66	162
	50	16-May-16	144	2.3	2.0	2.0		142	71.7	8.10	1.21	169
	2	11-Jul-16	118	1.8	2.4	2.0		170	68.3	8.06	0.41	165
	5	11-Jul-16	119	2.5	2.0	2.0		166	67.7	8.00	0.51	161
	10	11-Jul-16	123	1.4	2.9	2.0		188	64.9	8.05	0.39	156
	15	11-Jul-16	122	2.0	3.4	2.0		169	63.8	8.04	0.36	154
	20	11-Jul-16	129	1.8	2.6	2.0		160	66.4	8.05	0.62	157
	40	11-Jul-16	128	2.7	2.8	2.0		170	64.1	8.01	1.67	153
	60	11-Jul-16	130	2.0	2.2	2.8		161	68.2	8.07	0.68	165
		11-Jul-16										
	2	8-Aug-16	99	1.5	2.0	2.0		159	62.0	8.04	0.66	152
	5	8-Aug-16	99	3.4	2.3	2.6		157	63.5	8.04	0.55	154
	10	8-Aug-16	102	1.4	3.0	2.1		147	60.6	8.08	0.62	154
	15	8-Aug-16	101	1.1	2.7	2.5		157	59.5	8.05	0.65	152
	20	8-Aug-16	85	3.7	4.0	2.0		119	60.6	8.05	4.59	145
	40	8-Aug-16	80	1.0	5.0	2.0		120	61.5	8.01	16.80	140
	60	8-Aug-16	135	1.0	3.7	2.0		193	66.5	8.06	3.82	162
	2	12-Sep-16	80	1.0	2.0	2.0		144	67.2	8.06	0.37	148
	5	12-Sep-16	80	1.0	2.0	2.0		146	61.6	8.07	0.41	148
	10	12-Sep-16	78	1.0	2.5	3.1		156	62.7	8.08	1.55	148
	15	12-Sep-16	73	2.6	4.6	2.9		124	62.0	8.06	5.01	145
	20	12-Sep-16	71	2.2	2.4	2.0		155	62.8	8.08	4.72	145
	40	12-Sep-16	107	1.4	2.1	2.0		173	65.4	7.98	2.13	150
	55	12-Sep-16	156	3.7	8.4	2.3		227	69.9	8.07	1.96	163
	2	11-Oct-16	76	1.0	2.0	2.0			61.1	7.98	0.46	149
	5	11-Oct-16	75	1.0	2.0	2.0			58.2	7.92	0.39	148
	10	11-Oct-16	77	1.0	2.0	2.0			60.7	7.96	0.40	148
	15	11-Oct-16	77	1.0	2.0	2.0			60.1	7.96	0.42	149
	20	11-Oct-16	76	1.0	3.4	2.6			60.8	7.98	0.38	149
	40	11-Oct-16	86	3.0	4.2	2.0			63.0	7.99	2.93	155
	55	11-Oct-16	162	4.8	4.8	2.0			69.2	7.96	1.92	162
	0 - 20	11-Apr-16					2.82					
	0 - 20	16-May-16					2.96					
	0 - 20	11-Jul-16					3.21					
	0 - 20	8-Aug-16					3.12					

	0 - 20	12-Sep-16					2.71					
	0 - 20	11-Oct-16					2.24					
KIN	2	12-Apr-16	109	1.0	2.5	2.0		173	84.4	8.13	0.28	197
Columbia	5	12-Apr-16	111	1.0	2.5	2.0		161	83.1	8.09	0.30	196
	10	12-Apr-16	107	2.8	4.3	2.0		164	83.8	8.11	0.29	197
	15	12-Apr-16	109	1.0	2.9	2.0		171	83.0	8.12	0.30	197
	20	12-Apr-16	108	1.0	3.1	2.0		170	83.2	8.06	0.29	197
	40	12-Apr-16	109	1.0	2.8	2.0			83.6	8.12	0.30	197
	60	12-Apr-16	112	2.9	2.1	2.0			87.2	8.13	0.46	204
	80	12-Apr-16	112	1.0	2.3	2.0			88.9	8.13	0.62	208
	150	12-Apr-16	127	1.0	2.5	2.0			96.6	8.12	0.76	224
	2	17-May-16	212	1.0	4.0	2.0		231	94.0	8.20	1.01	213
	5	17-May-16	213	1.3	3.7	2.0		236	95.4	8.22	1.00	214
	10	17-May-16	195	2.2	4.0	2.0		233	93.4	8.21	0.87	209
	15	17-May-16	150	1.2	2.6	2.0		165	83.4	8.18	0.50	193
	20	17-May-16	115	1.0	2.0	2.0		122	70.9	8.11	0.36	170
	40	17-May-16	121	1.0	2.0	2.0		117	79.5	8.15	0.36	185
	60	17-May-16	117	1.0	2.0	2.0		146	90.9	8.16	0.35	210
	80	17-May-16	124	1.0	2.0	2.0		264	92.8	8.08	0.35	216
	155	17-May-16	122	1.5	2.0	2.0		126	97.0	8.11	0.41	224
	2	12-Jul-16	128	2.7	2.0	2.0		167	76.2	8.09	0.59	179
	5	12-Jul-16	123	2.5	2.0	2.0		167	73.6	8.09	0.61	174
	10	12-Jul-16	119	2.7	3.3	2.0		176	74.2	8.09	0.76	174
	15	12-Jul-16	123	2.4	3.3	2.0		168	76.7	8.07	1.01	176
	20	12-Jul-16	119	2.7	2.8	2.0		162	75.2	8.08	1.19	176
	40	12-Jul-16	153	2.1	3.5	2.0		196	78.0	8.07	1.25	180
	60	12-Jul-16	122	2.4	2.0	2.0		160	78.6	8.12	0.25	189
	80	12-Jul-16	132	1.7	2.0	2.0		170	89.9	8.05	0.25	207
	170	12-Jul-16	130	1.7	2.1	2.5		167	96.2	8.17	0.18	228
	2	8-Aug-16	65	1.4	3.3	2.1		127	69.4	8.09	1.40	170
	5	8-Aug-16	65	4.7	3.0	2.0		136	67.7	8.13	0.90	172
	10	8-Aug-16	67	2.2	2.6	2.0		127	69.5	8.11	1.29	170
	15	8-Aug-16	78	1.7	4.4	2.3		131	68.0	8.10	2.08	167
	20	8-Aug-16	88	2.4	3.1	2.1		130	66.1	8.03	2.66	163
	40	8-Aug-16	130	1.8	2.6	2.7		170	80.3	8.08	1.38	172
	60	8-Aug-16	140	1.3	2.2	2.4		179	74.8	8.05	0.75	182
	80	8-Aug-16	135	1.0	2.5	4.9		164	84.9	8.06	0.48	205
	170	8-Aug-16	131	1.0	2.8	2.0		180	94.9	8.09	0.28	226
	2	13-Sep-16	68	1.0	2.0	2.2		180	64.9	8.07	0.65	152
	5	13-Sep-16	67	1.0	2.0	2.0		121	63.1	8.05	0.64	152
	10	13-Sep-16	69	1.0	2.0	2.0		234	63.8	8.06	0.61	152
	15	13-Sep-16	69	5.0	2.2	2.0		188	64.5	8.06	0.63	152
	20	13-Sep-16	66	1.0	2.0	2.0		183	64.9	8.05	0.76	153
	40	13-Sep-16	94	1.0	2.5	2.0		198	70.3	8.07	0.87	163
	60	13-Sep-16	151	1.0	2.0	2.0		208	79.5	8.07	0.40	185
	80	13-Sep-16	141	1.0	2.0	3.6		180	87.4	8.07	0.31	203
	170	13-Sep-16	140	1.0	2.3	2.8		302	96.6	8.09	0.48	226
	2	11-Oct-16	61	1.0	2.0	2.0			65.9	7.98	0.36	161
	5	11-Oct-16	60	1.0	2.0	2.0			66.6	8.03	0.57	163
	10	11-Oct-16	58	5.2	2.4	2.0			66.0	7.96	0.5	
	15	11-Oct-16	60	1.0	2.2	2.0			66.5	7.99	0.4	162
	20	11-Oct-16	61	2.2	2.1	2.0			65.2	8	0.42	161
	40	11-Oct-16	106	1.1	3.5	2.0			70.9	8	0.58	168
	60	11-Oct-16	154	1.0	2.0	2.0			80.0	8.02	0.24	186
	80	11-Oct-16	143	1.0	2.0	2.0			86.9	8.05	0.35	203
	170	11-Oct-16	143	1.0	2.9	2.0			95.2	8.08	0.4	225
	0 - 20	12-Apr-16					3.08					
	0 - 20	17-May-16					3.94					
	0 - 20	12-Jul-16					3.29					
	0 - 20	8-Aug-16					2.91					
	0 - 20	13-Sep-16					2.66					
	0 - 20	11-Oct-16					2.05					
REV	2	19-Apr-16	110	1.0	2.0	2.0		171	64.8	8.04	0.28	156
FB	5	19-Apr-16	111	1.0	2.0	2.0		164	66.1	8.02	0.26	155
	10	19-Apr-16	112	1.0	2.0	2.0		172	66.3	8.03	0.29	158
	15	19-Apr-16	111	1.0	2.0	2.0		169	66.3	8.10	0.26	156
	20	19-Apr-16	114	1.0	2.0	2.0		177	66.0	8.02	0.30	156
	40	19-Apr-16	112	1.0	2.0	2.1		151	66.8	8.02	0.30	158
	60	19-Apr-16	112	1.0	2.0	2.0		153	76.2	8.02	0.27	159
	80	19-Apr-16	112	1.0	2.2	2.0		171	67.0	8.02	0.28	159
	100	19-Apr-16	114	1.0	2.1	2.0		151	66.8	8.02	0.40	160
	2	25-May-16	134	1.2	2.0	2.0		225	52.4	7.99	0.36	125
	5	25-May-16	138	3.6	2.9	2.0		275	53.4	7.99	0.44	125
	10	25-May-16	151	1.0	2.4	2.0		273	54.2	8.00	0.46	129
	15	25-May-16	162	1.0	2.0	2.0		298	59.0	7.96	0.42	136
	20	25-May-16	160	1.0	3.2	2.0		256	61.2	8.02	0.35	143
	40	25-May-16	126	1.0	2.0	2.0		190	67.8	8.07	0.24	158
	60	25-May-16	120	1.0	2.2	2.0		214	67.7	8.07	0.32	161
	80	25-May-16	125	1.0	2.0	2.0		231	67.8	8.08	0.27	161
	115	25-May-16	124	1.0	2.0	2.0		221	67.4	8.07	0.34	160
	2	21-Jun-16	168	1.8	4.1	2.9		226	42.4	7.90	1.39	102
	5	21-Jun-16	170	1.6	4.0	2.7		203	44.4	7.89	1.43	102
	10	21-Jun-16	172	1.8	5.3	2.4		182	43.9	7.90	1.59	103
	15	21-Jun-16	172	2.3	5.4	2.9		189	45.6	7.90	1.57	104
	20	21-Jun-16	171	1.4	4.6	2.6		190	44.6	7.88	1.45	104
	2	19-Jul-16	122	2.8	2.6	2.0		176	37.9	7.83	0.60	91
	5	19-Jul-16	125	4.7	3.5	2.0		160	38.8	7.83	0.75	90
	10	19-Jul-16	138	3.0	5.0	2.5		179	39.2	7.80	0.81	94

	15	19-Jul-16	139	2.8	3.1	2.0		178	38.3	7.80	0.58	92
	20	19-Jul-16	139	1.9	2.4	2.0		162	37.9	7.82	0.48	93
	40	19-Jul-16	135	3.9	2.0	2.3		173	40.8	7.80	0.38	98
	60	19-Jul-16	163	1.6	2.2	2.0		193	55.9	7.93	0.36	135
	80	19-Jul-16	142	2.6	2.3	2.0		185	66.0	8.01	0.33	154
	115	19-Jul-16	126	2.3	2.0	2.0		189	66.6	8.02	0.36	156
	2	16-Aug-16	92	1.3	2.0	2.0		132	39.6	7.87	0.40	94
	5	16-Aug-16	93	1.0	2.0	2.0		119	37.3	7.86	0.37	94
	10	16-Aug-16	96	1.2	2.0	2.0		130	39.3	7.88	0.44	94
	15	16-Aug-16	98	1.0	2.0	2.0		143	40.4	7.86	0.64	96
	20	16-Aug-16	106	1.1	2.0	2.0		138	46.8	7.90	1.21	110
	40	16-Aug-16	119	1.0	2.0	2.0		159	48.9	7.93	0.45	124
	60	16-Aug-16	143	1.0	2.0	2.0		172	47.2	7.92	0.40	121
	80	16-Aug-16	149	2.2	2.0	2.0		184	61.9	8.04	0.38	149
	110	16-Aug-16	149	1.0	2.0	2.0		163	63.7	8.03	0.45	151
	2	20-Sep-16	91	1.1	3.9	7.3		164	47.1	7.92	0.69	118
	5	20-Sep-16	108	1.0	3.3	2.4		203	52.0	7.90	0.61	130
	10	20-Sep-16	115	1.0	3.1	4.9		204	58.5	7.94	0.66	139
	15	20-Sep-16	120	1.0	2.5	2.1		153	58.2	7.98	0.64	143
	20	20-Sep-16	124	1.0	2.7	2.0		188	56.7	7.92	0.68	142
	40	20-Sep-16	125	1.2	2.5	2.1		185	57.0	7.88	0.58	142
	60	20-Sep-16	130	1.2	2.5	2.0		175	55.1	7.84	0.59	137
	80	20-Sep-16	151	1.7	2.6	2.9		198	61.2	7.90	0.63	144
	115	20-Sep-16	153	1.7	2.6	2.4		210	64.2	7.92	0.86	149
	2	18-Oct-16	103	1.0	2.0	3.4		173	51.1	7.88	0.25	131
	5	18-Oct-16	104	1.0	5.3	2.0		203	51.3	7.72	0.26	131
	10	18-Oct-16	103	1.0	2.0	2.0		144	64.4	7.67	0.39	130
	15	18-Oct-16	126	1.0	2.4	2.0		216	57.8	7.90	0.28	141
	20	18-Oct-16	125	1.0	2.4	2.0		266	56.3	7.91	0.27	141
	40	18-Oct-16	129	1.0	2.0	2.0		198	57.2	7.89	0.34	141
	60	18-Oct-16	138	1.0	2.1	2.0		231	57.5	7.88	0.39	140
	80	18-Oct-16	155	1.0	2.0	2.0		225	58.1	7.90	0.54	148
	105	18-Oct-16	158	1.0	2.8	4.0		324	60.6	7.90	0.93	149
	0 - 20	19-Apr-16					3.27					
	0 - 20	25-May-16					3.77					
	0 - 20	21-Jun-16					4.02					
	0 - 20	19-Jul-16					3.72					
	0 - 20	16-Aug-16					3.31					
	0 - 20	20-Sep-16					3.20					
	0 - 20	18-Oct-16					3.18					
REV	2	18-Apr-16	109	1.0	2.0	2.2		171	66.3	8.02	0.29	156
Middle	5	18-Apr-16	111	2.8	2.0	2.0		172	65.5	8.01	0.35	156
	10	18-Apr-16	115	1.5	2.0	2.0		170	65.9	7.96	0.56	154
	15	18-Apr-16	117	1.2	2.1	2.1		228	66.2	8.02	0.75	157
	20	18-Apr-16	119	1.3	2.2	2.0		178	67.9	8.02	0.44	159
	40	18-Apr-16	110	1.0	2.0	2.0		168	68.8	8.03	0.29	161
	60	18-Apr-16	120	1.0	2.0	2.0		166	70.0	8.04	0.28	163
	80	18-Apr-16	152	1.0	2.0	2.0		195	72.1	8.06	0.51	166
	2	24-May-16	196	2.5	2.0	2.0		311	49.6	7.95	0.81	116
	5	24-May-16	204	2.4	2.0	2.0		350	48.1	7.94	1.01	112
	10	24-May-16	197	2.5	2.3	2.0		295	48.0	7.94	0.79	115
	15	24-May-16	203	1.0	2.1	2.0		276	48.8	7.95	0.92	116
	20	24-May-16	207	1.0	2.1	2.0		318	51.0	7.98	1.19	122
	40	24-May-16	209	1.0	2.2	2.0		274	52.3	7.97	0.86	124
	60	24-May-16	132	1.0	6.7	2.0		306	65.1	8.07	0.39	158
	80	24-May-16	129	1.8	3.2	2.0		203	67.5	8.06	0.30	160
	2	22-Jun-16	162	1.6	4.2	3.1		183	45.9	7.90	1.07	104
	5	22-Jun-16	162	1.7	7.4	2.5		176	44.5	7.90	1.35	105
	10	22-Jun-16	160	1.4	4.3	9.4		184	44.5	7.92	1.49	102
	15	22-Jun-16	161	1.5	12.8	3.3		179	41.3	7.90	1.72	99
	20	22-Jun-16	158	1.3	4.9	3.1		190	41.5	7.86	1.88	96
	2	18-Jul-16	126	3.6	10.4	2.0		172	41.3	7.84	0.54	95
	5	18-Jul-16	127	2.4	3.0	2.0		193	41.2	7.84	0.51	95
	10	18-Jul-16	109	4.2	15.3	2.5		168	46.3	7.90	3.44	109
	15	18-Jul-16	105	2.4	9.0	2.0		136	45.0	7.86	3.21	106
	20	18-Jul-16	103	3.8	3.7	2.0		136	43.5	7.86	1.28	108
	40	18-Jul-16	113	4.2	3.8	2.0		151	47.4	7.90	0.52	120
	60	18-Jul-16	158	3.3	2.9	7.8		195	54.4	7.92	0.36	125
	80	18-Jul-16	145	2.6	3.7	2.0		193	63.2	7.98	0.36	151
	2	15-Aug-16	87	1.0	2.0	2.0		125	40.8	7.91	0.59	102
	5	15-Aug-16	87	1.0	2.0	2.0		117	43.7	7.91	0.80	104
	10	15-Aug-16	96	1.4	2.3	2.0		126	47.2	7.93	1.43	111
	15	15-Aug-16	111	2.0	2.5	2.0		142	49.1	7.95	1.48	125
	20	15-Aug-16	115	1.0	2.0	2.0		154	54.0	7.97	1.14	135
	40	15-Aug-16	126	1.0	2.0	2.0		170	56.7	7.99	0.86	136
	60	15-Aug-16	134	1.0	11.3	2.0		161	50.2	7.96	0.43	126
	80	15-Aug-16	158	1.0	2.0	2.0		165	61.5	8.00	0.46	145
	2	19-Sep-16	73	1.0	3.3	2.1		143	44.2	7.89	0.80	108
	5	19-Sep-16	70	1.0	2.5	5.9		123	45.3	7.89	0.67	108
	10	19-Sep-16	72	1.4	2.7	2.0		112	46.2	7.89	0.68	108
	15	19-Sep-16	80	1.0	2.7	2.3		178	48.1	7.92	1.04	116
	20	19-Sep-16	107	1.7	3.8	2.4		149	55.1	7.96	1.08	133
	40	19-Sep-16	119	1.2	2.9	2.2		167	58.8	7.99	0.97	141
	60	19-Sep-16	140	1.4	2.6	5.0		174	55.9	7.95	0.89	135
	80	19-Sep-16	159	1.0	3.3	2.2		212	61.8	7.97	1.07	145
	2	17-Oct-16	95	1.0	2.0	2.0		199	49.5	7.83	0.61	125
	5	17-Oct-16	93	1.0	2.0	2.0		238	61.6	7.68	0.31	126
	10	17-Oct-16	94	1.0	2.0	2.0		189	52.3	7.89	0.30	126

	15	17-Oct-16	93	1.0	2.0	2.4		177	50.1	7.85	0.35	127
	20	17-Oct-16	94	1.0	2.0	2.0		222	52.0	7.88	0.35	127
	40	17-Oct-16	122	1.0	2.1	2.0		253	57.9	7.88	0.40	142
	60	17-Oct-16	117	1.0	2.1	2.0		202	56.4	7.85	0.57	141
	75	17-Oct-16	164	1.4	3.3	2.0		292	57.7	7.75	0.77	142
	0 - 20	18-Apr-16					3.66					
	0 - 20	24-May-16					4.34					
	0 - 20	22-Jun-16					3.94					
	0 - 20	18-Jul-16					3.47					
	0 - 20	15-Aug-16					3.09					
	0 - 20	19-Sep-16					3.08					
	0 - 20	17-Oct-16					3.11					
REV	2	18-Apr-16	139	1.0	2.2	2.0		214	61.1	8.00	0.41	148
Upper	5	18-Apr-16	138	1.0	2.0	2.0		171	62.2	7.99	0.33	149
	10	18-Apr-16	135	1.3	2.0	2.0		210	63.6	7.98	0.36	149
	15	18-Apr-16	127	1.0	2.0	2.0		190	62.4	7.95	0.34	152
	20	18-Apr-16	117	1.0	2.0	2.0		190	66.3	8.01	0.45	157
	35	18-Apr-16	117	1.0	2.0	2.3		166	69.3	8.11	0.37	168
	2	24-May-16	242	1.0	2.8	2.3		306	34.4	7.79	0.73	85
	5	24-May-16	236	1.3	2.0	2.0		308	33.7	7.78	0.88	85
	10	24-May-16	240	1.0	2.8	2.0		361	33.6	7.79	1.04	85
	15	24-May-16	239	1.0	2.2	2.0		328	34.2	7.81	0.90	85
	20	24-May-16	242	1.0	2.0	2.0		341	36.7	7.78	0.92	89
	35	24-May-16	236	1.0	2.0	2.0		327	42.4	7.89	0.89	104
	2	18-Jul-16	88	2.2	2.5	2.0		138	37.3	7.84	0.54	94
	5	18-Jul-16	84	2.7	2.0	2.1		124	39.7	7.78	0.57	97
	10	18-Jul-16	95	3.5	2.0	2.0		170	41.8	7.86	0.72	107
	15	18-Jul-16	105	3.4	2.5	2.0		137	49.9	7.91	0.76	124
	20	18-Jul-16	109	3.9	2.5	2.0		151	52.3	7.94	0.66	131
	35	18-Jul-16	110	1.4	2.1	2.0		148	54.3	7.94	0.83	134
	2	15-Aug-16	121	1.4	2.0	2.0		133	57.3	8.00	1.33	141
	5	15-Aug-16	121	1.6	2.8	2.0		143	58.1	8.00	1.33	140
	10	15-Aug-16	121	1.9	2.0	2.0		149	58.0	8.00	1.08	144
	15	15-Aug-16	126	3.2	2.0	2.1		126	59.4	8.01	1.04	146
	20	15-Aug-16	131	1.0	2.0	2.0		179	59.7	8.02	1.06	148
	35	15-Aug-16	127	1.0	2.0	2.0		177	62.1	8.01	1.05	148
	2	19-Sep-16	98	1.0	3.0	3.2		157	55.8	7.97	1.12	136
	5	19-Sep-16	98	1.0	2.5	2.9		138	56.0	7.94	1.11	137
	10	19-Sep-16	99	1.1	2.9	2.4		156	56.6	7.98	1.00	138
	15	19-Sep-16	109	1.0	2.3	2.0		140	57.8	7.98	1.06	143
	20	19-Sep-16	113	1.0	2.7	2.0		145	57.6	7.88	0.94	146
	35	19-Sep-16	118	1.0	3.5	2.0		176	60.9	7.96	0.92	149
	2	17-Oct-16	121	1.0	2.0	2.0		188	58.6	7.92	0.42	146
	5	17-Oct-16	121	1.0	2.2	2.0		232	56.3	7.84	0.38	145
	10	17-Oct-16	122	1.0	2.0	2.0		199	57.5	7.93	0.46	146
	15	17-Oct-16	118	1.0	2.2	2.1		193	57.3	7.87	0.43	144
	20	17-Oct-16	122	1.0	2.0	2.0		268	58.1	7.90	0.44	146
	35	17-Oct-16	123	1.0	2.1	2.0		237	56.4	7.91	0.53	146
	0 - 20	18-Apr-16					3.83					
	0 - 20	24-May-16					5.00					
	0 - 20	18-Jul-16					3.51					
	0 - 20	15-Aug-16					3.22					
	0 - 20	19-Sep-16					3.16					
	0 - 20	17-Oct-16					3.27					

Appendix 5

Primary Productivity Kinbasket and Revelstoke Reservoirs, 2016

Shannon Harris and Jennifer Sarchuk
Ministry of Environment

PRIMARY PRODUCTIVITY IN KINBASKET AND REVELSTOKE RESERVOIRS, 2016

Shannon Harris and Jennifer Sarchuk
Ministry of Environment,
BCCF

2018

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Introduction

In order to determine trophic status of a lake or reservoir there are a number of criteria that can be used such as chemical characteristics (Total Phosphorus, Total Nitrogen, Total Dissolved Solid, etc.) or dominance of particular biological organisms from bacteria to fish. However, it is generally acknowledged that the best methodology for determination of trophic status is using a parameter that can quantitatively determine rate of growth and one that integrates a variety of environmental parameters (Wetzel 2001). Currently the best existing parameter available is measurement of rates of primary productivity.

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 supported 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 2016.

Methods

Field & Laboratory

The field sampling strategy and laboratory methodology were consistent with previous study years and can be found in Harris (2012). Appendix A provides field and incubation information for the study period. It is important to note that the values for primary productivity in this report are different than previously reported values due to calculation error in the alkalinity measurement. For productivity calculations, alkalinity as mg $CaCO_3$/L must be converted to DIC as mg/L and an error was detected in this conversion calculation. Values for primary productivity for all study years have been recalculated and are provided in Appendix B.

Results

Photosynthetically active radiation (PAR), defined as the radiation in the 400-700 nm waveband, varied from month to month and site to site during the 2016 sampling season. PAR was the highest in June on Revelstoke Middle; the highest in August for Revelstoke Forebay; and the highest in September on Kinbasket (Figure 1). PAR was low at all locations in July around < 400 $\mu mol/m^2/s$, which is not optimal for production as solar radiation is the major energy source driving productivity. This was evident from Appendix A, as it was overcast at all sites in July.

As shown in Figure 1 the 1% depth was generally lower in Kinbasket compared to Revelstoke Middle and Revelstoke Forebay. In 2016, the mean euphotic zone depth was deepest at Kinbasket Forebay (20.25 m), followed by Revelstoke Forebay (15.25 m) and Revelstoke Middle (13 m) (Appendix A and Figure 1). The euphotic zone average depth in Kinbasket

Forebay was 5 to 8 meters deeper than Revelstoke Forebay and Revelstoke Middle, respectively (Figure 1). Between the sampling months, June to September, the euphotic zone lowered each month with the exception of Revelstoke Middle in September where the euphotic zone raised.

Secchi disk depths were generally higher in Kinbasket than in Revelstoke (Figure 2). In 2016, the mean Secchi disk depth in Kinbasket was 8.8 m followed by Revelstoke Forebay at 6.1 m and then Revelstoke Middle at 5.8 m. In general, Secchi disk depths increased as the season progressed reaching maximum depths in September, as observed in Kinbasket (Figure 2). In Revelstoke Middle and Forebay both experienced a slight decrease from August to September.

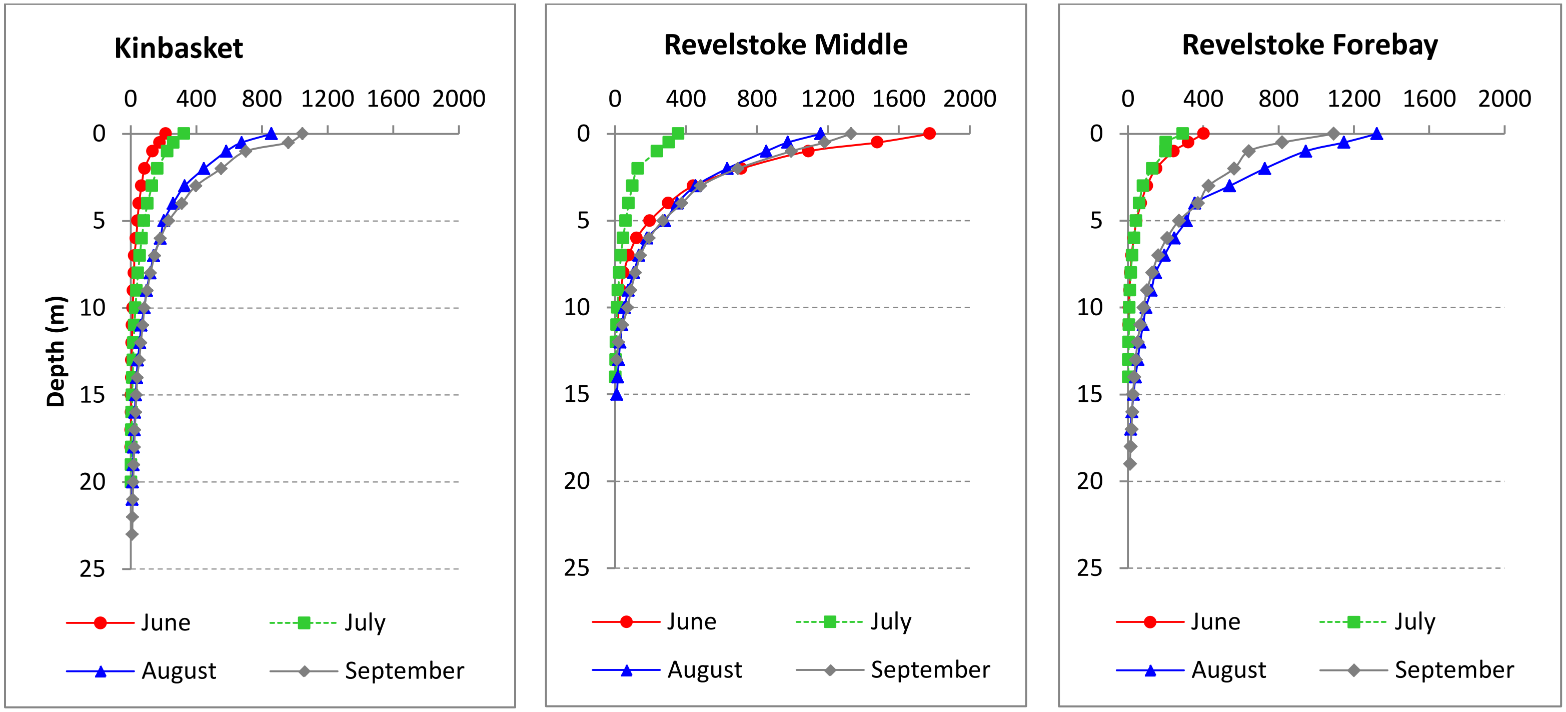

Figure 1. Photosynthetic active radiation (μmol/m^2/s) at Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2016. PAR measurements recorded to the depth of 1% of surface light.

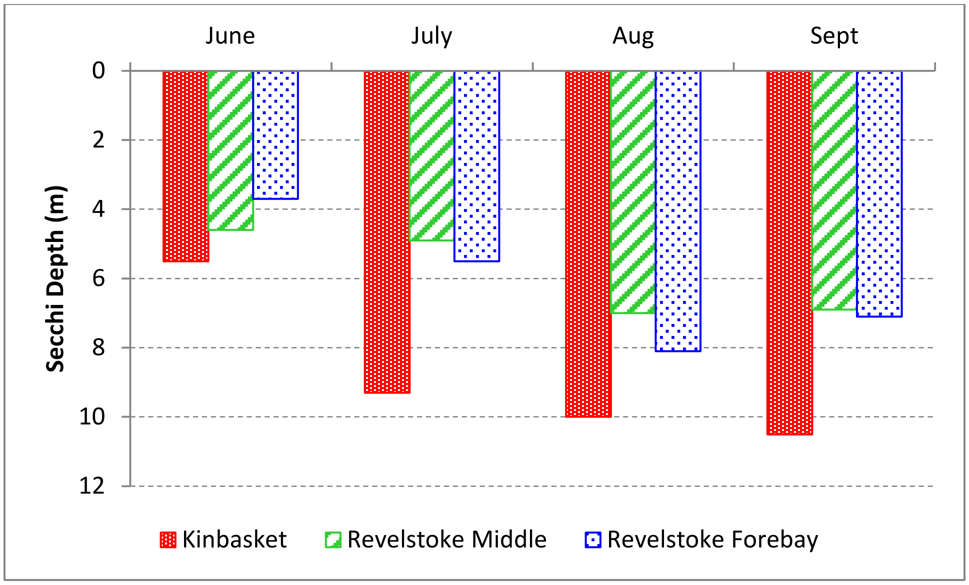

Figure 2. Secchi disk depths (m) in Kinbasket, Revelstoke Middle and Revelstoke Forebay in 2016.

The relative trends between stations 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 0.27 cm^{-1}, (about 73% transmission m^{-1}) and the highest attenuation coefficient was measured at Revelstoke Middle at 0.37 cm^{-1} (about 63% transmission m^{-1}) (Figure 3). A high attenuation coefficient is indicative of low transparency/high turbidity and a low attenuation coefficient indicates high transparency and low turbidity. In 2016, the attenuation coefficients were similar at all stations and the lowest attenuation coefficient was measured at Kinbasket Forebay at 0.25 cm^{-1}, (about 75% transmission m^{-1}) and the highest attenuation coefficient was measured at Revelstoke Middle at 0.45 cm^{-1}, (about 55% transmission m^{-1}). On average, the seasonal mean attenuation coefficient was 0.26 cm^{-1} at Kinbasket Forebay, followed by 0.34 cm^{-1} at Revelstoke Forebay and highest at Revelstoke Middle at 0.36 cm^{-1} (Figure 3).

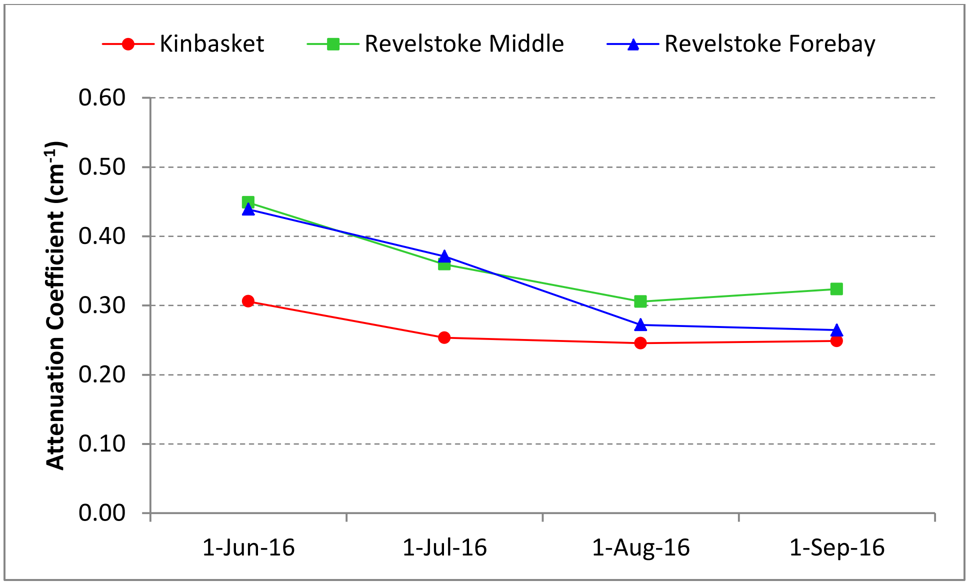

Figure 3. Attenuation coefficients for Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2016.

Chlorophyll a

Biomass in Kinbasket and Revelstoke reservoirs were low with results below 2.0 mg/m^3 (Figure 4), which is indicative of oligotrophic conditions (Wetzel 2001). In 2016, the discrete seasonal averages were 1.12 mg/m^3 in Kinbasket, 0.79 mg/m^3 in Revelstoke Middle and 0.88 mg/m^3 in Revelstoke Forebay. In most months very little heterogeneity throughout the water column was observed. As seen in previous study years (Harris 2012; 2013; 2015; 2017), the depth integrated biomass was higher in Kinbasket Forebay than in Revelstoke Middle or Revelstoke Forebay for most months with the exception of August where depth integrated biomass at Revelstoke Forebay was higher than Kinbasket (Figure 5). Biomass in Kinbasket Forebay generally exceeded 20 mg/m^2 whereas at Revelstoke biomass was generally below 20 mg/m^2 and often around 10 mg/m^2 (Figure 5). The seasonal cycles at the three stations differed, the seasonal lowers were observed in June for Revelstoke Middle and Revelstoke Forebay whereas seasonal lowers were observed in Kinbasket in August. This suggests different factors are controlling biomass values in the two reservoirs. The depth integrated seasonal averages were 23.7 mg/m^2 in Kinbasket, 11.8 mg/m^2 in Revelstoke Middle, and 15.4 mg/m^2 in Revelstoke Forebay (Table 2; Figure 5). These means were similar to the concentrations measured in 2015, which had means of 28.6, 18.6 and 14.6 mg/m^2 for Kinbasket, Revelstoke Middle and Forebay, respectively (Harris 2017).

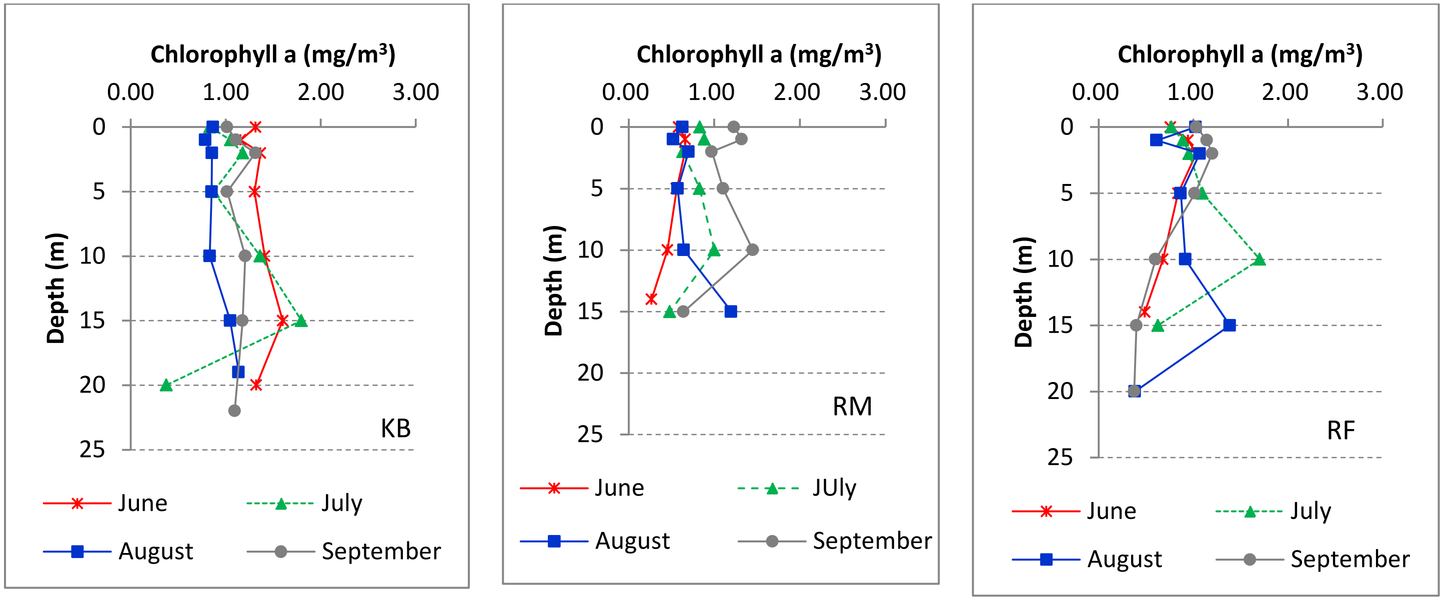

Figure 4. Vertical profiles of chlorophyll *a* (mg/m^3) for Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2016.

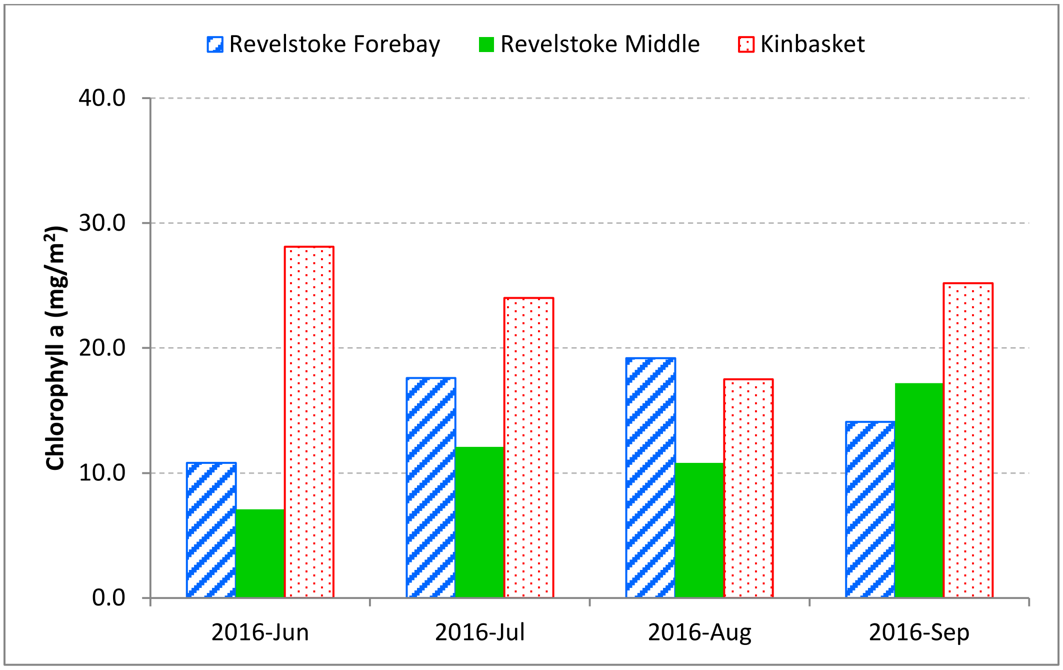

Figure 5. Integrated chlorophyll *a* (mg Chl *a*/m^2) in Kinbasket and Revelstoke in 2016.

It is important to examine the size structure of the phytoplankton community as it plays an important role in the structuring of the food web and provides some insight into the community structure and functional relationships in the ecosystem. On average, picoplankton sized cells (0.2-2 µm) accounted for 50% of the total phytoplankton biomass followed closely by nanoplankton sized cells (2.0-20 µm) at 44% whereas the large sized microplankton (>20 µm) accounted for only 6% (Figure 6). Picoplankton and nanoplankton sized cells (cells >20 µm) accounted for 94% of the biomass in Kinbasket and Revelstoke in 2016; this is similar to the values measured in 2015 where these two size structures accounted for 91% and 87% of the biomass, respectively (Harris 2017).

The relative contribution of the picoplankton, nanoplankton and microplankton varied slightly in 2016 (Figure 6). For instance, at Kinbasket Forebay picoplankton biomass was highest in June and July at 57% of the total biomass and the lowest in July at 40%. Compared to both Revelstoke Middle and Revelstoke Forebay where picoplankton biomass was highest in August at 61% and 56% and lowest in September at 39% and 38%, respectively. The relatively high contribution of nanoplankton to the food web should support the growth of large sized zooplankton. The high proportion of picoplankton, owing to their small size, suggests relative scarcity of available nutrients and also suggests the importance of the microbial food web in Kinbasket and Revelstoke (Stockner and Porter 1988). For all sites microplankton biomass was highest in September (Figure 6). Microplankton generally accounted for fewer than 15% of the community, again suggesting nutrient limitation, specifically limitation of nitrate (Dugdale and Wilkerson 1998).

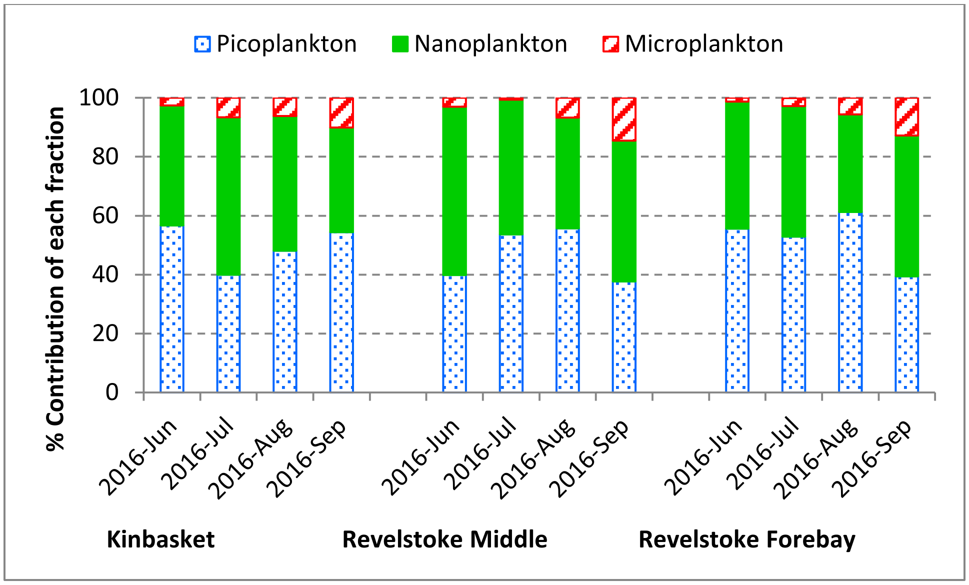

Figure 6. Relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to chlorophyll in Kinbasket and Revelstoke in 2016.

Primary Productivity

Total primary production of all algal size fractions, measured as the radioactive carbon retained on the 0.2 µm filter generally did not exceed 200 mg C/m^2/d on Kinbasket Reservoir and 110 mg C/m^2/d on Revelstoke. The seasonal average primary productivity was generally higher in Kinbasket than in Revelstoke, except on two occasions in July and September where primary productivity was higher at both Revelstoke Forebay and Revelstoke Middle. The seasonal average primary productivity was on average 40% higher at Kinbasket than in Revelstoke Reservoir, where Kinbasket seasonal average of primary productivity was 107.8 mg C/m^2/d and 86.9 mg C/m^2/d at Revelstoke Forebay followed closely by Revelstoke Middle at 53.2 mg C/m^2/d (Figure 7; Table 2). Seasonal variability was observed as primary productivity was highest in June for Kinbasket whereas it was highest in July for Revelstoke Middle and Revelstoke Forebay. Production rates in Kinbasket and Revelstoke Reservoirs are within Wetzel's oligotrophic trophic type (50-300 mg C/m^2/d); production rate at Revelstoke Middle was near the low end of the range at 50 mg C/m^2/d (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; 2013; 2015; 2017). 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 that physical factors may play an important role in the regulation of primary productivity in Kinbasket and Revelstoke reservoirs.

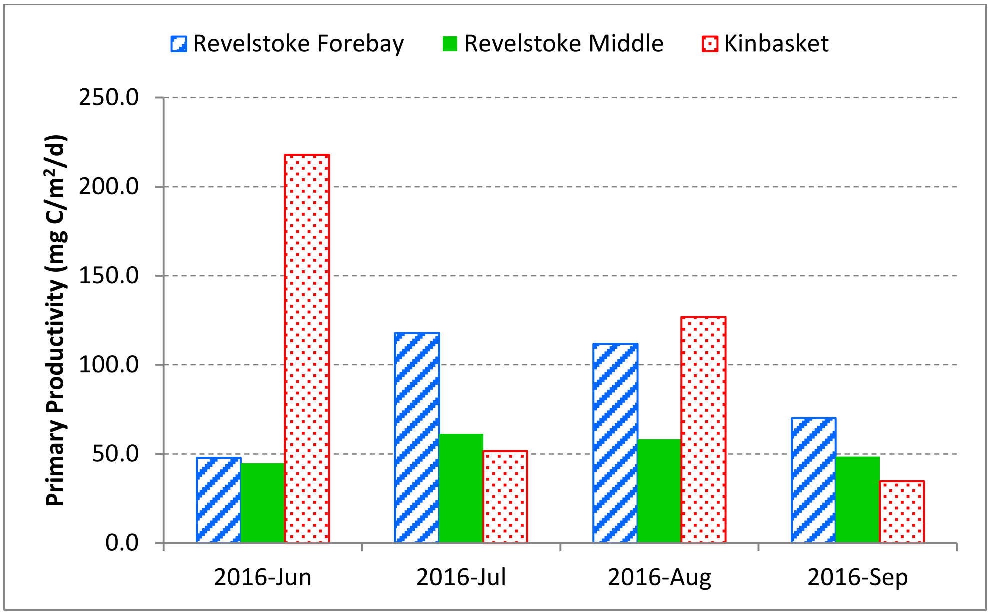

Figure 7. Primary productivity (mg C/m^2/d) in Kinbasket Forebay, Revelstoke Middle and Revelstoke Forebay in 2016.

As was observed in early years, production in Kinbasket and Revelstoke in 2016 was dominated by phytoplankton less than 20.0 µm in size. Picoplankton and nanoplankton, phytoplankton less than 20.0 µm in size, accounted for 91% of the total production in Revelstoke and 90% in Kinbasket (Figure 8). Microplankton was the least productive fraction, accounting for on average 9 % and 10 % of total production for Revelstoke and Kinbasket, respectively (Figure 8).

In 2016 in Kinbasket Reservoir and Revelstoke Middle, nanoplankton was the most productive fraction followed closely by picoplankton and then microplankton (Figure 8). For Kinbasket, nanoplankton production accounted for 47% of the total production, followed by picoplankton at 43% and microplankton at 10% and for Revelstoke Middle nanoplankton production accounted for 48% of the total production, followed by picoplankton at 41% and microplankton at 11%. For Revelstoke Forebay, picoplankton was the most productive fraction followed closely by nanoplankton (Figure 8). For Revelstoke Forebay picoplankton production accounted for 48% of the total production, followed by nanoplankton at 45% and microplankton at 7%. The relative importance of nanoplankton production varied seasonally in both Revelstoke and Kinbasket. Microplankton production was also dynamic in Kinbasket Reservoir and Revelstoke with a general increasing trend from June to September, with the exception of a decrease in August in Kinbasket.

From 2009-2011 the relative importance of picoplankton production was increasing (Harris 2013) along with a decrease in the relative importance of the larger fractions, nanoplankton and microplankton (Figure 9). This implied the reservoir was still in a state of decreasing productivity or oligotrophication. In 2012 this trend was reversed where the relative contribution of production accounted for by phytoplankton cells less than 20.0 µm increased. From 2013 to 2016 there was increased nanoplankton production. Also in 2012, microplankton production was the lowest level measured in the time series in both Kinbasket and Revelstoke (Figure 9).

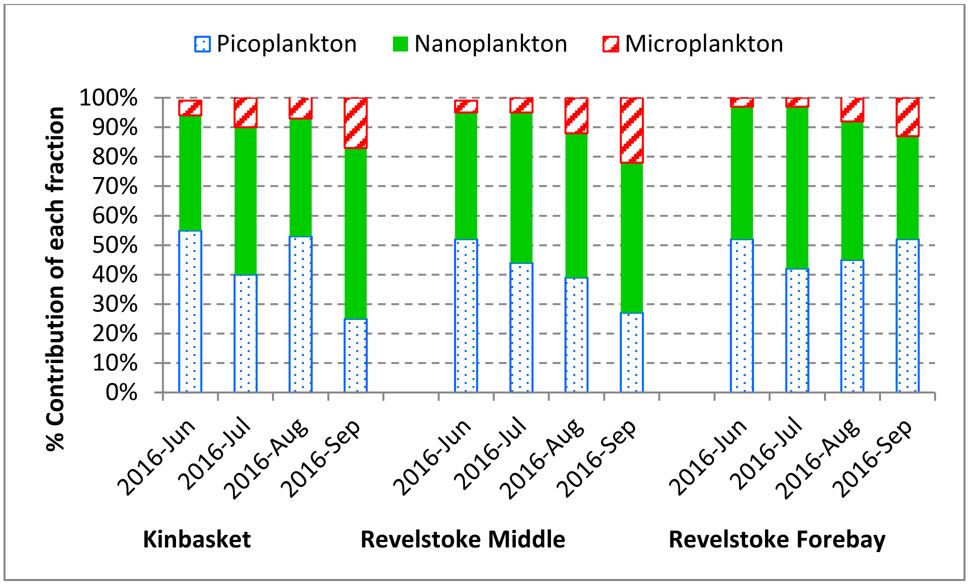

Figure 8. Relative contribution of picoplankton (0.2-2 µm), nanoplankton (2-20 µm), and microplankton (>20 µm) to primary productivity in Kinbasket and Revelstoke in 2016.

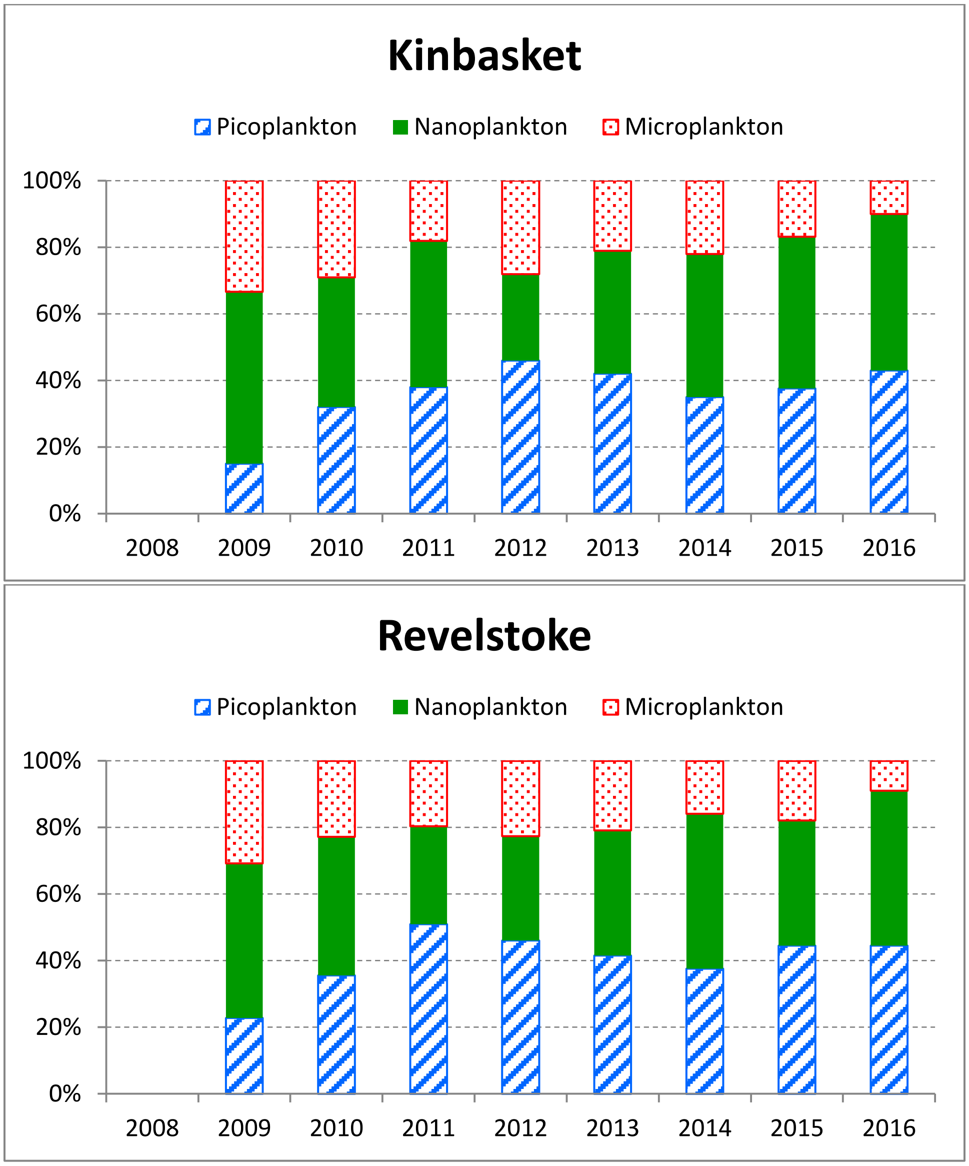

Figure 9. Mean annual size structure of primary productivity in Kinbasket and Revelstoke in 2008-2016. Note: 2008 was not completed using the same methods thus are not included in this table. Additionally, monthly means for Kinbasket and Revelstoke were averaged.

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 summarizes data collected on the base of 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 sets the upper threshold for productivity at upper trophic levels. The results of the 2016 study confirm earlier findings of low phytoplankton biomass of ~20 mg/m^2 in Kinbasket and ~10-15 mg/m^2 in Revelstoke and low rates of primary productivity of ~100 mg C/m^2/d in Kinbasket and under 100 mg C/m^2/d in Revelstoke. Both parameters in this study (chlorophyll and primary productivity) fall within the general ranges of the oligotrophic category as defined by Wetzel (2001).

The percentage of energy transferred from one trophic level to the next is extremely low, between 5-15%, so the number of trophic levels in a food chain is an important determinant of productivity of upper trophic levels (Wetzel 2001). The size structure of the phytoplankton community can provide some insight into the structure of the food web. Nanoplankton (2.0-20.0 µm) are effectively consumed by many zooplankton species, which is important for the efficient transfer of organic matter up the food chain. The high contribution of nanoplankton suggests a strong linkage from this trophic level to the microzooplankton trophic level. While nanoplankton biomass and production are high in both Kinbasket and Revelstoke and often dominate the phytoplankton community, the strong prevalence of picoplankton-sized cells suggests that the microbial food web is also important in both Kinbasket and Revelstoke reservoirs. The microbial food web, or microbial loop, likely has an important function in providing a pathway for small cells to be incorporated into the food web, and plays an equally important role in efficient nutrient recycling (Stockner and Porter 1988).

The size structure also provides some clues as to the nutrient dynamics of Kinbasket and Revelstoke reservoirs. Small cells often dominate in oligotrophic waters as their large surface area to volume ratio supports efficient uptake and subsequently high growth rates. On the other hand, large cells often dominate in nutrient-rich eutrophic conditions due to the larger uptake kinetics and the large storage vacuoles of large microplankton sized cells. The prevalence of small cells and the low contribution of large cells in Kinbasket and Revelstoke suggests that nutrient availability is low and that the microbial loop likely plays an important role in nutrient recycling in these large oligotrophic reservoirs.

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 Kinbasket and Revelstoke reservoirs in BC in 2016.

Site	Study Year	Chlorophyll *a* (mg m^{-2})	Primary Productivity (mg C m^{-2} d^{-1})
Kinbasket Forebay	2016	23.7	108
Revelstoke Middle	2016	11.8	53
Revelstoke Forebay	2016	15.4	87

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Appendix A Field observations and incubation information for the 2016 primary productivity study. Stations are: KB = Kinbasket-Forebay, RM = Revelstoke-Middle (also called Downie), RF = Revelstoke-Forebay.

Date	**Stn**	**Weather**	**Inc. Start**	**Inc. End**	**Total Inc Time (hr.min)**
23-Jun-16	KB	overcast and light drizzle	10:09	14:11	4.02
21-Jul-16	KB	overcast	08:27	12:25	3.58
24-Aug-16	KB	sunny with few scattered clouds	09:17	13:17	4.00
22-Sep-16	KB	sunny with scattered clouds	10:16	14:14	3.58
21-Jun-16	RF	overcast and light drizzle	10:18	14:18	4.00
19-Jul-16	RF	overcast and raining	08:50	12:51	4.01
16-Aug-16	RF	sunny with few small clouds	09:30	13:35	4.05
20-Sep-16	RF	low cloud with sun	08:37	12:40	4.03
22-Jun-16	RM	sunny with scattered clouds	09:58	14:01	4.03
20-Jul-16	RM	overcast	09:20	13:20	4.00
17-Aug-16	RM	sunny with scattered clouds	09:35	13:37	4.02
21-Sep-16	RM	sunny with scattered clouds	09:45	13:45	4.00

Appendix B Raw Chlorophyll and Primary Productivity

Table B1 Raw chlorophyll and primary productivity data for 2016.

Station	Date	Depth (m)	Filter Size (μm)	Chl (mg/m^3)	PP (mg C/m^3/h)	PP (mg C/m^3/day)
KIN	23-Jun-16	0	I-0.2	1.32	0.39	17.94
KIN	23-Jun-16	1	I-0.2	1.16	0.47	21.66
KIN	23-Jun-16	2	I-0.2	1.37	0.44	20.42
KIN	23-Jun-16	5	I-0.2	1.30	0.42	19.57
KIN	23-Jun-16	10	I-0.2	1.41	0.15	7.19
KIN	23-Jun-16	15	I-0.2	1.60	0.10	4.71
KIN	23-Jun-16	20	I-0.2	1.32	0.07	3.48
KIN	23-Jun-16	0	I-2.0	0.57	0.22	10.39
KIN	23-Jun-16	1	I-2.0	0.57	0.33	15.37
KIN	23-Jun-16	2	I-2.0	0.56	0.26	12.31
KIN	23-Jun-16	5	I-2.0	0.46	0.20	9.11
KIN	23-Jun-16	10	I-2.0	0.55	0.06	2.57
KIN	23-Jun-16	15	I-2.0	0.72	0.01	0.48
KIN	23-Jun-16	20	I-2.0	0.66	0.00	0.11
KIN	23-Jun-16	0	I-20.0	0.06	0.04	1.70
KIN	23-Jun-16	1	I-20.0	0.04	0.05	2.38
KIN	23-Jun-16	2	I-20.0	0.04	0.04	1.84
KIN	23-Jun-16	5	I-20.0	0.02	0.02	0.89
KIN	23-Jun-16	10	I-20.0	0.02	0.00	0.13
KIN	23-Jun-16	15	I-20.0	0.03	0.00	0.13
KIN	23-Jun-16	20	I-20.0	0.03	0.00	0.01
KIN	21-Jul-16	0	I-0.2	0.83	0.58	4.77
KIN	21-Jul-16	1	I-0.2	1.05	0.44	3.61
KIN	21-Jul-16	2	I-0.2	1.18	0.57	4.74
KIN	21-Jul-16	5	I-0.2	0.87	0.46	3.83
KIN	21-Jul-16	10	I-0.2	1.36	0.28	2.36
KIN	21-Jul-16	15	I-0.2	1.80	0.23	1.94
KIN	21-Jul-16	20	I-0.2	0.38	0.10	0.84
KIN	21-Jul-16	0	I-2.0	0.63	0.34	2.80
KIN	21-Jul-16	1	I-2.0	0.55	0.36	3.01
KIN	21-Jul-16	2	I-2.0	0.38	0.35	2.94
KIN	21-Jul-16	5	I-2.0	0.53	0.28	2.29
KIN	21-Jul-16	10	I-2.0	0.60	0.19	1.58
KIN	21-Jul-16	15	I-2.0	0.66	0.09	0.73
KIN	21-Jul-16	20	I-2.0	0.45	0.04	0.31
KIN	21-Jul-16	0	I-20.0	0.10	0.07	0.59
KIN	21-Jul-16	1	I-20.0	0.08	0.09	0.71
KIN	21-Jul-16	2	I-20.0	0.09	0.09	0.71
KIN	21-Jul-16	5	I-20.0	0.08	0.05	0.45
KIN	21-Jul-16	10	I-20.0	0.03	0.01	0.12
KIN	21-Jul-16	15	I-20.0	0.03	0.00	0.03
KIN	21-Jul-16	20	I-20.0	0.02	0.00	0.00
KIN	24-Aug-16	0	I-0.2	0.87	0.25	2.18

Station	Date	Depth (m)	Filter Size (μm)	Chl (mg/m^3)	PP (mg C/m^3/h)	PP (mg C/m^3/day)
KIN	24-Aug-16	1	I-0.2	0.79	0.49	4.20
KIN	24-Aug-16	2	I-0.2	0.86	1.10	9.44
KIN	24-Aug-16	5	I-0.2	0.85	0.78	6.70
KIN	24-Aug-16	10	I-0.2	0.83	0.81	6.93
KIN	24-Aug-16	15	I-0.2	1.05	0.74	6.35
KIN	24-Aug-16	19	I-0.2	1.14	0.73	6.28
KIN	24-Aug-16	0	I-2.0	0.39	0.19	1.62
KIN	24-Aug-16	1	I-2.0	0.43	0.31	2.64
KIN	24-Aug-16	2	I-2.0	0.44	0.44	3.78
KIN	24-Aug-16	5	I-2.0	0.32	0.52	4.43
KIN	24-Aug-16	10	I-2.0	0.52	0.34	2.94
KIN	24-Aug-16	15	I-2.0	0.52	0.35	2.97
KIN	24-Aug-16	19	I-2.0	0.72	0.19	1.63
KIN	24-Aug-16	0	I-20.0	0.05	0.03	0.22
KIN	24-Aug-16	1	I-20.0	0.05	0.07	0.61
KIN	24-Aug-16	2	I-20.0	0.06	0.08	0.66
KIN	24-Aug-16	5	I-20.0	0.05	0.08	0.72
KIN	24-Aug-16	10	I-20.0	0.06	0.06	0.53
KIN	24-Aug-16	15	I-20.0	0.06	0.05	0.45
KIN	24-Aug-16	19	I-20.0	0.06	0.01	0.10
KIN	22-Sep-16	0	I-0.2	1.02	0.05	0.38
KIN	22-Sep-16	1	I-0.2	1.11	0.47	3.67
KIN	22-Sep-16	2	I-0.2	1.31	0.41	3.18
KIN	22-Sep-16	5	I-0.2	1.02	0.06	0.50
KIN	22-Sep-16	10	I-0.2	1.21	0.04	0.35
KIN	22-Sep-16	15	I-0.2	1.18	0.32	2.53
KIN	22-Sep-16	22	I-0.2	1.09	0.20	1.59
KIN	22-Sep-16	0	I-2.0	0.54	0.21	1.62
KIN	22-Sep-16	1	I-2.0	0.53	0.27	2.11
KIN	22-Sep-16	2	I-2.0	0.42	0.38	2.99
KIN	22-Sep-16	5	I-2.0	0.47	0.34	2.68
KIN	22-Sep-16	10	I-2.0	0.54	0.37	2.91
KIN	22-Sep-16	15	I-2.0	0.58	0.13	1.04
KIN	22-Sep-16	22	I-2.0	0.50	0.08	0.61
KIN	22-Sep-16	0	I-20.0	0.13	0.03	0.27
KIN	22-Sep-16	1	I-20.0	0.11	0.06	0.46
KIN	22-Sep-16	2	I-20.0	0.12	0.08	0.66
KIN	22-Sep-16	5	I-20.0	0.11	0.08	0.67
KIN	22-Sep-16	10	I-20.0	0.12	0.09	0.72
KIN	22-Sep-16	15	I-20.0	0.11	0.03	0.24
KIN	22-Sep-16	22	I-20.0	0.09	0.01	0.07
REV-FB	21-Jun-16	0	I-0.2	0.76	0.41	4.11
REV-FB	21-Jun-16	1	I-0.2	0.95	0.67	6.74
REV-FB	21-Jun-16	2	I-0.2	1.03	0.94	9.51
REV-FB	21-Jun-16	5	I-0.2	0.84	0.42	4.25
REV-FB	21-Jun-16	10	I-0.2	0.68	0.06	0.60
REV-FB	21-Jun-16	14	I-0.2	0.49	0.01	0.11
REV-FB	21-Jun-16	0	I-2.0	0.30	0.30	3.00

Station	Date	Depth (m)	Filter Size (µm)	Chl (mg/m^3)	PP (mg C/m^3/h)	PP (mg C/m^3/day)
REV-FB	21-Jun-16	1	I-2.0	0.47	0.34	3.42
REV-FB	21-Jun-16	2	I-2.0	0.37	0.34	3.43
REV-FB	21-Jun-16	5	I-2.0	0.49	0.23	2.29
REV-FB	21-Jun-16	10	I-2.0	0.30	0.04	0.39
REV-FB	21-Jun-16	14	I-2.0	0.19	0.00	0.04
REV-FB	21-Jun-16	0	I-20.0	0.01	0.01	0.08
REV-FB	21-Jun-16	1	I-20.0	0.01	0.01	0.13
REV-FB	21-Jun-16	2	I-20.0	0.01	0.02	0.22
REV-FB	21-Jun-16	5	I-20.0	0.01	0.02	0.17
REV-FB	21-Jun-16	10	I-20.0	0.01	0.00	0.03
REV-FB	21-Jun-16	14	I-20.0	0.02	0.00	0.00
REV-FB	19-Jul-16	0	I-0.2	0.77	0.29	10.29
REV-FB	19-Jul-16	1	I-0.2	0.89	0.40	14.39
REV-FB	19-Jul-16	2	I-0.2	0.96	0.33	11.79
REV-FB	19-Jul-16	5	I-0.2	1.10	0.29	10.52
REV-FB	19-Jul-16	10	I-0.2	1.70	0.15	5.47
REV-FB	19-Jul-16	15	I-0.2	0.63	0.06	2.09
REV-FB	19-Jul-16	0	I-2.0	0.39	0.22	7.77
REV-FB	19-Jul-16	1	I-2.0	0.36	0.23	8.27
REV-FB	19-Jul-16	2	I-2.0	0.40	0.29	10.28
REV-FB	19-Jul-16	5	I-2.0	0.38	0.18	6.57
REV-FB	19-Jul-16	10	I-2.0	0.63	0.05	1.83
REV-FB	19-Jul-16	15	I-2.0	0.48	0.01	0.25
REV-FB	19-Jul-16	0	I-20.0	0.02	0.01	0.34
REV-FB	19-Jul-16	1	I-20.0	0.02	0.01	0.42
REV-FB	19-Jul-16	2	I-20.0	0.02	0.02	0.75
REV-FB	19-Jul-16	5	I-20.0	0.02	0.01	0.40
REV-FB	19-Jul-16	10	I-20.0	0.04	0.00	0.04
REV-FB	19-Jul-16	15	I-20.0	0.03	0.00	0.03
REV-FB	16-Aug-16	0	I-0.2	1.03	0.33	2.44
REV-FB	16-Aug-16	1	I-0.2	0.61	0.90	6.64
REV-FB	16-Aug-16	2	I-0.2	1.07	0.97	7.22
REV-FB	16-Aug-16	5	I-0.2	0.87	1.19	8.83
REV-FB	16-Aug-16	10	I-0.2	0.92	0.71	5.29
REV-FB	16-Aug-16	15	I-0.2	1.39	0.74	5.45
REV-FB	16-Aug-16	20	I-0.2	0.38	0.02	0.18
REV-FB	16-Aug-16	0	I-2.0	0.34	0.25	1.83
REV-FB	16-Aug-16	1	I-2.0	0.32	0.57	4.20
REV-FB	16-Aug-16	2	I-2.0	0.37	0.65	4.84
REV-FB	16-Aug-16	5	I-2.0	0.32	0.76	5.65
REV-FB	16-Aug-16	10	I-2.0	0.36	0.41	3.05
REV-FB	16-Aug-16	15	I-2.0	0.37	0.24	1.77
REV-FB	16-Aug-16	20	I-2.0	0.18	0.02	0.19
REV-FB	16-Aug-16	0	I-20.0	0.06	0.06	0.41
REV-FB	16-Aug-16	1	I-20.0	0.04	0.10	0.75
REV-FB	16-Aug-16	2	I-20.0	0.04	0.09	0.68
REV-FB	16-Aug-16	5	I-20.0	0.06	0.12	0.87
REV-FB	16-Aug-16	10	I-20.0	0.05	0.07	0.52

Station	Date	Depth (m)	Filter Size (μm)	Chl (mg/m^3)	PP (mg C/m^3/h)	PP (mg C/m^3/day)
REV-FB	16-Aug-16	15	I-20.0	0.05	0.04	0.29
REV-FB	16-Aug-16	20	I-20.0	0.02	0.00	0.03
REV-FB	20-Sep-16	0	I-0.2	1.03	0.18	2.16
REV-FB	20-Sep-16	1	I-0.2	1.14	0.55	6.69
REV-FB	20-Sep-16	2	I-0.2	1.20	0.65	7.97
REV-FB	20-Sep-16	5	I-0.2	1.02	0.54	6.55
REV-FB	20-Sep-16	10	I-0.2	0.60	0.00	0.00
REV-FB	20-Sep-16	15	I-0.2	0.40	0.21	2.52
REV-FB	20-Sep-16	20	I-0.2	0.38	0.25	3.02
REV-FB	20-Sep-16	0	I-2.0	0.57	0.28	3.38
REV-FB	20-Sep-16	1	I-2.0	0.73	0.34	4.17
REV-FB	20-Sep-16	2	I-2.0	0.61	0.38	4.63
REV-FB	20-Sep-16	5	I-2.0	0.51	0.23	2.75
REV-FB	20-Sep-16	10	I-2.0	0.43	0.15	1.77
REV-FB	20-Sep-16	15	I-2.0	0.29	0.04	0.49
REV-FB	20-Sep-16	20	I-2.0	0.23	0.03	0.31
REV-FB	20-Sep-16	0	I-20.0	0.17	0.10	1.26
REV-FB	20-Sep-16	1	I-20.0	0.15	0.09	1.14
REV-FB	20-Sep-16	2	I-20.0	0.17	0.14	1.66
REV-FB	20-Sep-16	5	I-20.0	0.11	0.06	0.78
REV-FB	20-Sep-16	10	I-20.0	0.08	0.03	0.38
REV-FB	20-Sep-16	15	I-20.0	0.04	0.00	0.06
REV-FB	20-Sep-16	20	I-20.0	0.04	0.01	0.07
REV-Mid	22-Jun-16	0	I-0.2	0.59	0.37	3.40
REV-Mid	22-Jun-16	1	I-0.2	0.66	0.78	7.12
REV-Mid	22-Jun-16	2	I-0.2	0.66	0.57	5.22
REV-Mid	22-Jun-16	5	I-0.2	0.56	0.40	3.64
REV-Mid	22-Jun-16	10	I-0.2	0.45	0.22	1.98
REV-Mid	22-Jun-16	14	I-0.2	0.27	0.11	1.03
REV-Mid	22-Jun-16	0	I-2.0	0.32	0.14	1.23
REV-Mid	22-Jun-16	1	I-2.0	0.32	0.29	2.64
REV-Mid	22-Jun-16	2	I-2.0	0.31	0.32	2.96
REV-Mid	22-Jun-16	5	I-2.0	0.40	0.26	2.34
REV-Mid	22-Jun-16	10	I-2.0	0.30	0.07	0.61
REV-Mid	22-Jun-16	14	I-2.0	0.19	0.01	0.07
REV-Mid	22-Jun-16	0	I-20.0	0.02	0.02	0.14
REV-Mid	22-Jun-16	1	I-20.0	0.02	0.06	0.56
REV-Mid	22-Jun-16	2	I-20.0	0.01	0.03	0.24
REV-Mid	22-Jun-16	5	I-20.0	0.01	0.02	0.17
REV-Mid	22-Jun-16	10	I-20.0	0.01	0.00	0.03
REV-Mid	22-Jun-16	14	I-20.0	0.01	0.00	0.03
REV-Mid	20-Jul-16	0	I-0.2	0.83	0.49	4.24
REV-Mid	20-Jul-16	1	I-0.2	0.88	0.80	6.95
REV-Mid	20-Jul-16	2	I-0.2	0.63	0.78	6.83
REV-Mid	20-Jul-16	5	I-0.2	0.83	0.75	6.55
REV-Mid	20-Jul-16	10	I-0.2	1.00	0.27	2.38
REV-Mid	20-Jul-16	15	I-0.2	0.48	0.02	0.17
REV-Mid	20-Jul-16	0	I-2.0	0.35	0.32	2.76

Station	Date	Depth (m)	Filter Size (µm)	Chl (mg/m^3)	PP (mg C/m^3/h)	PP (mg C/m^3/day)
REV-Mid	20-Jul-16	1	I-2.0	0.41	0.55	4.83
REV-Mid	20-Jul-16	2	I-2.0	0.32	0.44	3.80
REV-Mid	20-Jul-16	5	I-2.0	0.35	0.37	3.26
REV-Mid	20-Jul-16	10	I-2.0	0.47	0.16	1.38
REV-Mid	20-Jul-16	15	I-2.0	0.24	0.02	0.15
REV-Mid	20-Jul-16	0	I-20.0	0.02	0.03	0.24
REV-Mid	20-Jul-16	1	I-20.0	0.02	0.05	0.40
REV-Mid	20-Jul-16	2	I-20.0	0.02	0.04	0.34
REV-Mid	20-Jul-16	5	I-20.0	0.02	0.04	0.33
REV-Mid	20-Jul-16	10	I-20.0	0.03	0.01	0.08
REV-Mid	20-Jul-16	15	I-20.0	0.00	0.00	0.00
REV-Mid	17-Aug-16	0	I-0.2	0.63	0.42	3.31
REV-Mid	17-Aug-16	1	I-0.2	0.52	0.69	5.46
REV-Mid	17-Aug-16	2	I-0.2	0.70	0.38	3.05
REV-Mid	17-Aug-16	5	I-0.2	0.57	0.77	6.12
REV-Mid	17-Aug-16	10	I-0.2	0.65	0.39	3.08
REV-Mid	17-Aug-16	15	I-0.2	1.20	0.26	2.08
REV-Mid	17-Aug-16	0	I-2.0	0.24	0.24	1.87
REV-Mid	17-Aug-16	1	I-2.0	0.27	0.38	3.02
REV-Mid	17-Aug-16	2	I-2.0	0.28	0.41	3.27
REV-Mid	17-Aug-16	5	I-2.0	0.28	0.37	2.94
REV-Mid	17-Aug-16	10	I-2.0	0.36	0.29	2.31
REV-Mid	17-Aug-16	15	I-2.0	0.37	0.10	0.80
REV-Mid	17-Aug-16	0	I-20.0	0.05	0.03	0.27
REV-Mid	17-Aug-16	1	I-20.0	0.04	0.08	0.60
REV-Mid	17-Aug-16	2	I-20.0	0.04	0.09	0.70
REV-Mid	17-Aug-16	5	I-20.0	0.04	0.09	0.73
REV-Mid	17-Aug-16	10	I-20.0	0.05	0.05	0.39
REV-Mid	17-Aug-16	15	I-20.0	0.04	0.01	0.08
REV-Mid	21-Sep-16	0	I-0.2	1.23	0.14	1.01
REV-Mid	21-Sep-16	1	I-0.2	1.32	0.56	4.04
REV-Mid	21-Sep-16	2	I-0.2	0.97	0.51	3.69
REV-Mid	21-Sep-16	5	I-0.2	1.10	0.73	5.23
REV-Mid	21-Sep-16	10	I-0.2	1.45	0.37	2.67
REV-Mid	21-Sep-16	15	I-0.2	0.64	0.13	0.94
REV-Mid	21-Sep-16	0	I-2.0	0.64	0.26	1.84
REV-Mid	21-Sep-16	1	I-2.0	0.80	0.40	2.89
REV-Mid	21-Sep-16	2	I-2.0	0.71	0.41	2.94
REV-Mid	21-Sep-16	5	I-2.0	0.62	0.44	3.15
REV-Mid	21-Sep-16	10	I-2.0	0.88	0.36	2.61
REV-Mid	21-Sep-16	15	I-2.0	0.46	0.01	0.05
REV-Mid	21-Sep-16	0	I-20.0	0.15	0.06	0.40
REV-Mid	21-Sep-16	1	I-20.0	0.14	0.09	0.67
REV-Mid	21-Sep-16	2	I-20.0	0.17	0.15	1.08
REV-Mid	21-Sep-16	5	I-20.0	0.16	0.12	0.83
REV-Mid	21-Sep-16	10	I-20.0	0.26	0.12	0.85
REV-Mid	21-Sep-16	15	I-20.0	0.09	0.00	0.03

Appendix B Integrated Chlorophyll and Primary Productivity

Table B1 Integrated chlorophyll *a* (mg Chl *a*/m^3) for Kinbasket and Revelstoke Reservoir in 2016. Stations are: KB = Kinbasket-Forebay, RM = Revelstoke-Middle (also called Downie), RF = Revelstoke-Forebay.

Year	**Month**	**Chlorophyll a (mg Chl *a*/m^2)**		
		KB	RF	RM
2016	Jun	28.1	10.8	7.1
2016	Jul	24.0	17.6	12.1
2016	Aug	17.5	19.2	10.8
2016	Sep	25.2	14.1	17.2
2016	**Mean**	**23.7**	**15.4**	**11.8**

Table B2 Total daily primary productivity (mg C/m^3/d) in Kinbasket and Revelstoke in 2002 and 2008-2016.

Year	**Month**	**Primary Productivity (mg C/m^3/d)**		
		KB	**RM**	**RF**
2002	Aug	77.6	-	-
2008	Jul	84.4	33.6	51.8
2008	Aug	42.2	9.6	13.4
2008	Sep	25.3	11.0	18.8
2009	Jun	61.9	18.4	30.6
2009	Jul	22.6	19.8	54.9
2009	Aug	34.1	18.5	25.3
2009	Sep	26.7	15.1	1.4
2010	Jun	30.2	28.4	66.4
2010	Jul	72.3	41.2	20.4
2010	Aug	106.2	38.3	35.1
2010	Sept	149.7	45.0	71.8
2011	Jun	46.2	54.1	57.9
2011	Jul	75.3	74.1	80.5
2011	Aug	-	61.2	69.2
2011	Sep	-	91.3	77.6
2012	Jun	26.4	11.6	23.0
2012	Jul	77	26.5	114.2
2012	Aug	52.7	58.5	78.7
2012	Sep	98.7	51.4	99.3
2013	Jun	179.1	78.2	59.8
2013	Jul	122	63.5	75.2
2013	Aug	89.5	59.6	76.8
2013	Sept	161	182.5	95.5
2014	Jun	156.5	143.0	55.0
2014	Jul	87.8	97.6	186.6
2014	Aug	97.3	99.8	125.9
2014	Sep	262.1	131.6	132.4
2015	Jun	50.5	33.2	21.2
2015	Jul	190.4	75.8	126.5
2015	Aug	191.4	64.8	135.2
2015	Sep	177.7	150.3	361.7

Year	Month	Primary Productivity (mg C/m^3/d)		
		KB	RM	RF
2016	Jun	217.9	44.8	47.8
2016	Jul	51.6	61.3	117.8
2016	Aug	126.8	58.2	111.8
2016	Sep	34.7	48.5	70.1
2008	Mean	50.6	6.0	9.3
2009	Mean	36.4	17.9	28.1
2010	Mean	90.0	38.0	48.0
2011	Mean	60.8	70.2	71.3
2012	Mean	63.7	37.0	78.8
2013	Mean	137.9	96.0	76.8
2014	Mean	150.9	118.0	125.0
2015	Mean	152.5	81.0	161.2
2016	Mean	107.8	53.2	86.9

Appendix 6

Phytoplankton
Kinbasket and Revelstoke Reservoirs, 2016

Advanced Eco-Solutions

PHYTOPLANKTON POPULATIONS IN KINBASKET AND REVELSTOKE RESERVOIRS, UPPER COLUMBIA BASIN, BRITISH COLUMBIA – 2016

PREPARED FOR:

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June 2017

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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 2016, 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 2016. Canoe and Wood Arms had samples collected April through September. The Columbia station was sampled from May through September and the Forebay station was sampled from April through October. Samples from three stations in Revelstoke Reservoir (Revelstoke-Forebay, Revelstoke-Mid and Revelstoke-Upper) were taken monthly from April to October in 2016. 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 2015 is compatible with the previous sampling methodology; however, the taxa richness could be higher in the composited samples from 2010 through 2016 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 – 2016

A complete list of the taxa identified in Kinbasket and Revelstoke Reservoirs in 2016 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). Peak phytoplankton density occurred at the Canoe Station in May (8,561 cells/mL) (Figure 3).The Wood Station had the lowest phytoplankton density at 1,520 cells/mL in October. On a seasonal average the Canoe and Columbia stations had similar mean phytoplankton densities, both higher than the Forebay and Wood stations.

In terms of biovolume, the major contributors throughout the season were greens, flagellates and blue-greens, followed by diatoms, and dinoflagellates (Figure 2). The Canoe 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 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Kin-Canoe	Blue-greens	2805	4366		1358	1716	1911	667	2137
	Coccoid Greens, Desmids, etc.	138	81		81	81	179	24	98
	Diatoms	33	16		33	1301	276	57	286
	Dinoflagellates	8	24		114	33	89	16	47
	Flagellates	1325	4073		1529	1529	1594	927	1829
	Sum of All Groups	4309	8561		3114	4659	4049	1691	4397
Kin-Columbia	Blue-greens		3821		1772	2008	1585	846	2007
	Coccoid Greens, Desmids, etc.		114		73	8	236	49	96
	Diatoms		65		16	659	195	106	208
	Dinoflagellates		16		146	49	57	41	62
	Flagellates		3667		2163	1894	1106	846	1935
	Sum of All Groups		7683		4171	4618	3179	1886	4308
Kin-Forebay	Blue-greens	1935	1561	1366	1016	984	837	829	1218
	Coccoid Greens, Desmids, etc.	301	57	154	65	41	81	41	106
	Diatoms	16	16	16	57	935	163	57	180
	Dinoflagellates	16	65	130	65	33	33	33	53
	Flagellates	1634	1919	1903	1244	1171	650	829	1336
	Sum of All Groups	3903	3618	3569	2447	3163	1764	1789	2893
Kin-Wood	Blue-greens	1618	2081		943	902	1756	642	1324
	Coccoid Greens, Desmids, etc.	179	57		41	24	16	41	60
	Diatoms	0	8		49	1122	325	65	314
	Dinoflagellates	8	106		130	57	98	24	70
	Flagellates	1520	2675		1228	1122	878	748	1362
	Sum of All Groups	3325	4927		2390	3228	3073	1520	3077

Table 2 Kinbasket Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Kin-Canoe	Blue-greens	0.0179	0.0175		0.0054	0.0068	0.0076	0.0027	0.0097
	Coccoid Greens, Desmids, etc.	0.0117	0.0453		0.0469	0.0057	0.0314	0.0010	0.0237
	Diatoms	0.0033	0.0016		0.0073	0.0772	0.0187	0.0183	0.0211
	Dinoflagellates	0.0004	0.0081		0.0333	0.0098	0.0228	0.0081	0.0138
	Flagellates	0.0304	0.0363		0.0163	0.0236	0.0251	0.0234	0.0259
	Sum of All Groups	0.0638	0.1088		0.1093	0.1231	0.1055	0.0534	0.0188
Kin-Columbia	Blue-greens		0.0153		0.0071	0.0080	0.0063	0.0034	0.0080
	Coccoid Greens, Desmids, etc.		0.0098		0.0056	0.0002	0.0110	0.0246	0.0102
	Diatoms		0.0063		0.0037	0.0459	0.0102	0.0281	0.0188
	Dinoflagellates		0.0065		0.0370	0.0134	0.0179	0.0085	0.0167
	Flagellates		0.0304		0.0316	0.0307	0.0187	0.0215	0.0266
	Sum of All Groups		0.0682		0.0849	0.0983	0.0640	0.0862	0.0161
Kin-Forebay	Blue-greens	0.0073	0.0062	0.0074	0.0041	0.0039	0.0033	0.0033	0.0051
	Coccoid Greens, Desmids, etc.	0.0266	0.0263	0.0077	0.0443	0.0062	0.0098	0.0829	0.0291
	Diatoms	0.0016	0.0016	0.0037	0.0094	0.0516	0.0130	0.0179	0.0141
	Dinoflagellates	0.0020	0.0183	0.0346	0.0110	0.0130	0.0114	0.0130	0.0148
	Flagellates	0.0366	0.0241	0.0287	0.0187	0.0176	0.0214	0.0270	0.0249
	Sum of All Groups	0.0742	0.0766	0.0821	0.0874	0.0924	0.0589	0.1441	0.0176
Kin-Wood	Blue-greens	0.0063	0.0083		0.0038	0.0036	0.0070	0.0026	0.0053
	Coccoid Greens, Desmids, etc.	0.0119	0.0263		0.0251	0.0015	0.0005	0.0217	0.0145
	Diatoms	0.0000	0.0008		0.0098	0.0659	0.0215	0.0057	0.0173
	Dinoflagellates	0.0033	0.0240		0.0321	0.0569	0.0264	0.0085	0.0252
	Flagellates	0.0239	0.0259		0.0164	0.0140	0.0195	0.0217	0.0202
	Sum of All Groups	0.0454	0.0853		0.0871	0.1419	0.0750	0.0603	0.0165

Figure 1 Average phytoplankton density (Cells/mL) in Kinbasket Reservoir in 2016 derived from the 2, 5, 10 meter laboratory composites

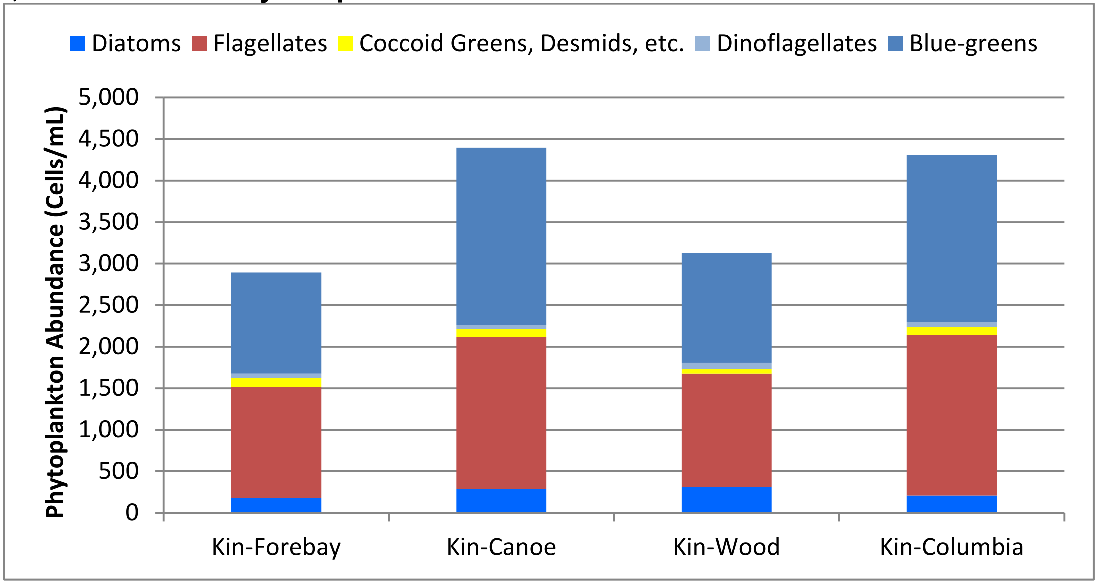


Figure 2 Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir in 2016 derived from the 2, 5, and 10 meter laboratory composites

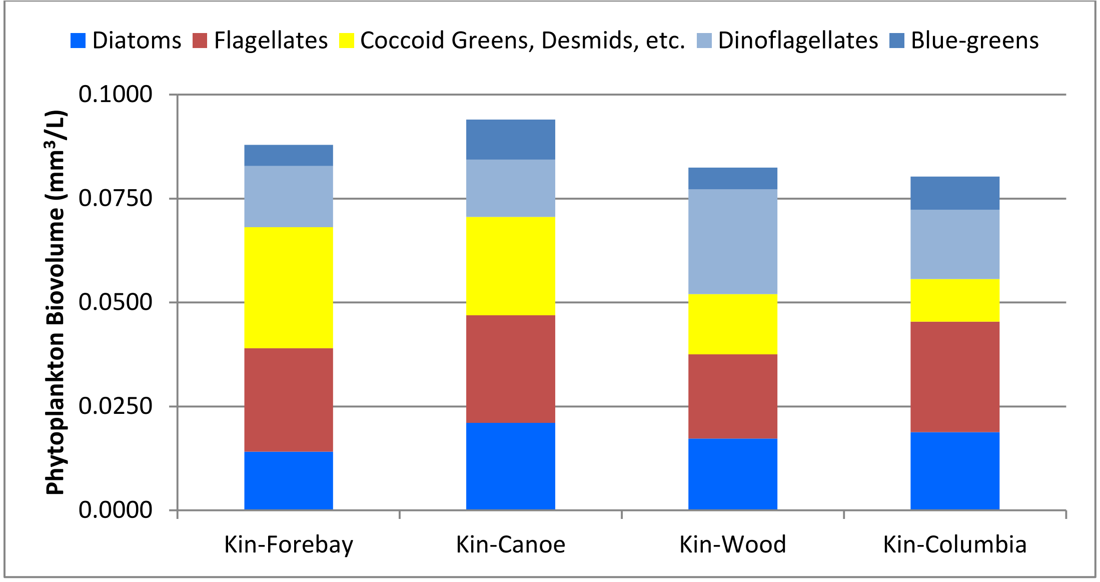


Figure 3 Kinbasket mean epilimnetic phytoplankton density by month for 2016

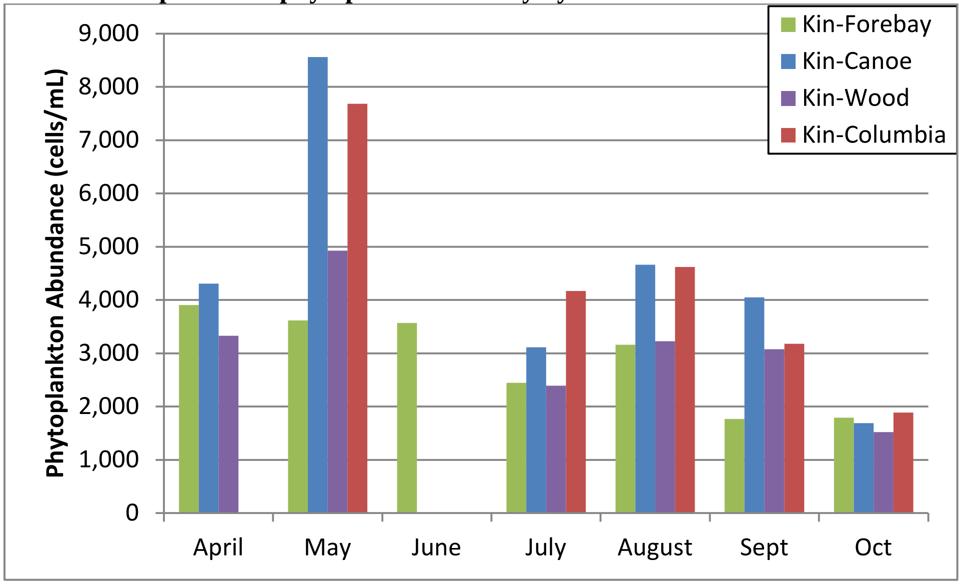
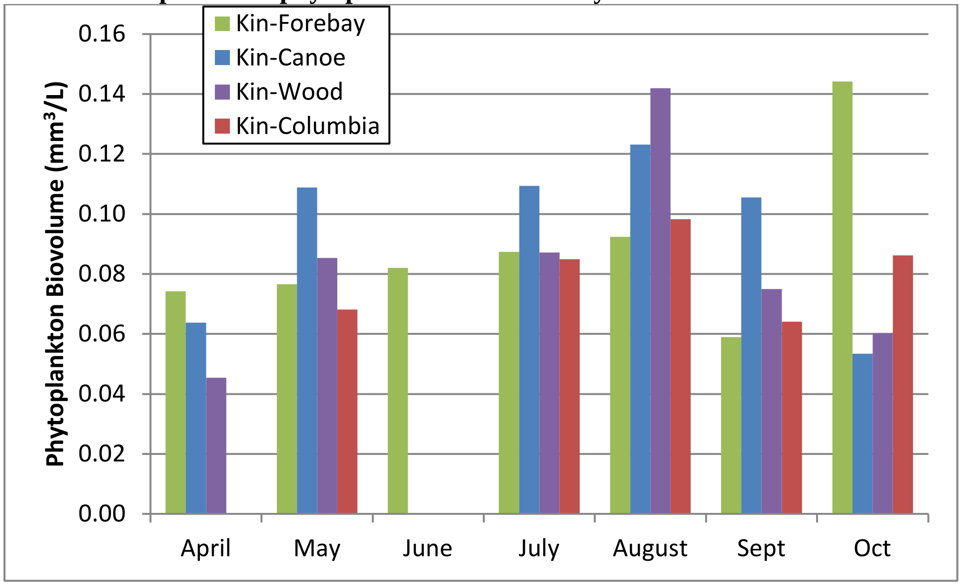


Figure 4 Kinbasket mean epilimnetic phytoplankton biovolume by month for 2016



Revelstoke

The dominant taxonomic groups in Revelstoke are the blue-greens and flagellates (Table 3 and Figure 5). The mean overall cell density is slightly higher than those observed in Kinbasket (3,669 cells/mL) compared to Revelstoke (3,971 cells/mL). Based on biovolume, the taxonomic groups 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 epilimnetic phytoplankton density occurred at the Forebay station in September and in terms of biovolume the peak occurred in July at the Upper station (7,073 cells/mL and 0.1175 mm^3/L) (Figure 7 and Figure 8). The Forebay station also had the lowest phytoplankton density in October (1,276 cells/mL), and in biovolume (0.04 mm^3/L) in June.

Table 3 Revelstoke Reservoir mean phytoplankton density (Cells/mL) by group and month from the 2, 5 and 10 meter laboratory composites 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Rev-Forebay	Blue-greens	1,976	1,659	2,423	1,415	488	5,309	512	1,969
	Coccoid Greens, Desmids, etc.	228	154	33	24	163	57	24	98
	Diatoms	8	8	0	57	33	89	65	37
	Dinoflagellates	0	138	57	65	65	89	33	64
	Flagellates	1,919	1,764	2,691	1,504	756	1,529	642	1,544
	Sum of All Groups	4,130	3,724	5,203	3,065	1,504	7,073	1,276	3,711
Rev-Mid	Blue-greens	2,553	2,683	2,220	2,903	1,724	1,488	585	2,022
	Coccoid Greens, Desmids, etc.	171	49	16	33	24	65	98	65
	Diatoms	16	24	8	114	33	106	122	60
	Dinoflagellates	16	98	65	57	49	122	33	63
	Flagellates	2,764	3,033	2,277	2,846	1,813	1,561	829	2,160
	Sum of All Groups	5,521	5,886	4,586	5,951	3,642	3,342	1,667	4,371
Rev-Upper	Blue-greens	1,764	1,870		2,325	1,992	1,488	813	1,709
	Coccoid Greens, Desmids, etc.	130	57		130	33	73	49	79
	Diatoms	41	0		73	41	0	24	30
	Dinoflagellates	41	81		114	24	81	24	61
	Flagellates	2,252	2,342		2,366	2,236	1,659	870	1,954
	Sum of All Groups	4,228	4,350		5,008	4,325	3,301	1,781	3,832

Table 4 Revelstoke Reservoir mean phytoplankton biovolume (mm^3/L) by group and month from the 2, 5 and 10 meter laboratory composites in 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Rev-Forebay	Blue-greens	0.0077	0.0066	0.0097	0.0057	0.0020	0.0212	0.0020	0.0078
	Coccoid Greens, Desmids, etc.	0.0219	0.0276	0.0016	0.0212	0.0476	0.0232	0.0246	0.0240
	Diatoms	0.0008	0.0008	0.0000	0.0055	0.0016	0.0132	0.0260	0.0069
	Dinoflagellates	0.0000	0.0321	0.0122	0.0195	0.0183	0.0236	0.0130	0.0170
	Flagellates	0.0370	0.0193	0.0188	0.0164	0.0191	0.0332	0.0149	0.0227
	Sum of All Groups	0.0674	0.0864	0.0423	0.0683	0.0886	0.1144	0.0806	0.0783
Rev-Mid	Blue-greens	0.0120	0.0107	0.0089	0.0116	0.0069	0.0060	0.0023	0.0083
	Coccoid Greens, Desmids, etc.	0.0115	0.0026	0.0045	0.0411	0.0007	0.0312	0.0279	0.0171
	Diatoms	0.0016	0.0035	0.0028	0.0167	0.0118	0.0224	0.0187	0.0111
	Dinoflagellates	0.0008	0.0179	0.0154	0.0195	0.0146	0.0305	0.0114	0.0157
	Flagellates	0.0448	0.0304	0.0199	0.0213	0.0206	0.0261	0.0188	0.0260
	Sum of All Groups	0.0707	0.0650	0.0516	0.1102	0.0547	0.1161	0.0791	0.0782
Rev-Upper	Blue-greens	0.0071	0.0075		0.0093	0.0080	0.0060	0.0033	0.0068
	Coccoid Greens, Desmids, etc.	0.0373	0.0098		0.0455	0.0411	0.0054	0.0046	0.0240
	Diatoms	0.0061	0.0000		0.0059	0.0028	0.0000	0.0012	0.0027
	Dinoflagellates	0.0134	0.0187		0.0313	0.0053	0.0309	0.0069	0.0178
	Flagellates	0.0304	0.0259		0.0255	0.0275	0.0289	0.0237	0.0270
	Sum of All Groups	0.0943	0.0619		0.1175	0.0847	0.0711	0.0398	0.0782

Figure 5 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between April - September 2016 derived from the 2, 5, and 10 meter laboratory composites

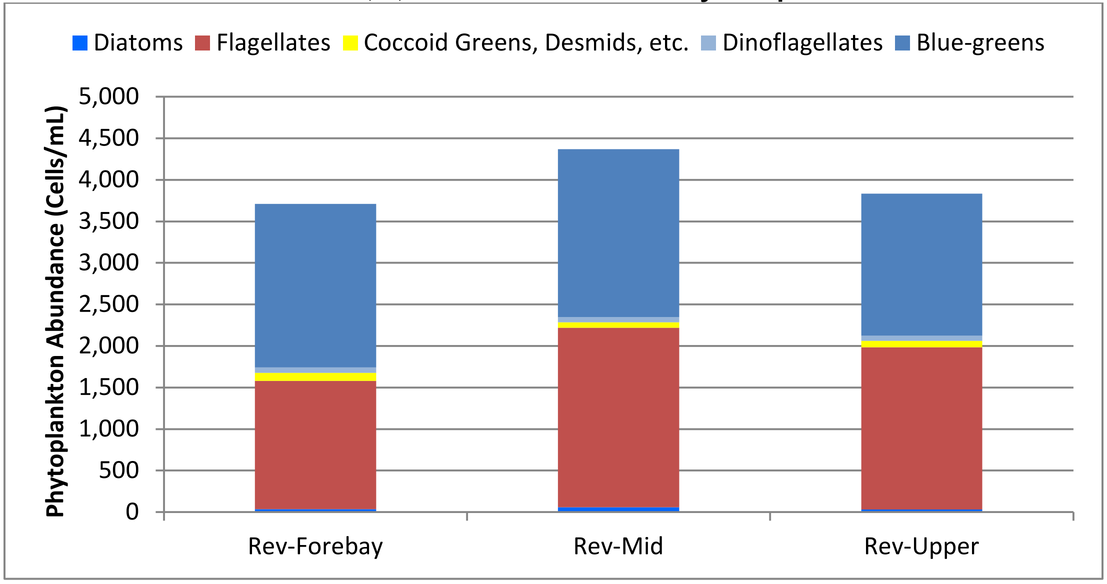


Figure 6 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2016 derived from the 2, 5, and 10 meter laboratory composites

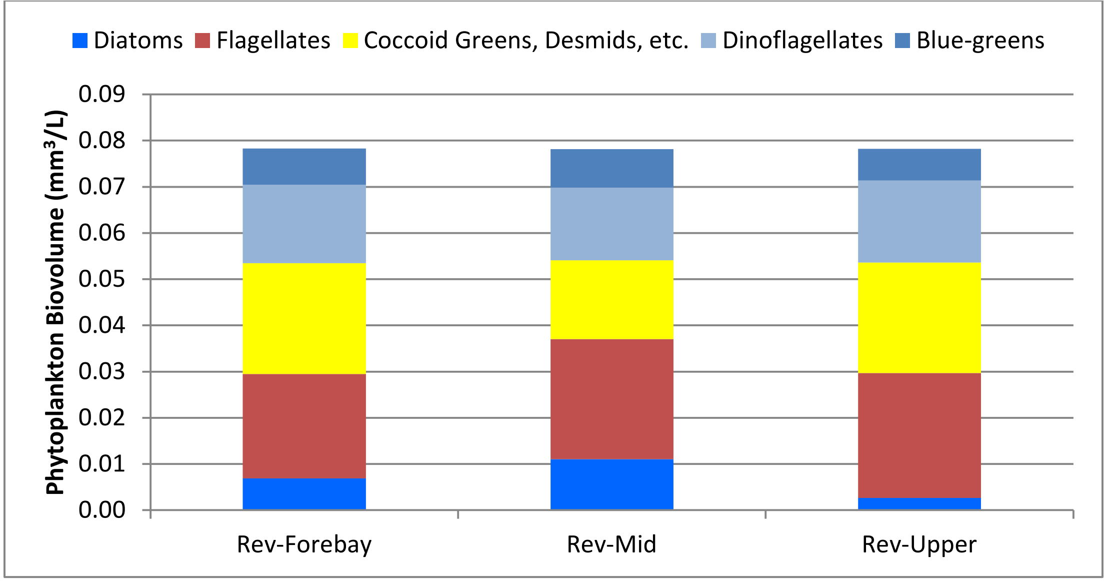


Figure 7 Revelstoke mean epilimnetic phytoplankton density by month

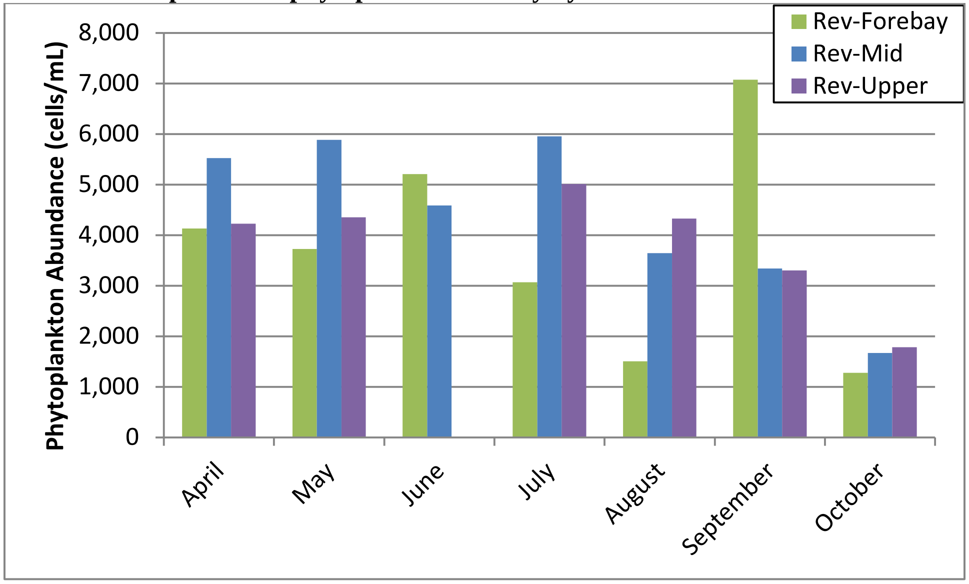
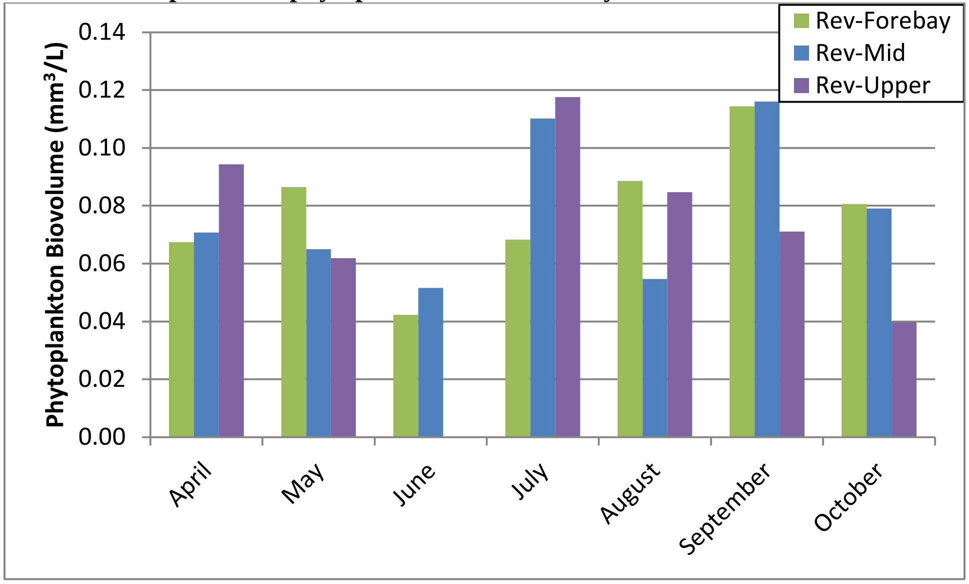


Figure 8 Revelstoke mean epilimnetic phytoplankton biovolume by month



3.2.2 Hypolimnion

Kinbasket

Hypolimnetic phytoplankton densities in Kinbasket Reservoir were lower than epilimnetic densities. 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 (5,066 cells/mL) and the Columbia and Canoe stations had the highest seasonal average of biovolume (0.023

mm^3/L). The Wood station had the highest hypolimnetic phytoplankton cell densities of the year in August and September (Figure 11). The hypolimnetic biovolume was considerably higher in July-September than in April and May (Figure 12).

Table 5 Kinbasket Reservoir hypolimnion phytoplankton density (Cells/mL) by group and month from the 15, and 25 meter laboratory composites in 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Kin-Canoe	Blue-greens	1,524	2,988		1,012	1,781	1427	256	1284
	Coccoid Greens, Desmids, etc.	207	49		73	12	134	49	75
	Diatoms	37	49		49	610	110	122	139
	Dinoflagellates	0	49		98	37	98	12	42
	Flagellates	1,524	3,061		2,427	1,622	1268	585	1498
	Sum of All Groups	3,293	6,195		3,659	4,061	3037	1024	3038
Kin-Columbia	Blue-greens		2,220		2,781	3,207	1159	634	1667
	Coccoid Greens, Desmids, etc.		98		61	110	171	24	77
	Diatoms		24		49	232	341	122	128
	Dinoflagellates		49		134	122	49	24	63
	Flagellates		2,451		2,915	3,366	1281	939	1825
	Sum of All Groups		4,842		5,939	7,037	3000	1744	3760
Kin-Forebay	Blue-greens	1,683	1,317	1,146	890	1,012	1610	646	1186
	Coccoid Greens, Desmids, etc.	183	61	37	171	49	61	159	103
	Diatoms	37	24	37	12	488	195	61	122
	Dinoflagellates	12	37	61	85	49	73	73	56
	Flagellates	1,232	1,561	1,317	976	1,085	915	927	1145
	Sum of All Groups	3,146	3,000	2,598	2,134	2,683	2854	1866	2612
Kin-Wood	Blue-greens	2,403	2,671		1,646	4,817	4695	622	2408
	Coccoid Greens, Desmids, etc.	354	24		61	0	73	37	78
	Diatoms	0	0		12	451	61	134	94
	Dinoflagellates	12	61		61	0	159	49	49
	Flagellates	1,988	3,427		1,732	4,208	4708	1000	2437
	Sum of All Groups	4,756	6,183		3,512	9,476	9696	1842	5066

Table 6 Kinbasket Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Kin-Canoe	Blue-greens	0.0061	0.0119		0.0039	0.0071	0.0057	0.0010	0.0060
	Coccoid Greens, Desmids, etc.	0.0244	0.0079		0.0957	0.0305	0.0382	0.0918	0.0481
	Diatoms	0.0037	0.0265		0.0045	0.0305	0.0098	0.0445	0.0199
	Dinoflagellates	0.0000	0.0061		0.0317	0.0122	0.0250	0.0024	0.0129
	Flagellates	0.0306	0.0236		0.0340	0.0188	0.0177	0.0345	0.0265
	Sum of All Groups	0.0648	0.0759		0.1698	0.0991	0.0964	0.1743	0.0227
Kin-Columbia	Blue-greens		0.0089		0.0111	0.0128	0.0046	0.0025	0.0080
	Coccoid Greens, Desmids, etc.		0.0363		0.0026	0.0363	0.0702	0.0610	0.0413
	Diatoms		0.0024		0.0134	0.0262	0.0360	0.0183	0.0193
	Dinoflagellates		0.0043		0.0348	0.0341	0.0146	0.0073	0.0190
	Flagellates		0.0228		0.0271	0.0422	0.0282	0.0145	0.0270
	Sum of All Groups		0.0747		0.0890	0.1517	0.1537	0.1036	0.0229
Kin-Forebay	Blue-greens	0.0067	0.0053	0.0046	0.0036	0.0040	0.0064	0.0025	0.0047
	Coccoid Greens, Desmids, etc.	0.0255	0.0040	0.0071	0.0760	0.0922	0.0082	0.0368	0.0357
	Diatoms	0.0037	0.0024	0.0061	0.0012	0.0402	0.0140	0.0030	0.0101
	Dinoflagellates	0.0049	0.0104	0.0171	0.0226	0.0146	0.0244	0.0250	0.0170
	Flagellates	0.0270	0.0187	0.0149	0.0156	0.0215	0.0331	0.0344	0.0236
	Sum of All Groups	0.0677	0.0408	0.0497	0.1189	0.1727	0.0860	0.1018	0.0182
Kin-Wood	Blue-greens	0.0120	0.0107		0.0066	0.0193	0.0188	0.0025	0.0116
	Coccoid Greens, Desmids, etc.	0.0226	0.0012		0.0382	0.0000	0.0627	0.0038	0.0214
	Diatoms	0.0000	0.0000		0.0012	0.0226	0.0030	0.0494	0.0127
	Dinoflagellates	0.0049	0.0134		0.0152	0.0000	0.0482	0.0128	0.0158
	Flagellates	0.0489	0.0312		0.0135	0.0277	0.0454	0.0179	0.0308
	Sum of All Groups	0.0884	0.0565		0.0747	0.0696	0.1781	0.0864	0.0185

Figure 9 Average phytoplankton density (Cells/mL) in Kinbasket Reservoir between April - August 2016 derived from the 15, and 25 meter laboratory composites

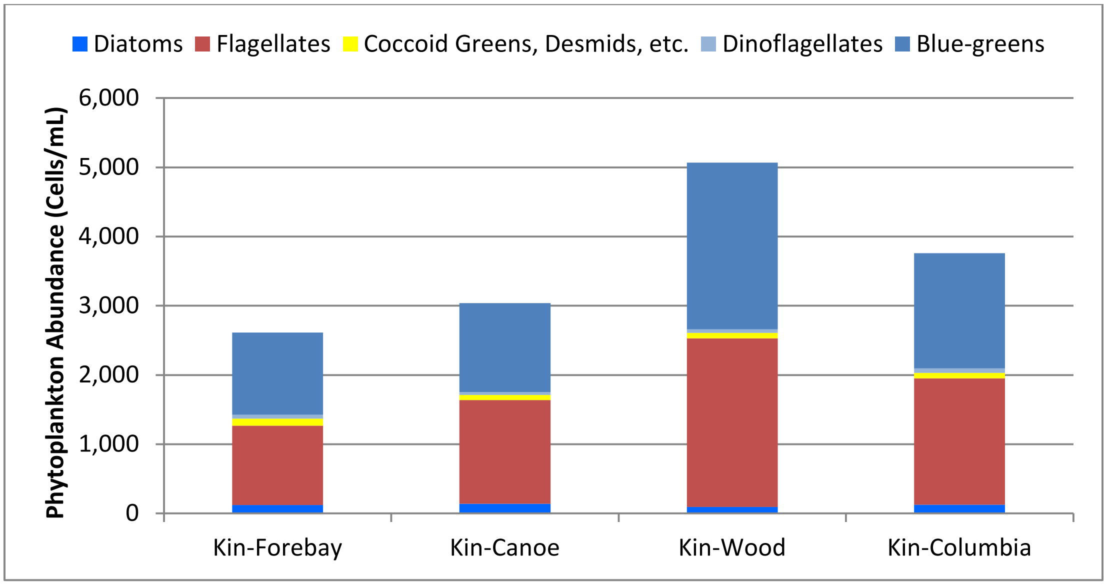


Figure 10 Average phytoplankton biovolume (mm^3/L) in Kinbasket Reservoir between April - August 2016 derived from the 15, and 25 meter laboratory composites

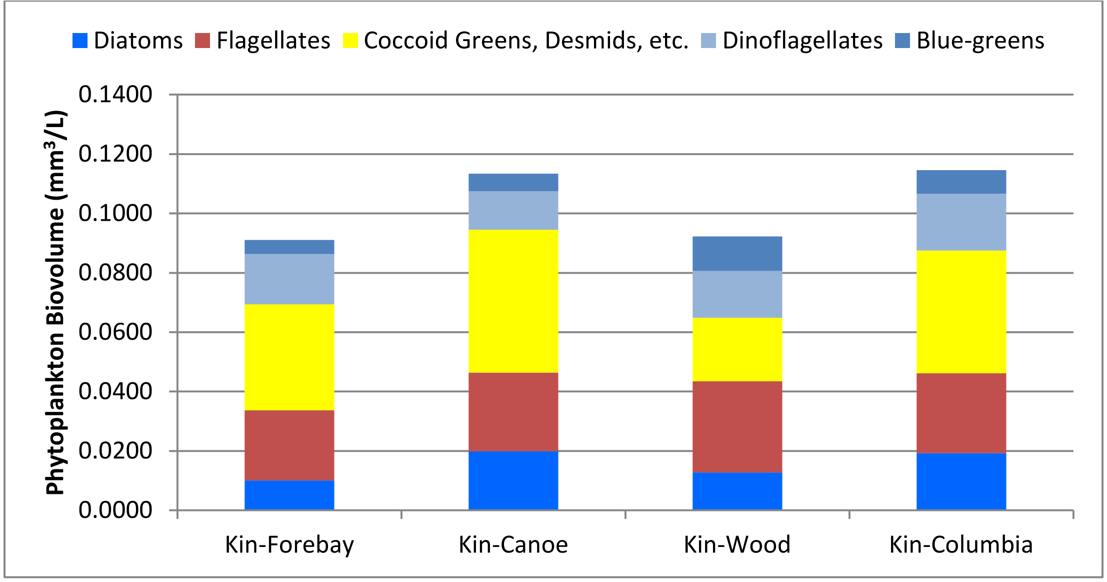


Figure 11 Kinbasket mean hypolimnetic phytoplankton density by month

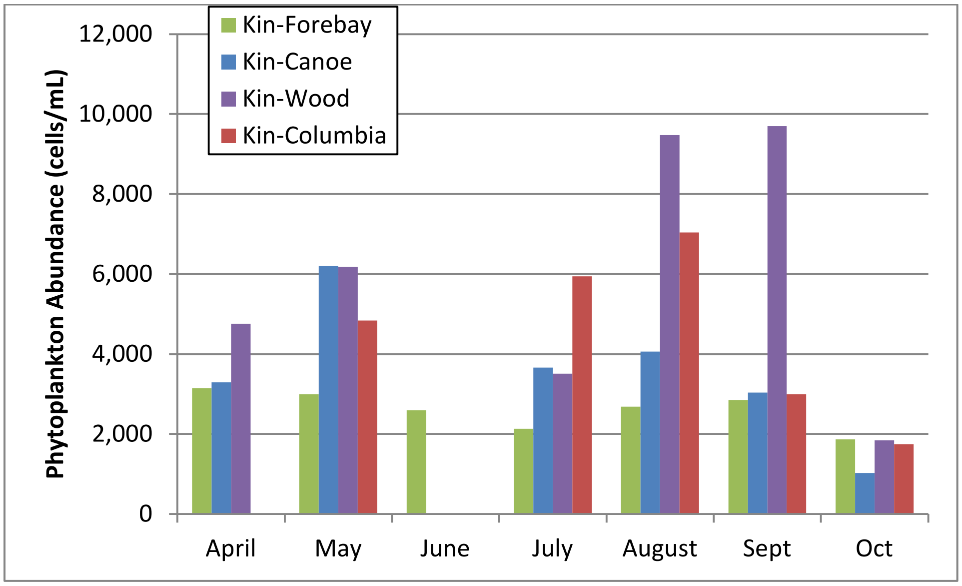
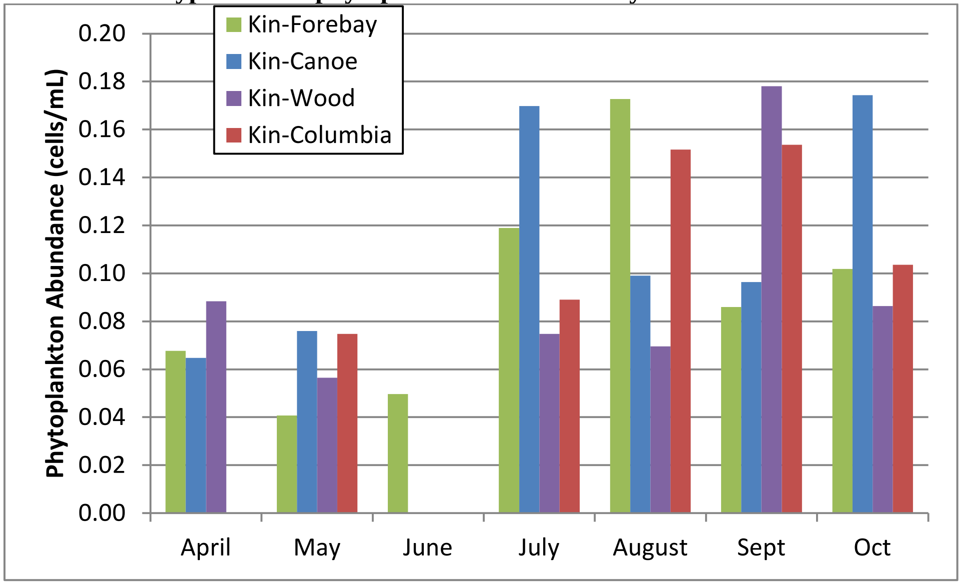


Figure 12 Kinbasket mean hypolimnetic phytoplankton biovolume by month



Revelstoke

The most abundant groups in the hypolimnion of Revelstoke Reservoir in 2016 were blue-greens and flagellates. The least abundant groups present were dinoflagellates and diatoms (Table 7 and Figure 13). The greatest contributors to biovolume at all stations were flagellates and the greens. Diatoms and dinoflagellates contributed the least to biovolume (Table 8 and Figure 14). The Middle station had the highest mean cell density and biovolumes of the three Revelstoke stations, followed by the Upper and Forebay stations.

The highest hypolimnion phytoplankton density in the Middle and Upper station occurred in July. The Forebay station had its highest hypolimnion phytoplankton density in June (Figure 15 and Figure 16).

Table 7 Revelstoke Reservoir phytoplankton density (Cells/mL) by group and month from the 15, and 25 meter laboratory composites in 2016

Station	Group	April	May	June	July	August	Sept.	Oct.	Seasonal Average
Rev-Forebay	Blue-greens	1,890	1,866	2,293	1,512	842	1,646	927	1,568
	Coccoid Greens, Desmids, etc.	305	61	49	37	122	49	37	94
	Diatoms	0	0	0	37	73	24	49	26
	Dinoflagellates	12	146	61	37	49	61	24	56
	Flagellates	1,976	2,061	2,659	1,695	1,305	1,598	1,073	1,767
	Sum of All Groups	4,183	4,134	5,061	3,317	2,390	3,378	2,110	3,511
Rev-Mid	Blue-greens	1,171	3,061	2,195	4,159	3,049	1,354	695	2,241
	Coccoid Greens, Desmids, etc.	73	37	37	0	61	49	24	40
	Diatoms	12	0	24	73	98	73	61	49
	Dinoflagellates	12	85	61	37	73	134	12	59
	Flagellates	1,232	3,610	2,293	4,598	3,293	1,707	951	2,526
	Sum of All Groups	2,500	6,793	4,610	8,866	6,573	3,317	1,744	4,915
Rev-Upper	Blue-greens	1,463	1,610		2,549	1,342	1,354	659	1,496
	Coccoid Greens, Desmids, etc.	122	49		159	61	73	12	79
	Diatoms	12	0		61	37	0	0	18
	Dinoflagellates	37	73		73	98	61	24	61
	Flagellates	1,903	1,964		2,793	1,805	1,768	1,122	1,892
	Sum of All Groups	3,537	3,695		5,634	3,342	3,256	1,817	3,547

Table 8 Revelstoke Reservoir phytoplankton biovolume (mm^3/L) by group and month from the 15, and 25 meter laboratory composites in 2016

Station	Group	May	June	July	August	Sept.	Oct.	Seasonal Average
Rev-Forebay	Blue-greens	0.0076	0.0075	0.0092	0.0060	0.0033	0.0066	0.0037
	Coccoid Greens, Desmids, etc.	0.0212	0.0338	0.0620	0.0011	0.0659	0.0015	0.0312
	Diatoms	0.0000	0.0000	0.0000	0.0061	0.0079	0.0018	0.0220
	Dinoflagellates	0.0049	0.0409	0.0110	0.0079	0.0146	0.0152	0.0098
	Flagellates	0.0269	0.0181	0.0270	0.0181	0.0187	0.0340	0.0134
	Sum of All Groups	0.0606	0.1003	0.1091	0.0393	0.1104	0.0591	0.0800
Rev-Mid	Blue-greens	0.0047	0.0122	0.0088	0.0166	0.0122	0.0054	0.0028
	Coccoid Greens, Desmids, etc.	0.0029	0.0016	0.0016	0.0000	0.0018	0.0930	0.0309
	Diatoms	0.0012	0.0000	0.0052	0.0131	0.0067	0.0159	0.0140
	Dinoflagellates	0.0006	0.0159	0.0128	0.0122	0.0250	0.0378	0.0049
	Flagellates	0.0137	0.0318	0.0173	0.0376	0.0346	0.0390	0.0272
	Sum of All Groups	0.0232	0.0615	0.0457	0.0796	0.0804	0.1910	0.0797
Rev-Upper	Blue-greens	0.0059	0.0064		0.0102	0.0054	0.0054	0.0026
	Coccoid Greens, Desmids, etc.	0.0114	0.0020		0.0422	0.0076	0.0137	0.0061
	Diatoms	0.0012	0.0000		0.0073	0.0018	0.0000	0.0000
	Dinoflagellates	0.0122	0.0226		0.0201	0.0299	0.0195	0.0098
	Flagellates	0.0213	0.0310		0.0270	0.0412	0.0339	0.0347
	Sum of All Groups	0.0520	0.0619		0.1068	0.0859	0.0725	0.0532

Figure 13 Average phytoplankton density (Cells/mL) in Revelstoke Reservoir between May - October 2016 derived from the 15, and 25 meter laboratory composites

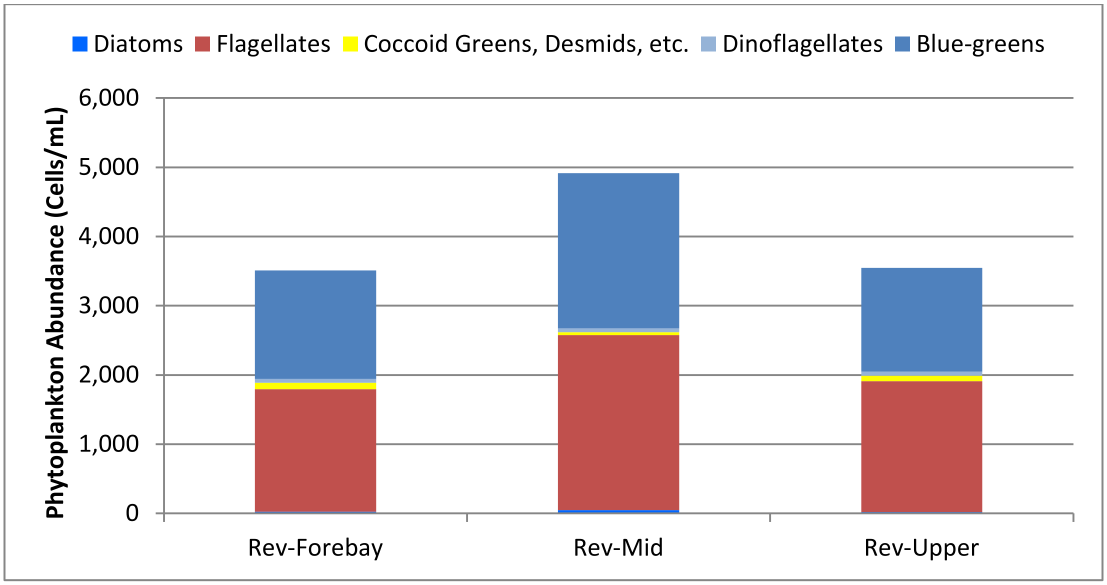


Figure 14 Average phytoplankton biovolume (mm^3/L) in Revelstoke Reservoir between May - October 2016 derived from the 15, and 25 meter laboratory composites

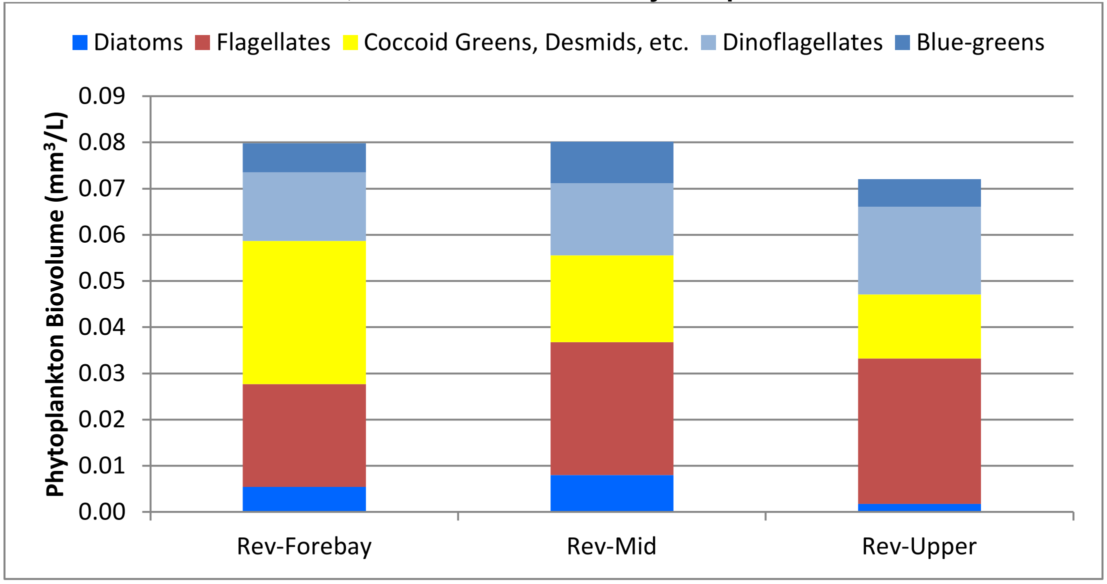


Figure 15 Revelstoke mean hypolimnetic phytoplankton density by month

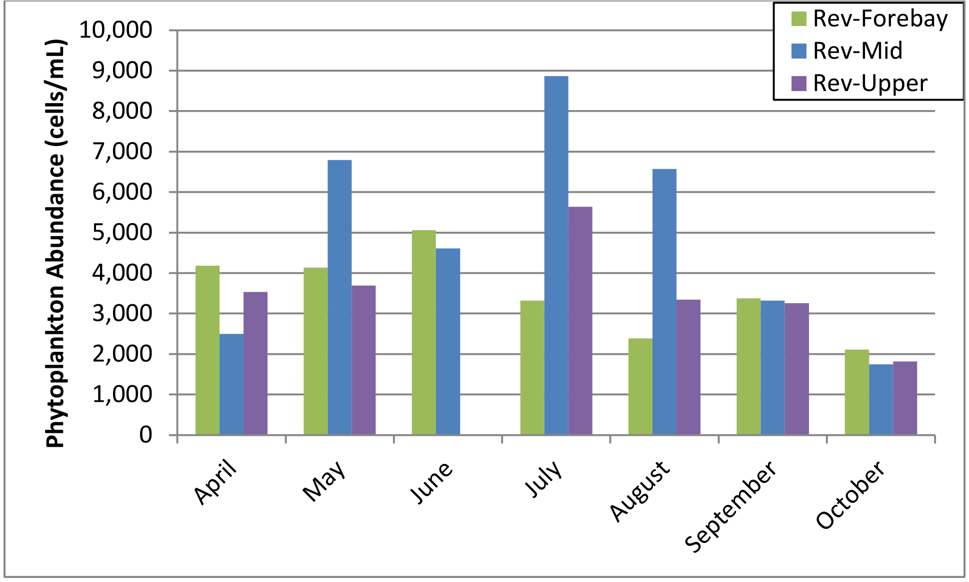
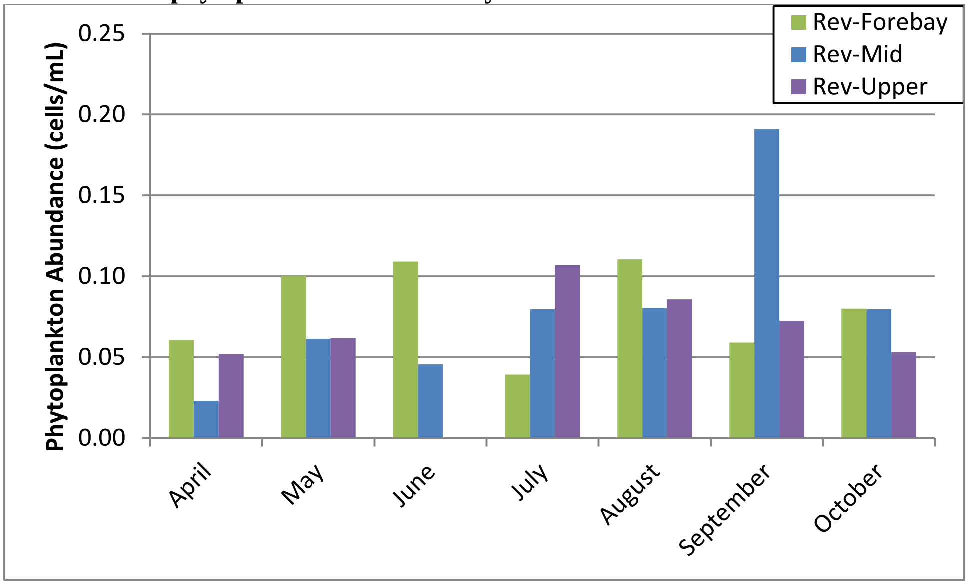


Figure 16 Revelstoke mean phytoplankton biovolume by month



3.3 Vertical Distribution- Phytoplankton Density and Biovolume – 2016

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 2016 sampling season.

Kinbasket

Blue-Greens and flagellates dominated the community at all depths (Figure 17). The average density was the highest at 25 meters. The 2016 biovolume of the phytoplankton community exhibits a slight but not significant difference with depth with the greatest biovolume occurring at 15metere of depth (Figure 18).

Figure 17 Average phytoplankton density (Cells/mL), by depth and group, in Kinbasket Reservoir in 2016

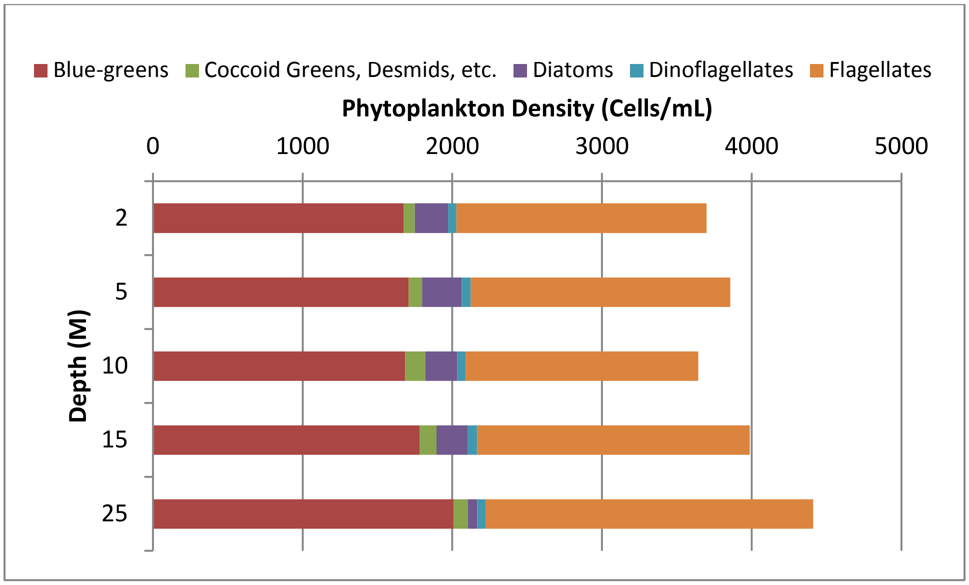
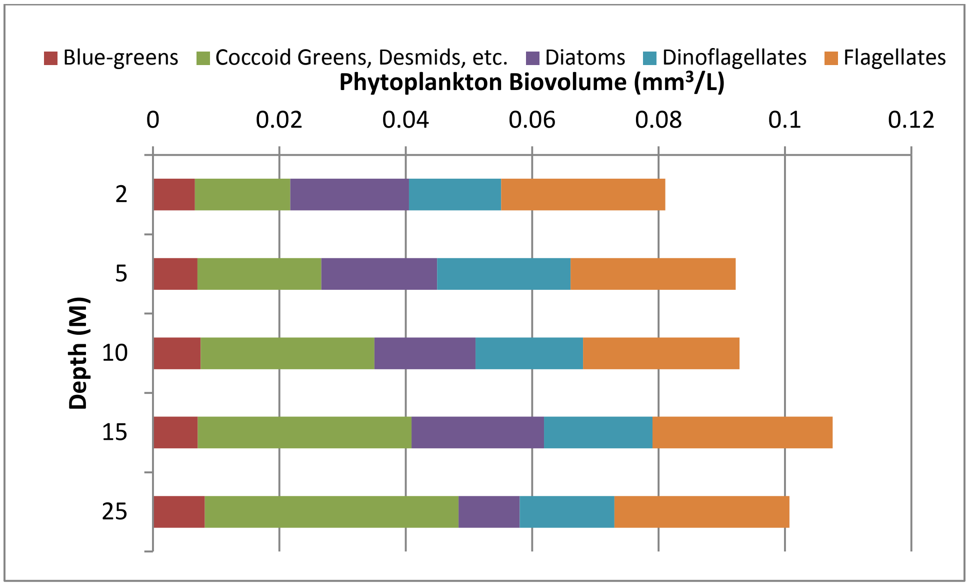


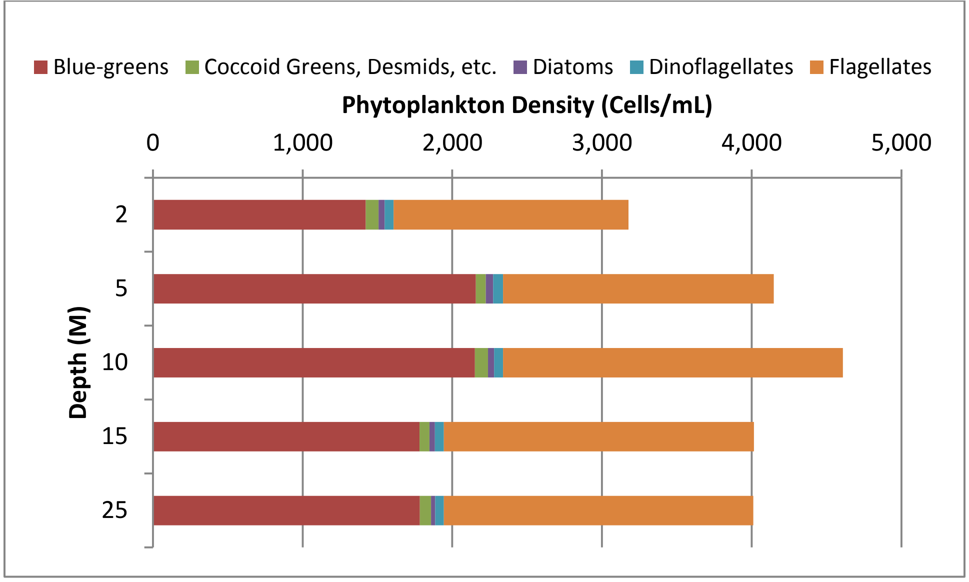
Figure 18 Average phytoplankton biovolume (mm^3/L), by depth and group, in Kinbasket Reservoir in 2016



Revelstoke

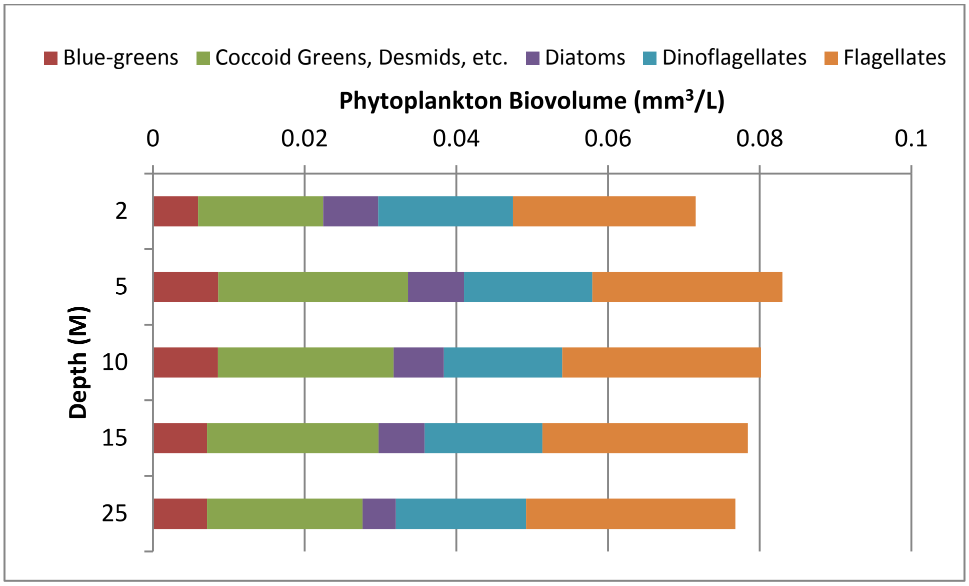
The highest average cell density in Revelstoke reservoir occurred at 10 meters of depth. The most abundant group at all depths were the blue-greens and flagellates. Dinoflagellate and diatoms were the least abundant groups (Figure 19).

Figure 19 Average phytoplankton density (Cells/mL), by depth, in Revelstoke Reservoir in 2016



The greatest average biovolume in Revelstoke Reservoir was at 5 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 in 2016



3.4 Phytoplankton in 2008-2016

To compare the 2008 through 2016 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 was an increase in phytoplankton density between 2008 and 2015; however, 2016 has a distinct reduction in both cell density and biovolume (Table 10). 2016 was most comparable to phytoplankton levels see in 2010 and 2011 (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**	1,672	1,284	1,276	1,238	1,368
	2009	2,215	2,066	2,208	2,110	2,150
	2010	2,797	3,133	3,075	2,569	2,893
	2011[ŧ]	2,476	2,717	5,558	3,586	3,584
	2012	3,823	4,541	5,522	4,490	4,594
	2013	5,995	7,838	7,864	8,885	7,645
	2014	5,999	7,083	6,953	7,507	6,886
	2015	7,055	9,227	7,695	8,958	7,734
	2016	2,893	4,397	3,077	4,080	3,612
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	0.1	0.07	0.08
	2012	0.09	0.08	0.13	0.12	0.11
	2013	0.17	0.18	0.25	0.19	0.2
	2014	0.18	0.19	0.17	0.21	0.19
	2015	0.28	0.27	0.26	0.37	0.3
	2016	0.09	0.09	0.08	0.07	0.09

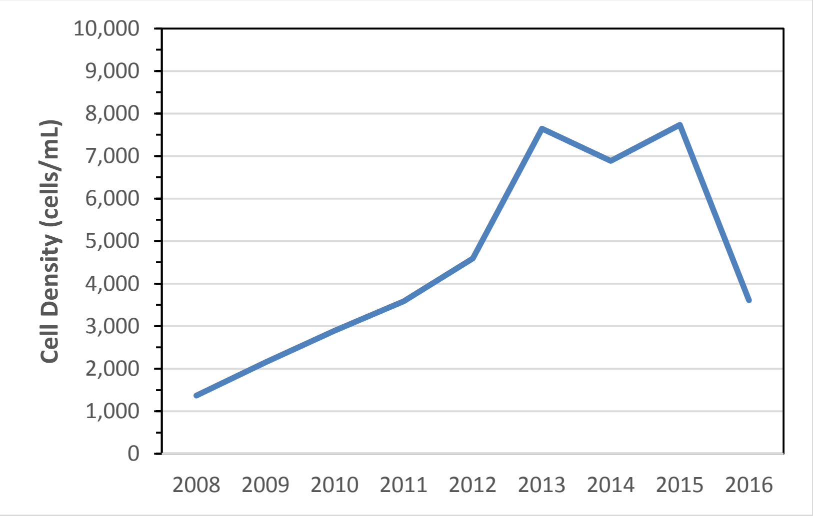


Figure 21 Mean epilimnetic phytoplankton density by year for Kinbasket

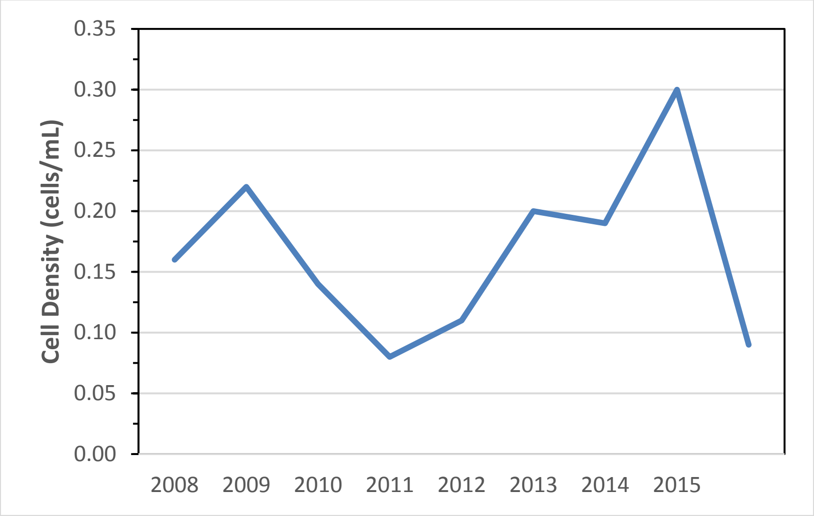


Figure 22 Mean epilimnetic phytoplankton biovolume by year for Kinbasket

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). From 2008 through 2013 the means cell densities increased consistently (Table 10). The densities observed in 2016 are considerably lower than the previous three years. The density and biovolume in 2016 was similar to densities and biovolumes observed in 2010 and 2011.

Table 10 Average seasonal phytoplankton density and biomass in Revelstoke Reservoir

Revelstoke	Year	Forebay	Mid	Upper	Reservoir Average
Average Density (Cells/mL)	2008	2,604	1,829	1,544	1,992
	2009	2,416	1,901	1,683	2,000
	2010	1,940	2,502	1,684	2,375
	2011	3,823	5,143	4,395	4,154
	2012	5,708	6,425	7,561	6,565
	2013	7,839	8,328	12,400	9,523
	2014	6,736	6,949	6,865	6,850
	2015	7,307	10,194	7,843	8,448
	2016	3,711	4,371	3,832	3,971
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	0.10	0.09	0.08	0.09
	2013	0.21	0.18	0.48	0.29
	2014	0.16	0.18	0.15	0.17
	2015	0.20	0.25	0.24	0.23
	2016	0.08	0.08	0.08	0.08

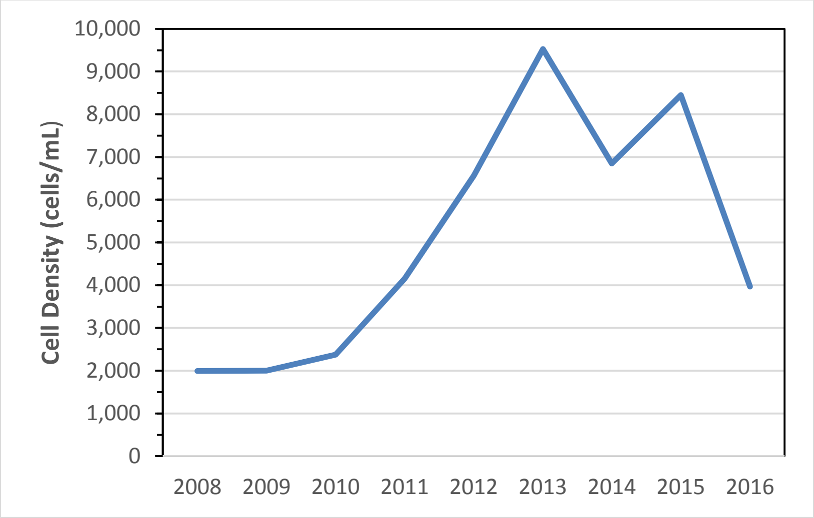


Figure 23 Mean epilimnetic phytoplankton density by year for Revelstoke

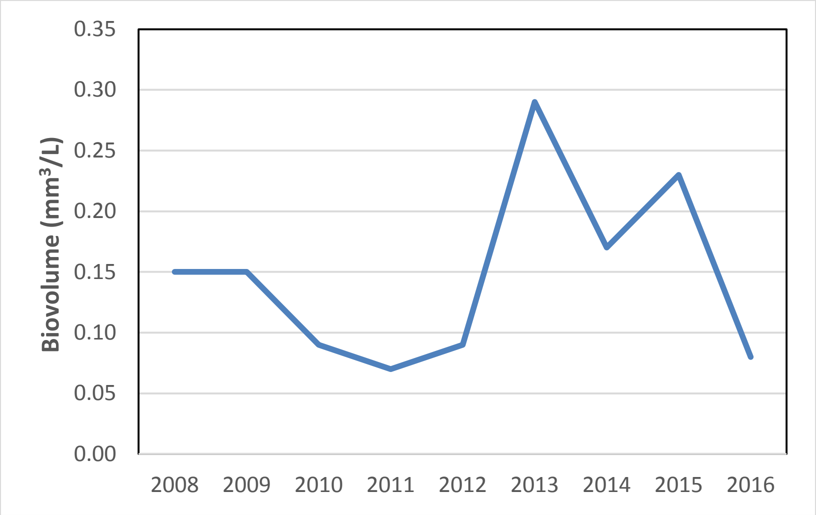


Figure 24 Mean epilimnetic phytoplankton biovolume by year for Revelstoke

3.5 Bacteria and Pico-cyanobacteria Density in 2016

3.5.1 Bacteria.

Kinbasket

The epilimnetic and hypolimnetic heterotrophic bacteria densities ranged from a low of 50,669 cells/mL in October in the Wood Arm epilimnion to high or 453,043 cells/mL in the epilimnion of the Wood Arm in the August samples. The overall average density in the epilimnion was 145,621 cells/mL. This density is similar to 2015 (181,758 cells/mL) but considerably lower than 2011-2014 four year average of 405,290 cells/mL. There was very little difference in the monthly averages between stations or months in 2016, with the exception of the August densities in Kinbasket Reservoir (Figure 26).

Table 10 2016 Picoplankton densities

		Heterotrophic Bacteria (Cells/mL)							
		April	May	June	July	August	Sept.	Oct.	Avg.
Epilimnion	Kin-Canoe	118,228	121,209	149,027	141,079	194,729	60,604	214,599	142,782
	Kin-Columbia	98,358	157,969		107,300	194,729	131,144	194,729	147,371
	Kin-Forebay	99,352	136,112		147,040	158,963	147,040	66,566	135,686
	Kin-Wood	87,429	109,287		108,293	453,043	131,144	50,669	156,644
	Rev-Forebay	121,209	130,151	163,930	190,755		182,807	69,546	143,066
	Rev-Middle	120,215	132,138	215,593	124,189	226,522	139,092	222,548	168,614
	Rev-Upper	63,585	134,125		174,859	186,781	194,729	158,963	152,173
Hypolimnion	Kin-Canoe	111,274	112,267	153,995	200,690	181,217	174,859	74,514	144,117
	Kin-Columbia	119,222	160,950		136,112	246,392	143,066	158,963	160,784
	Kin-Forebay	131,144	146,047		173,865	218,573	123,196	79,481	151,582
	Kin-Wood	91,403	121,209		174,859	182,807	135,118	230,496	155,982
	Rev-Forebay	78,488	164,924	164,924	190,755	286,133	154,988	63,585	157,685
	Rev-Middle	141,079	118,228	149,027	115,248	226,522	135,118	278,184	166,201
	Rev-Upper	79,481	146,047		246,392	242,418	162,937	250,366	187,940

		Pico-cyano Bacteria (Cells/mL)							
		April	May	June	July	August	Sept.	Oct.	Avg.
Epilimnion	Kin-Canoe	7,507	5,961	31,130	6,623	9,935	16,890	7,948	12,285
	Kin-Columbia	2,981	6,182		19,208	12,585	12,585	10,598	10,689
	Kin-Forebay	9,494	8,610		25,500	11,591	13,247	5,961	18,293
	Kin-Wood	6,403	1,987		3,312	10,929	9,604	12,585	7,470
	Rev-Forebay	45,702	15,896	7,727	11,260		11,591	20,533	18,785
	Rev-Middle	11,260	5,961	10,156	6,403	7,617	21,195	19,208	11,686
	Rev-Upper	1,104	4,195		4,968	6,623	9,273	3,312	4,912
Hypolimnion	Kin-Canoe	6,182	8,610	38,416	7,286	13,578	12,916	8,610	13,657
	Kin-Columbia	14,572	5,299		17,221	13,247	6,955	8,279	10,929
	Kin-Forebay	12,805	19,208		30,468	21,526	9,273	9,604	21,321
	Kin-Wood	12,805	4,195		2,870	12,253	4,968	8,610	7,617
	Rev-Forebay	8,831	14,572	7,065	2,429	6,292	4,305	25,500	9,856
	Rev-Middle	11,392	2,208	4,195	3,312	2,318	5,961	19,605	6,999
	Rev-Upper	4,416	2,429		4,416	4,636	4,968	4,857	4,287

Figure 25 Average density (Cells/mL) of heterotrophic bacteria at four sampling stations in Kinbasket Reservoir between the months of April through October 2016

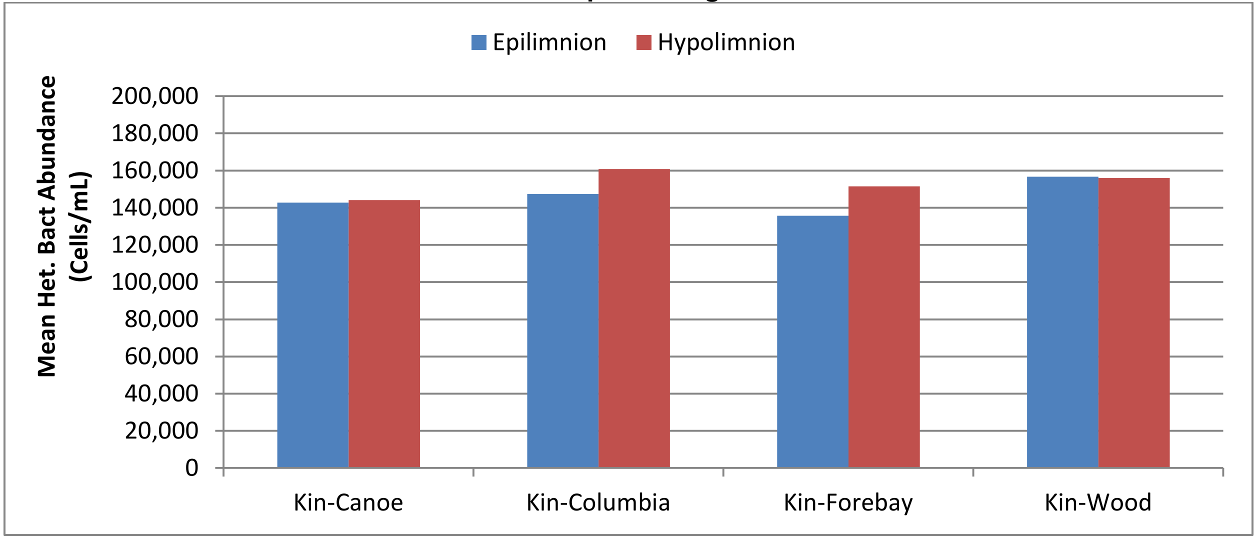
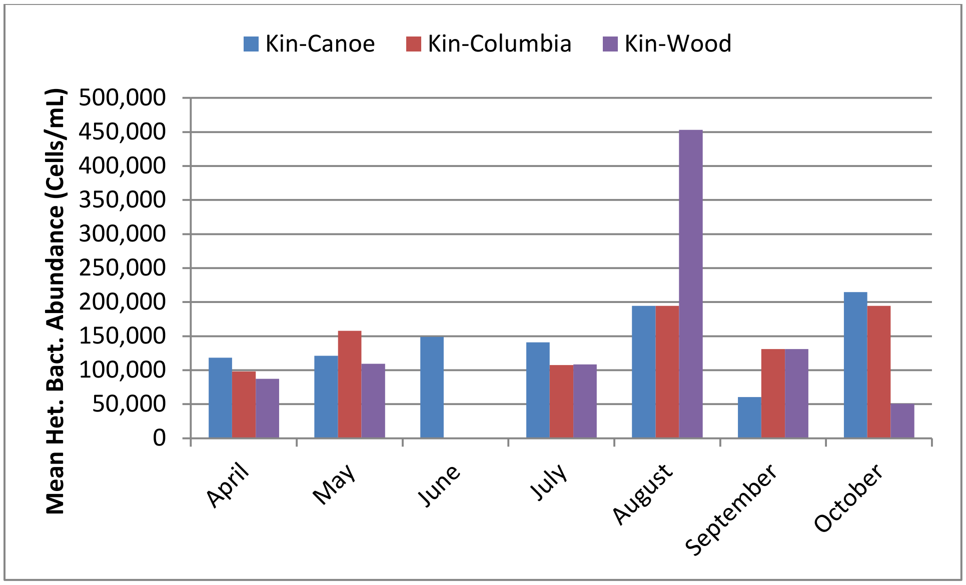


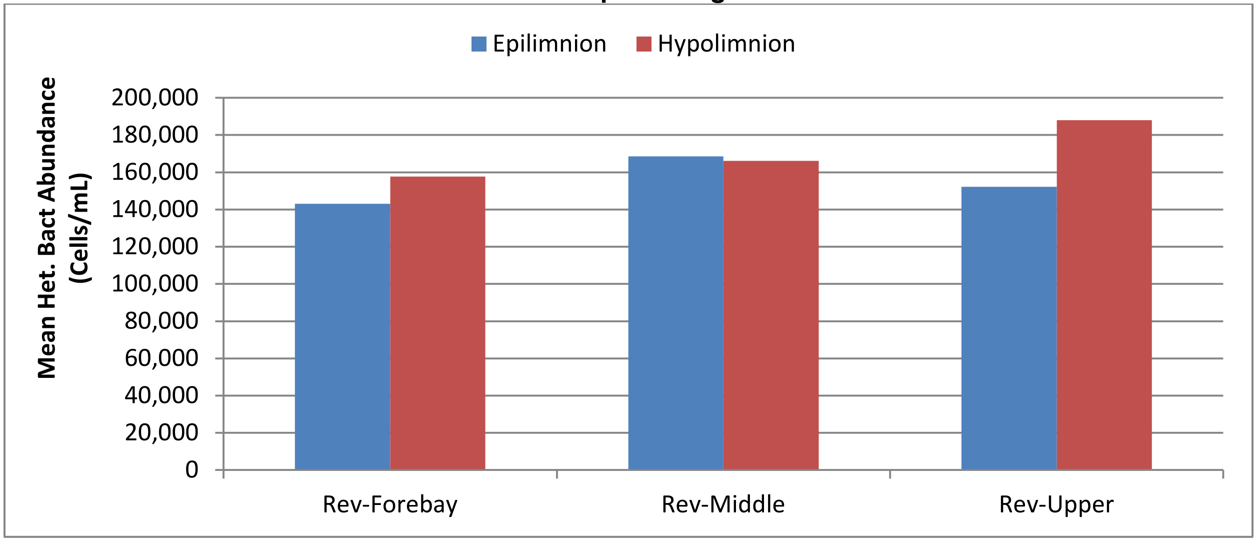
Figure 26 Kinbasket Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at four sampling stations in 2016



Revelstoke

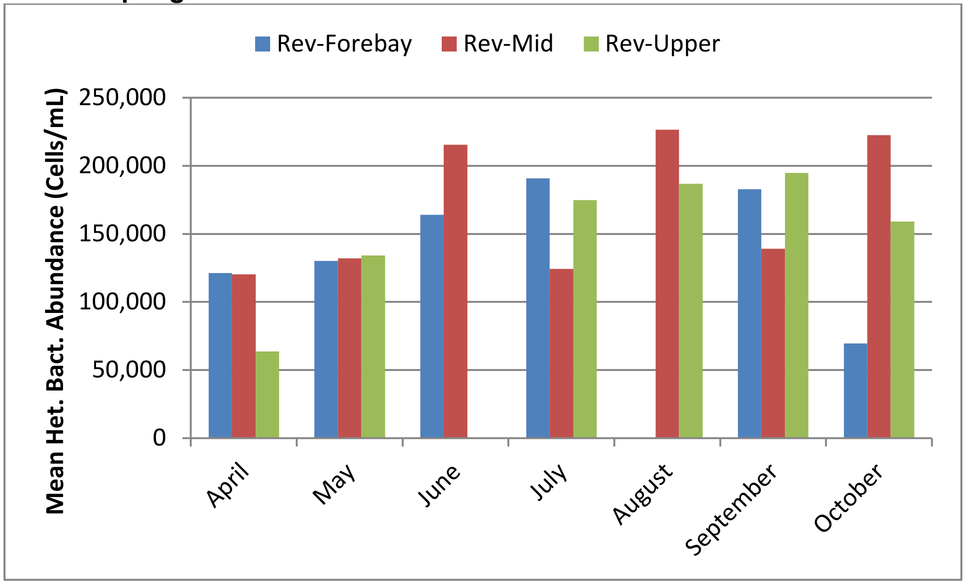
The epilimnetic average of heterotrophic bacteria ranged from 143,066 to 168,614 cells/mL (Table 10). These values are similar slightly lower than those observed in Revelstoke in 2014 and 2015 and more than 50% lower than observed in Revelstoke in 2011 and 2012. The Middle Station had the highest epilimnion and the greatest average hypolimnion densities was found at the upper station (Figure 27).

Figure 27 Average density (Cells/mL) of heterotrophic bacteria at three sampling stations in Revelstoke Reservoir between the months of Apri through October 2016



Reservoir mean heterotrophic bacteria densities were low in April and May (Figure 28). The densities in June through October were variable between months and stations but were generally higher than the spring values. The three highest densities were all observed in the mid station.

Figure 28 Revelstoke Reservoir monthly average density (Cells/mL) of epilimnetic heterotrophic bacteria at three sampling stations in 2016



3.5.2 Pico-cyanobacteria.

Kinbasket

Total seasonal average density of epilimnetic pico-cyanobacteria in Kinbasket Reservoir was 12,184 cells/mL. The forebay station had the highest average pico-cyanobacteria density in both the epilimnion and hypolimnion samples (Table 10 and Figure 29). The densities observed in 2016, 2015 and 2014 were considerably lower than the densities observed in 2011 and in line with the 2010 and 2012, and 2013 densities.

The highest epilimnetic densities were observed in June and July. Hypolimnetic total seasonal average density of pico-cyanobacteria averaged 13,381 cells/mL (Figure 30).

Figure 29 Average density (Cells/mL) of pico-cyanobacteria at four sampling stations in Kinbasket Reservoir between the months of May through October 2016

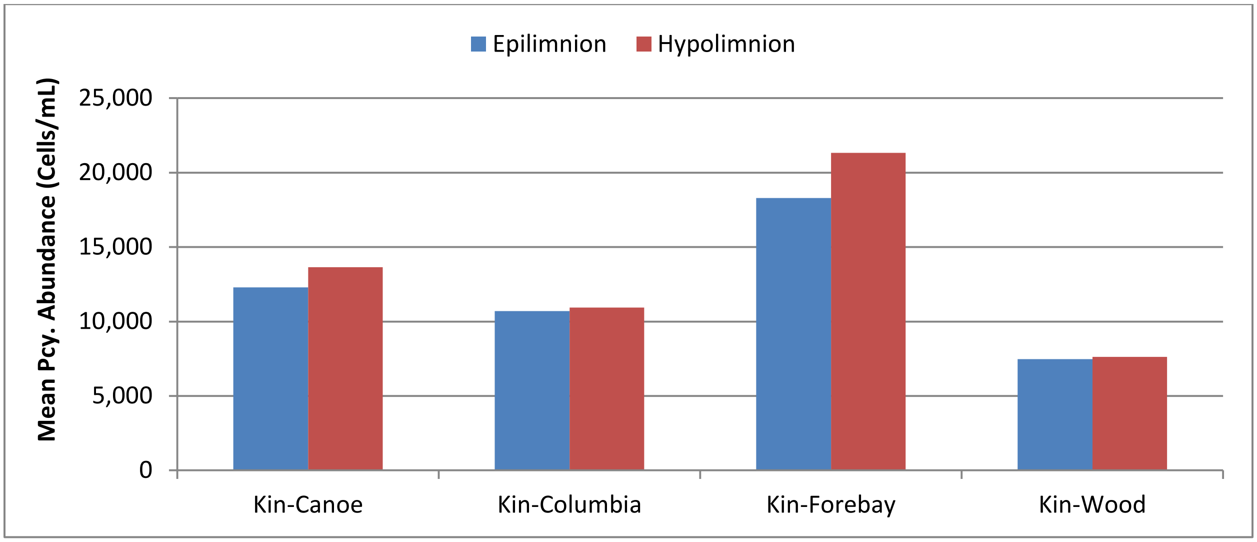
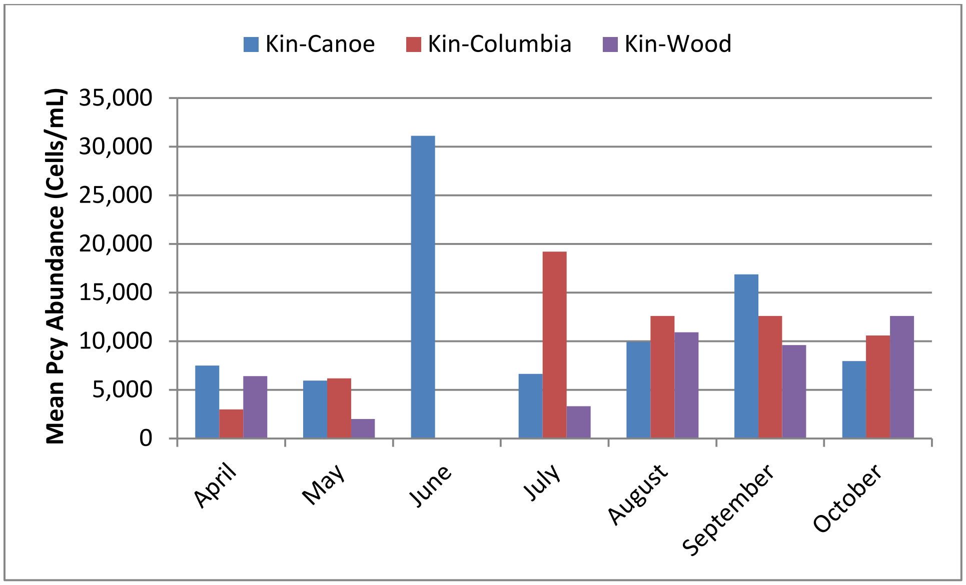


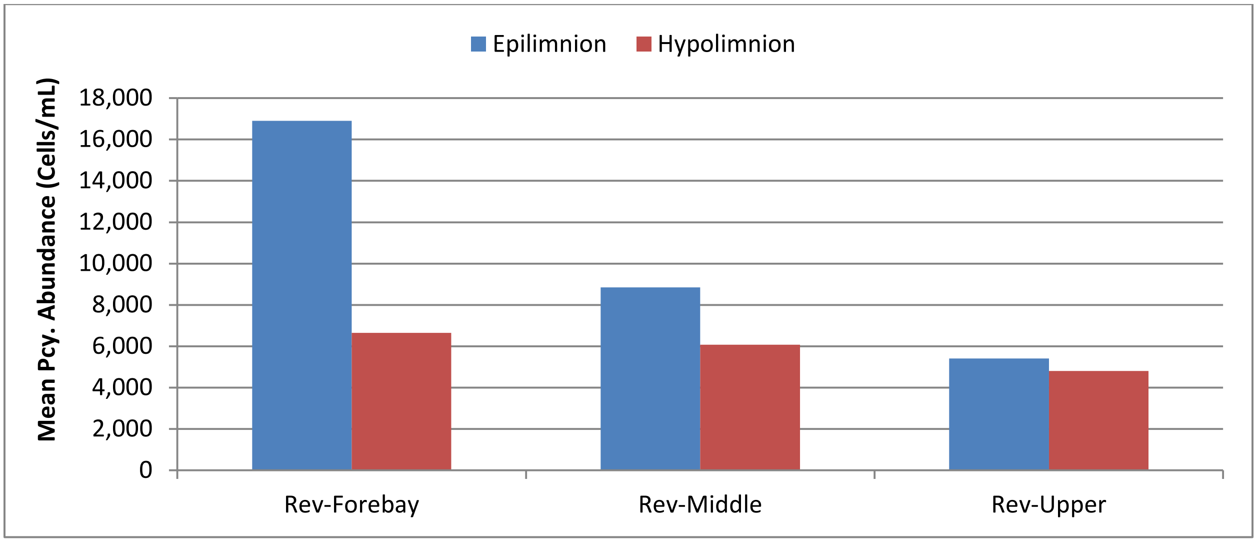
Figure 30 Average monthly density (Cells/mL) of epilimnetic pico-cyanobacteria at four sampling stations in Kinbasket Reservoir



Revelstoke

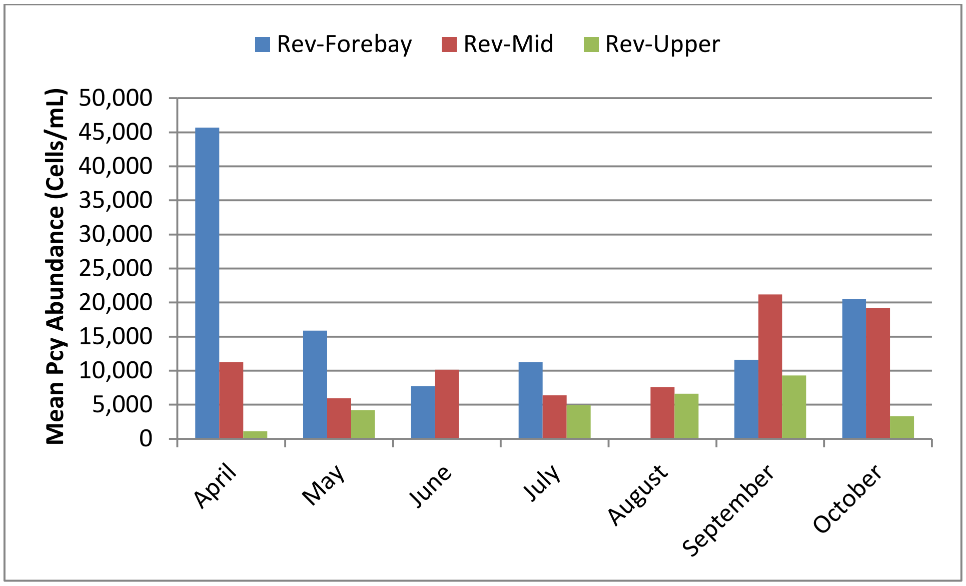
The average density in the epilimnion was approximately 11,794 cells/mL in Revelstoke Reservoir (Table 10). In the hypolimnion, the average density was 7,047 cells/mL. The Forebay station had the highest average density in the epilimnion but there was little difference in hypolimnetic densities between the three stations (Figure 31).

Figure 31 Average density (Cells/mL) of pico-cyanobacteria at three sampling stations in Revelstoke Reservoir between the months of May through October 2016



Following an April peak, the Forebay station returned to densities similar to the other two stations for the remainder of the year, with the lowest densities occurring in the summer months followed by a slight increase in cell density in September and October (Figure 32).

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 phytoplankton community in 2016 was considerably lower in density and biovolume compared to the previous 3 years. The changes observed in phytoplankton density and biovolume should be examine in conjunction with both environmental and operational differences between years. 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 2016 Taxa List and Number of Occurrences

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
Bacillariophyte	Diatoms	Cyclotella comta	37	18
		Cyclotella glomerata	61	44
		Fragilaria capucina		4
		Fragilaria crotonensis	1	
		Gomphonema sp. (medium)		2
		Stephanodiscus sp. (large)	12	4
		Stephanodiscus sp. (small)	7	10
		Synedra acus	44	25
		Synedra nana	3	
		Synedra ulna	1	
		Diatoma sp.	1	1
		Gyrosigma	1	
		Amphora (small)		1
		Achnanthidium sp.		1
		Hannaea arcus		1
Chlorophyte	Coccoid Greens, Desmids, Etc.	Coelastrum sp. (cells)	10	9
		Cosmarium sp.	11	3
		Dictyosphaerium (cells)	1	
		Elakatothrix sp.	5	7
		Euglena	30	22
		Golenkinia sp.	1	
		Monomastix sp.	3	1
		Monoraphidium	7	6
		Nephroselmis	9	5
		Oocystis sp. (cells)	18	7
		Phacus (medium)	4	7
		Planctonema sp.	1	
		Planktosphaeria	3	1
		Scenedesmus sp.	7	
		Scourfieldia	61	52
		Tetraedron	61	28
		Pediastrum sp. (small)	1	
		Phacus (small)	10	7
		Ankistrodesmus sp.	3	1
		Staurastrum sp. (small)		1
Chryso- & Cryptophyte	Flagellates	Chromulina sp.	9	2
		Chroomonas acuta	113	96
		Chrysococcus	34	15
		Cryptomonas sp. (large)	16	15
		Cryptomonas sp. (medium)	89	68
		Dinobryon sp. (medium)	22	8
		Kephyrion sp.	54	47
		Komma sp.	31	22

Scientific Group Name	Common Group Name	Taxa	Kinbasket	Revelstoke
		Mallomonas sp. (medium)	2	4
		Ochromonas sp.	50	30
		Pseudokephrion sp.	45	43
		Small microflagellates	123	99
		Trachelomonas sp.	5	2
		Cryptomonas sp. (small)	71	65
		Mallomonas sp. (small)	2	1
		Conradiella	1	
Cyanophyte	Blue-greens	Aphanothece minutissimus	13	6
		Chroococcus sp. (cells)	2	1
		Merismopedia sp. (cells)	23	13
		Synechococcus sp. (coccoid)	122	99
		Synechococcus sp. (rod)	75	73
		Synechocystis	5	4
		Planktothrix agardhii	1	
Dinophyte	Dinoflagellates	Amphidinium	33	33
		Ceratium	1	
		Gymnodinium sp. (medium)	82	73
		Gymnodinium sp. (small)	73	67

Appendix 7

Zooplankton
Kinbasket and Revelstoke Reservoirs, 2016

Lidija Vidmanic
Limno Lab

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1. Introduction

This report summarises the zooplankton data collected in 2016, 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 reservoirs. 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.

In Revelstoke Reservoir samples were collected at three stations. 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 October in both reservoirs during 2016 sampling season, with a vertically hauled 153 µm mesh Wisconsin net with a 0.2 m throat diameter. The depth of each haul was 30 m. Duplicate samples were taken at each site of the reservoir. Due to a technical problem June samples could not be collected in Kinbasket reservoir from stations Canoe Reach, Columbia Reach and Wood Arm, and in Revelstoke reservoir at station Rev Upper .

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. 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 *Daphnia* 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

Three calanoid copepod species were identified in the samples from Kinbasket Reservoir (Tab. 1). *Leptodiaptomus sicilis* (Forbes) and *Epischura nevadensis* (Lillj.) were present in samples during each sampling season, while *Leptodiaptomus ashlandi* (Marsh) was 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 2003-2016. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2004	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cladocera												
Alona sp.						r			r		r	
Bosmina longirostris	+	+	+	+	+	+	+	+	+	+	+	+
Chydorus sphaericus			+		+	+			r			r
Daphnia galeata mendotae	+	+	+	+	+	+	+	+	+	+	+	+
Daphnia rosea	+	+	+	+	+	+	+	+	+	+	+	+
Daphnia schoedleri	+	+	+	+	+	+	+	+	+	+	+	+
Diaphanosoma brachyurum		+	+		+	+		+	+	+	+	+
Holopedium gibberum	r			r	r	r				r	r	r
Leptodora kindtii	+	+	+	+		+	+	+	+	+	+	+
Macrothrix sp.					r							
Scapholeberis rammneri	+	+	+	+	+	+	+	+	+	+	+	+
Copepoda												
Aglaodiaptomus leptopus		r		r					r	r	r	
Diacyclops bicuspidatus	+	+	+	+	+	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+	+	+	+	+	+
Leptodiaptomus ashlandi		r	r		r	r	r	r	r	r	r	r
Leptodiaptomus sicilis	+	+	+	+	+	+	+	+	+	+	+	+

Nine species of Cladocera were present in 2016 (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.

3.2 Density and Biomass

For comparison with historical data the average at Mica Forebay station in Kinbasket was used. Zooplankton density values from 2003 to 2016 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 in Kinbasket Reservoir increased in 2016 to 7.25 individuals/L from 6.34 individuals/L in 2015 (Fig. 2). The zooplankton density was numerically dominated by copepods, which averaged 74% of the 2016 community with 5.33 individuals/L. *Daphnia* spp comprised 11% with 0.81 individuals/L, and other cladocerans 15% with 1.11 individuals/L.

The average zooplankton densities for all four sampling stations in Kinbasket Reservoir fluctuated over the course of the studied period. It increased from 2.09 individuals/L in April to 13.28 individuals/L in June, and then gradually decreased to 4.74 individuals/L at the end of the sampling season (Tab. 2). Monthly averaged density of *Daphnia* for the whole reservoir increased gradually during the sampling season reaching its peak in August with 2.34 individuals/L (Fig.3).

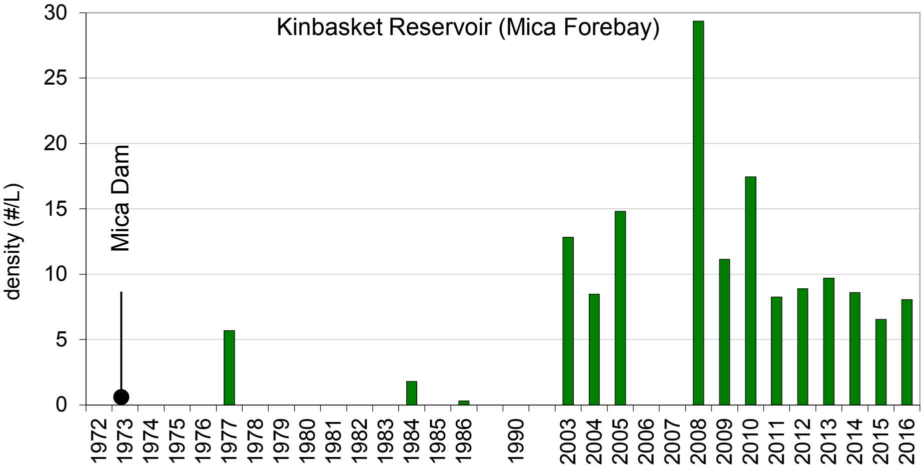

Figure 1. Zooplankton density 1977-2016 at Mica Forebay in Kinbasket Reservoir

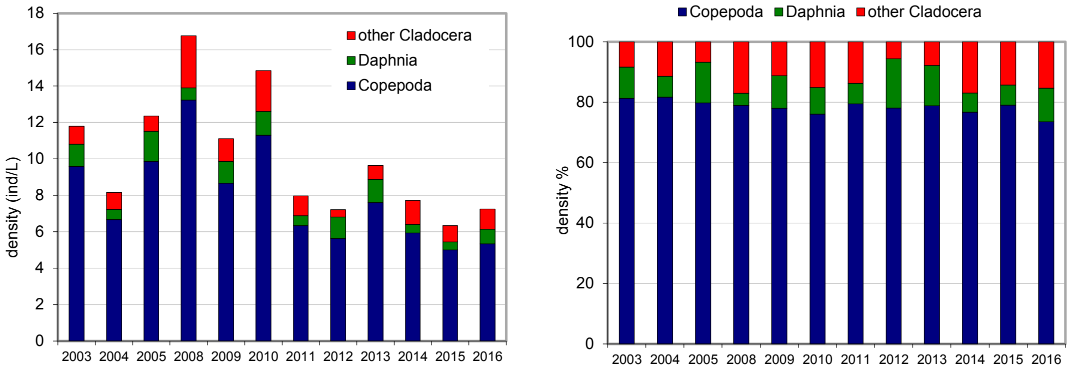

Figure 2. Seasonal average zooplankton density in Kinbasket Reservoir 2003-2016

Table 2. Monthly average density and biomass of zooplankton in Kinbasket Reservoir in 2016. Density is in units of individuals/L and biomass is in units of μg/L.

Density		11-Apr	16-May	23-Jun	11-Jul	08-Aug	12-Sep	12-Oct
	Copepoda	1.97	7.00	10.90	7.71	7.66	3.35	2.93
	Daphnia	0.03	0.09	0.34	0.70	2.34	0.81	0.98
	Other Cladocera*	0.09	0.43	0.51	2.34	2.43	0.33	0.83
	Total Zooplankton	**2.09**	**7.52**	**13.28**	**10.75**	**12.43**	**4.49**	**4.74**
Biomass		11-Apr	16-May	23-Jun	11-Jul	08-Aug	12-Sep	12-Oct
	Copepoda	4.04	12.22	15.77	13.10	12.47	5.35	5.11
	Daphnia	0.48	1.07	10.03	13.79	36.24	20.30	26.07
	Other Cladocera**	0.35	1.30	1.55	7.58	8.87	1.56	3.03
	Total Zooplankton	**4.87**	**14.59**	**32.01**	**34.46**	**57.59**	**27.21**	**34.21**

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

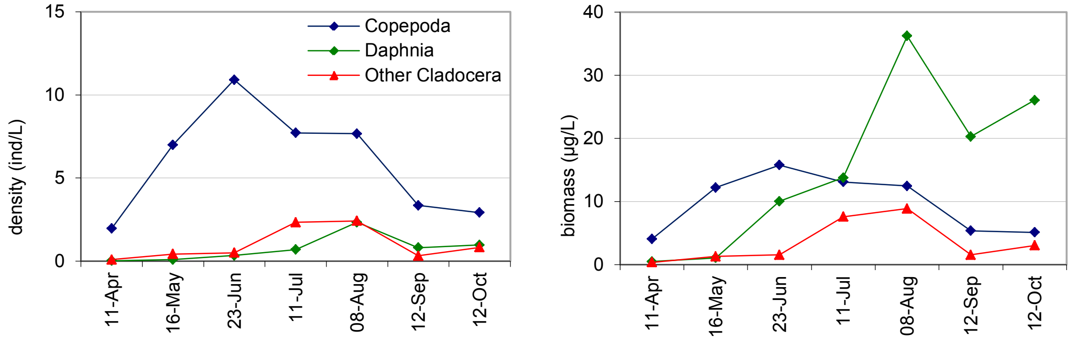

Figure 3. Monthly zooplankton density and biomass averaged for the whole Kinbasket Reservoir 2016

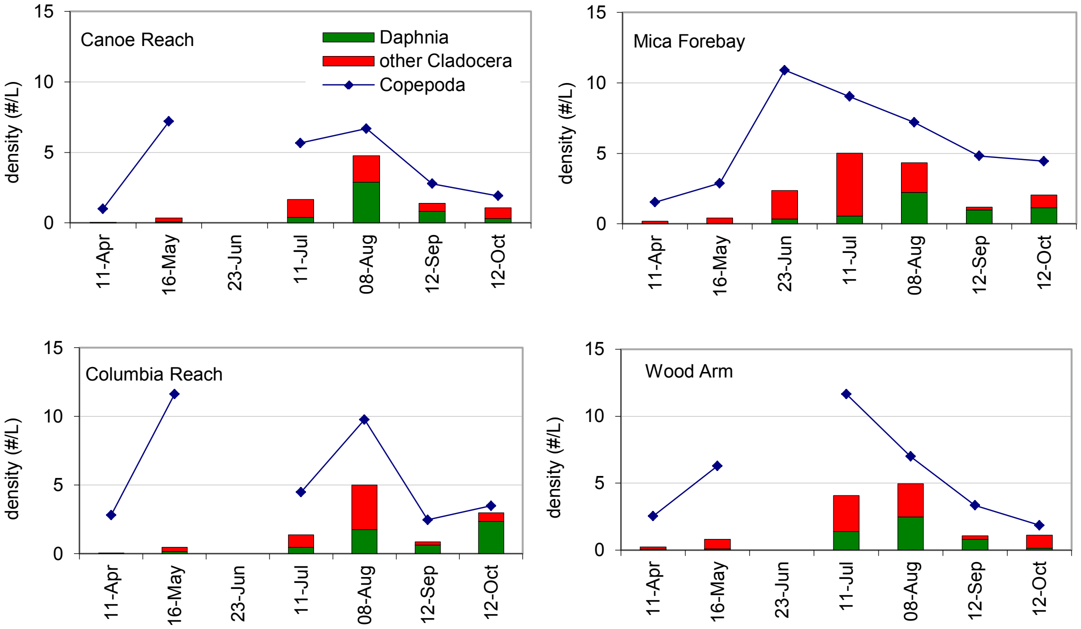

Figure 4. Density of cladoceran and copepod zooplankton at four stations in Kinbasket Reservoir 2016

Copepods were the most abundant zooplankton at all four stations. They numerically prevailed during the whole sampling season, with populations usually peaking in June-July, however June samples were collected only at Mica station in 2016. The highest copepod density was found in July at station Wood Arm with 15.73 individuals/L. (Fig. 4). The number of Cladocerans, mostly *Bosmina,* varied by season as well as along the reservoir. Cladocerans other than *Daphnia* were the most numerous in July-August at each sampling station. The highest density was found in July at Mica Forebay with 4.48 individuals/L. *Daphnia* was present during the whole sampling season at each station. The highest density of *Daphnia* was found in August at Canoe Reach with 2.89 individuals/L. The proportion of *Daphnia* density was the highest at Canoe Reach (13%), while at other stations it varied between 9 and 12%. (Tab. 3, Fig. 5)

Table 3. Seasonal average zooplankton density and biomass at four sampling stations in Kinbasket Reservoir in 2016. Density is in units of individuals/L; biomass is in units of µg/L.

		Canoe Reach	**Mica Forebay**	**Columbia Reach**	**Wood Arm**
Density	Copepoda	4.21	5.83	5.77	5.44
	Daphnia	0.75	0.76	0.90	0.83
	Other Cladocera	0.80	1.47	0.89	1.22
	Total	**5.76**	**8.06**	**7.56**	**7.49**
Biomass	Copepoda	7.23	9.16	9.94	9.63
	Daphnia	12.61	16.62	19.61	15.35
	Other Cladocera	2.82	5.64	1.43	5.33
	Total	**22.67**	**31.42**	**30.99**	**30.31**

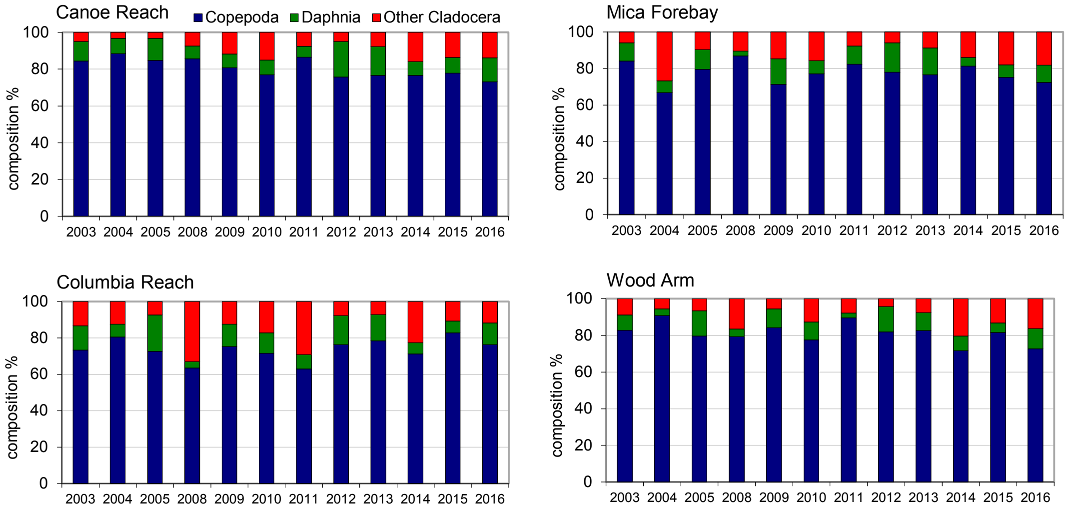

Figure 5. Seasonal average % of zooplankton density composition at four stations in Kinbasket Reservoir in 2003-2016

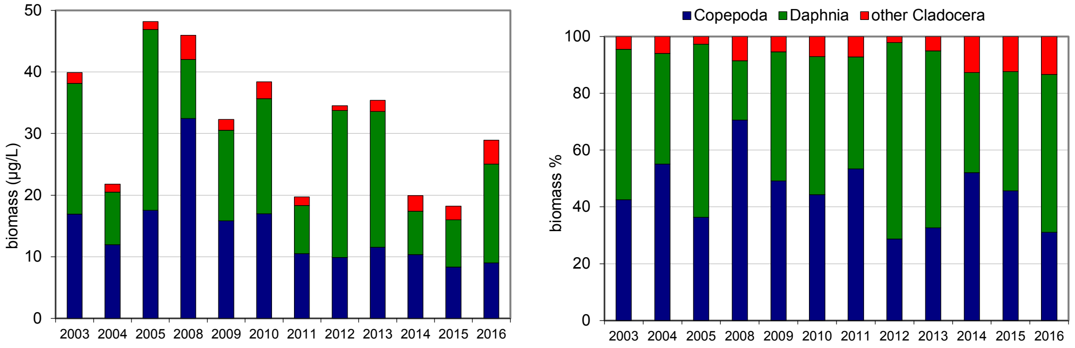

Figure 6. Seasonal average zooplankton biomass in Kinbasket Reservoir 2003-2016

Total zooplankton biomass, averaged for the whole reservoir, was 28.95 µg/L. Copepods contributed to 31% of the total zooplankton biomass with annual average biomass of 9.00 µg/L. *Other Cladocera* had average biomass 3.88 µg/L which comprised 13%, while *Daphnia* made up to 56% of the total zooplankton biomass with 16.07 µg/L (Fig. 6). Average zooplankton biomass for the four stations was low at the beginning of the sampling season. During the rest of the sampling season zooplankton biomass increased reaching its peak in August with 57.59 µg/L, dominated by *Daphnia* with 36.24 µg/L, which made up 63% of the total biomass at that time (Tab. 2, Fig. 3).

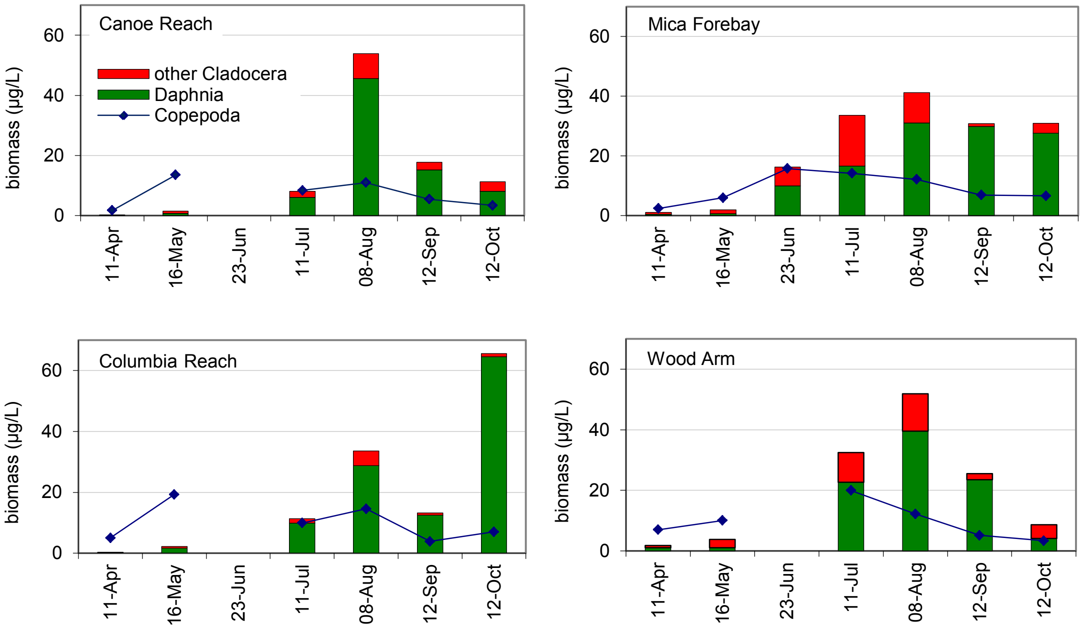

Figure 7. Zooplankton biomass at four stations in Kinbasket Reservoir 2016

Daphnia biomass increased over the course of the study in Kinbasket Reservoir. Although *Daphnia* were present in the samples during the entire season with high biomass from August through October, they accounted for the highest proportion of zooplankton biomass in September and October (75%) (Fig. 3). The highest biomass of *Daphnia* was found in October at Columbia Reach with 64.50 µg/L (Fig. 7). *Daphnia* density and biomass in 2016 were the lowest at Canoe Reach station averaging 0.75 individuals/L contributing to 13% of zooplankton density, and 12.61 µg/L which made up 56% of total zooplankton biomass. During the same time period the highest annual average *Daphnia* density and biomass were found at station Columbia Reach with 0.90 individuals/L and 19.61 µg/L when contributed to 12% of the zooplankton density and 63% of the zooplankton biomass (Fig. 5, Fig.8, Fig. 9).

In 2016 peak total zooplankton density occurred in June at 13.28 individuals/L while the highest biomass was found in August with 57.59 µg/L (Tab. 2, Fig. 3). *Daphnia* was the most numerous in August with 2.34 individuals/L, and the highest biomass of 36.24 µg/L.

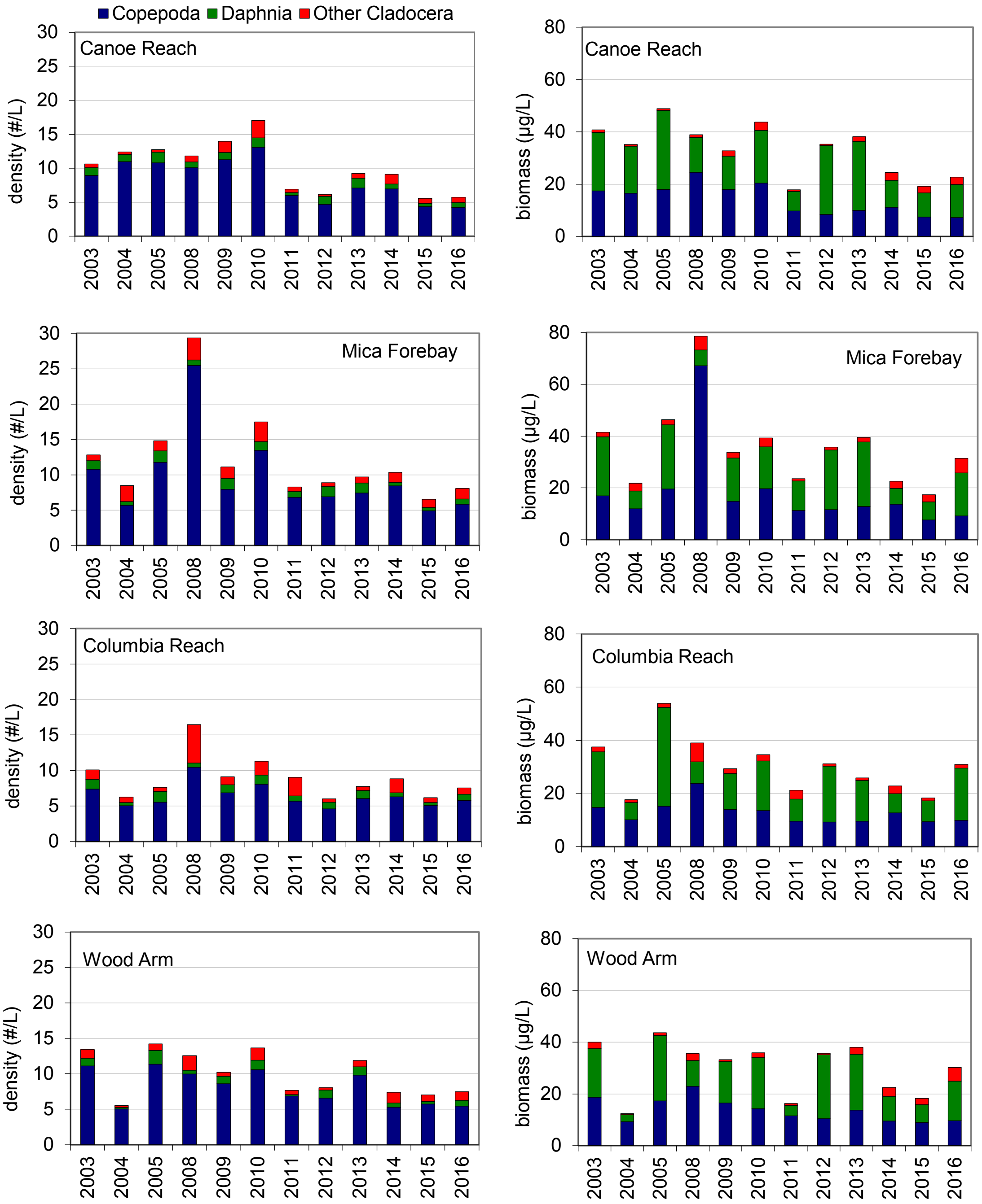

Figure 8. Annual average zooplankton density (left) and biomass (right) at four stations in Kinbasket Reservoir 2003-2016

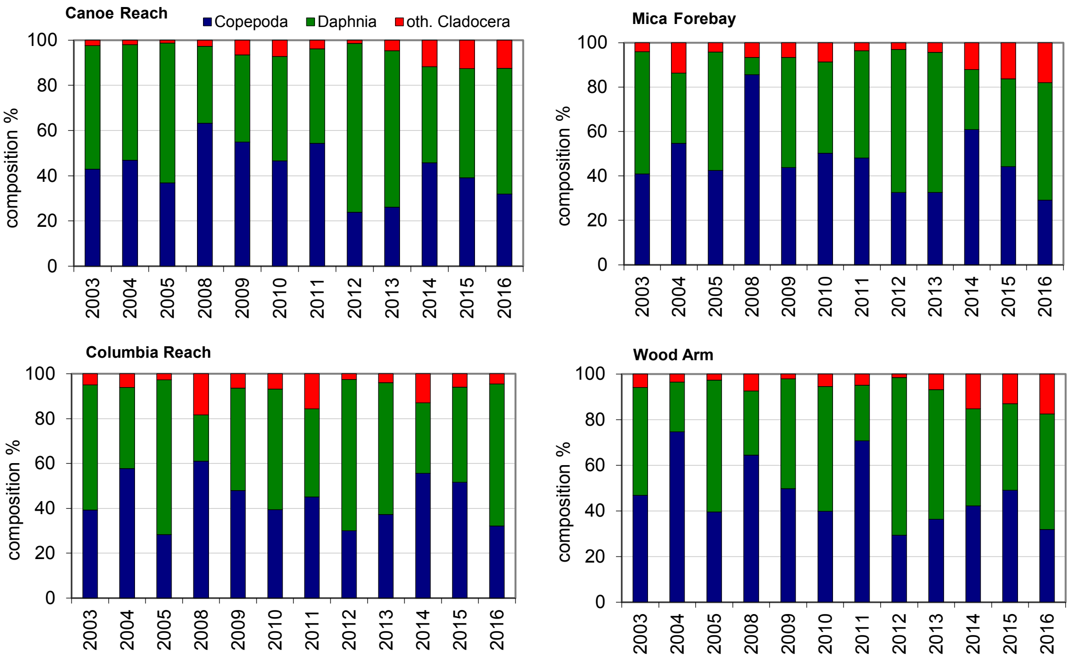

Figure 9. Seasonal average % of zooplankton biomass composition at four stations in Kinbasket Reservoir in 2003-2016

3.3 Daphnia Fecundity

In Kinbasket Reservoir *Daphnia* gravid females were present in samples during the entire sampling season 2016. The proportion of gravid females averaged 0.18 (Tab. 5). The seasonal average number of eggs per gravid female was 2.07. Across the sampling season the number of eggs per water volume averaged 0.18 eggs/L and the number of eggs per capita averaged 0.45 eggs/individual.

Table 4. Fecundity data for *Daphnia* spp. in Kinbasket Reservoir in 2016. Values are seasonal averages, calculated for samples collected between April and October 2016.

	2016
Proportion of gravid females	0.18
# Eggs per gravid Female	2.07
# Eggs per Litre	0.18
# Eggs per Capita	0.45

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 Revelstoke Reservoirs.

Eight species of Cladocera were identified in Revelstoke Reservoir during the study period in 2016 (Tab. 6). *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), *Holopedium gibberum* (Zaddach) and *Leptodora kindtii* (Focke) were common during the entire sampling season, while others were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

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

4.2 Density and Biomass

The seasonal average zooplankton densities observed in 2003, 2008-2016 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 Reservoir was used.

The zooplankton community was primarily composed of copepods, which made up 69% of the zooplankton density and 30% of the zooplankton biomass during the studied period in 2016. *Daphnia* accounted for 12% of the density and 60% of the biomass during the same time period, while other cladocerans comprised 18% of both density and biomass (Fig. 11 and Fig. 12).

Table 5. List of zooplankton species identified in Revelstoke Reservoir in 2003-2016. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2003	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cladocera										
Acroperus harpae	r									
Alona sp.	r			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				r	
Daphnia galeata mendotae	+	+	+	+	+	+	+	+	+	+
Daphnia rosea	+	+	+	+	+	+	+	+	+	+
Daphnia pulex	+	+	+	+	+	+	+	+	+	+
Diaphanosoma brachyurum			r			r	r		r	r
Holopedium gibberum	+	+	+	+	+	+	+	+	+	+
Ilyocryptus sp.									r	
Leptodora kindtii	+	+	+	+	+	+	+	+	+	+
Scapholeberis rammneri	r	r	r	r	r	r	+	+	r	r
Copepoda										
Diacyclops bicuspidatus	+	+	+	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+	+	+	+	+	+	+
Leptodiaptomus sicilis	+	+	+	+	+	+	+	+	+	+

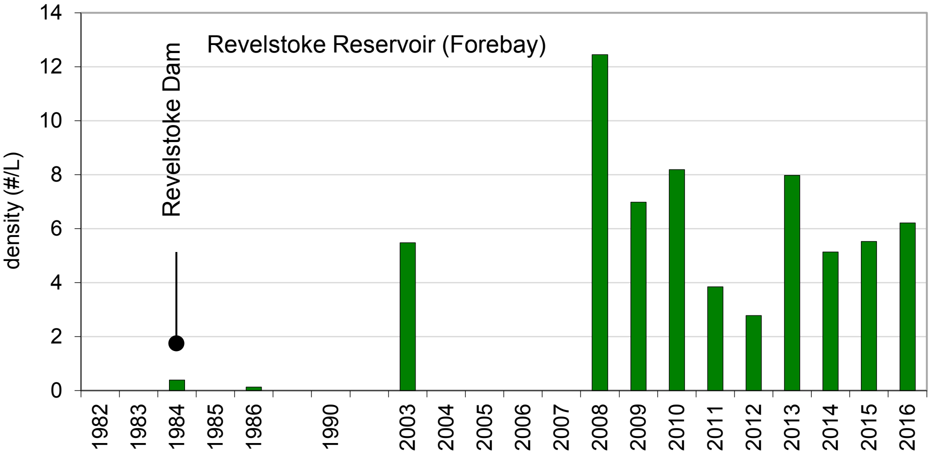

Figure 10. Zooplankton density 1984-2016 at Rev Forebay in Revelstoke Reservoir

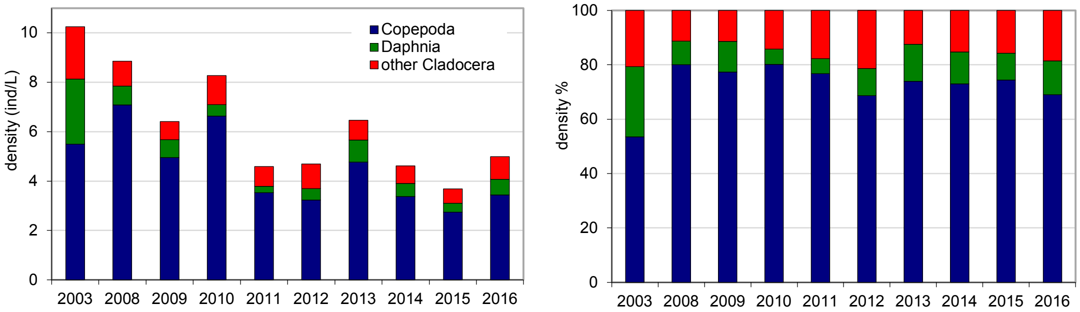

Figure 11. Seasonal average composition of zooplankton density in Revelstoke Reservoir in 2003, 2008 – 2016

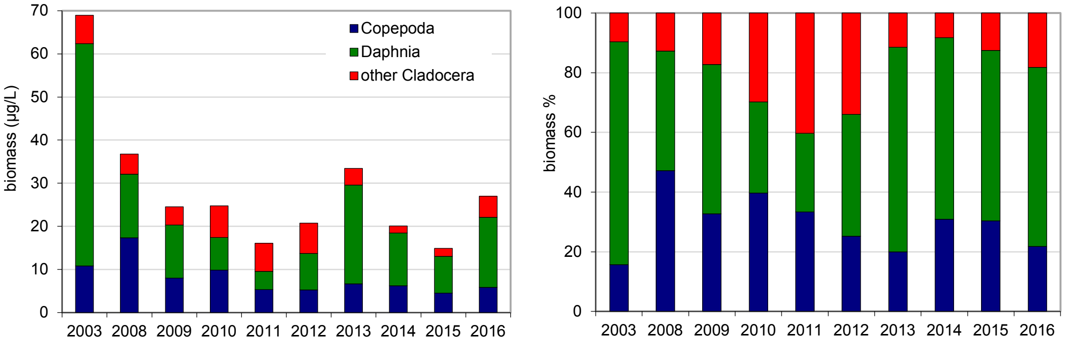

Figure 12. Seasonal average composition of zooplankton biomass in Revelstoke Reservoir in 2003, 2008 – 2016

The seasonal average zooplankton density in 2016 (April to October) increased to 4.99 individuals/L from 3.68 individuals/L in 2015. Copepods were the most abundant with 3.44 individuals/L. Annual average density of *Daphnia* was 0.62 individuals/L, while density of other Cladocera (mainly *Bosmina*) was 0.92 individual/L. (Tab. 7, Fig. 11). Total zooplankton biomass, averaged for the whole reservoir was 27.01 µg/L. Copepods annual average biomass was 5.87 µg/L, while *Daphnia* and other cladocerans biomass was 16.22 µg/L, and 4.92 µg/L respectively (Tab. 7; Fig. 12).

Table 6. Annual average zooplankton abundance and biomass in Revelstoke Reservoir 2016 (April to October).

		ind/L	**%**
Density	Copepoda	3.44	69
	Daphnia	0.62	13
	other Cladocera	0.92	19
	Total	**4.99**	
		µg/L	**%**
Biomass	Copepoda	5.87	22
	Daphnia	16.22	60
	other Cladocera	4.92	18
	Total	**27.02**	

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 June with 9.97 individuals/L (Fig. 13). Seasonal average zooplankton biomass in 2016 also increased in comparison to the previous year (Fig. 12). The highest zooplankton biomass averaged for the whole reservoir was found in August with 55.03 µg/L (Fig. 13). Among the stations, the highest total zooplankton density was seen at Rev Forebay in May with 14.85 individuals/L, while the highest biomass was found in August at station Rev Middle with 119.85 µg/L (Fig. 14).

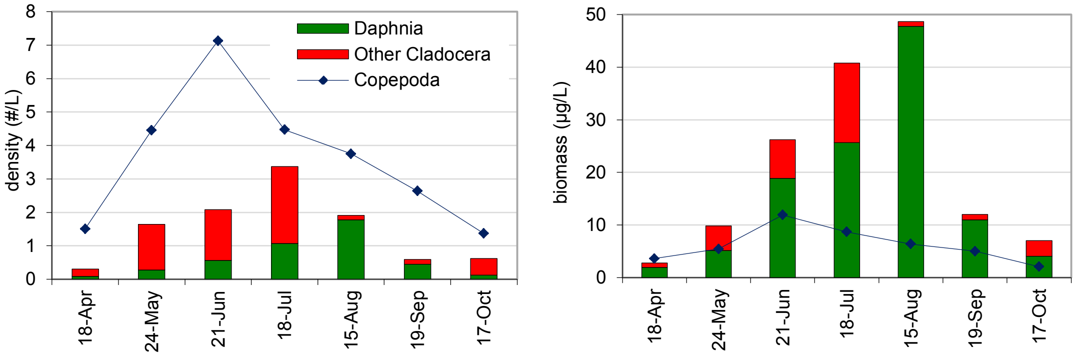

Figure 13. Monthly average zooplankton density (top) and biomass (bottom) in Revelstoke Reservoir in 2016

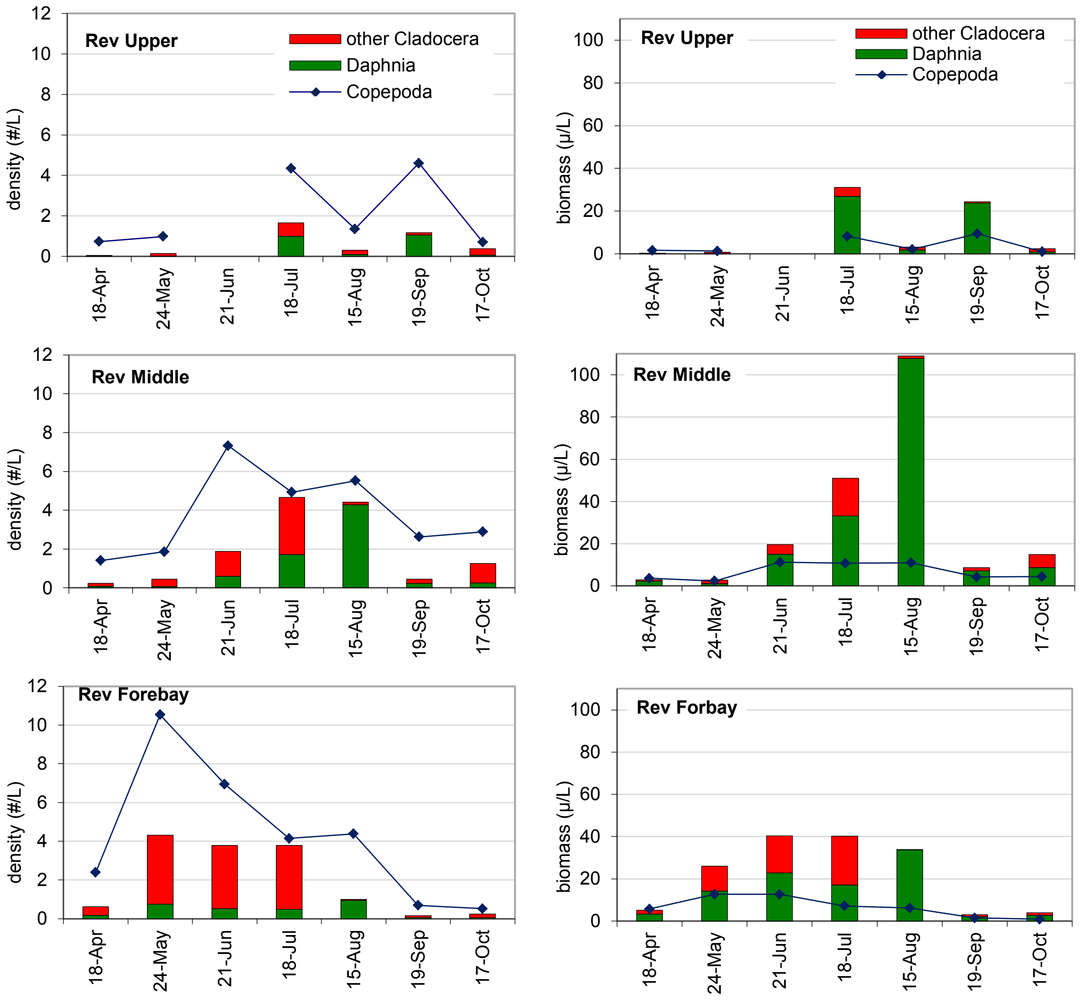

Figure 14. Zooplankton density and biomass at three stations in Revelstoke Reservoir 2016

During 2016 sampling season Copepods were the most numerous in May and June consisting mainly of *D. bicuspidatus thomasi.* They numerically prevailed during the whole sampling season, with the most numerous populations of 10.53 individuals/L found at station Rev Forebay in May (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 May-August, and decreasing during the fall. *Daphnia* density increased at the end of summer and trough fall, while number of other Cladocera peaked in June or July (Fig. 13). Other Cladocerans were composed mainly of *Bosmina*, averaging 0.86 individuals/L in the whole reservoir. In May 2016, at station Rev Forebay the number of other cladocerans was the highest in the season due to a peak of *Bosmina* with 3.57 individuals/L (Fig. 14). In terms of biomass, other cladocerans contributed 18% to the total zooplankton biomass.

Number of *Daphnia* was low during the entire sampling season in 2016. It was less than 1 individual/L at each station except in July and August at Rev Middle. Although *Daphnia* were present in samples during the entire season, they accounted for 5 to 31% of the zooplankton community from April to October. Its density was relatively low averaging 0.09 to 0.78 individual/L at all three stations (Fig. 13). However, *Daphnia* biomass was the highest of three zooplankton groups averaging 16.22 µg/L during the sampling season 2016 (Fig. 12, Tab.7). The highest *Daphnia* biomass was found at Rev Middle station with 107.82 µg/L in August, when *Daphnia* accounted for 90% of the total zooplankton biomass at that time (Fig. 14).

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 early summer, and a cladoceran increase in the summer and 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 October.

During 2016 peak total zooplankton density occurred in June with 9.97 individuals/L (Tab. 8, Fig. 13). The peak total zooplankton biomass occurred in August with 55.03 µg/L, when *Daphnia* biomass contributed to 87% of the total zooplankton biomass with 47.78 µg/L.

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).

Table 7. Monthly average density and biomass of zooplankton in Revelstoke Reservoir in 2016. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		18-Apr	24-May	21-Jun	18-Jul	15-Aug	19-Sep	17-Oct
	Copepoda	1.51	4.46	7.13	4.47	3.75	2.64	1.37
	Daphnia	0.09	0.28	0.56	1.07	1.78	0.45	0.12
	Other Cladocera*	0.22	1.36	1.52	2.30	0.13	0.15	0.50
	Total Zooplankton	**1.81**	**6.10**	**9.97**	**7.84**	**5.66**	**3.23**	**1.99**
Biomass		18-Apr	24-May	21-Jun	18-Jul	15-Aug	19-Sep	17-Oct
	Copepoda	3.62	5.44	11.89	8.68	6.38	5.01	2.06
	Daphnia	1.91	5.16	18.86	25.69	47.78	10.99	4.07
	Other Cladocera**	0.84	4.66	7.38	15.09	0.88	1.02	2.94
	Total Zooplankton	**6.38**	**15.26**	**41.82**	**49.46**	**55.03**	**17.02**	**9.07**

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

4.4 Daphnia Fecundity

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 0.18 in 2016 (Tab. 10). The seasonal average number of eggs per gravid female was 2.80. Across the sampling season the number of eggs per water volume averaged 0.17 eggs/L, and the number of eggs per capita averaged 0.52 eggs/individual over the study period in 2016.

Table 8. Fecundity data for *Daphnia* spp. in Revelstoke Reservoir 2016. Values are seasonal averages, calculated for samples collected between April and October.

	2016
Proportion of gravid females	0.18
# Eggs per gravid Female	2.80
# Eggs per Litre	0.17
# Eggs per Capita	0.52

5. Conclusions

Both Reservoirs Kinbasket and Revelstoke are 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. In both reservoirs increased in 2016 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, 2016

Roger Pieters and Greg Lawrence
University of British Columbia

Moorings, Kinbasket and Revelstoke Reservoirs, 2016

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The mooring at Upper Revelstoke being towed behind the boat just before deployment, 25 August 2016.

Prepared for

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January 8, 2018

Contents

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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 selected 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 goal of the CLBMON-56 addendum is to collect data from moorings of temperature recorders at fixed locations.

Included in this work is collection of data from 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 also been moored at other locations, such as at the mid and upper sampling stations in Revelstoke Reservoir. These moorings may be moved in subsequent years to examine processes at other locations.

Data from moored temperature recorders will complement data gathered by conductivity-temperature-depth (CTD) surveys for CLBMON-3, conducted on average once a month from May to October (Pieters and Lawrence 2018). 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 includes 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 all linked to understanding pelagic productivity.

2. Methods

During the summer of 2012, a trial of four different types of moorings was undertaken in the forebay of Revelstoke Reservoir. These four types have subsequently been used for moorings at other locations. The four types of moorings are given in Table 2.1 and illustrated in Figure 2.1. The location of all moorings is given in Table 2.2.

Table 2.1 Type of moorings

Name	Description
SUB	Subsurface mooring
BOOM	Line from log boom near dam
SPAR	Spar mooring
PROF	Autonomous profiler

Table 2.2 Location of moorings

Name	UTM Easting(11U)/Northing	Latitude/ Longitude
Rev FB SUB	416,926E 5,657,518N	51° 3.790 N 118° 11.132 W
Rev FB BOOM	416,468E 5,656,304N	51° 3.131 N 118° 11.507 W
Rev FB PROF	417,057E 5,657,845N	51° 3.968 N 118° 11.024 W
Rev FB SPAR	416,846E 5,657,294N	51° 3.668 N 118° 11.197 W
Rev LAF* PROF	413,627E 5,677,983N	51° 14.799 N 118° 14.250 W
Rev LAF* SPAR	413,857E 5,677,722N	51° 14.662 N 118° 14.049 W
Rev MID SUB	398,452E 5,699,022N	51° 25.997 N 118° 27.652 W
Rev UP SUB	385,521E 5,731,847N	51° 43.550 N 118° 39.451 W
Kin FB SUB	393,754E 5,772,744N	52° 5.702N 118° 33.058 W
Kin FB BOOM	392,223E 5,771,051N	52° 4.772 N 118° 34.368 W
Kin MID SPAR	400,307E 5,775,586N	52° 7.309 N 118° 27.371 W

* Near La Forme Creek, ~18 km north of Revelstoke Dam, and 30 km south of Rev MID at Downie.

From July 2012 to August 2017, 53 moorings were successfully deployed and recovered in a variety of locations. The location, type and duration of moorings are summarized in Table 2.3.

Table 2.3 Moorings, 2012 to 2017

N	RES	LOC	TYPE	START	END
201	REV	FB	SUB	16-Aug-2012	11-Oct-2012
202	REV	FB	TB*	18-Jul-2012	11-Oct-2012
203	REV	FB	SPAR	16-Aug-2012	11-Oct-2012
204	REV	FB	PROF	11-Sep-2012	11-Oct-2012
205	REV	FB	SUB	11-Oct-2012	26-Aug-2013
206	REV	FB	BOOM	11-Oct-2012	26-Aug-2013
207	REV	MID	SUB	12-Sep-2012	26-Aug-2013
208	REV	UP	SUB	12-Sep-2012	26-Aug-2013
209	KIN	FB	SUB	13-Sep-2012	30-Aug-2013
210	KIN	FB	BOOM	13-Sep-2012	30-Aug-2013
211	REV	FB	SPAR	25-Apr-2013	20-May-2014
212	REV	FB	PROF	25-Apr-2013	20-May-2014
213	REV	MID	SPAR	26-Apr-2013	20-May-2014
214	REV	MID	PROF	26-Apr-2013	20-May-2014
215	REV	FB	SUB	28-Aug-2013	22-Aug-2014
216	REV	FB	BOOM	28-Aug-2013	22-Aug-2014
217	REV	MID	SUB	29-Aug-2013	22-Aug-2014
218	REV	UP	SUB	29-Aug-2013	22-Aug-2014
219	REV	UP	PROF	29-Aug-2013	22-Aug-2014
220	KIN	FB	SUB	30-Aug-2013	29-Aug-2014
221	KIN	FB	BOOM	30-Aug-2013	29-Aug-2014
222	REV	FB	PROF	23-May-2014	22-Aug-2014
223	REV	MID	SPAR	11-Jul-2014	22-Aug-2014
224	REV	MID	PROF	11-Jul-2014	22-Aug-2014
225	REV	FB	SUB	27-Aug-2014	28-Aug-2015
226	REV	FB	BOOM	27-Aug-2014	28-Aug-2015
227	REV	FB	PROF	27-Aug-2014	28-May-2015
228	REV	MID	SUB	28-Aug-2014	28-Aug-2015
229	REV	MID	PROF	28-Aug-2014	28-May-2015
230	REV	UP	SUB	28-Aug-2014	28-Aug-2015
231	KIN	FB	SUB	29-Aug-2014	02-Sep-2015
232	KIN	FB	BOOM	29-Aug-2014	11-Dec-2014
233	KIN	FB	BOOM2	25-May-2015	02-Sep-2015
234	REV	MID	PROF	02-Jun-2015	26-May-2016
235	REV	FB	PROF	03-Jun-2015	26-May-2016
236	REV	LAF	PROF	03-Jun-2015	26-May-2016
237	REV	LAF	SPAR	03-Jun-2015	26-May-2016
238	REV	FB	SUB	01-Sep-2015	19-Aug-2016
239	REV	FB	BOOM	01-Sep-2015	19-Aug-2016
240	REV	MID	SUB	01-Sep-2015	19-Aug-2016
241	REV	UP	SUB	01-Sep-2015	19-Aug-2016
242	KIN	FB	SUB	02-Sep-2015	24-Aug-2016
243	KIN	FB	BOOM	02-Sep-2015	24-Aug-2016

Table 2.3 Moorings, 2012 to 2017 continued

N	RES	LOC	TYPE	START	END
244	KIN	MID	SPAR	01-Jun-2016	24-Aug-2016
245	REV	FB	PROF	01-Jun-2016	31-May-2017
246	REV	LAF	PROF	02-Jun-2016	31-May-2017
247	REV	MID	PROF	02-Jun-2016	31-May-2017
248	REV	FB	SUB	23-Aug-2016	29-Aug-2017
249	REV	FB	BOOM	23-Aug-2016	22-Jun-2017
250	REV	MID	SUB	25-Aug-2016	25-Aug-2017
251	REV	UP	SUB	25-Aug-2016	28-Aug-2017
252	KIN	FB	SUB	24-Aug-2016	30-Aug-2017
253	KIN	FB	BOOM	24-Aug-2016	25-Apr-2017

* Trial line of Onset TidBits at Revelstoke Dam boom, see Pieters and Lawrence (2016b).

Temperature recorders consisted of Onset Hobo Water Temp Pro V2 (HWTP) recorders, Seabird SBE56 recorders and RBR SoloT recorders. The characteristics of the temperature recorders are given in Table 2.4. Because of their low cost, HWTP recorders were typically used every 2 m while the more accurate, but more expensive SBE56 or SoloT recorders were used every 20 m.

Table 2.4 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 SoloT	0.00005 °C	±0.002 °C	~1 sec	5 sec	1700 m

To assess movement of the moorings, pressure (depth) recorders were also used. These were either RBR Duo TD recorders which measure both temperature and pressure, or RBR SoloD recorders.

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/100 m, average strength 3000 kg). The line was chosen to be buoyant, have good handling, low abrasion and little stretch.

All except the BOOM moorings use an Interocean Model 111 acoustic release, which 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 (or frees the spar). 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. The option of extended-life battery enables deployments for up to one year.

A schematic of the four types of moorings is shown in Figure 2.1 for Revelstoke Forebay, and are described as follows. Moorings at other locations were similar in design.

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 (below). This line rises and falls with water level. 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) diameter 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 an 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.

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 profiler. This type of profiler is normally deployed in the open ocean where it parks at depth (e.g. 1000 m), and rises on a regular basis (e.g. every 10 days) to collect a profile of temperature, conductivity and other parameters; upon reaching the ocean surface, the data and GPS location of the profiler is telemetered by ARGO satellite. The profiler then returns to depth to await the next cycle. There are thousands of these profilers throughout the oceans collecting data that would otherwise be very costly to gather by boat.[1] Most of these ocean profilers are treated as expendable, lasting about three years.

We were able to purchase three Apex profilers through the NSERC Research Tools and Instruments program. The three profilers 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. The tether makes these profilers suitable for mooring in lakes and reservoirs. Since the profiler does not rise all the way to the surface, it does not have satellite communications, and instead data is recorded within the profiler. The

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[1] See http://www.argo.ucsd.edu/About_Argo.html

profiler 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 profilers each have a Seabird SBE 41cp CTD, and a Seapoint turbidity sensor.

3. Temperature Moorings

In this section, data from the temperature moorings are shown as both line and contour plots. In the line plots, the temperature is plotted on the y-axis, and the temperature at each depth is plotted in a different color (color gives depth). In the contour plots the depth is plotted on the y-axis, and each temperature is given a different color (color gives temperature). All data are shown in days of 2008, the first year of the CLBMON-3 program.

3.1 Temperature Moorings in Revelstoke Reservoir

REV FB SUB (Figure 3.1.1 and 3.1.2) Data from 2012 to 2017, are shown as both a line plot (Figure 3.1.1) and a contour plot (Figure 3.1.2). There were short (< 1 week) gaps in the data at the end of August during which time the mooring was serviced. There was also a gap of about one month in the data in September 2015 due to an acoustic release that malfunctioned and opened shortly after deployment. The mooring was found floating on the surface, recovered and redeployed. Temperature recorders were at nominal depths (relative to full pool) of 4.4 to 125 m.

The line plot shows that the near surface (4.4 m) temperature briefly reaches just over 20 °C in July or August of most years (Figure 3.1.1). The temperature near the bottom (125 m) varied around the temperature of maximum density (4 °C), rising slowly to just over 5 °C during the summer, and cooling below 4 °C in winter. What is evident is that there was significantly more cooling in the winters of 2013-2014 and 2016-2017 than in the other winters on record. This may have resulted from colder weather or windier conditions.

The mooring shows the seasonal temperature cycle as follows:

- The warm surface layer cools and deepens beginning in late August.
- Fall turnover begins in December and the entire water column cools from ~6 °C to a minimum of 1 to 3 °C in March.
- Some periods of reverse stratification were observed in the winters of 2013-2014 and 2016-2017. Reverse stratification occurs when the water column is < 4 °C; as the surface cools further, this colder and less dense water resists mixing into the warmer (closer to 4 °C) and more dense water at depth.
- Spring turnover begins in March as the entire reservoir warms from winter minimum up to 4.0 °C by April.
- Persistent summer temperature stratification occurs after April.
- The summer stratification is modulated by internal waves at a variety of time scales (see examples in Pieters and Lawrence 2016).

- During summer, the temperature at the bottom (125 m) is comparatively steady, rising very slowly by ~0.2 °C/month, which is similar to that observed in other deep lakes.

The contour plot (Figure 3.1.2) shows the warm (>15 °C) surface layer is limited to the top 10 to 20 m during the summer. At the same time, there is a layer of water around 8 °C that extends from about 10 to 50 m which indicates the interflow.

REV FB BOOM (Figures 3.2.1 and 3.2.2) A line with instruments was hung from the log boom just upstream of Revelstoke Dam as part of the base mooring in Revelstoke Forebay, to collect data from the top 10 m of the water column. Data were not available from 22 June to 31 August 2017 as the line was removed for replacement of the log boom during this time.

For the most part, the temperature was relatively uniform in the top 10 m, though there were some periods of stratification within the top 10 m during summer. The coldest temperature at 0.5 m was 0.25 °C in March 2017.

REV MID SUB (Figures 3.3.1 and 3.3.2) This mooring was deployed at the Rev MID sampling station near Downie Arm. At this location, about halfway up Revelstoke Reservoir, turnover occurred from late October to November each year, earlier than at the Rev FB station, but this may simply reflect that the Rev MID station is shallower. In addition, fall and spring turnover at the Rev MID mooring showed more periods of temporary stratification than at Rev FB, and included slightly longer and cooler periods of reverse stratification. Summer temperature stratification began at Rev MID after the reservoir reached ~4 °C in April in most years.

REV UP SUB (Figure 3.4.1 and 3.4.2) This mooring was deployed near the Rev UP sampling station. This station is not only shallower but more riverine, showing less temperature stratification than at the MID and FB sites, as can be seen by comparing the contour plots. Reduced stratification was particularly noticeable during high flows in the summer of 2015 (Figure 3.4.1).

At the start of the first deployment in September 2012 there was little temperature stratification, and fall turnover began on 4 October 2012 (day 1739, Figure 3.4.1). 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 to 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, in some years, summer stratification began sooner, in late March and early April.

3.2 Temperature Moorings in Kinbasket Reservoir

KIN FB SUB (Figures 3.5.1 and 3.5.2) Because of the large water level variations in Kinbasket Reservoir, the top of the Kin FB SUB mooring had to be kept deeper, just below the minimum water level (40 m below full pool). To provide data from the upper water column at high water level, the Kin FB BOOM mooring was longer, extending to 40 m depth.

Data from 40 to 180 m depth are shown in Figures 3.5.1 and 3.5.2. In summer, the temperature at 40 m reaches 10 to 13 °C (Figure 3.5.1). In fall, the temperature at shallower depths cools (Figure 3.5.1) as the surface layer deepens (Figure 3.5.2) until the entire water column is close to the temperature of maximum density (4 °C) in January of each year.

From February to April, reverse stratification is observed. As shallower water cools below the temperature of maximum density, 4 °C, it becomes less dense, and this colder buoyant water caps the warmer water near 4 °C. Like in Revelstoke, longer periods of reverse stratification were observed in the 2013-2014 and 2016-2017 winters, suggesting these winters were colder and/or windier. Note that in the winter of 2012-2013, the entire water column cooled slightly (0.2 °C) below 4 °C.

In Kinbasket forebay, there was no distinct period of either fall or spring turnover (Figure 3.5.1), in contrast to Revelstoke Reservoir (Figures 3.1.1, 3.3.1, and 3.4.1). For example, 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 seeming to mix with water below 100 m depth.

One possibility is that a small salinity stratification may have affected turnover. There was a slight salinity stratification observed in some 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 in Pieters and Lawrence 2014). Pressure effects may also play a role below ~150 m.

Also, complete spring turnover did not occur; rather, the top 80 m warmed through 4 °C, leaving the deep temperature below 4 °C (e.g. 3.6 °C in spring 2013). The deep water warmed gradually (~0.05 °C/mo) through the summer, suggesting a small degree of exchange with water above 100 m, similar to that observed in Revelstoke Reservoir. Note, that the Sea-Bird profiles indicated that the deep water remained well oxygenated (e.g. Figure B1e in Pieters and Lawrence 2018).

KIN FB BOOM (Figures 3.6.1 and 3.6.2) Unfortunately, in 2012-2013 the instruments on the boom mooring below 2 m were lost (likely due to a shackle that was not closed tightly). In 2013-2014, the mooring appeared to have rubbed against a line holding the log boom in place, and instruments below 16 m were lost. In December 2014 the boom broke, and the boom and instrument line were found on shore. The top two instruments were broken but the rest were undamaged and the mooring was redeployed in May 2015. Finally, the line was removed for repair of the boom from 25 April to 3 May 2017. Available data are plotted in Figures 3.6.1 and 3.6.2, and show a seasonal cycle similar to that in Revelstoke Reservoir.

4. Profilers

From 2012 to 2017, three profilers were deployed at various locations in Revelstoke Reservoir (Table 2.3). In this report, all available profiler data has been plotted over the same time period for a given year, May to November, which is the stratified productive season. The time, depth, temperature, salinity, and turbidity scales have been kept the same in all figures to facilitate comparison between locations and years. The only exception is the salinity scale for Rev UP in 2014, in which the lower bound of the salinity scale was set to 25 rather than 30 mg/L to accommodate fresh water observed during the spring (Figure 4.5c). The 1% light levels determined from Sea-Bird profiles (Pieters and Lawrence, 2018) are marked with black plus signs (+) in the second panel of each figure.

To understand the patterns observed in the profiler data, consider briefly the summer circulation of Revelstoke Reservoir. The flow and conductivity in Revelstoke Reservoir can be roughly divided into two periods (Pieters and Lawrence, 2018). In the first period, during spring and early summer, inflow from Kinbasket Reservoir is relatively low, and inflow to Revelstoke Reservoir is dominated by relatively fresh snowmelt from local tributaries. This typically results in the development of relatively low salinity which extends throughout the top 60 m of the reservoir by mid-July.

In mid-July, a big change occurs in most years with the sudden increase of deep outflow from Kinbasket Reservoir, from less than 100 m^3/s to greater than 1000 m^3/s. This outflow is cool and slightly more saline, and forms an interflow along the length of the reservoir centered on the outlet at Revelstoke Dam (30 m depth). This interflow is typically inserted into the less saline spring melt water, and remnants of the low salinity water can, in some years, be observed both near the surface and around 60 m depth all the way into October (e.g. Figure 4.3b). After October, fall cooling and deepening of the surface layer act to mix the interflow below with the remnants of spring inflow water near the surface.

Revelstoke FB Profiler, Sep-Oct 2012 (Figure 4.1) The first profiler was deployed as a trial for one month 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 4.1. This data is plotted on a large time scale for comparison with subsequent data. The profiler data was shown on expanded scale in the previous report (Figure 3.5, Pieters and Lawrence, 2016).

Revelstoke UP Profiler, Aug – Nov 2013 (Figure 4.2) In 2013-2014, the three profilers were deployed at the Rev FB, MID and UP stations. While the profilers were successfully recovered, data was accidently erased from the Rev FB and Rev MID profilers (the self-test command erases memory). The data from the Rev UP profiler is shown here for the 2013 productive season. There is little stratification in temperature (as observed in the temperature moorings, Figures 3.4.1 and 3.4.2), and little stratification in salinity and turbidity as well.

Revelstoke FB Profiler, May – Nov, 2014 (Figure 4.3) This is the first plot showing the evolution of temperature, salinity and turbidity over the whole productivity season. The emergence of thermal stratification is seen beginning in late May (Figure 4.3a). At the same time, a deepening layer of slightly fresher water is evident in salinity (Figure 4.3b, late May to mid-August).

From mid-August to mid-October the interflow is evident as a layer of slightly increased salinity centered on 30 m (Figure 4.3b). The interflow is modulated by internal motions with a period of 5 to 15 days, which can bring the interflow into the photic zone, and even bring the interflow to the surface. After mid-October, the interflow was mixed to the surface by fall cooling. By mid-November, the surface layer extended to the bottom of the interflow, 60-70 m depth. Turbidity shows occasional pulses, as well as an increase near the bottom in the fall (Figure 4.3c).

Revelstoke MID Profiler, May – Nov, 2014 (Figure 4.4) The profiler at Rev MID shows a similar seasonal pattern as that at Rev FB, except that the interflow appears a little sooner, in early August (Figure 4.4c). White bars mark occasions when the profiler failed to rise to the surface.

Revelstoke UP Profiler, May – Nov, 2014 (Figure 4.5) There were many occasions when the profiler failed to rise to the surface, especially toward the end of the record. As observed in the previous fall, there was little stratification in temperature, salinity, or turbidity at Rev UP (Figure 4.5). However, the presence of slightly more saline (and less turbid) water from Kinbasket Reservoir can be seen in late July, first below 20 m and then throughout the water column.

Revelstoke FB, LAF and MID Profilers, May – Nov, 2015 (Figure 4.6 - 4.8)

In May 2015, the profiler that had previously been at the Rev UP station was deployed near La Forme Creek (station Rev LAF), which is located about 18 km upstream of the Rev FB station, but downstream of the Rev MID station. The purpose was to understand the variation in internal motions between the Rev FB and Rev MID stations.

Note that, after 21 September 2015 (day 261), the Rev LAF profiler no longer rose to the surface. This coincided with an extraordinary rain event on 20 September 2015.

Elevated tributary turbidity was observed to originate from high elevations which lacked snow cover. This storm may have contributed to the heavy layer of fine material found on the profiler when it was recovered, and this material may have prevented the profiler from rising.

In 2015, the flow from Kinbasket Reservoir did not drop as much in the spring, remaining much higher through the summer. As a result, the interflow appeared earlier in the year: it was observed at the Rev MID station by the end of June 2015 (Figure 4.8b), at Rev LAF by early July 2015 (Figure 4.7b), and at Rev FB by mid-July 2015 (Figure 4.6b).

Revelstoke FB, LAF and MID Profilers, May – Nov, 2016 (Figure 4.9 - 4.11)

In May 2016, the profilers were re-deployed in the same locations along the lower reach of Revelstoke Reservoir (Figures 4.9 – 4.11). Note, there were times when a profiler did not reach the surface indicated by the white bars; the ballasting of each profiler was adjusted in May 2017. In October 2016, the profiler at LAF stopped rising, and testing revealed that the buoyancy pump was stuck; the profiler will be returned to the manufacturer for service.

In May 2016, the salinity of the surface water began to decline, and this layer of fresher water deepened through June to August (e.g. FB, Figure 4.9b). In 2016, the interflow of Kinbasket water was first observed in mid-July at the MID profiler (Figure 4.11b), then in late-July at the LAF profiler (Figure 4.10b), and finally in early August at the FB profiler (Figure 4.9b). The interflow was, at times, in the photic zone.

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Figure 2.1 Revelstoke Forebay Moorings, 2012

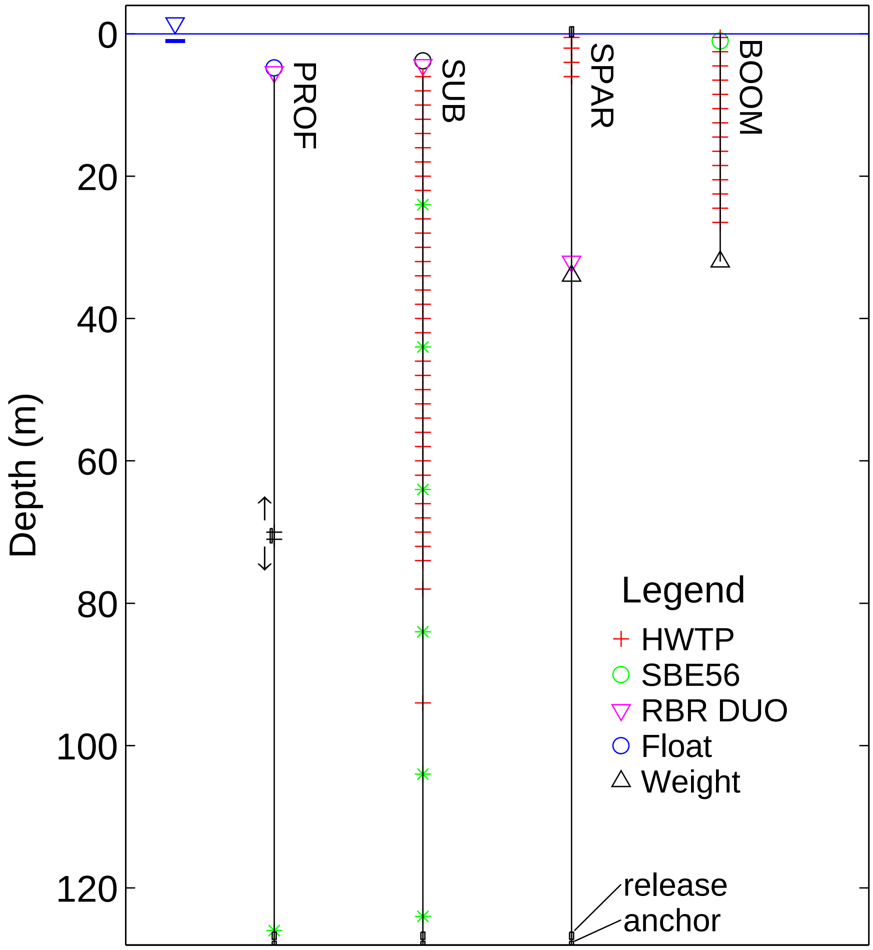

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Figure 3.1.1 Revelstoke Forebay Subsurface Mooring, 2012−2017

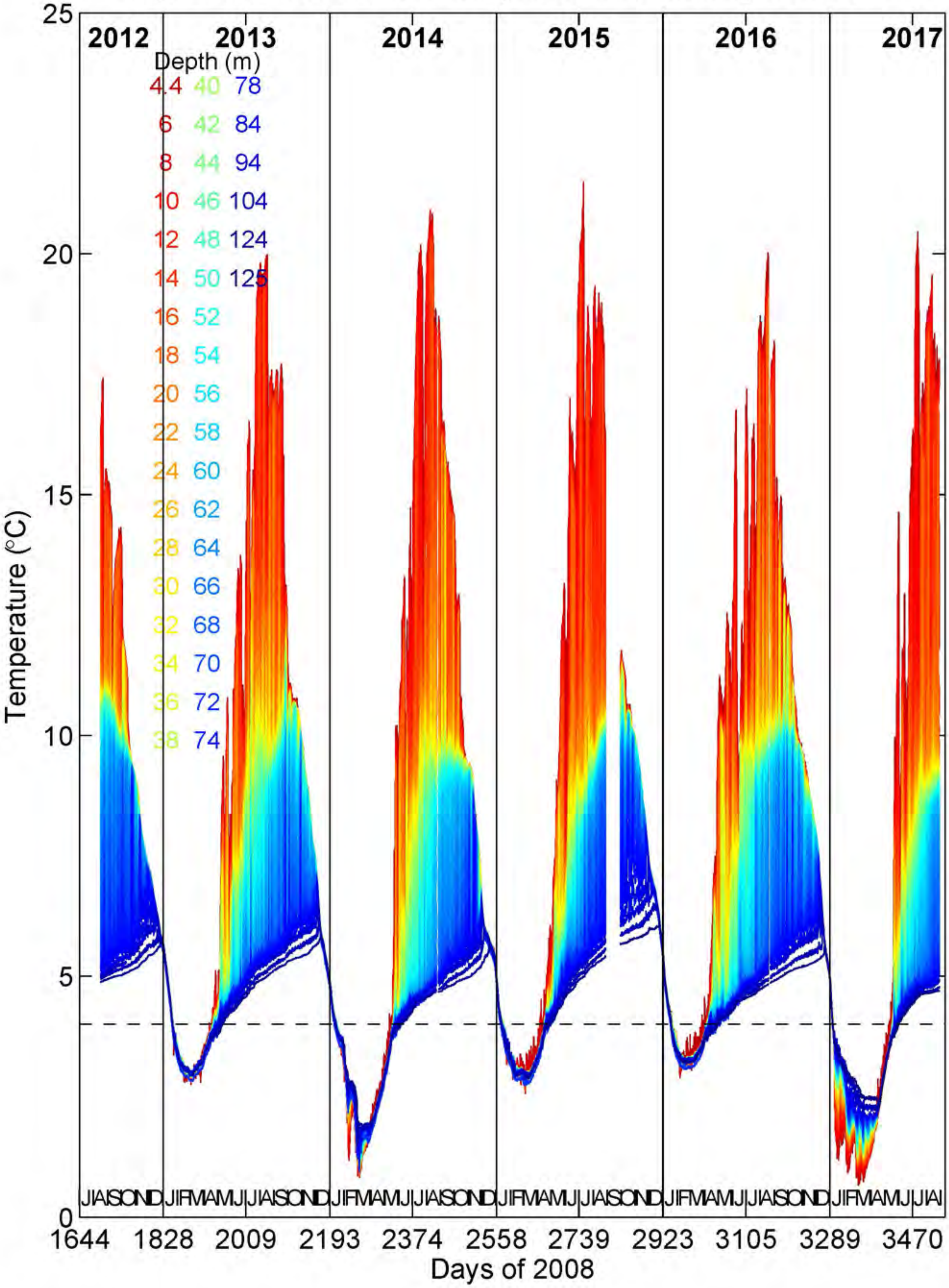

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Figure 3.1.2 Revelstoke Forebay Subsurface Mooring, 2012−2017

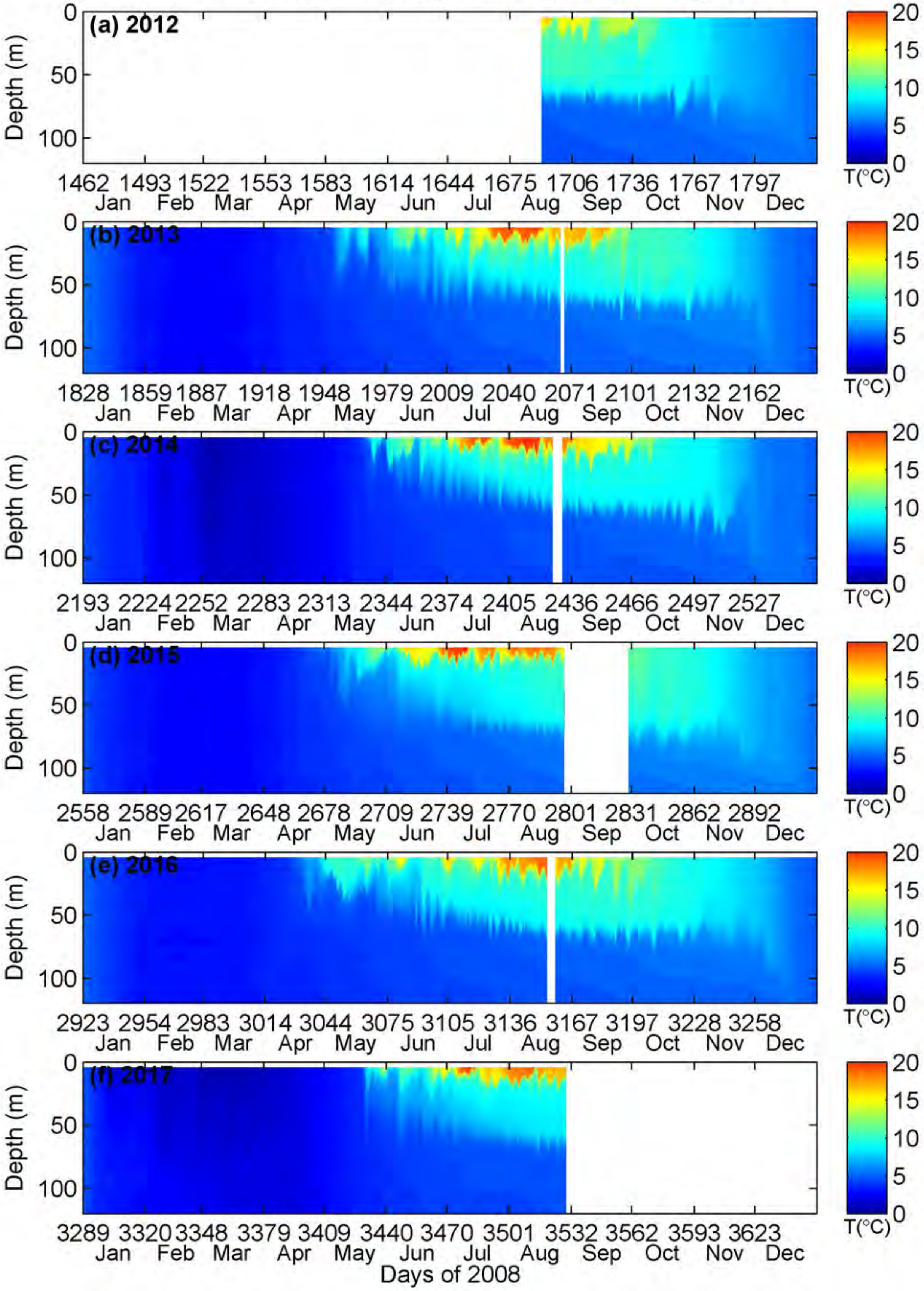

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Figure 3.2.1 Revelstoke Forebay Boom Mooring, 2012−2017

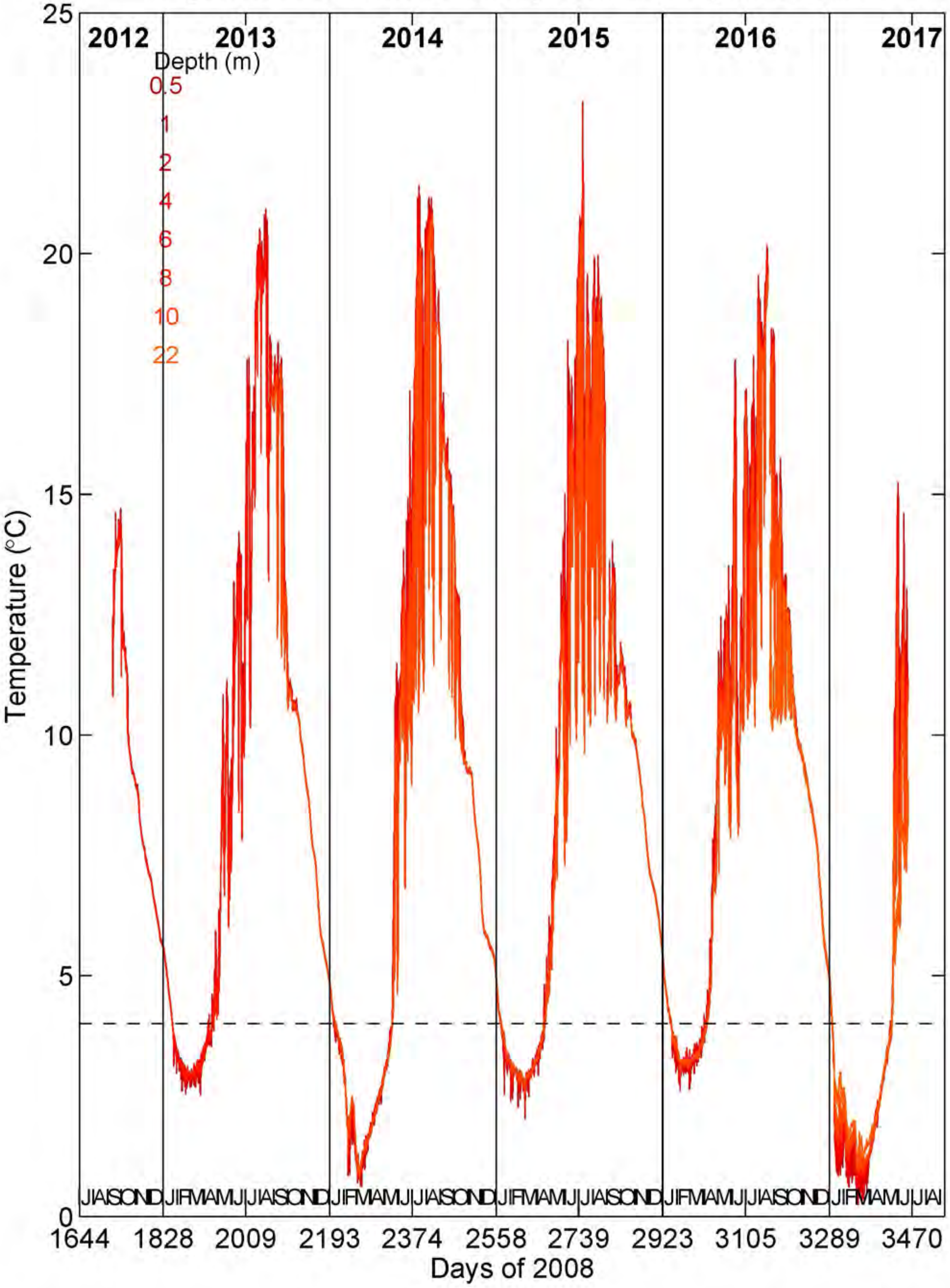

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Figure 3.2.2 Revelstoke Forebay Boom Mooring, 2012−2017

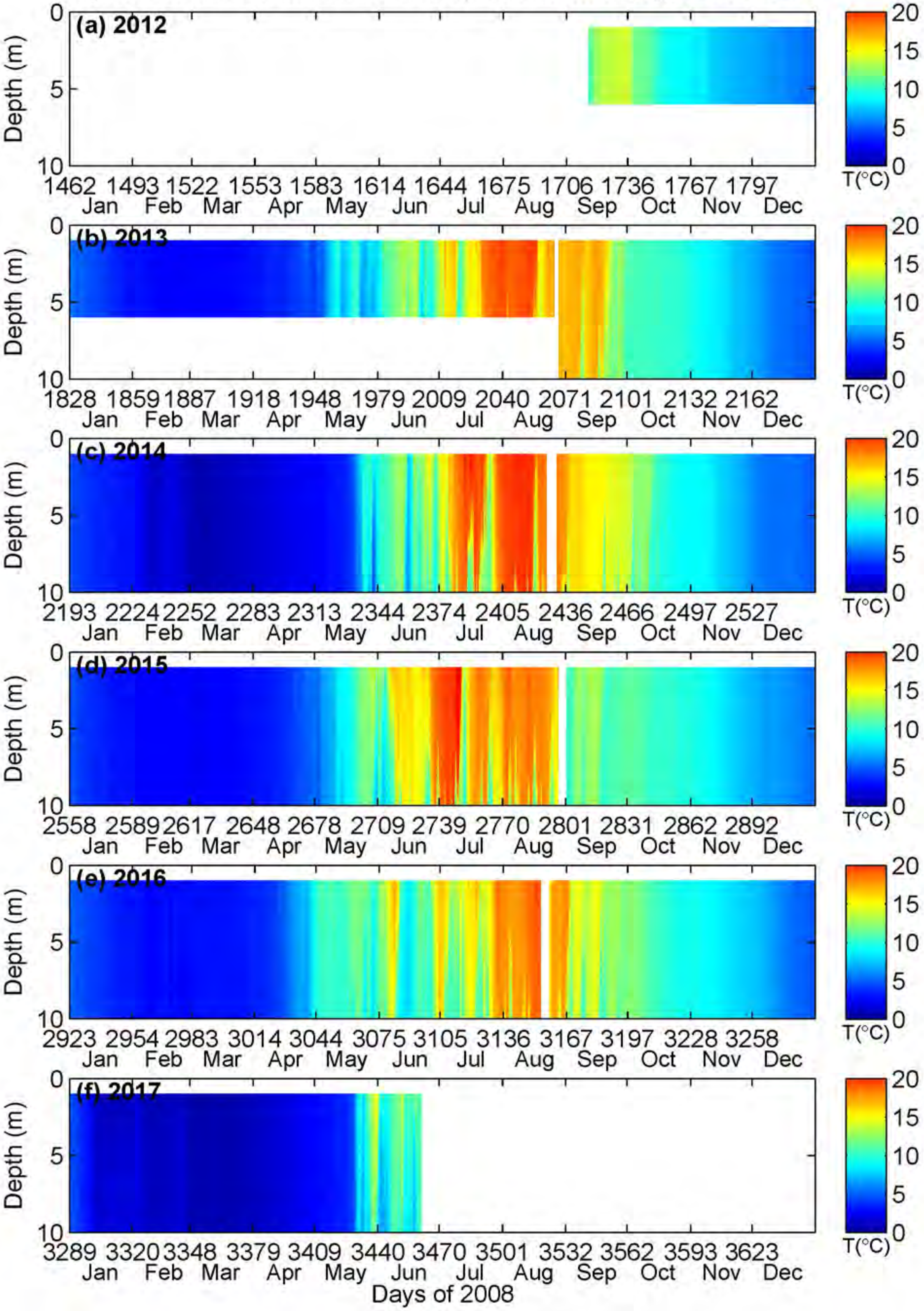

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Figure 3.3.1 Revelstoke Mid Subsurface Mooring, 2012−2017

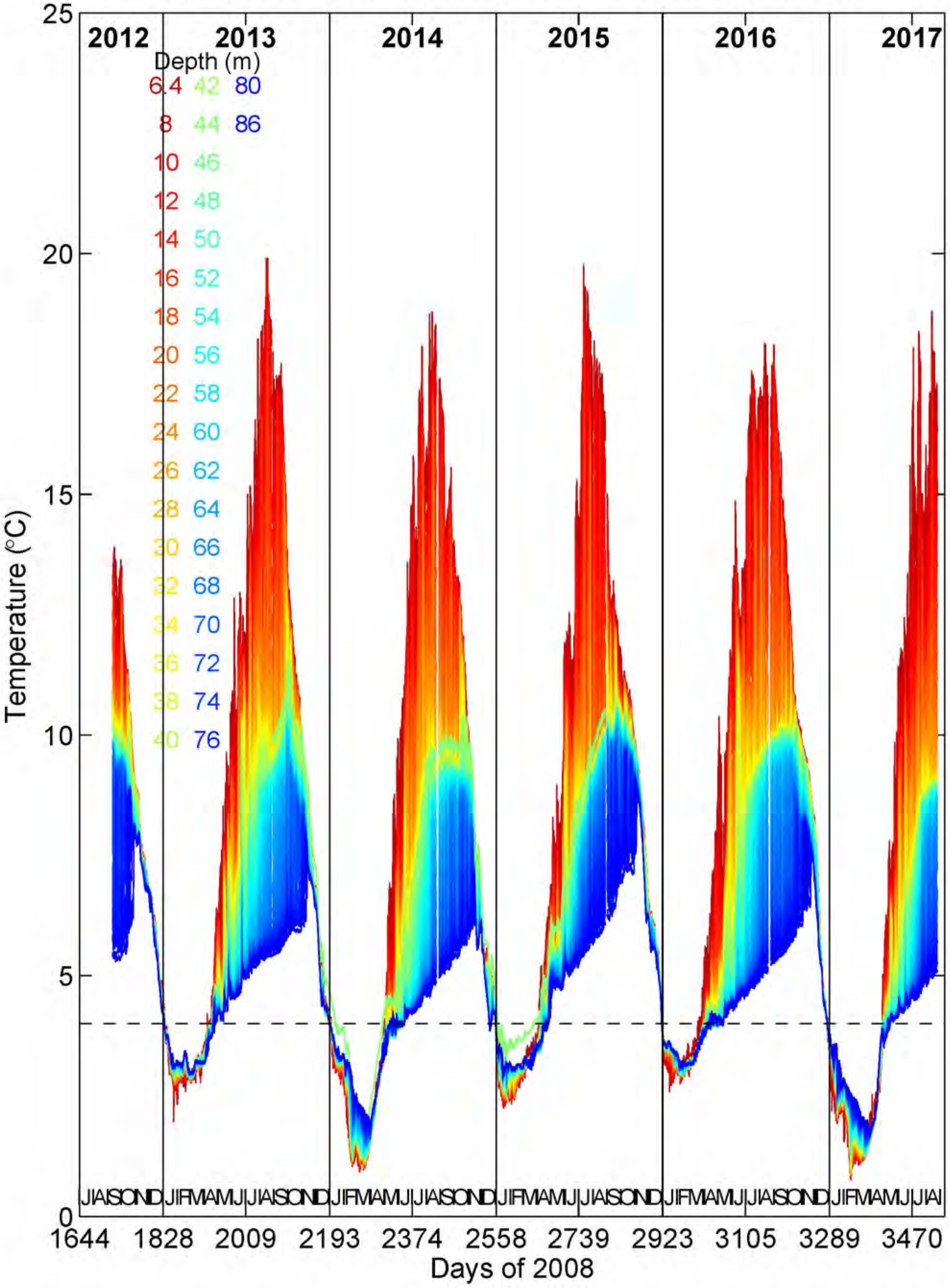

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Figure 3.3.2 Revelstoke Mid Subsurface Mooring, 2012−2017

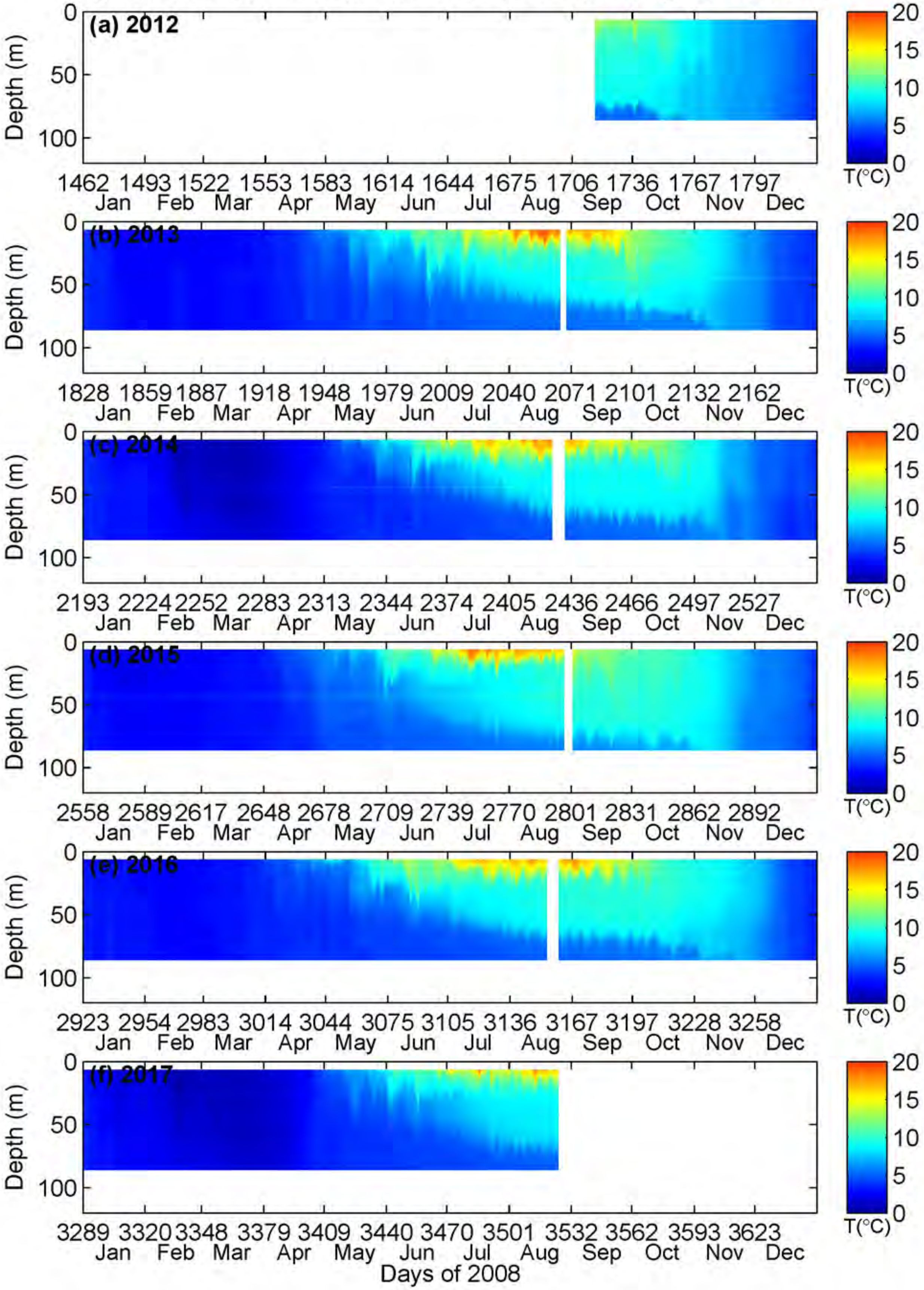

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Figure 3.4.1 Revelstoke Up Subsurface Mooring, 2012−2017

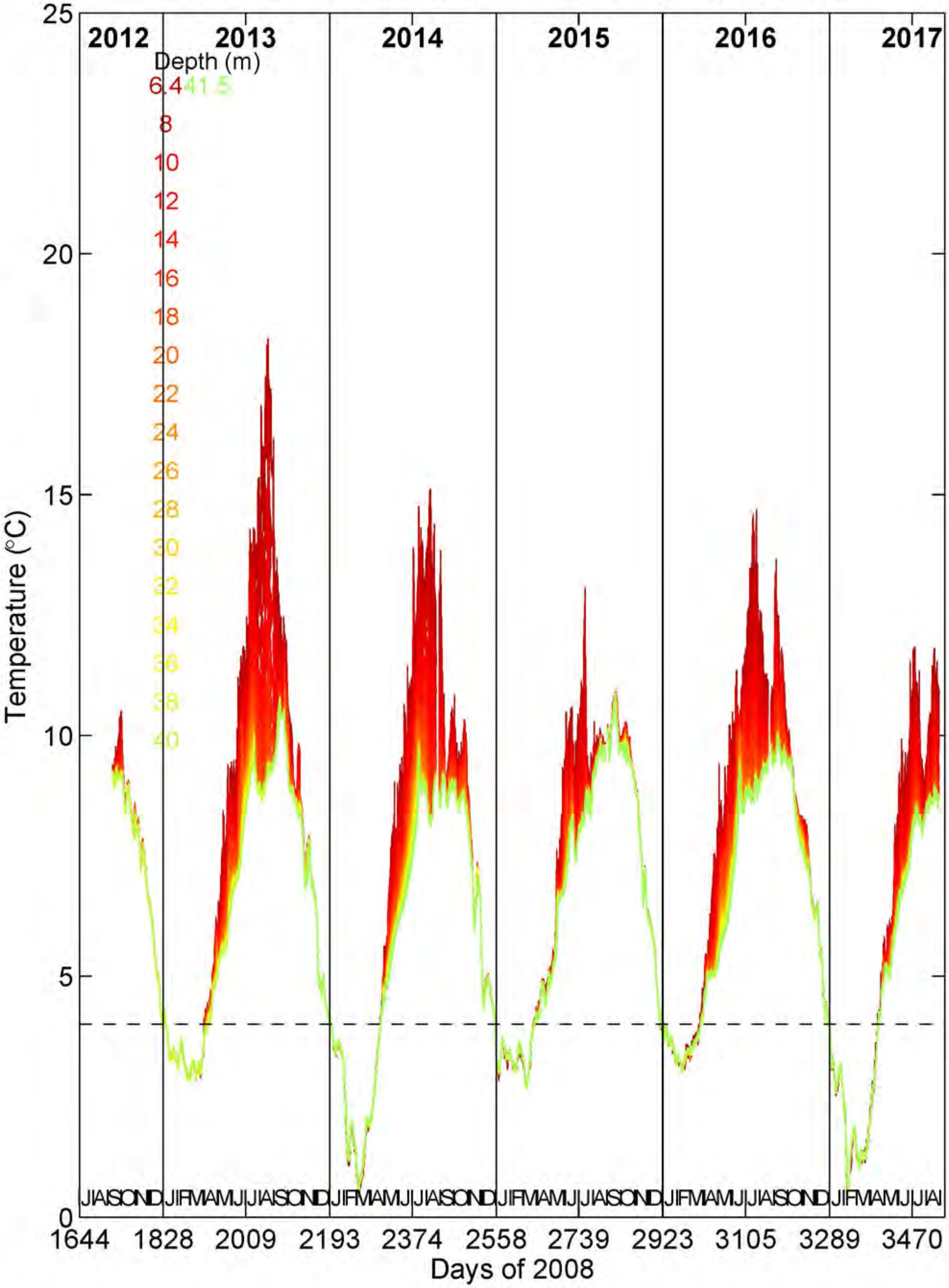

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Figure 3.4.2 Revelstoke Up Subsurface Mooring, 2012−2017

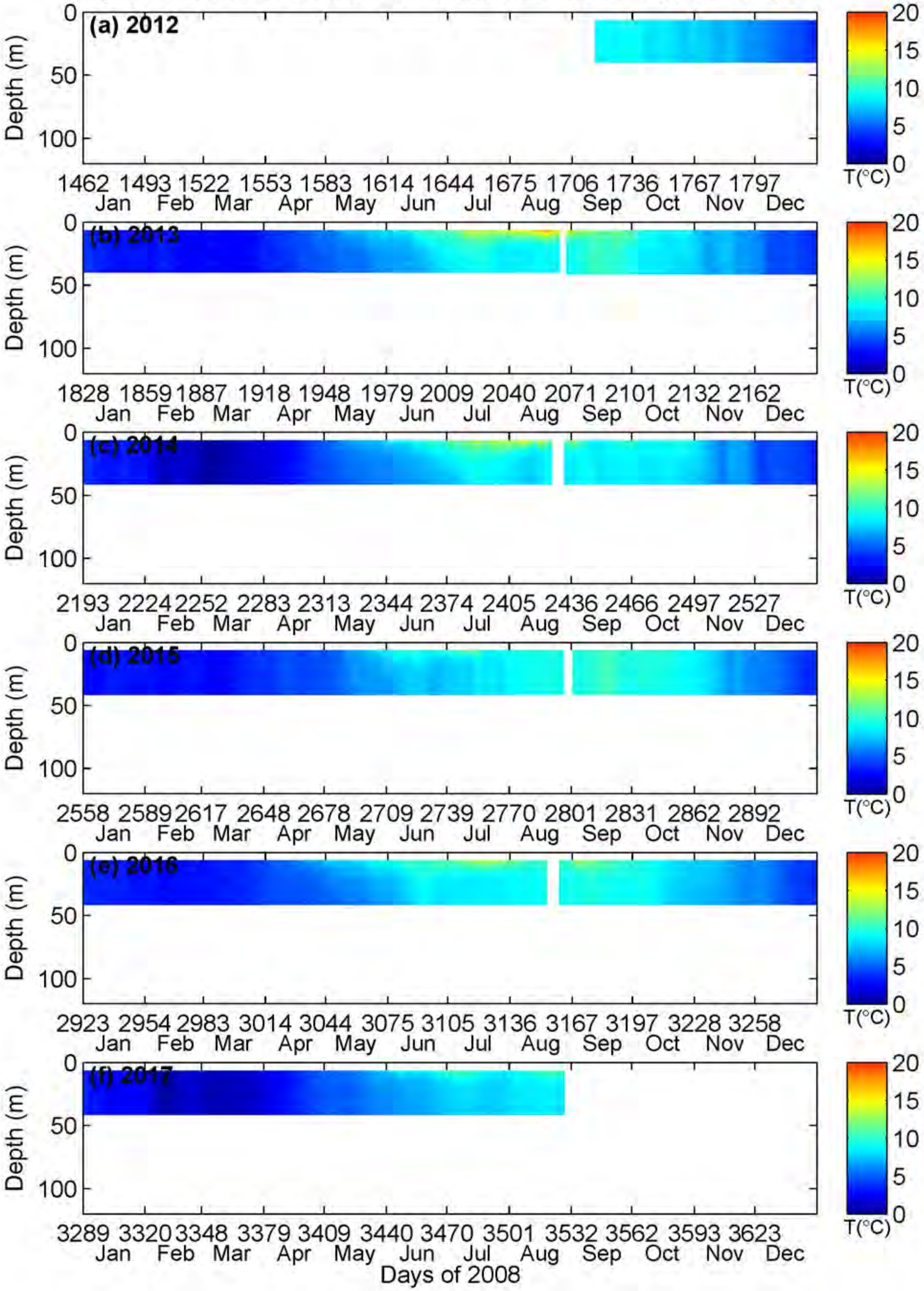

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Figure 3.5.1 Kinbasket Forebay Subsurface Mooring, 2012−2017

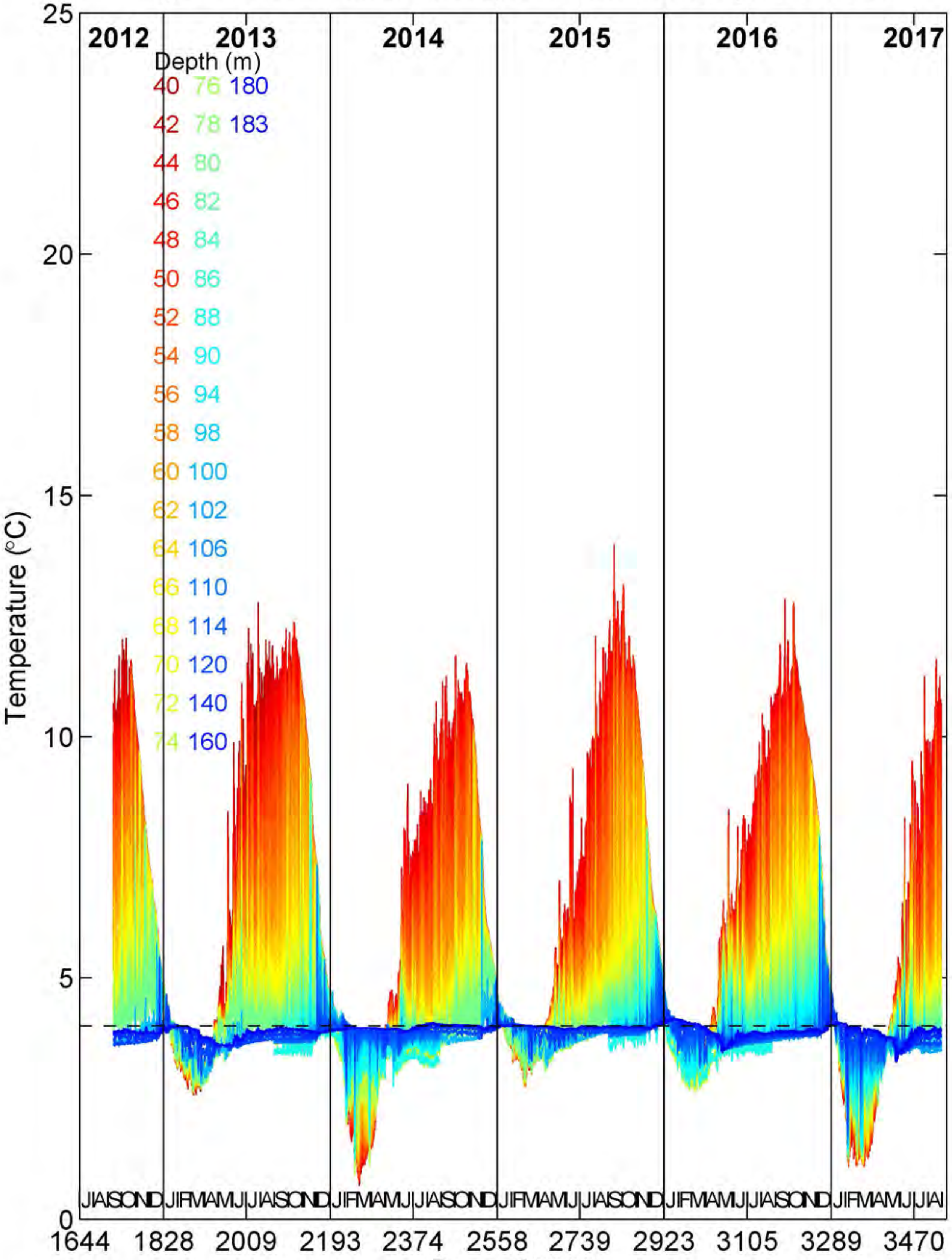

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Figure 3.5.2 Kinbasket Forebay Subsurface Mooring, 2012−2017

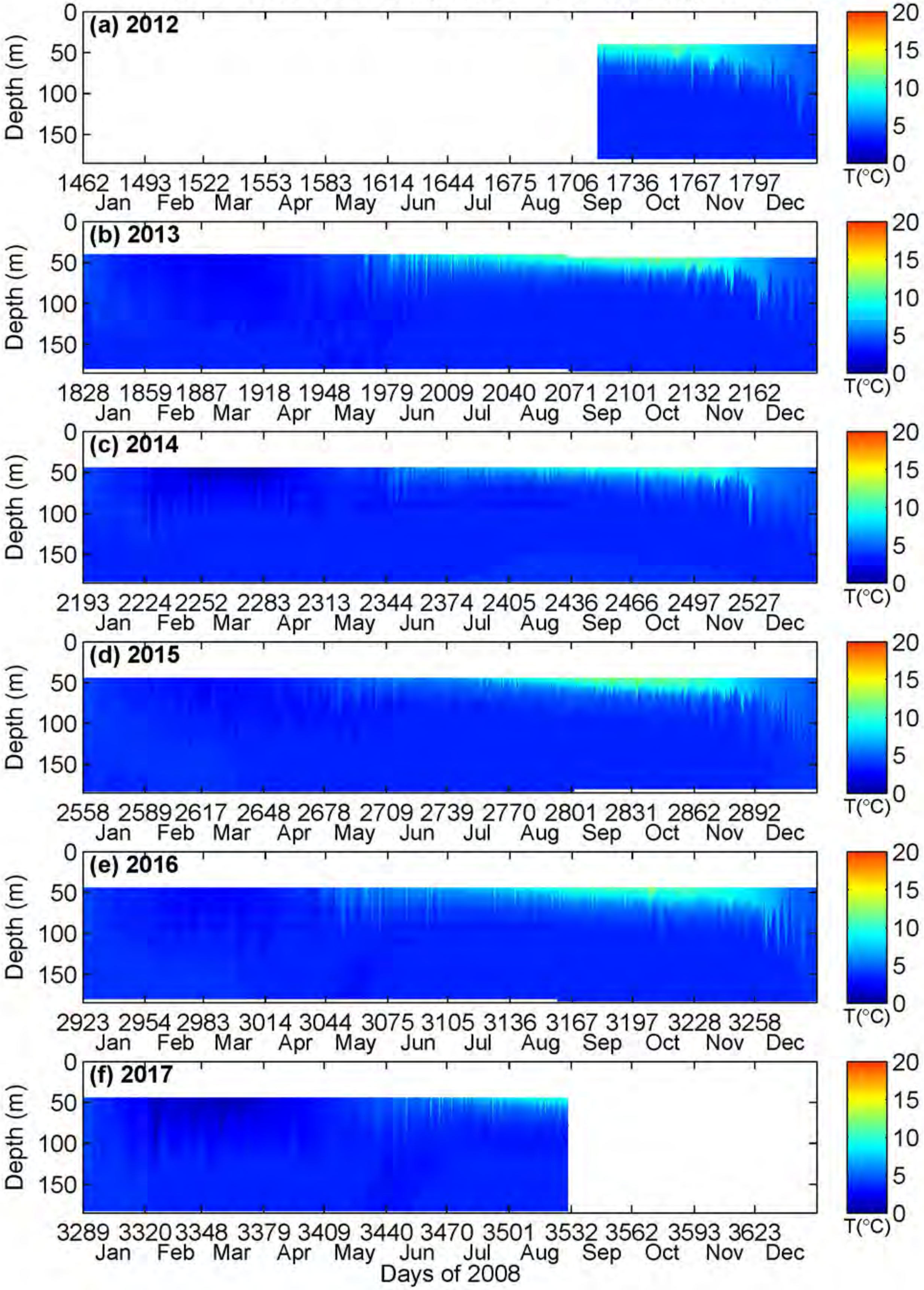

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Figure 3.6.1 Kinbasket Forebay Boom Mooring, 2012−2017

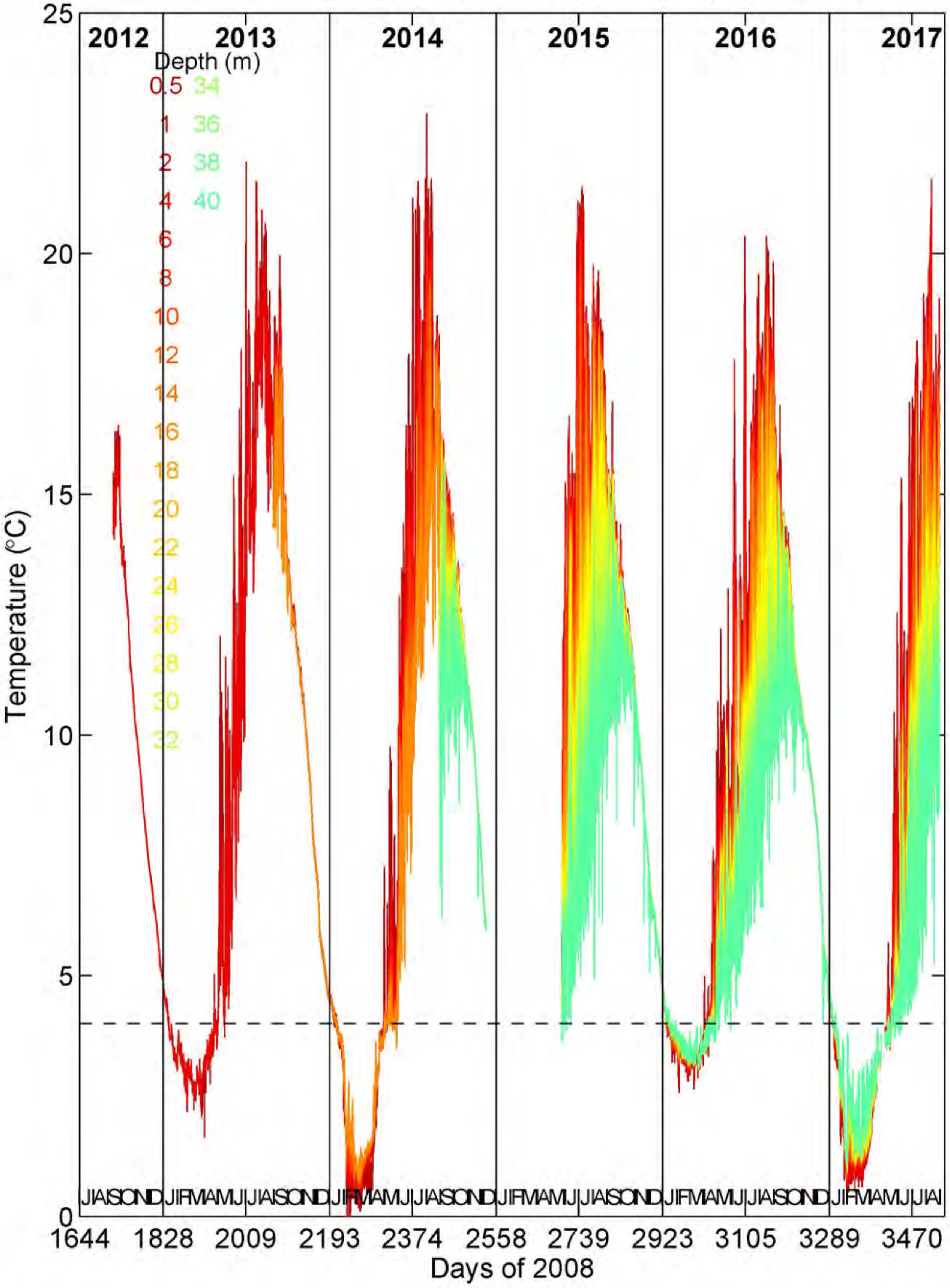

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Figure 3.6.2 Kinbasket Forebay Boom Mooring, 2012−2017

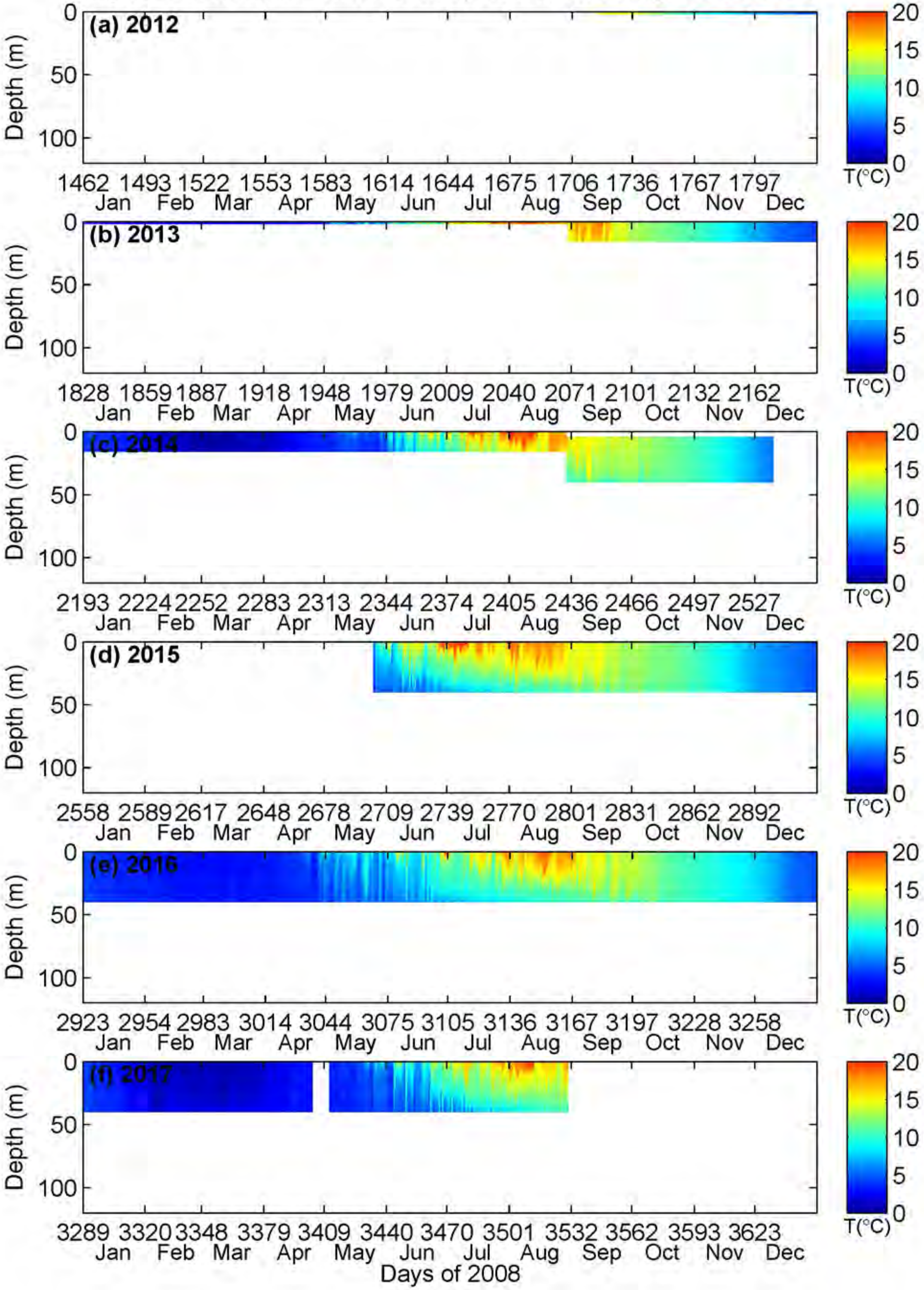

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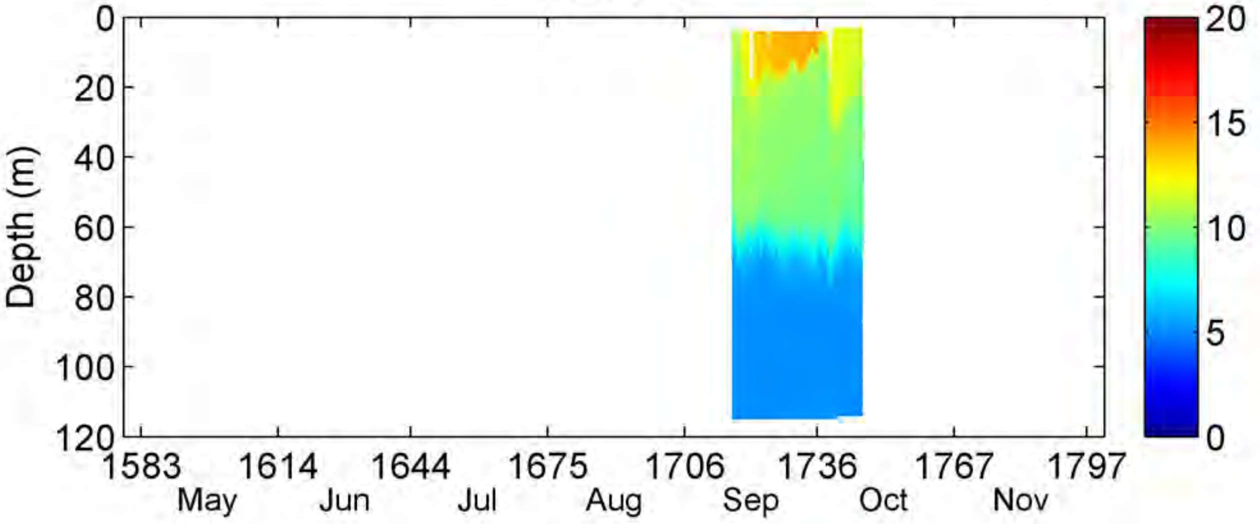
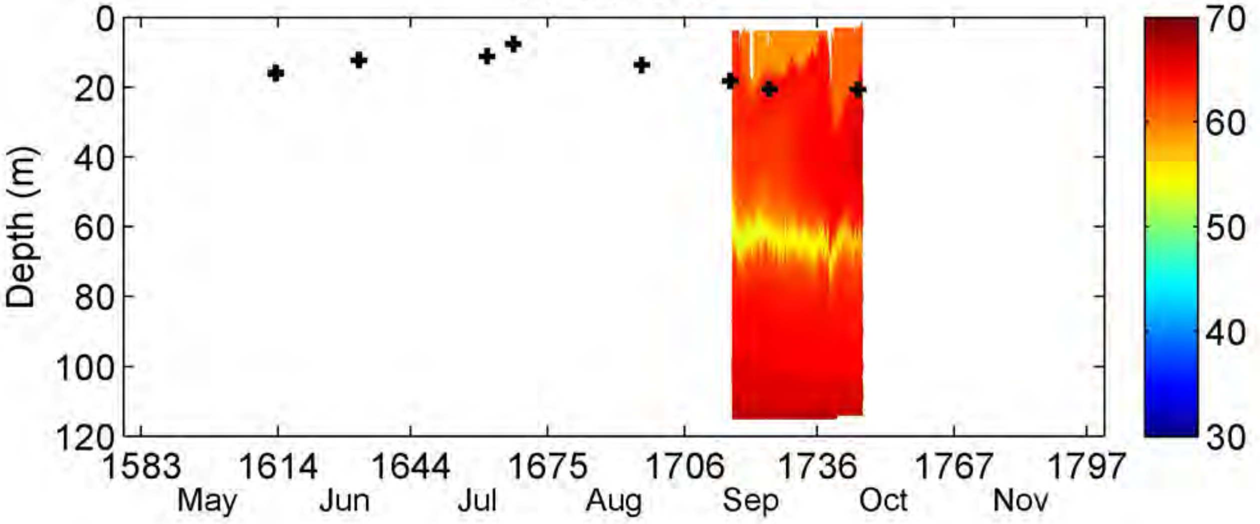
Figure 4.1 Rev FB Profiler, May to Nov, 2012

(a) T (°C)



(b) S (mg/L)



(c) Turbidity (NTU)

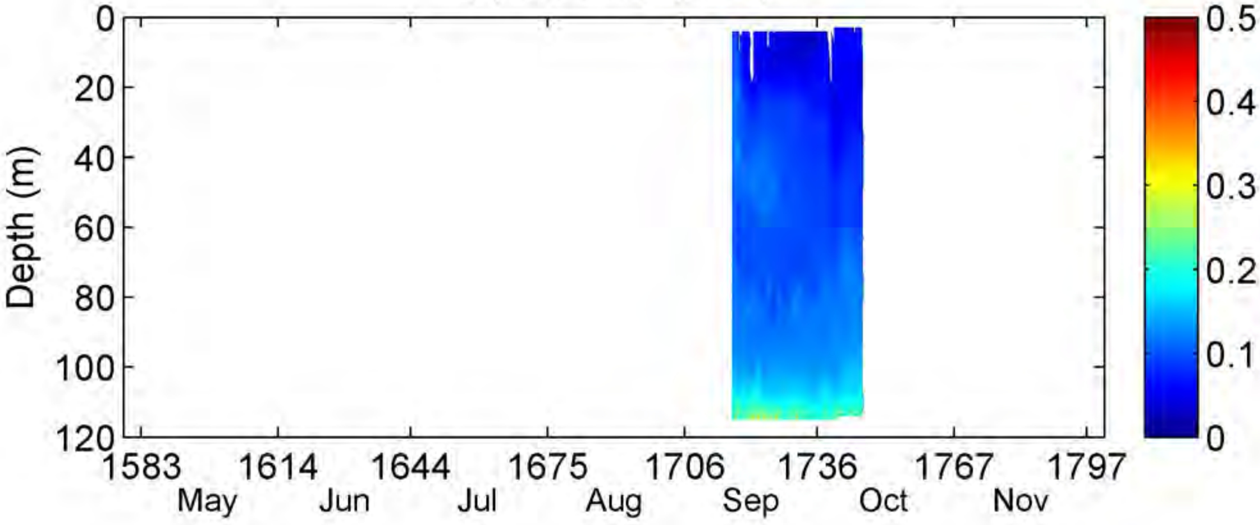


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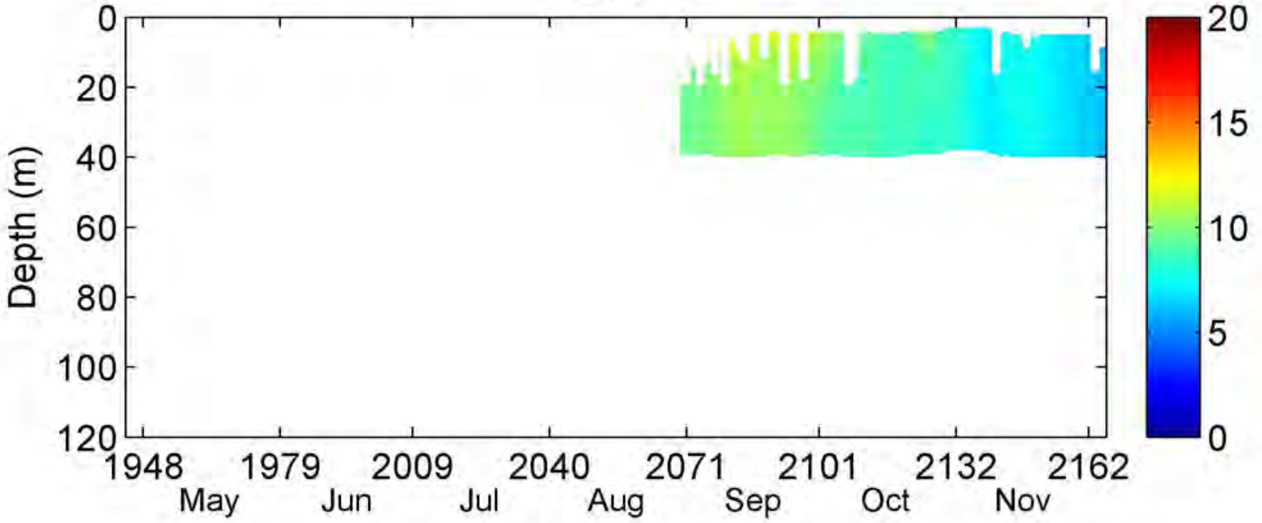
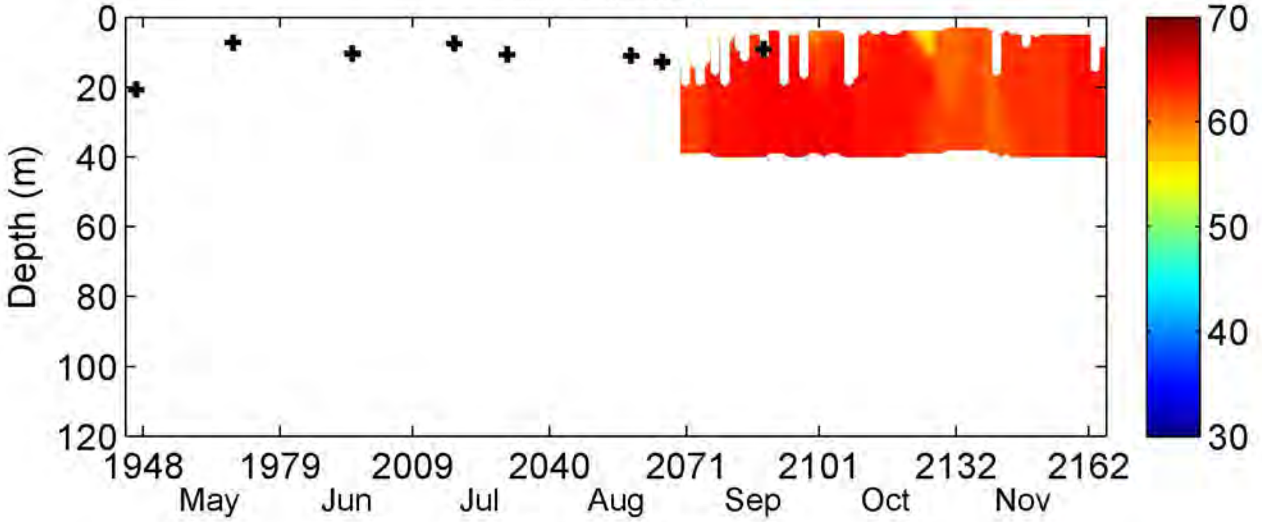
Figure 4.2 Rev Up Profiler, May to Nov, 2013

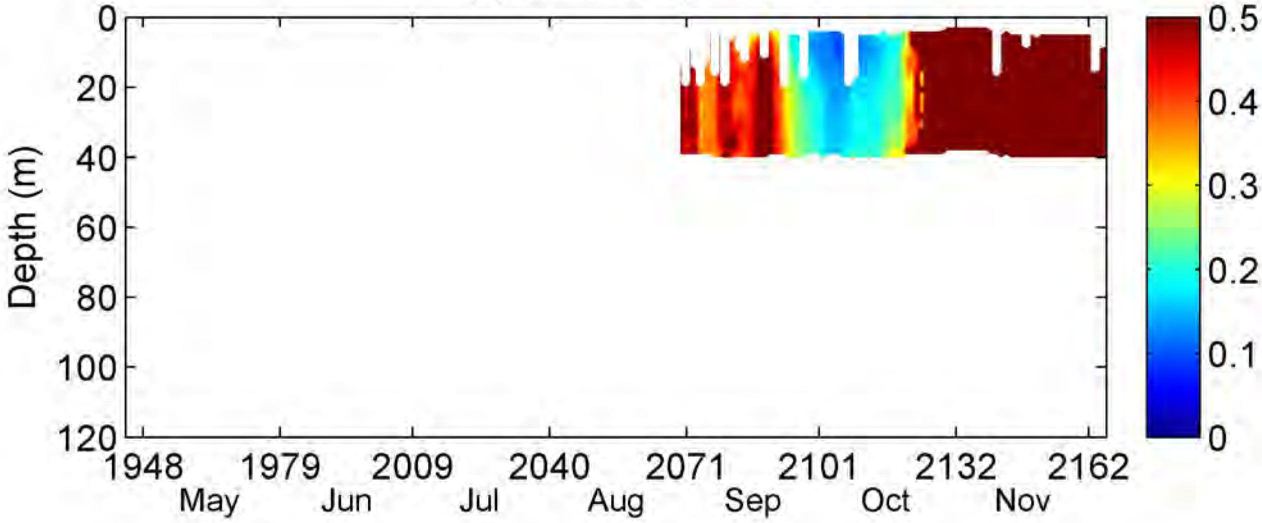
(a) T (°C)



(b) S (mg/L)



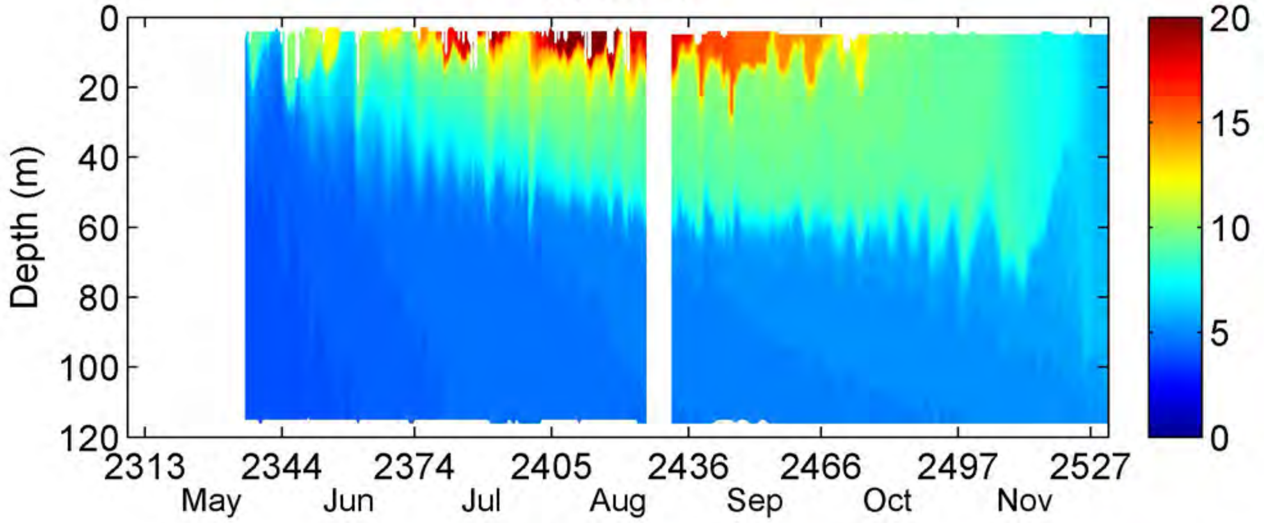
(c) Turbidity (NTU)



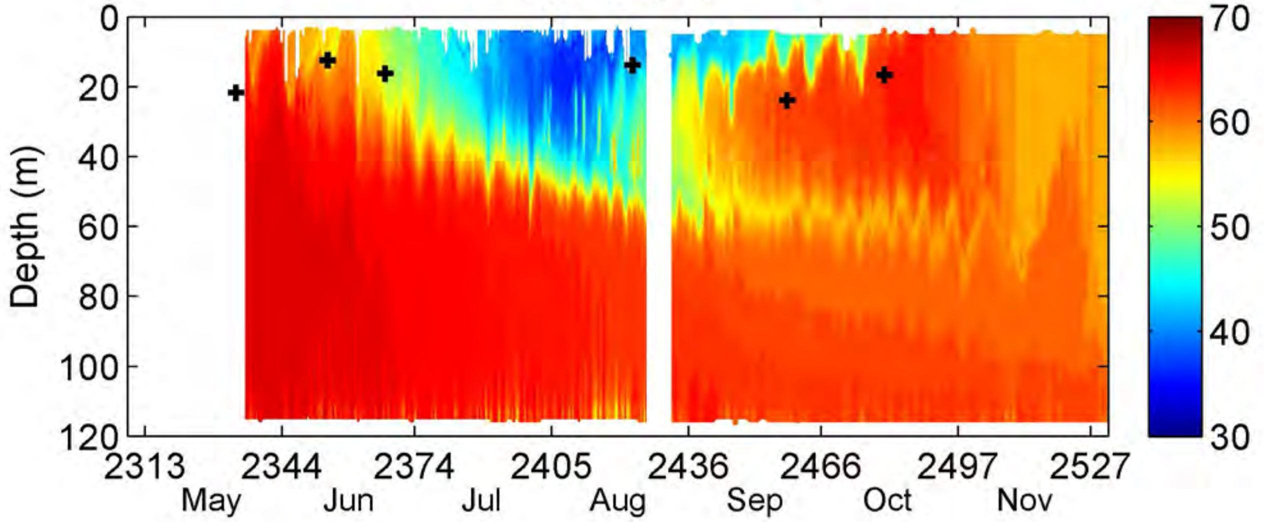
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 7 2018−Jan−02

Figure 4.3 Rev FB Profiler, May to Nov, 2014

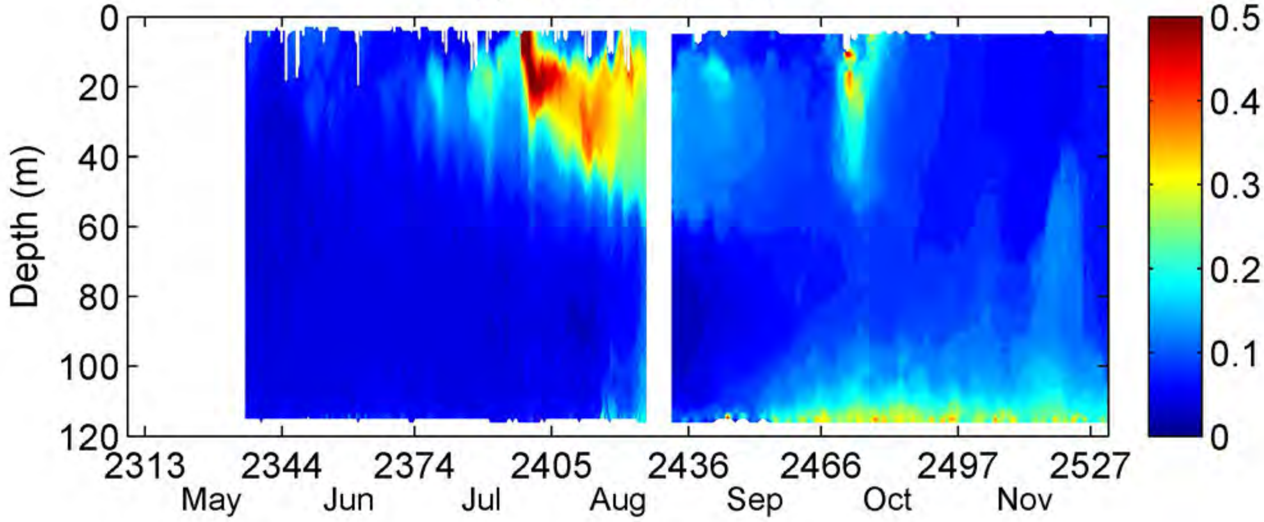
(a) T (°C)



(b) S (mg/L)



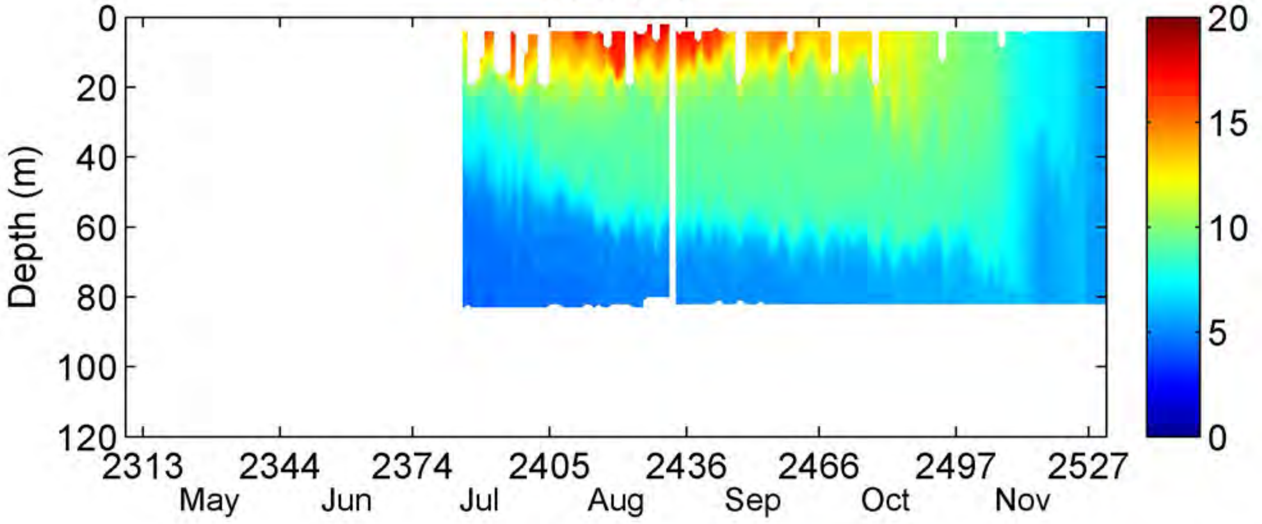
(c) Turbidity (NTU)



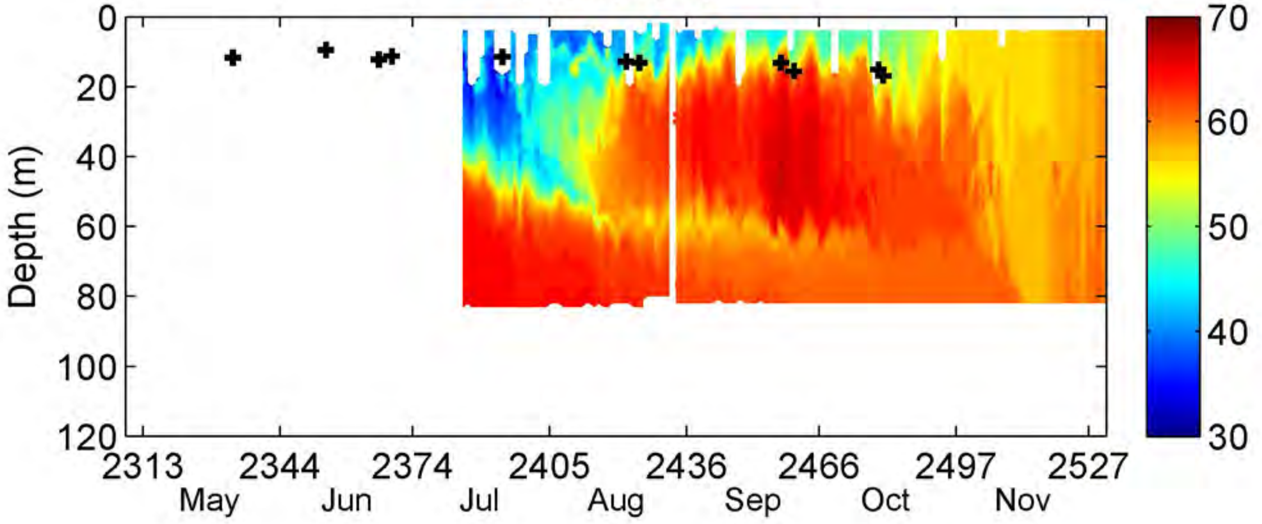
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 1 2018−Jan−02

Figure 4.4 Rev MID Profiler, May to Nov, 2014

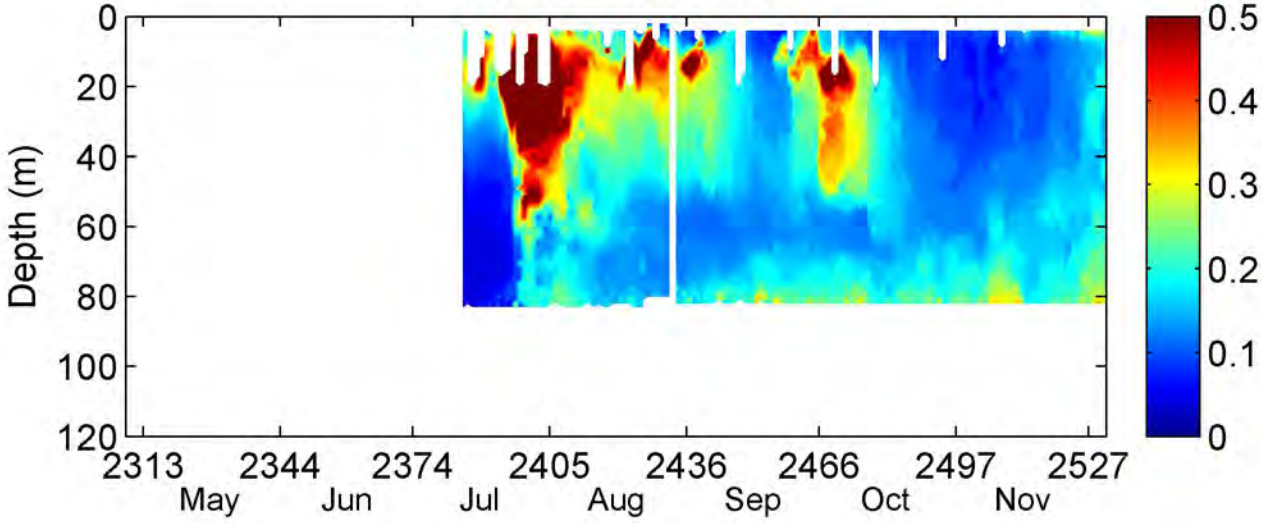
(a) T (°C)



(b) S (mg/L)



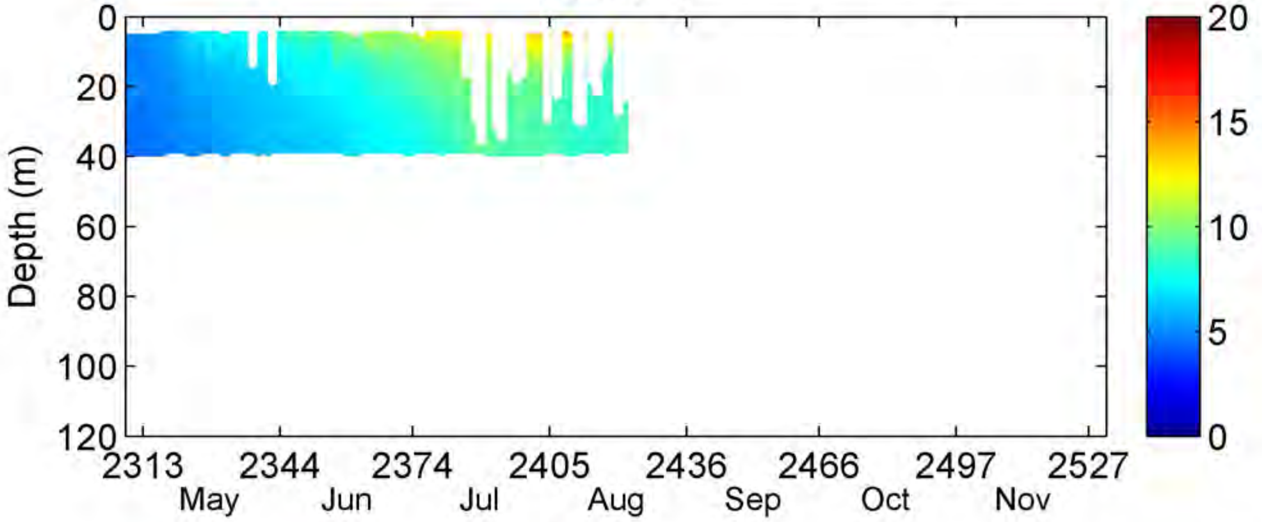
(c) Turbidity (NTU)



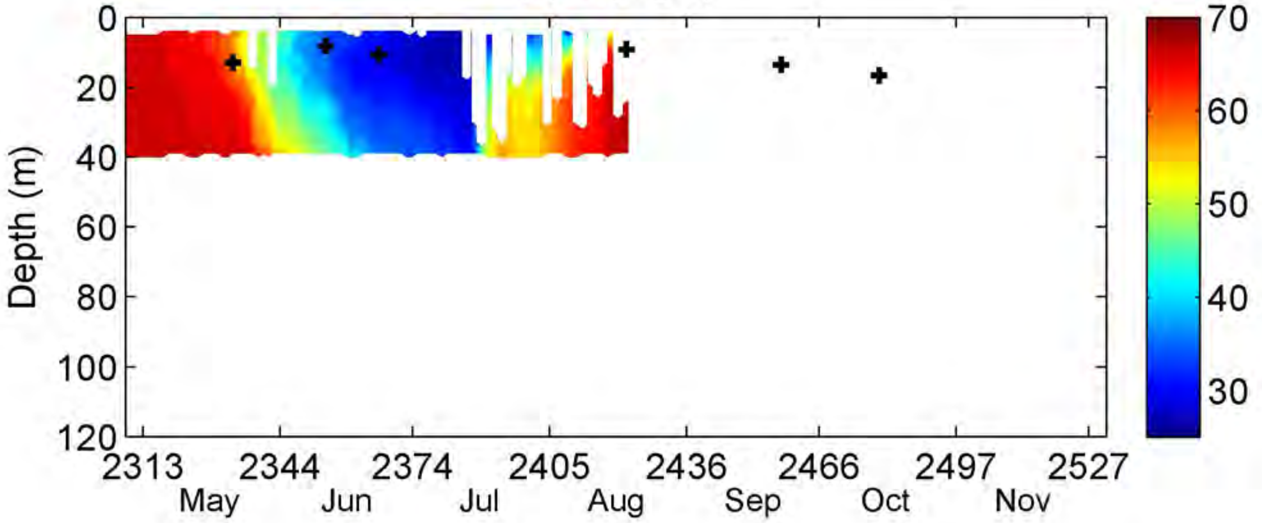
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 2 2018−Jan−02

Figure 4.5 Rev Up Profiler, May to Nov, 2014

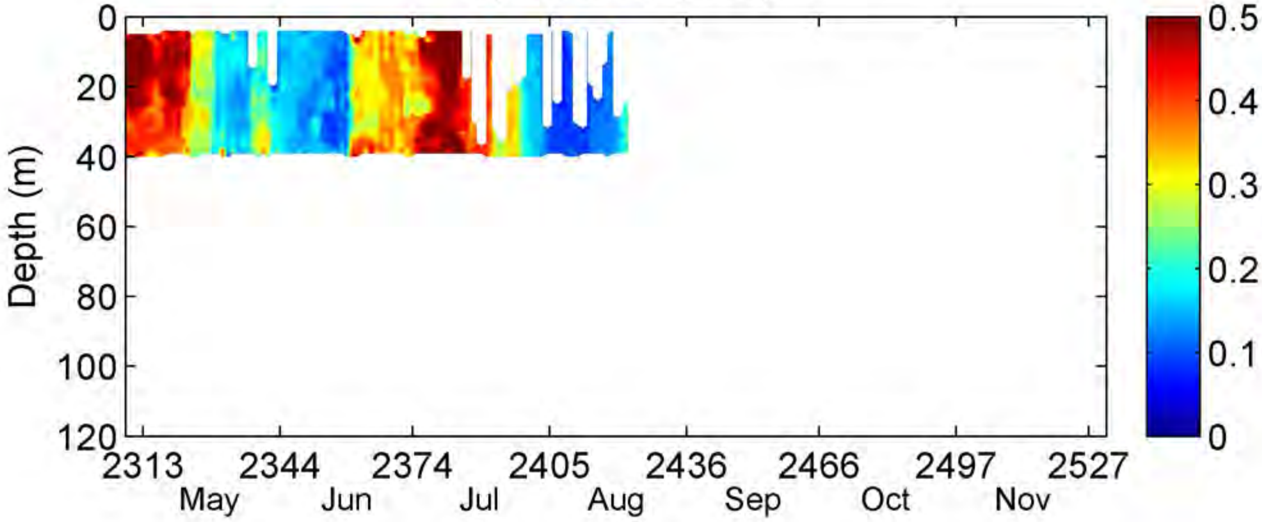
(a) T (°C)



(b) S (mg/L)



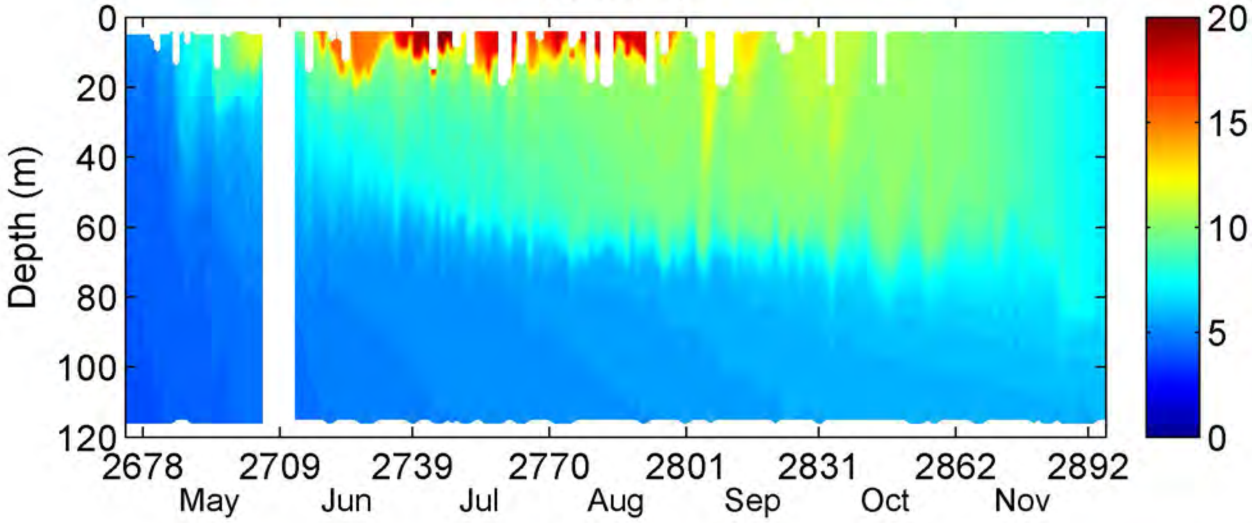
(c) Turbidity (NTU)



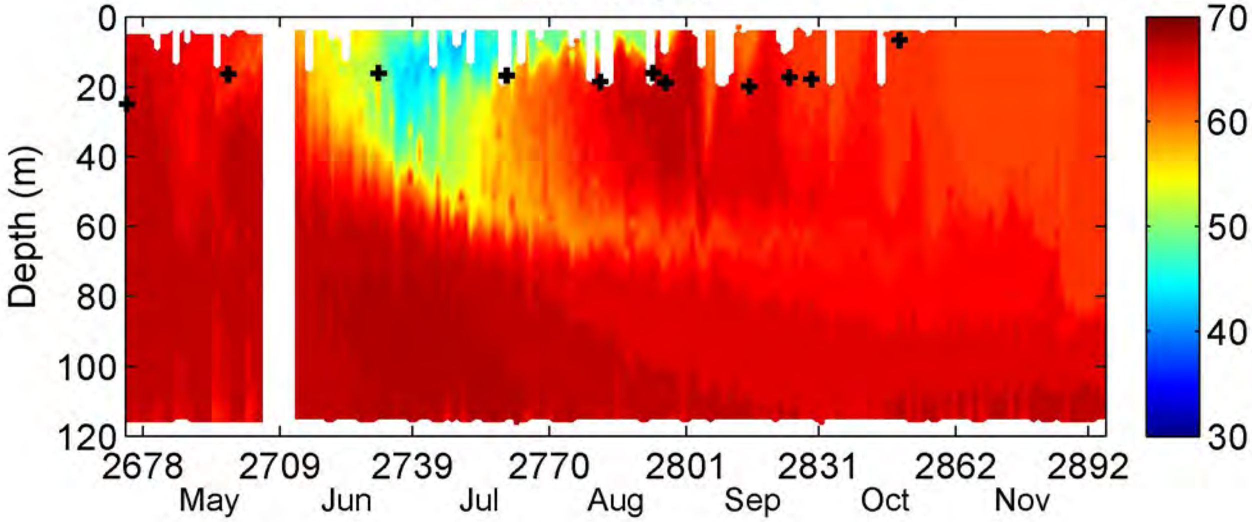
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 8 2018−Jan−02

Figure 4.6 Rev FB Profiler, May to Nov, 2015

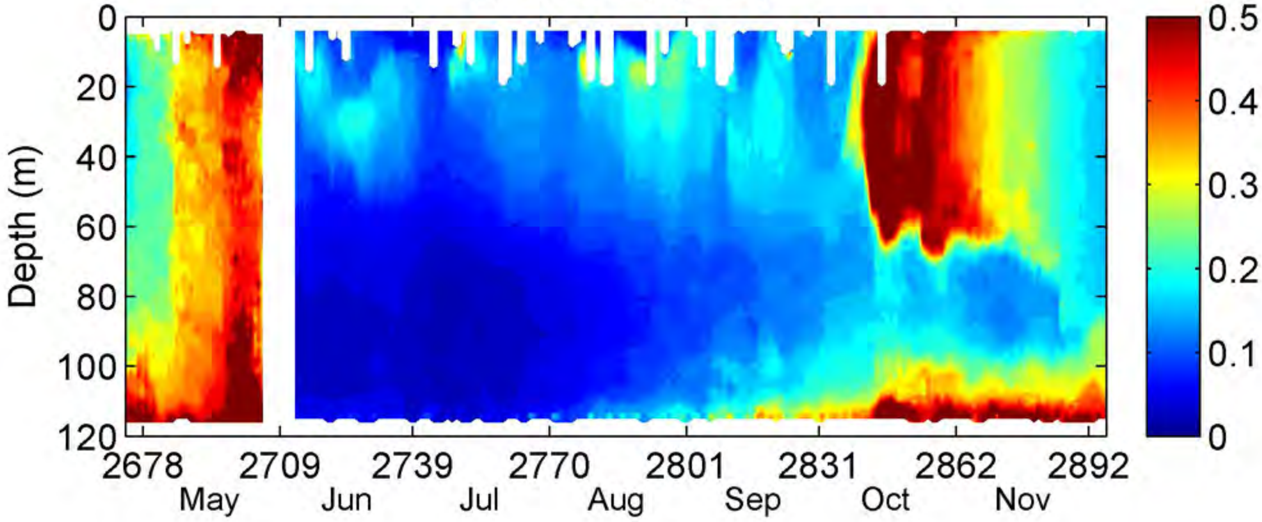
(a) T (°C)



(b) S (mg/L)



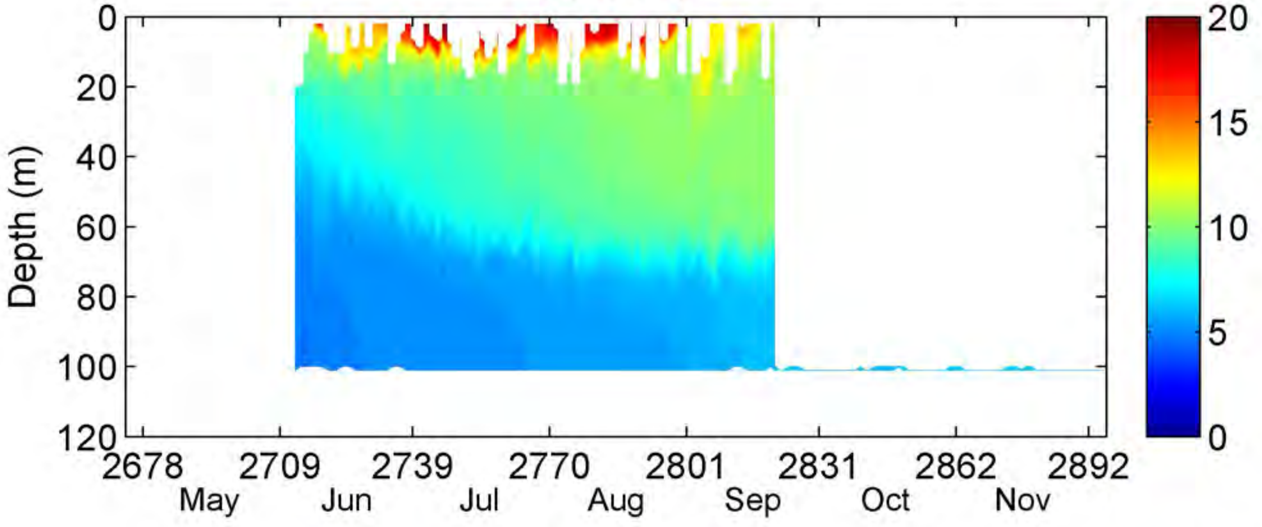
(c) Turbidity (NTU)



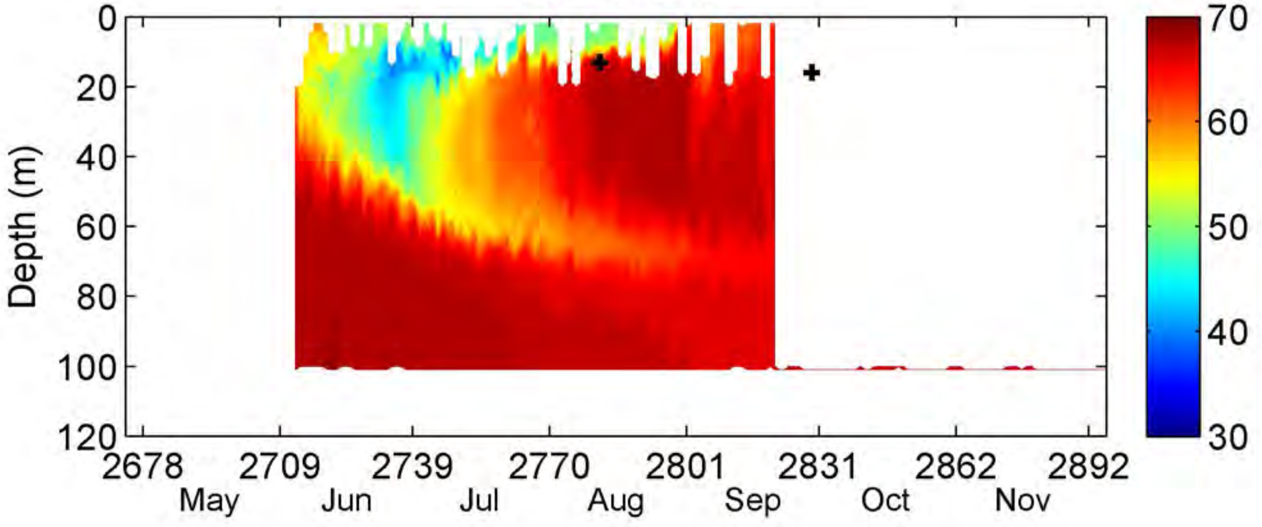
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 3 2018−Jan−02

Figure 4.7 Rev LA FORME Profiler, May to Nov, 2015

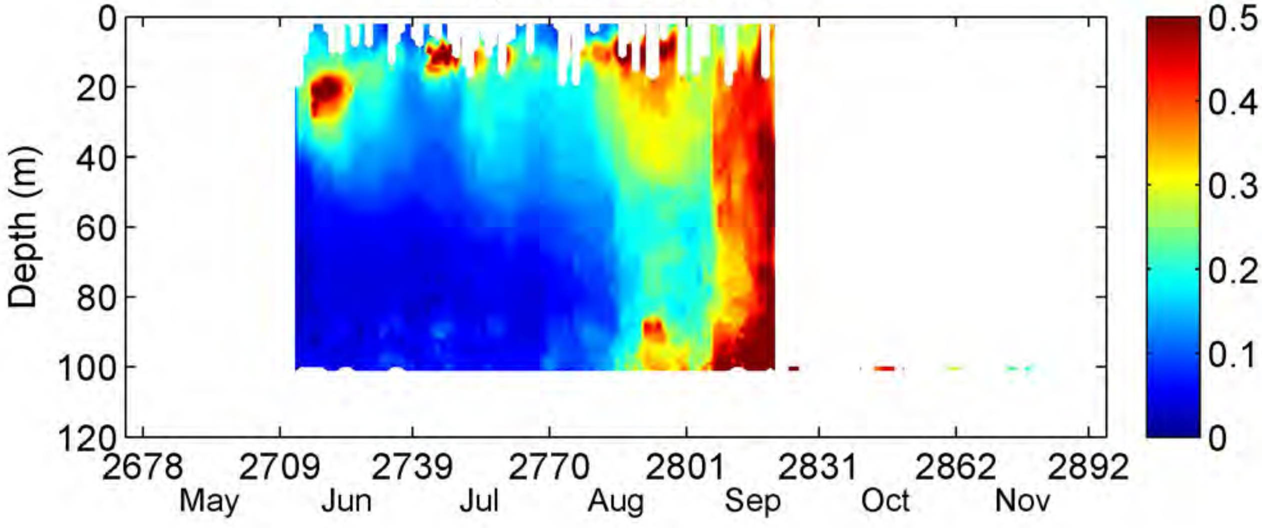
(a) T (°C)



(b) S (mg/L)



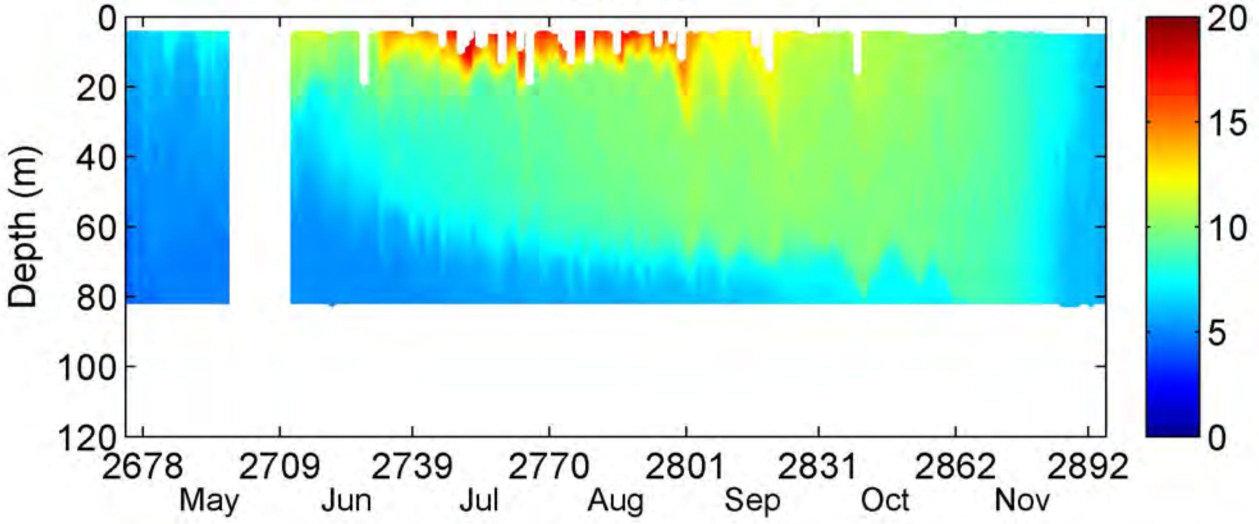
(c) Turbidity (NTU)



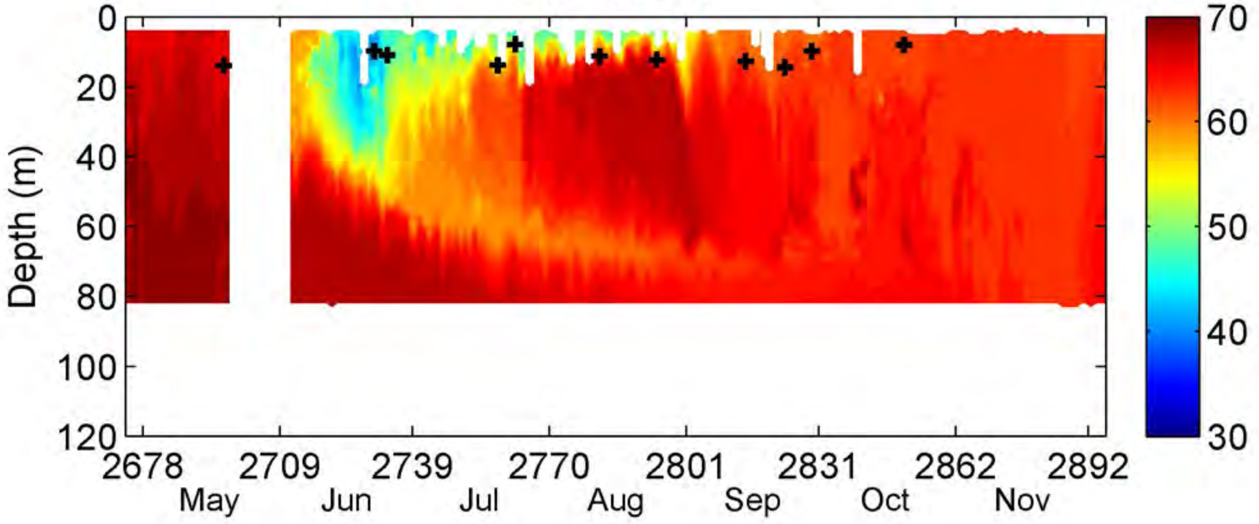
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 5 2018−Jan−02

Figure 4.8 Rev MID Profiler, May to Nov, 2015

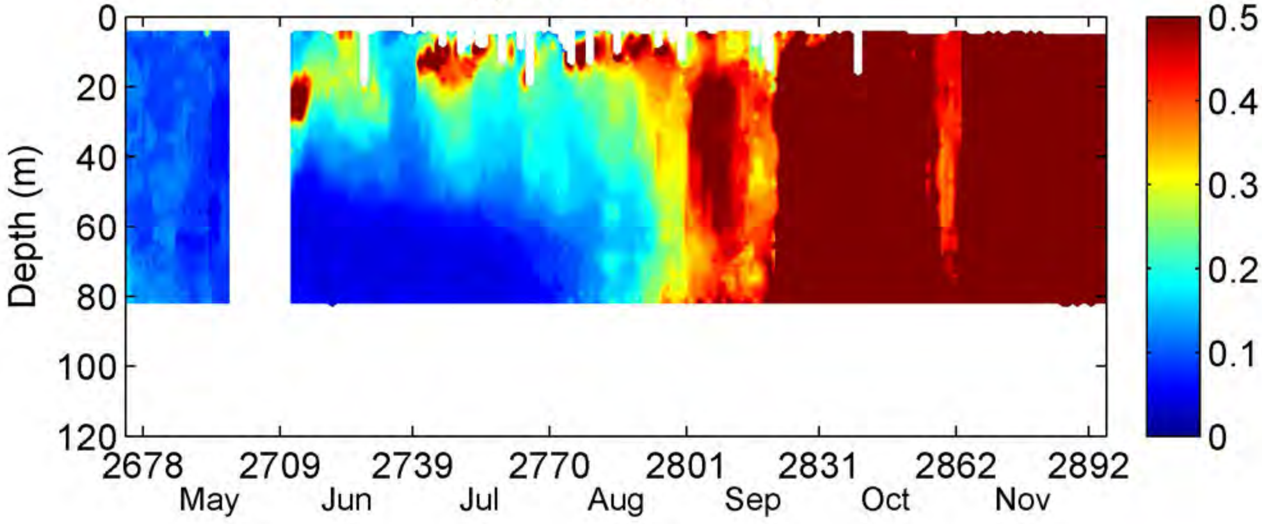
(a) T (°C)



(b) S (mg/L)



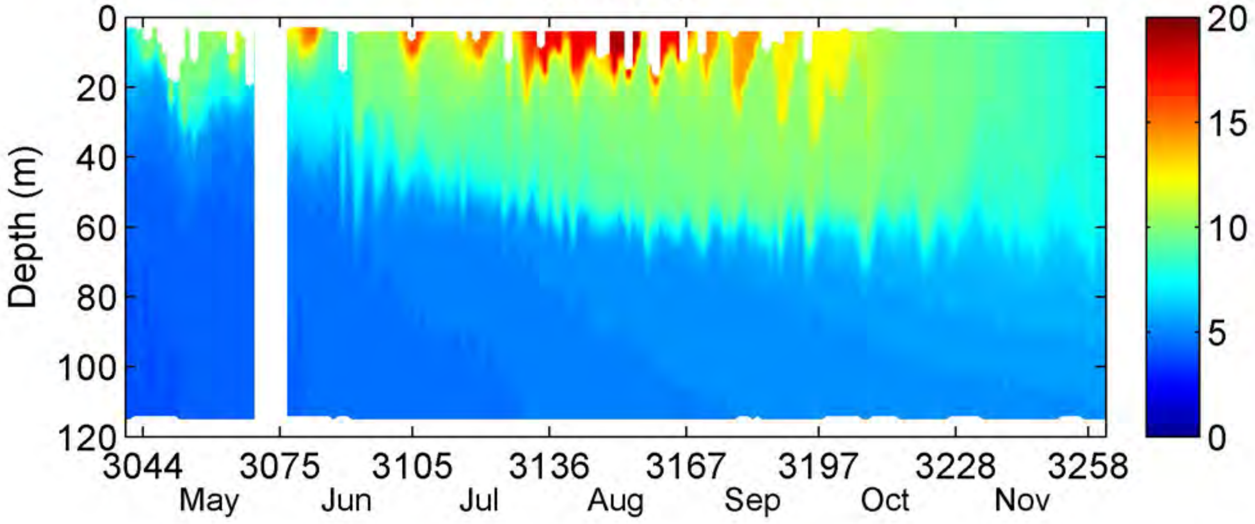
(c) Turbidity (NTU)



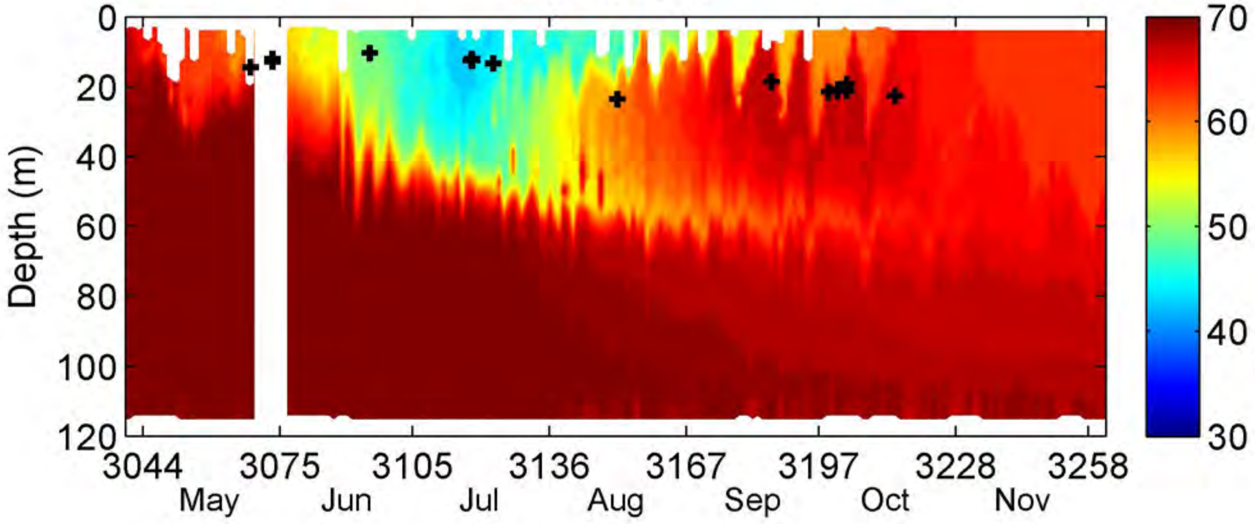
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 4 2018−Jan−02

Figure 4.9 Rev FB Profiler, May to Nov, 2016

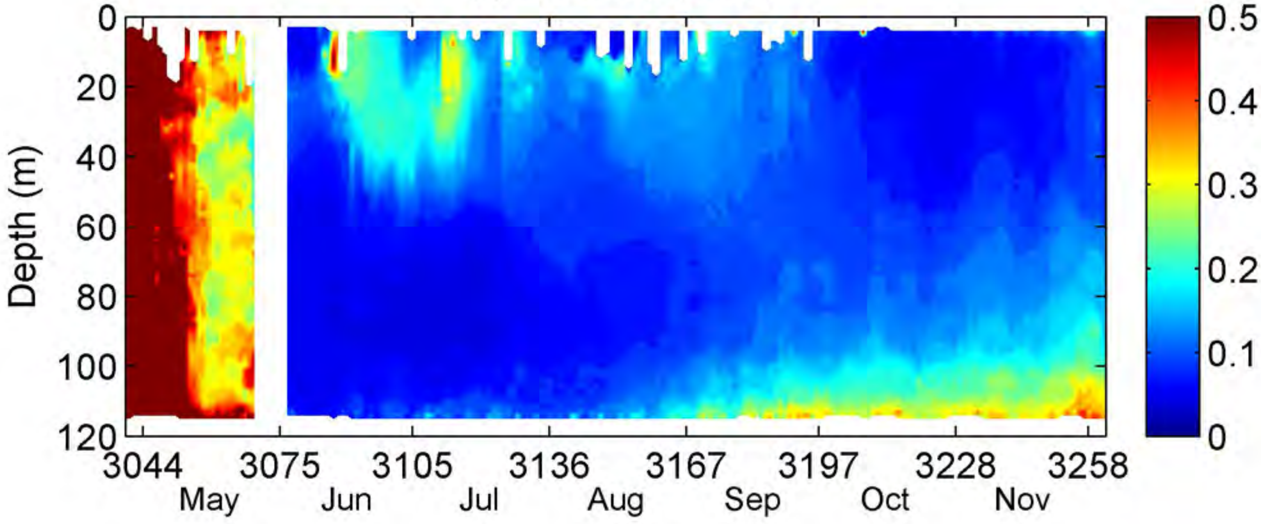
(a) T (°C)



(b) S (mg/L)



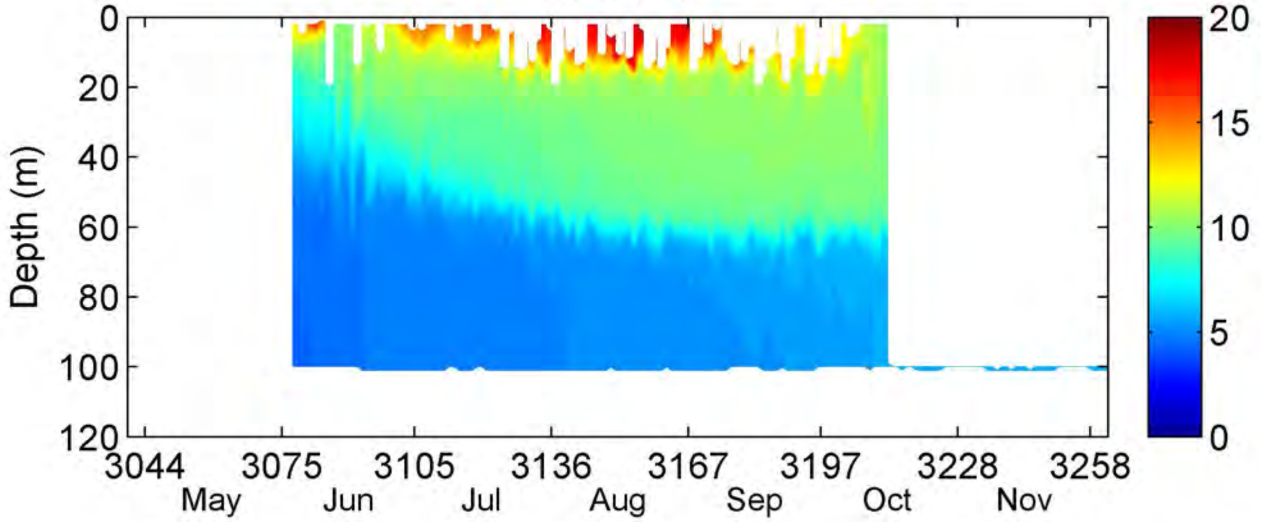
(c) Turbidity (NTU)



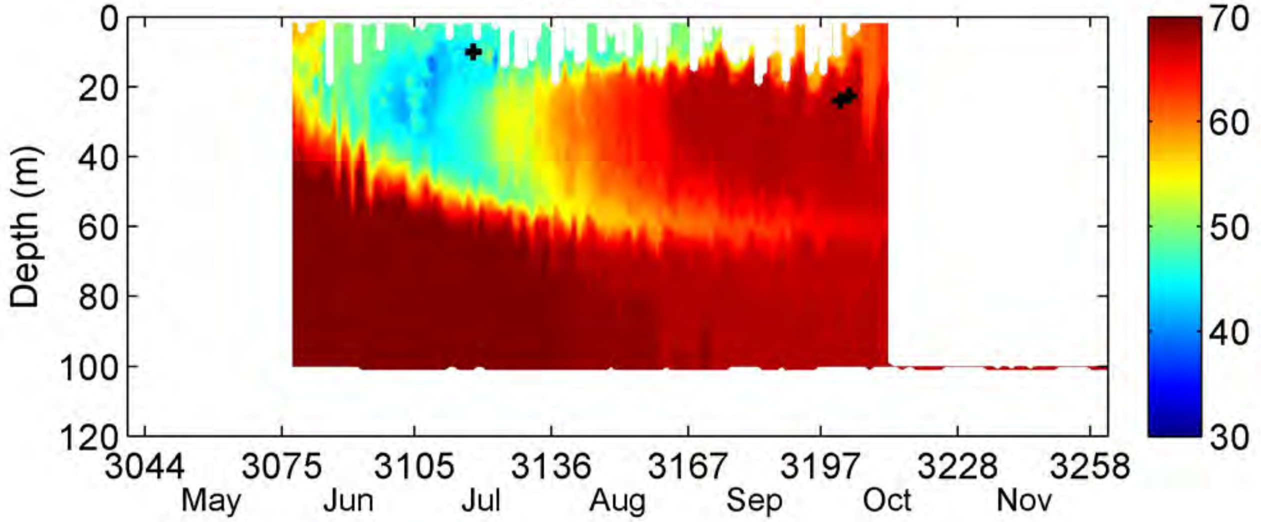
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 9 2018−Jan−02

Figure 4.10 Rev LA FORME Profiler, May to Nov, 2016

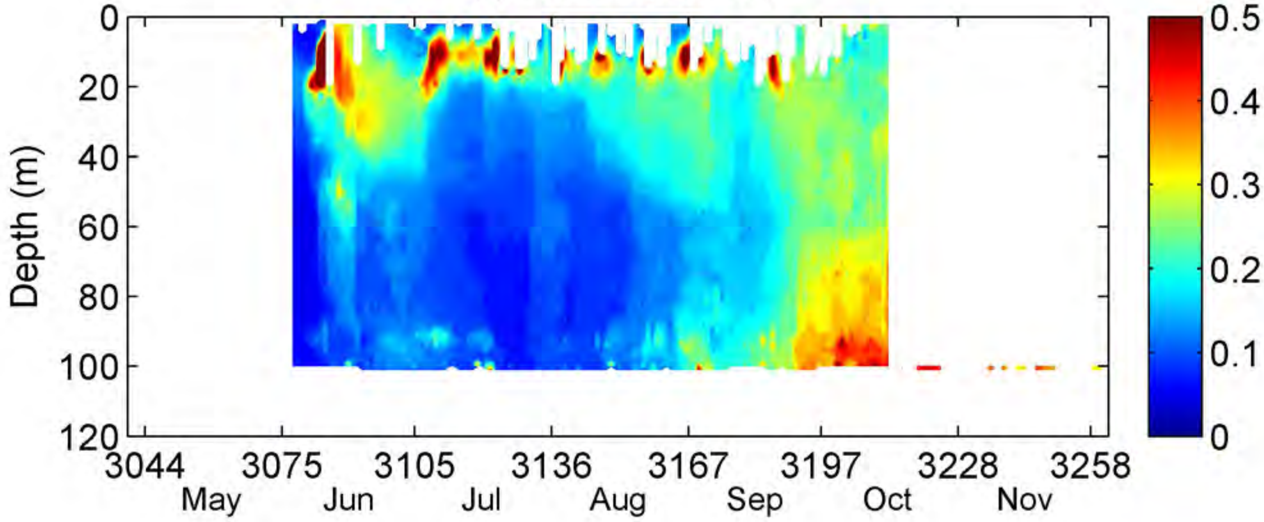
(a) T (°C)



(b) S (mg/L)



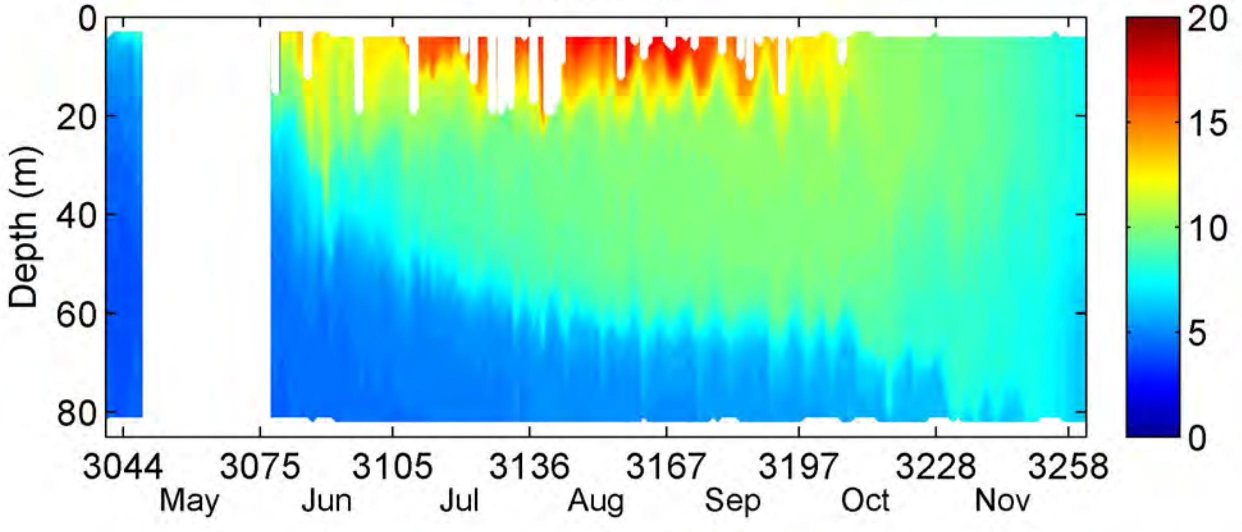
(c) Turbidity (NTU)



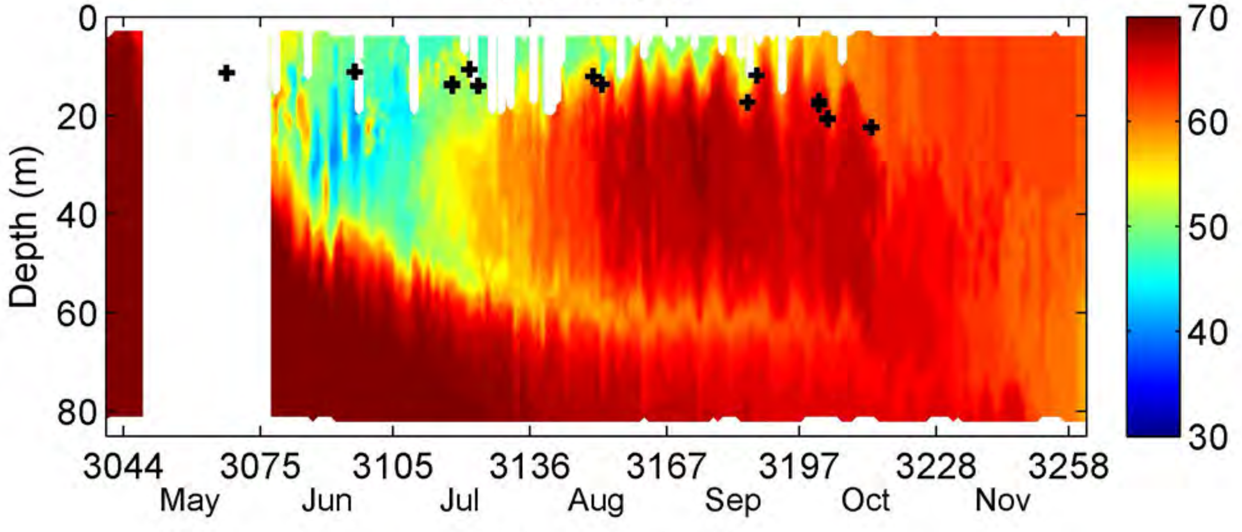
/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 10 2018−Jan−02

Figure 4.11 Rev MID Profiler, May to Nov, 2016

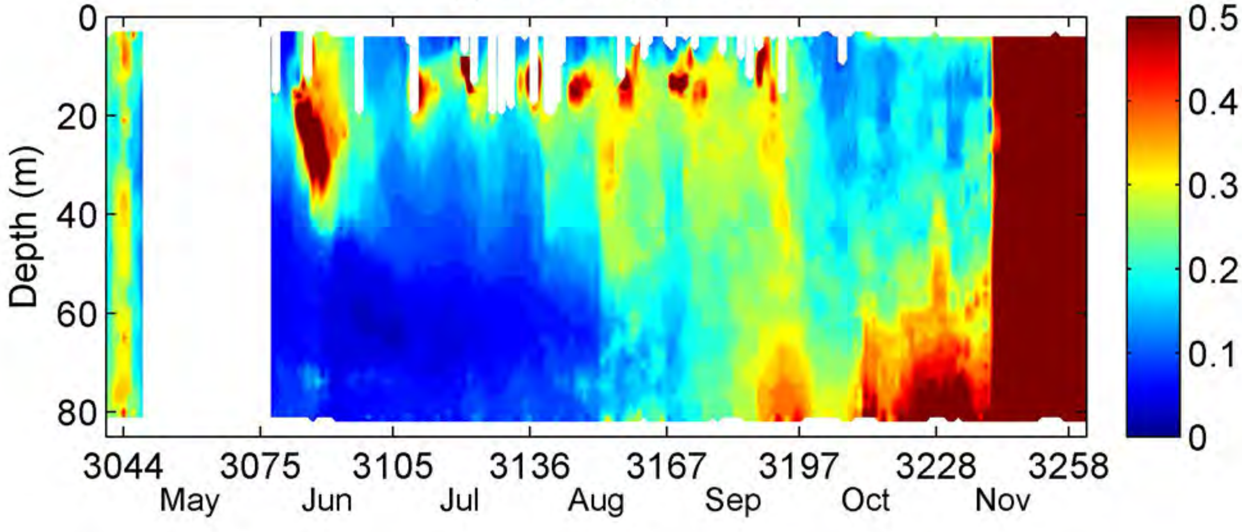
(a) T (°C)



(b) S (mg/L)



(c) Turbidity (NTU)



/ocean/rpieters/kr/prof/plot17/profcontcombo2.m fig= 11 2018−Jan−02