Limnological Assessment of the Oldman River Reservoir

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EXECUTIVE SUMMARY

The Oldman Reservoir was constructed to assure downstream water supplies for consumption and irrigation, and to provide additional water for future expansion of irrigated land. Additional benefits included enhancement of downstream fisheries, recreation and increased capability to meet flow commitments to the downstream province. The reservoir attenuates peak flows during flood events, although this capability is limited.

During the design of the project, water quality conditions in the reservoir and the Oldman River downstream were identified as issues to be assessed. Alberta Environment began a monitoring program on the three rivers that would flow into the reservoir, and then conducted a six-year study after the reservoir began filling in 1991. The study focussed on general water chemistry, especially as it pertains to expected uses; nutrient concentrations and loading from the watershed and inundated bottom soils (trophic upsurge); temperature and dissolved oxygen conditions near the bottom of the reservoir and the outflow; and mercury in the bottom sediments.

The reservoir and its inflow streams were sampled approximately monthly during the open-water seasons of 1991-1996 for physical characteristics, water chemistry, nutrients and other selected variables. River inflow and reservoir outflow volumes were measured and a water balance was developed.

The mean annual runoff to the reservoir averaged slightly above the long-term annual mean during the study years; the average was biased by the flood event of 1995, which had the highest flow on record for the basin. On average, 87% of the total annual inflow occurs during the April – October open-water period, most of this during May – July. The Crowsnest, Castle and Oldman rivers supply about 83% of the total runoff inflow. Of these, the Castle and Oldman rivers are similar in size, and the Crowsnest is considerably smaller. Between 1993 and 1996, the average water residence time of the reservoir was about 100 days.

Over each summer, the temperature at the bottom of the reservoir increased. This was moderated somewhat if a large volume of river water entered the reservoir and flowed along the bottom. The reservoir stratifies only weakly or temporarily during the summer due to disruption of the thermocline by inflow water and removal of cool hypolimnion water via the outflow. The highest recorded outflow temperature was 15° C. There was no statistical relationship between water level and outflow temperature.

A large amount of suspended sediment enters the reservoir each year, mainly in the inflow rivers (over 100,000 tonnes in 1996). About 97% of the suspended sediment entering the water body is retained as bottom sediment. Although the water is more turbid than would be expected for the reservoir's level of productivity, Secchi depths of 5 m were recorded on occasion.

Based on available data, the water quality in the Oldman Reservoir appears to be excellent. On most sampling dates, dissolved oxygen concentrations remained high from the surface to the bottom, even when the reservoir was stratified. The water is low in dissolved solids and moderately hard. Most metals analyzed met guidelines for the protection of aquatic life. Only aluminum levels were high enough that they exceeded guideline levels in about half of the samples analyzed. A few other metals also exceeded very infrequently, but concentrations were near the guideline value. These metals appear to be associated with high suspended solids concentrations, and therefore sources are likely natural. For the variables measured, the reservoir water is suitable for all intended uses, as is the outflow water.

Total phosphorus concentrations in the reservoir averaged 15 μg/L over the 1992-1996 sampling period, and varied little from year to year; concentrations of total nitrogen averaged about 300 μg/L but declined over this period. Total phosphorus concentrations in the inflow rivers averaged 54 μg/L over the 1994-1996 period, but 90% of this was in the particulate form. Total nitrogen concentrations in the inflow rivers were similar to those of the reservoir. The three inflow rivers contribute over 75% of the nutrient loading to the reservoir. Loading was highest during the flood year 1995. The phosphorus retention coefficient for the reservoir increased each year after 1991 to 0.76 in 1996; phosphorus is retained in the reservoir as settled particulate material. Most of the nitrogen entering the reservoir left it via the outflow.

Concentrations of chlorophyll *a* averaged 1.7 μg/L during 1992-1996, and varied little from year to year. Based on chlorophyll *a* concentrations, the reservoir is classified as oligotrophic. There was no evidence of “trophic upsurge”, which may occur in new reservoirs when inundated soils release nutrients. The decreased water clarity resulting from high suspended solids in the inflow rivers appears to suppress phytoplankton growth to some extent.

Sediment samples collected in 1996 from the reservoir bottom contained slightly elevated levels of arsenic and cadmium, probably from natural sources. Water collected from above the sediments met water quality guidelines for the protection of aquatic life. Phosphorus fractions in the sediments were relatively low.

ACKNOWLEDGEMENTS

The original sampling program for the Oldman Reservoir was designed and implemented in 1991 by Al Sosiak, Water Sciences Branch. The program has been managed by Karen Saffran, Water Sciences Branch, since 1995. Staff of Monitoring Branch, including Ray Walker, Chris Robertshaw and others collected samples from the Oldman Reservoir and the Oldman, Castle and Crowsnest rivers. Morna Hussey analyzed phosphorus and chlorophyll *a* in samples from the reservoir, and general water chemistry analyses were conducted at Maxxam Labs, Inc (formerly Chemex Labs). The Provincial Laboratory of Public Health in Calgary analyzed microbiological samples. Andy DeBoer of Hydrology Section, Water Sciences Branch, provided hydrological information. Bridgette Halbig produced graphs, formatted the report and helped with information gathering. Doug Clark, Sal Figliuzzi, John Englert, Karen Saffran, Roderick Hazewinkel and David Trew reviewed the report.

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1.0 INTRODUCTION

The Oldman River Dam, which was completed in 1991, impounds water from three rivers draining the eastern slopes of the Rocky Mountains in southern Alberta. The reservoir is located about 10 km north of Pincher Creek and 10 km west of Brocket. It lies in the semi-arid grasslands near the foothills of the Rocky Mountains. The reservoir inundates 12 km of the mainstem Oldman River and 5 km of the north fork of the Oldman River; 12 km of the Castle River; and 7.5 km of the Crowsnest River (Figure 1). The confluences of the Crowsnest and Castle rivers with the Oldman River are now within the reservoir.

The earth- and rock-fill dam, which is within the channel of the Oldman River, has a maximum height of 76 m above the original riverbed; the crest is 1200 m in length. The maximum depth of the reservoir is 68.6 m at elevation 1118.6 m, which is the full supply level (FSL). It releases water downstream through two diversion tunnels located at the bottom of the reservoir (inlet invert elevation 1048 m), and has a spillway over which water can be released when the level is 1109.9 m or higher (Oldman River Dam Operation and Maintenance Manual 1993). Before construction, infrastructure, buildings, trees and shrubs more than 3 m tall and most of the high quality topsoil were removed from the bottom of the future reservoir (Stanley Assoc. 1987, Alberta Environmental Protection 1999).

The project was designed to assure downstream water supplies for consumption and irrigation. An important benefit was the expected increase in irrigated land for crop and livestock production. Additional benefits included enhancement of downstream fisheries, new recreation opportunities on the reservoir, increased capability of meeting downstream flow commitments to Saskatchewan and hydroelectric potential. The dam evens out highly variable flows from the three rivers by storing water during periods of high runoff and releasing it when flows are lower. It also attenuates peak flows during flood events, although this capability is limited, especially for floods of high magnitude such as occurred in 1995.

When the project was being designed in the mid-1980s, it was recognized that water quality would be a major issue. Therefore, Alberta Environment began a monitoring program on the three rivers to obtain background information. From these data, models were set up to predict conditions in the reservoir. Specific issues to be addressed included:

- Will the water quality in the new reservoir be suitable for all intended uses?

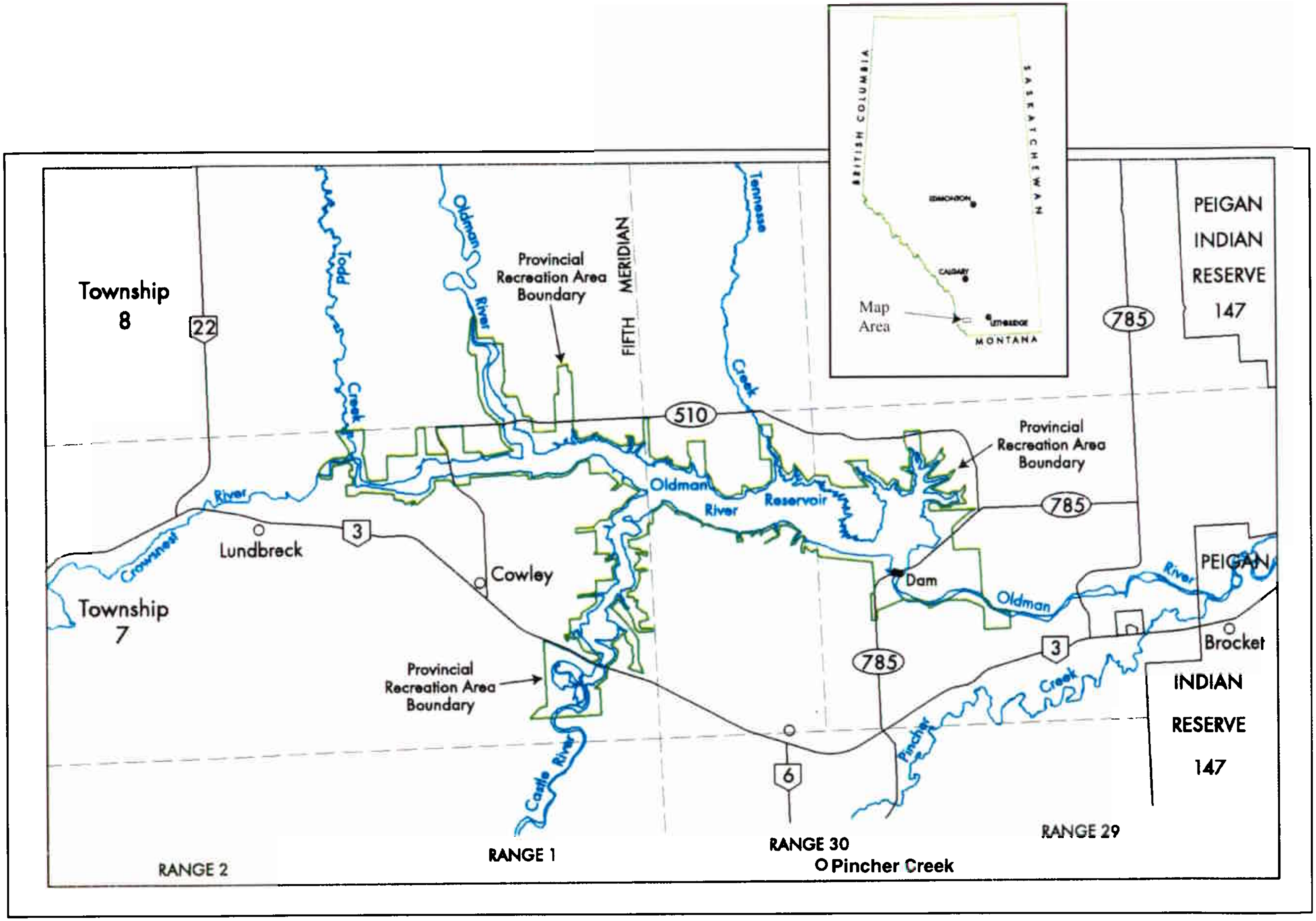


Figure 1. Site map showing the Oldman Reservoir, inflow streams and outflow.

- Will a "trophic upsurge" occur – that is, will there be a period of increased productivity due to the release of nutrients from inundated soils?
- Will the hypolimnion be anoxic? Would this affect water quality in the Oldman River downstream?
- How will the bottom temperature, and therefore the outflow temperature, vary?
- Is mercury building up in the bottom sediments and fish?

Alberta Environment began sampling the reservoir and its inflow streams in 1991 as the reservoir was filling. It was sampled each year through 1996, although inflow streams were not sampled in 1993. The sampling program was designed to address the above questions except the issue of mercury in fish, which was addressed by other researchers on the project (Wu *et al.* 1997, Wu *et al.* 1998). This report documents the general limnology of the reservoir, compares measured water quality with that predicted before construction and discusses outflow water quality relative to the Oldman River downstream. It expands upon and updates the previous report on the reservoir (Golder Associates 1995), and may be considered baseline information for future studies to address specific issues that may affect water quality in the Oldman Reservoir and the Oldman River downstream.

2.0 METHODS

The sampling program on the Oldman Reservoir focussed primarily on its nutrient status or level of productivity, including nutrient concentrations, algal biomass as indicated by chlorophyll *a* concentration, and water transparency. In addition, nutrient concentrations in major inflow streams were measured so that mass loads could be calculated. Other water quality characteristics were also documented, including temperature, dissolved oxygen concentrations, routine chemical variables and metals. Samples were collected with sufficient frequency that seasonal variability, including effects of varying climatic conditions, could be determined.

2.1 SAMPLING SITES AND FREQUENCY

When the sampling program began in 1991, it was thought that there could be important spatial differences in water quality, especially within the long bays or arms resulting from inundation of the Castle, Crowsnest and Oldman rivers. Initially, these areas were designated as “cells”, and given Roman numerals. Figure 2 shows a depth contour map of the reservoir indicating the five cells that were sampled. These areas were sampled for three years, but sampling of Cells III, IV and V was discontinued after 1993 because the observed differences in water chemistry from cell to cell were minor, and therefore did not warrant the extra effort required to obtain the samples. The main part of the reservoir (Cells I and II) were sampled separately for the entire six years. An arbitrary line running from Tennessee Creek south separated Cells I and II. The reservoir was sampled approximately every two weeks in 1991, 1992 and 1993 and monthly in 1994, 1995 and 1996. Winter samples were not collected because of unsafe ice conditions. Table 1 lists sampling sites and frequency.

The three main inflow rivers and the reservoir outflow were sampled throughout the open-water season in 1991-1996 (except 1993). In addition, samples were collected from the inflow streams in the mid-1980s, before reservoir construction began. Some of the sampling sites used in the 1980s were moved upstream as reservoir filling began. Table 2 lists river sampling sites and years sampled.

2.2 FIELD METHODS

On each sampling trip on the reservoir, temperature, dissolved oxygen, conductivity, pH and other field variables were measured in-situ at 1 m depth intervals from the surface to near the bottom, at each site. Transparency was measured with a Secchi disk, and light extinction was measured with an underwater photometer at 1 m intervals down through the water column to the point of 1% penetration.

Composite reservoir samples for water chemistry were collected with a specially cleaned, weighted, clear plastic hose that was lowered from the surface through the zone that

Table 1. Oldman Reservoir sampling sites, frequency and period of sampling.

	Cells Sampled	Frequency	Sampling Period
1991	I-V	2 x month	19 June – 4 Oct.
1992	I-V	2 x month	13 May – 27 Oct.
1993	I-V	2 x month	18 May – 19 Oct.
1994	I-II	1 x month	17 May – 12 Oct.
1995	I-II	1 x month	10 May – 13 Sept.
1996	I-II	1 x month	15 May – 17 Sept.

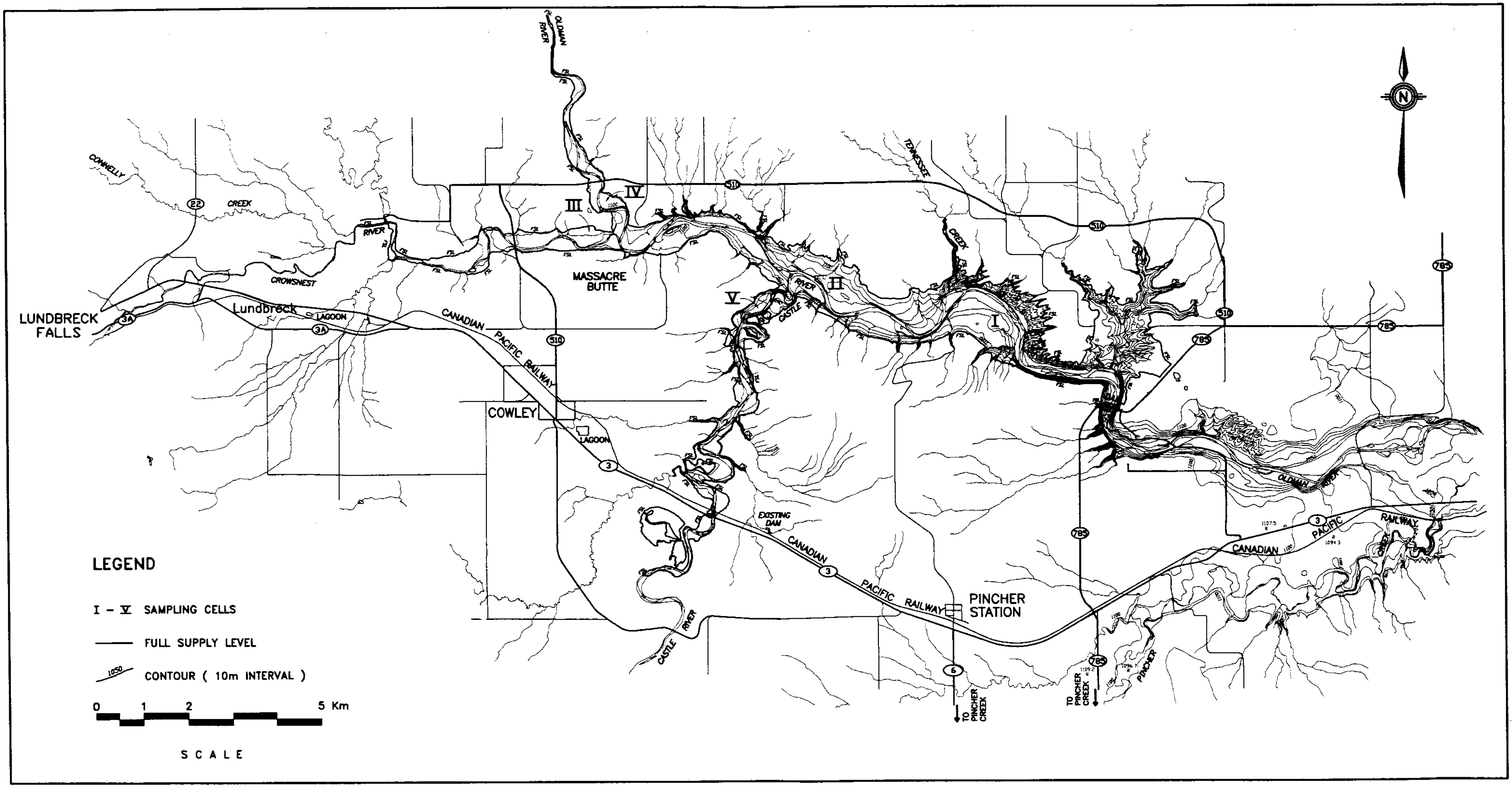


Figure 2. Bathymetric map of the Oldman River Reservoir

Alberta ENVIRONMENT

Table 2. Sampling sites and frequency for rivers flowing into Oldman Reservoir, and reservoir outflow (100 m downstream reservoir).

	Sampling Sites	Frequency	Sampling Period
1984	Castle R. at Hwy 3 Bridge near Cowley	2 x month	April 9 – Dec. 12
	Crowsnest R. near mouth		
	Oldman R. near Waldron's Corner		
1985	Castle R. at Hwy 3 Bridge near Cowley	2 x month	Jan. 8 – Dec. 17
	Crowsnest R. near mouth		
	Oldman R. near Waldron's Corner		
	Oldman R. near Olin Creek	Monthly	May 22 – Sept. 18
1991	Castle R. at Recreation Area	Every 2 months	April 23 – Dec. 2
	Crowsnest R. upst. Connelly Creek		
	Oldman R. near Waldron's Corner		
	Oldman R. 100 m downstream reservoir		
1992	Castle R. at Recreation Area	Every 2 months	Feb. 4 – Dec. 7
	Crowsnest R. upst. Connelly Creek		
	Oldman R. near Waldron's Corner		
	Oldman R. 100 m downstream reservoir		
1993	Castle R. at Recreation Area	Once	Feb. 1
	Crowsnest R. upst. Connelly Creek		
	Oldman R. near Waldron's Corner		
	Oldman R. 100 m downstream reservoir		
1994	Castle R. at Recreation Area	Monthly	May 16 – Oct. 11
	Crowsnest R. upst. Connelly Creek		
	Oldman R. near Olin Creek		
	Oldman R. 100 m downstream reservoir		
1995	Castle R. at Recreation Area	Monthly	April 18 – Oct. 23
	Crowsnest R. upst. Connelly Creek		
	Oldman R. near Olin Creek		
	Oldman R. 100 m downstream reservoir		
1996	Castle R. at Recreation Area	Monthly	April 24 – Oct. 28
	Crowsnest R. upst. Connelly Creek		
	Oldman R. near Olin Creek		
	Oldman R. 100 m downstream reservoir		Feb. 3 – Oct. 28

light penetrated on that day (1% of surface irradiation), as measured with the light meter. These vertically integrated samples from each cell or basin were combined into one sample container, so that separate composite samples were collected for the two or five cells sampled, depending on the year.

Fecal coliform bacteria were collected from inflow streams most years of the study, and also in 1984 and 1985. As well, samples for total coliform bacteria were collected in 1984-85, 1991-92 and 1994, and *Escherichia coli* samples were collected in 1994-1996. *E. coli* was analyzed only to the species level.

Samples were shipped on ice to a commercial analytical laboratory in Calgary, now called Maxxam Labs, for chemical analyses. Chlorophyll *a* and phosphorus fractions were analyzed by staff of Alberta Environment's Monitoring Branch, except for the inflow streams in 1991 and 1992, which were done by Maxxam Labs. Table 3 lists variables analyzed in most samples over the six years of the study. Pesticides and other organics have not yet been sampled in the reservoir or its inflow streams, although a few pesticide samples were collected downstream of the reservoir at Brocket.

Sediment samples from the bottom of the reservoir were collected in 1991, 1992, 1993 and 1996. In 1991-1993, one sample was collected from Cell I and one from Cell II, in the autumn of each year. A total of 13 samples were collected from the five cells in 1996. Texture, total and non-apatite inorganic phosphorus and total organic carbon were analyzed on all sediment samples. A full suite of metals was analyzed in the 1996 samples, collected in November; for the other years, a limited number of variables was analyzed. For 1991-1993, the metals were analyzed by inductively coupled plasma (ICP), except for mercury, which was done by cold vapour atomic absorption spectrometry (CVAA). In 1996, the metals were analyzed on acid-extracted samples using ICP-mass spectrometry.

Table 3. Variables analyzed in samples collected from the Oldman Reservoir and its inflow streams and outflow, 1991-1996.

Routine Water Chemistry		
	Calcium	Chloride
	Magnesium	Sulfate
	Sodium	Carbonate
	Potassium	Bicarbonate
	Alkalinity	Conductivity
	Hardness	Turbidity
	pH	Total dissolved solids
		Non-filterable residue
Nutrients		
	Total phosphorus	Total Kjeldahl nitrogen
	Total dissolved phosphorus	Nitrite+nitrate-nitrogen
	Reactive silica	Total ammonia-nitrogen
	Dissolved organic carbon	
Other		
	Selected metals (1991-94)	Conductivity
	Dissolved oxygen	pH
	Temperature	Light
	Fluoride	Colour
	Mercury, total	Chlorophyll *a* (phytoplankton)
	Total coliform bacteria (streams only)	Fecal coliform bacteria, *E. coli* (streams only)

2.3 HYDROLOGY

Flow data for the three major inflow rivers and the outflow were obtained from Water Survey of Canada flow gauging stations. These record water levels in the rivers and outflow continuously year round (station names and code numbers are in Appendix 1). The water level of the reservoir is also recorded, and there are nearby meteorological stations for precipitation and evaporation data. An area-capacity curve was used to generate reservoir area and volume for specific measured water levels. A water balance was computed for each of the study years, on a monthly basis (DeBoer 1997). Total inflow into the Oldman Reservoir was calculated by adding storage changes for the reservoir and net evaporation losses from the reservoir to recorded outflows from the reservoir. Thus, the ungauged inflow from outside of the watersheds of the three rivers was calculated as a residual in the water balance.

2.4 DATA ANALYSIS

Regressions were run to determine if certain variables were influenced by other variables, such as river flow and total suspended solids. If necessary, the data were log-transformed to normalize them. All statistical tests were performed using SYSTAT version 8.0 or Microsoft EXCEL 97.

Inflow river nutrient loads were calculated by multiplying the total monthly river flow volume with the nutrient concentration measured during the same month. Loading from the ungauged portion of the watershed was estimated from the monthly water balance residual and concentration data from the Oldman River above the reservoir; it was deemed most similar to the watershed area not drained by the three rivers. Nutrient loading via atmospheric deposition was estimated with coefficients from Shaw *et al.* (1989). The monthly loads for the open-water season (April-October) were added to produce a summer inflow load. Nutrient concentration data were not available for other months, and loads were therefore not estimated.

Data for the reservoir and its inflow streams were compared with water quality guidelines set out in *Surface Water Quality Guidelines for Use in Alberta* (Alberta Environment 1999). These are based on established Alberta guidelines, Canadian Environmental Quality Guidelines (Canadian Council of Ministers of the Environment 1999) and United States Environmental Protection Agency criteria. References to guidelines in the following report are exclusively to those listed in Alberta Environment (1999).

3.0 RESULTS AND DISCUSSION

3.1 PHYSICAL CHARACTERISTICS

3.1.1 Hydrology

The Oldman Reservoir is an on-stream water body in the Oldman River Basin. The outflow from the reservoir, the Oldman River, drains to the South Saskatchewan River, which joins the North Saskatchewan River in Saskatchewan on its way to Hudson Bay via Lake Winnipeg. The area drained by the basin above the dam is 4390 km^2, and the long-term mean annual runoff for the basin up until 1986 was 1298 million m^3 (Alberta Environment 1989). The highest flow on record downstream of the dam occurred in 1995, at 3500 m^3/s. Before this, the highest recorded flow was 2329 m^3/s, in 1923 (A. DeBoer, pers. comm.).

During the study years, the total annual flow into the reservoir averaged 1397 million m^3, or slightly above average. Of the six years, four were slightly to greatly above average, while two (1992 and 1994) were below average. Figure 3 shows the annual flow of the Oldman, Crowsnest and Castle rivers for the 1983-1998 period. The inflow volumes for the study years represent a range typical of the data set. Of the total annual inflow, nearly 70% occurred during the May-July period (a smaller percentage for the Crowsnest River), and 87% of the total annual inflow occurred during the April – October study period. The greatest flow occurred during June 1995 when large amounts of rain fell in the headwaters. Much of this extraordinary flow had to be passed through the reservoir, and flooding occurred downstream. For the six study years, the three rivers contributed an average of 83% of the total runoff inflow to the reservoir. In most years, the Castle River supplies the largest inflow volume of the three rivers, while the Crowsnest supplies only about 12% of the total runoff inflow (Figure 4).

Figure 5 is a graph of the monthly mean water levels in the reservoir for the study years and for 1997-98. The reservoir filled in 1991 and 1992, and full supply level was attained in 1993. The reservoir is operated to a spill line of about 1114 m above sea level (a.s.l.) during the fall and winter, and up to the FSL (1118.6 m a.s.l.) during mid-summer. There are requirements to supply flows for downstream uses, including fish habitat, during the April to September period (Alberta Environmental Protection 1994).

Table 4 presents a water balance for each of the study years. The water level increased by 31 m in 1992 as the reservoir filled, and therefore the storage volume of the reservoir increased greatly. Between 1993 and 1996, the average water residence time in the

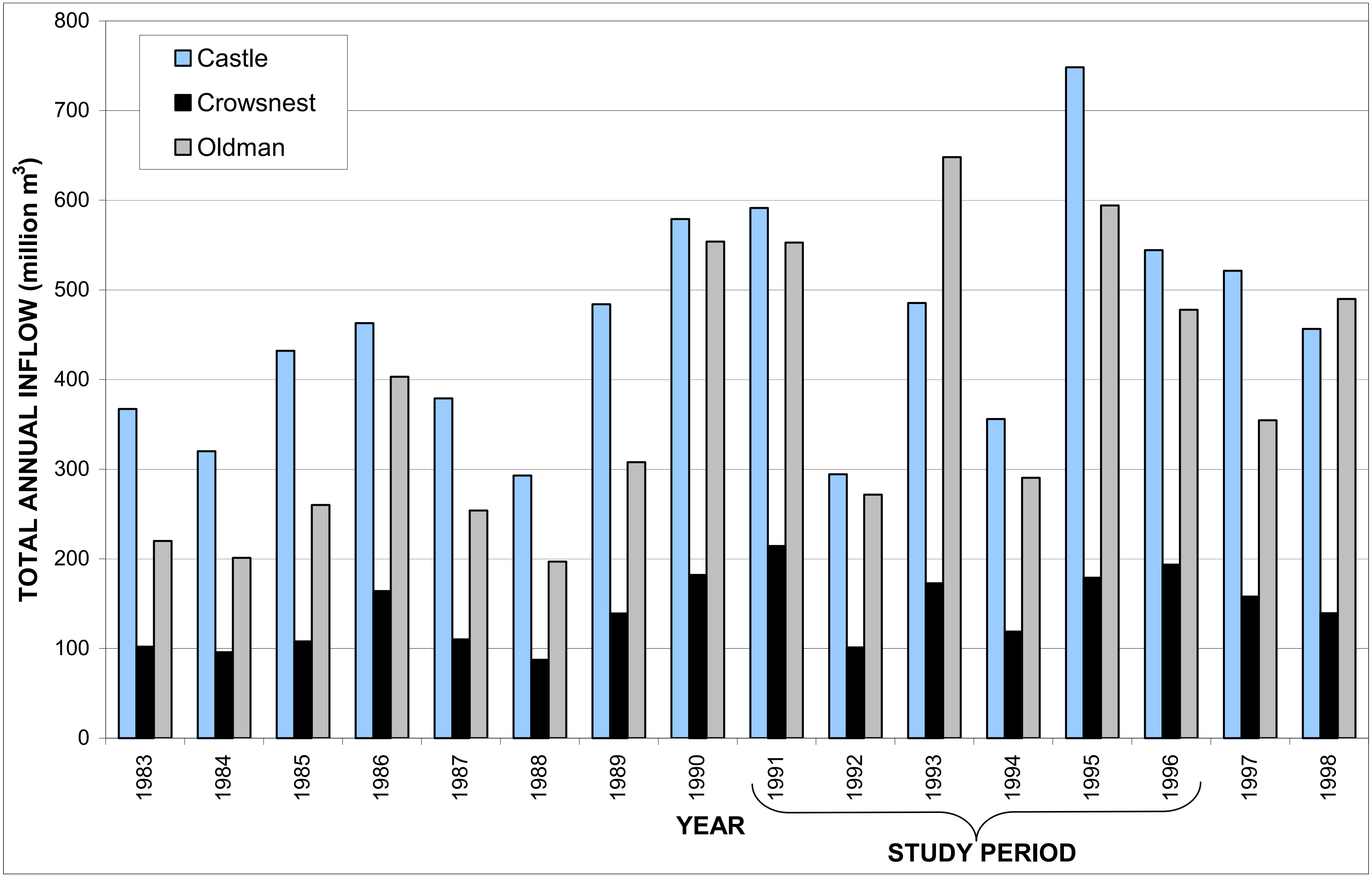


Figure 3. **Annual flow volume (million m^3) in the three major rivers above the Oldman dam site, January to December, 1983-1998**

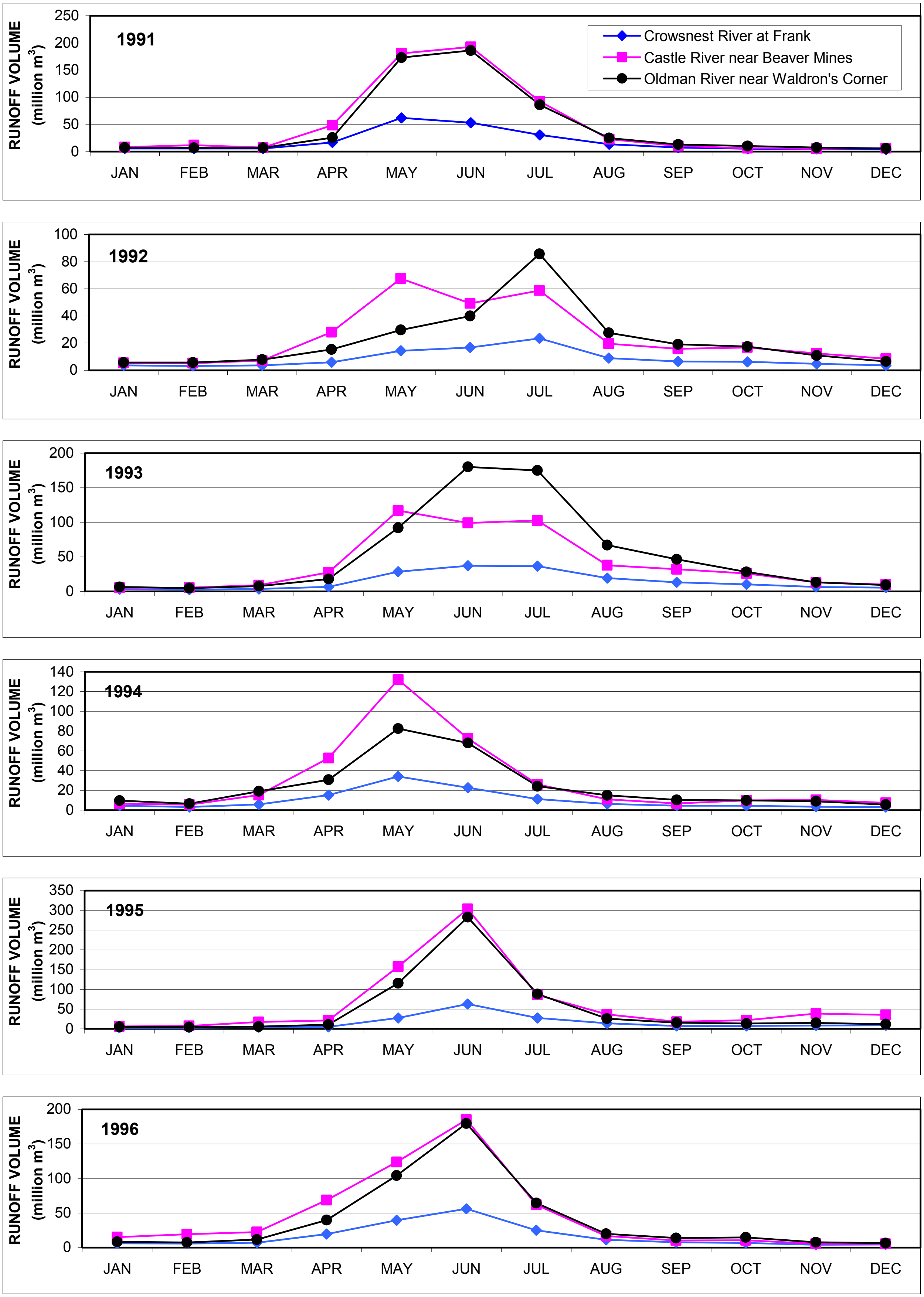


Figure 4. Seasonal inflow of the three major rivers entering the Oldman Reservoir, 1991-1996

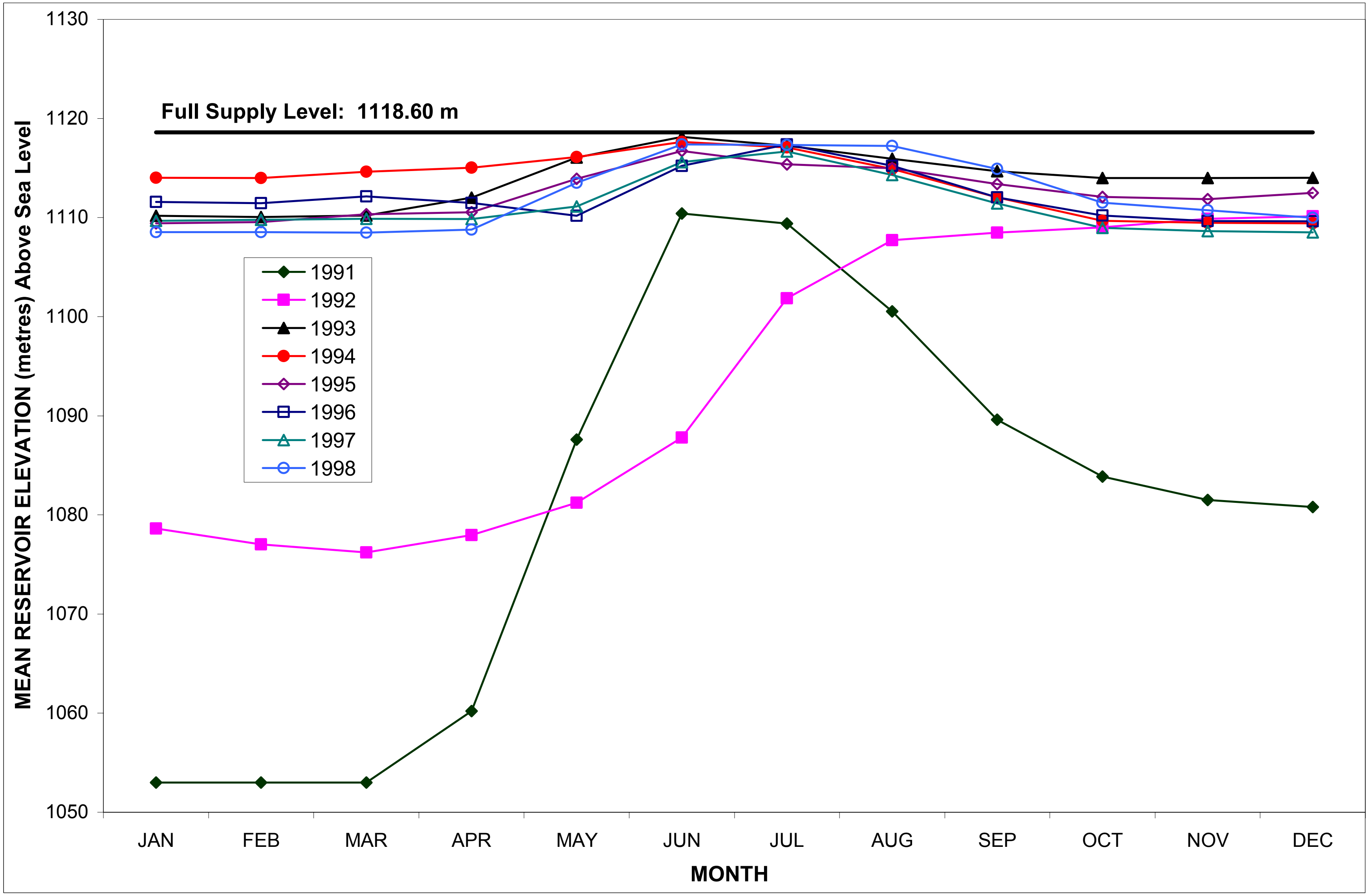


Figure 5. Mean monthly water elevation in the Oldman Reservoir, 1991-1998

Table 4. Oldman Reservoir Water Balance, in million m^3/year except where indicated (DeBoer 1997). Residence time = reservoir volume/outflow volume.

	Inflows					Outflows				
	Oldman	**Crowsnest**	**Castle**	**Ungauged**	**Precip**	**Evap**	**Gauged Outflow**	**Change in Storage**	**Residence Time, Days**	**Reservoir Volume**
1991	531.57	197.215	563.81	224.68	4.57	7.91	1467.21	46.701	31.	130.87
1992	271.72	101.098	294.26	92.47	7.01	6.94	479.31	280.317	81	168.45
1993	648.09	172.676	485.26	305.05	15.47	15.00	1542.38	69.160	90	395.95
1994	290.51	118.783	355.90	169.35	7.69	16.56	1007.76	-82.097	154	391.93
1995	594.13	178.899	748.19	576.24	14.45	14.96	2051.02	45.929	64	370.08
1996	477.82	193.645	544.28	248.25	9.05	14.56	1502.10	-43.609	91	363.38

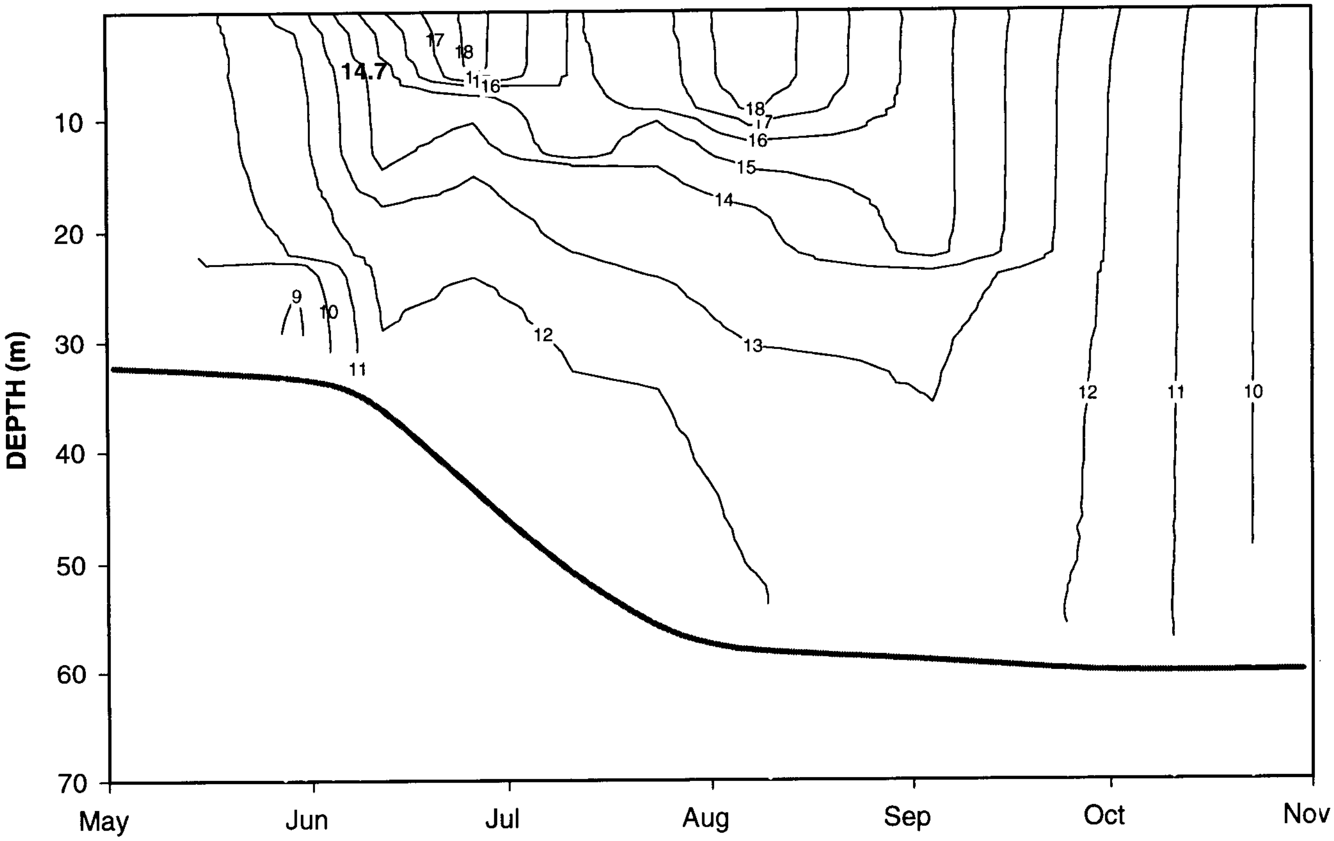
reservoir was about 100 days. The ungauged inflow was computed from the water balance, and would represent inputs from groundwater as well as measurement or estimation errors for water balance terms.

3.1.2 Thermal Characteristics

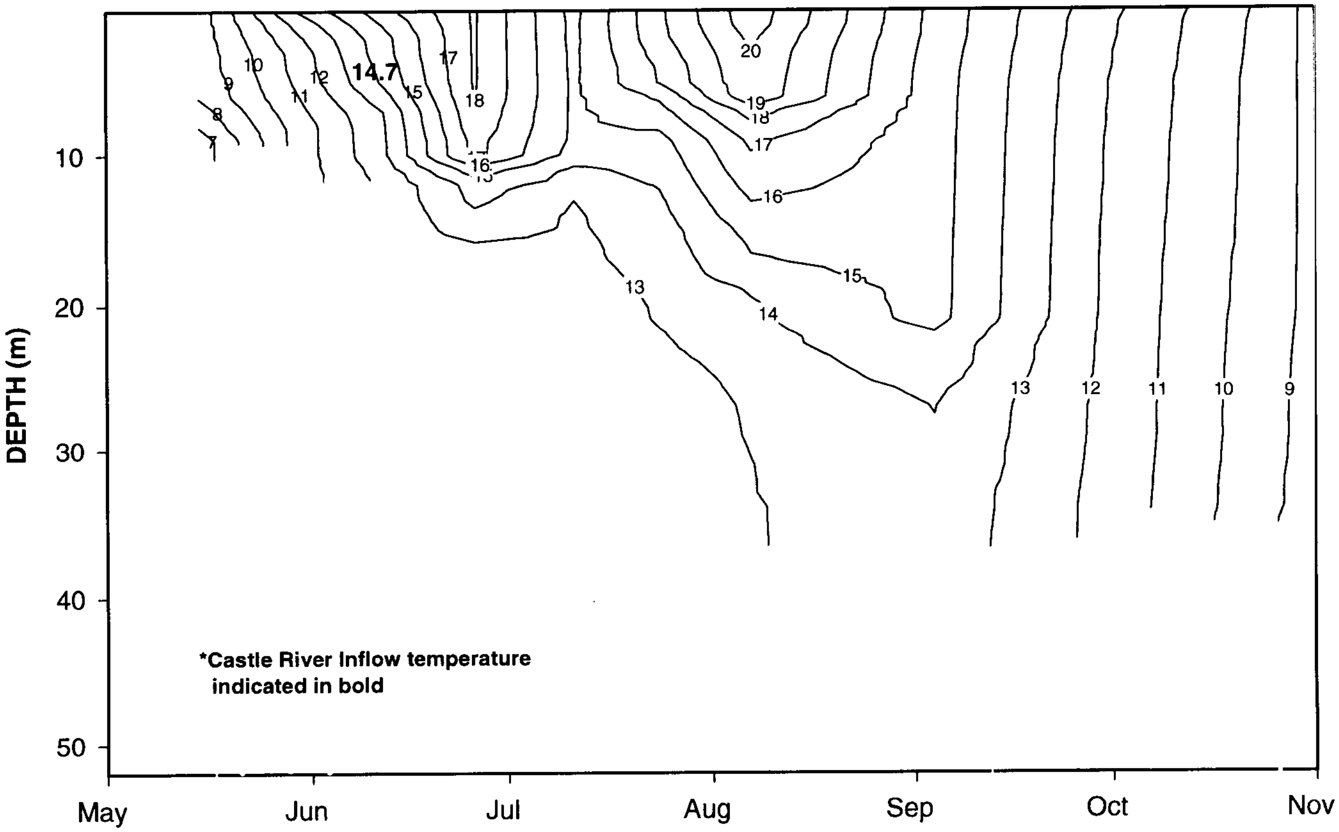
Figure 6 shows temperature plotted against time and depth in Cells I and II for the 1992-1996 sampling seasons. At the reservoir site nearest the dam (Cell I), temperature was measured in up to 68 m of water about 3 km upstream of the dam; in Cell II, it was measured in up to 50 m of water about 7 km upstream of the dam. In 1992, the reservoir was filling, so that the depth of temperature readings increased as the summer progressed. On each Cell I graph, the elevation of the diversion tunnels at the dam is shown relative to the depth of the water on the sampling date. For example, on May 28, 1992, the diversion tunnel was at 33 m depth, but the deepest temperature measurement was at 29 m depth. The site sampled was likely about 30 m deep (up-slope of dam). For some of the sampling dates, the depth of sampling was considerably shallower than the depth of the diversion tunnel, because the deepest part of the former river channel was not located on the particular sampling day.

When a river enters a reservoir, the incoming water will flow into a density layer similar to its own (Wetzel 1983). For the Oldman Reservoir, temperature is likely the main factor governing water density since levels of total dissolved solids in the inflow rivers are similar to those of the reservoir. In spring most years, the inflow river water was warmer than

CELL I



CELL II



*Castle River Inflow temperature indicated in bold

Figure 6a. Time-depth diagrams of temperature in the Oldman Reservoir, Cells I and II, 1992. ***Bold line on Cell I graph indicates depth of water over the diversion tunnel on day of sampling.***

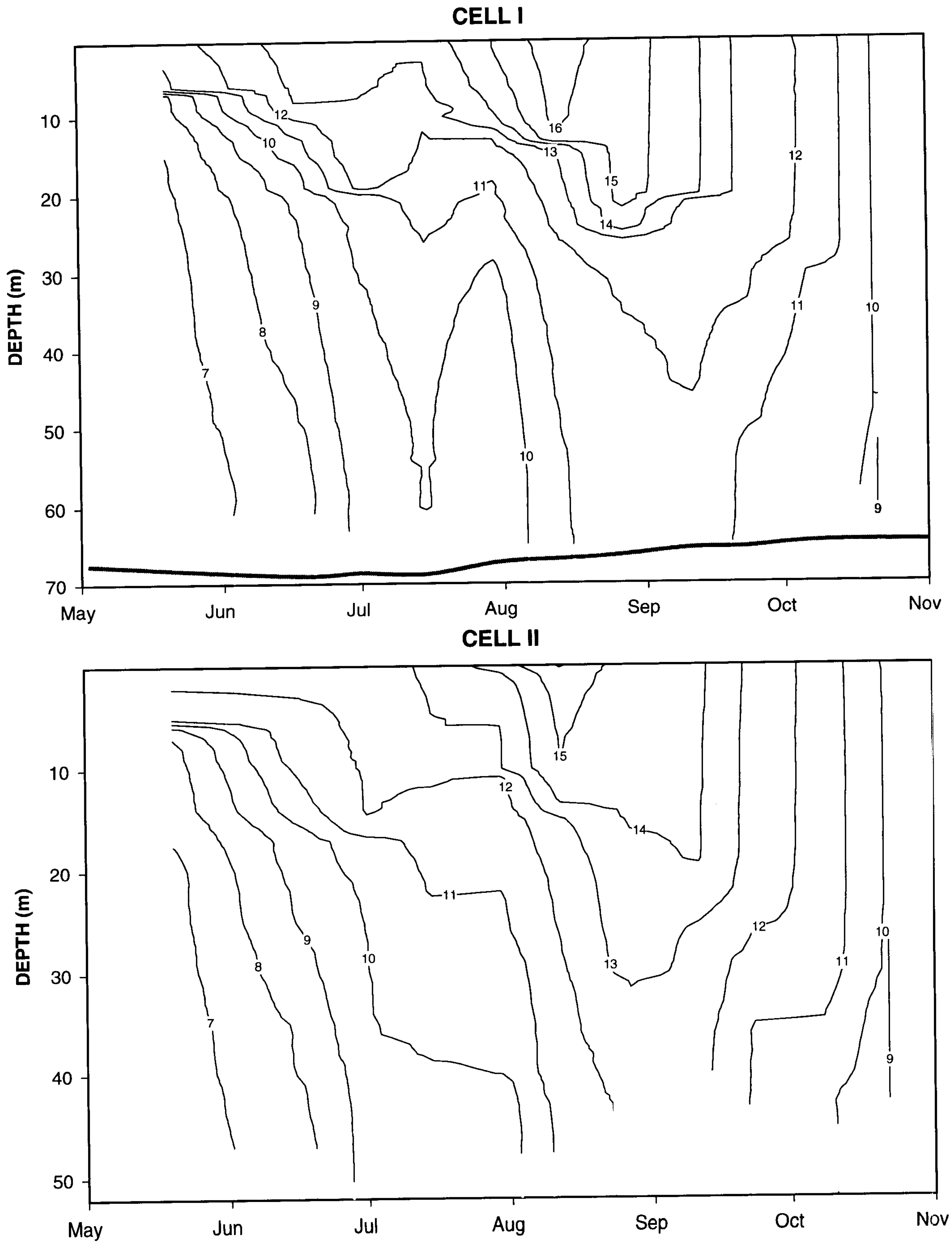


Figure 6b. Time-depth diagrams of temperature in the Oldman Reservoir, Cells I and II, 1993. *Bold line on Cell I graph indicates depth of water over the diversion tunnel on day of sampling.*

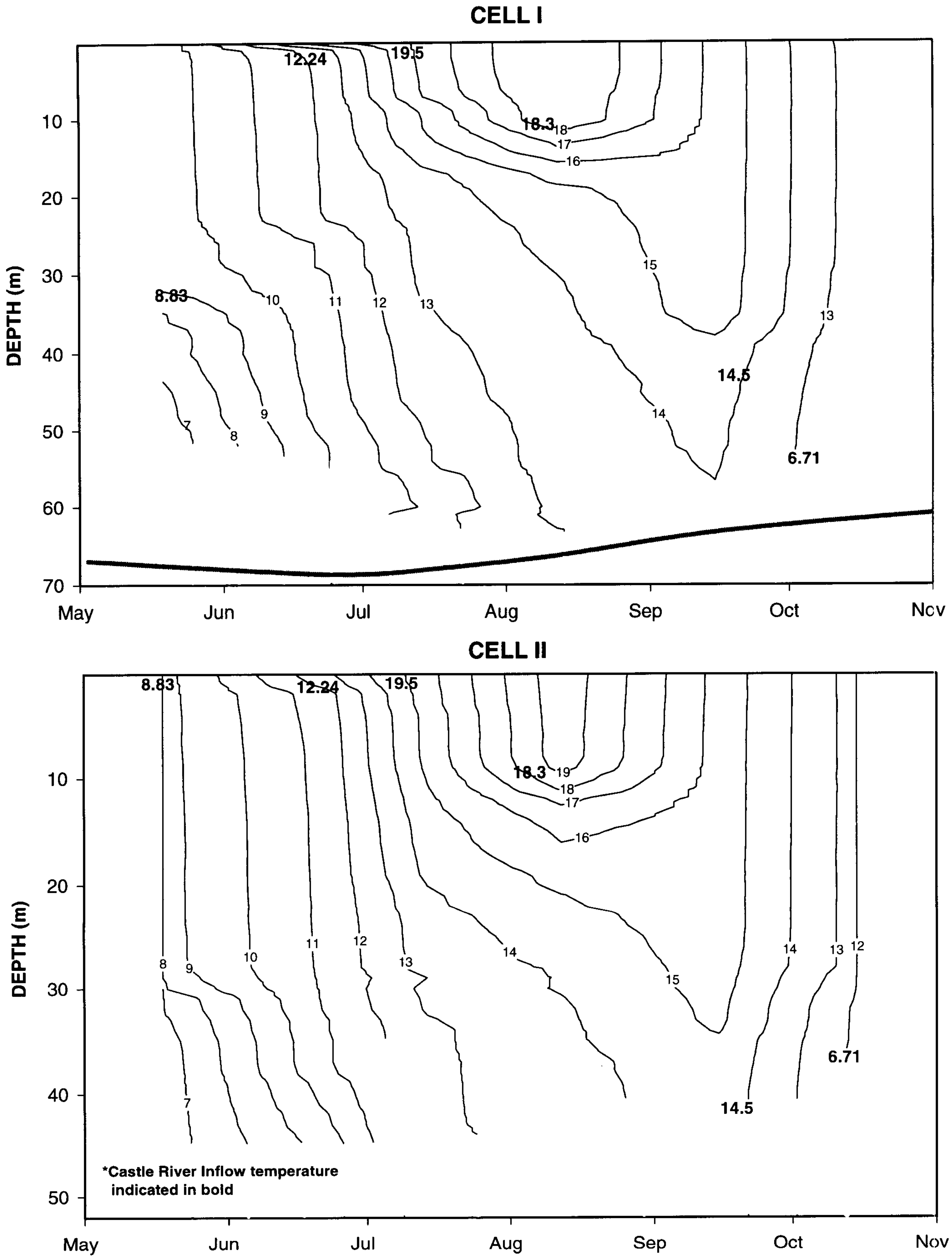


Figure 6c. **Time-depth diagrams of temperature in the Oldman Reservoir, Cells I and II, 1994.** ***Bold line on Cell I graph indicates depth of water over the diversion tunnel on day of sampling.***

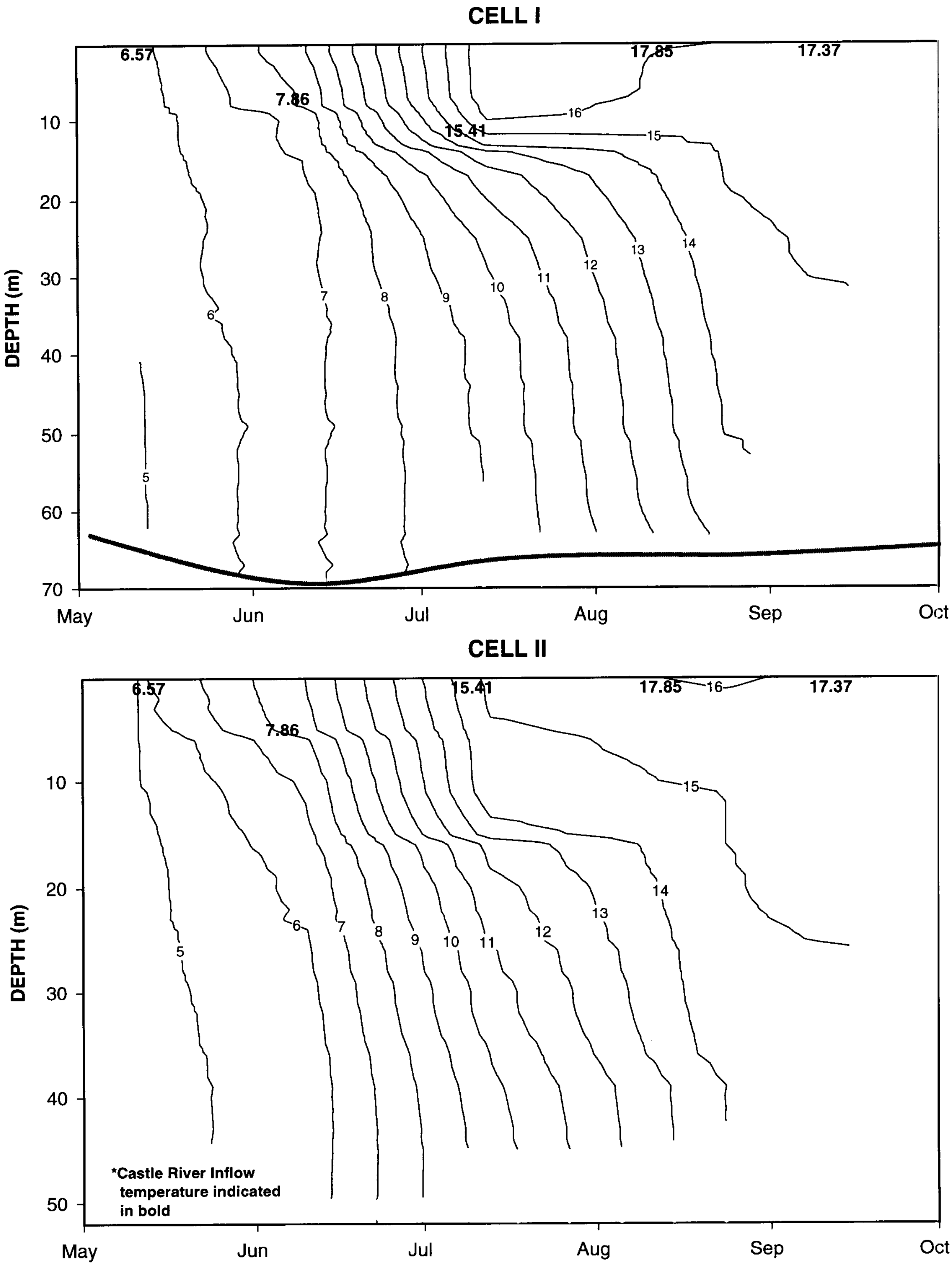


Figure 6d. **Time-depth diagrams of temperature in the Oldman Reservoir, Cells I and II, 1995.** ***Bold line on Cell I graph indicates depth of water over the diversion tunnel on day of sampling.***

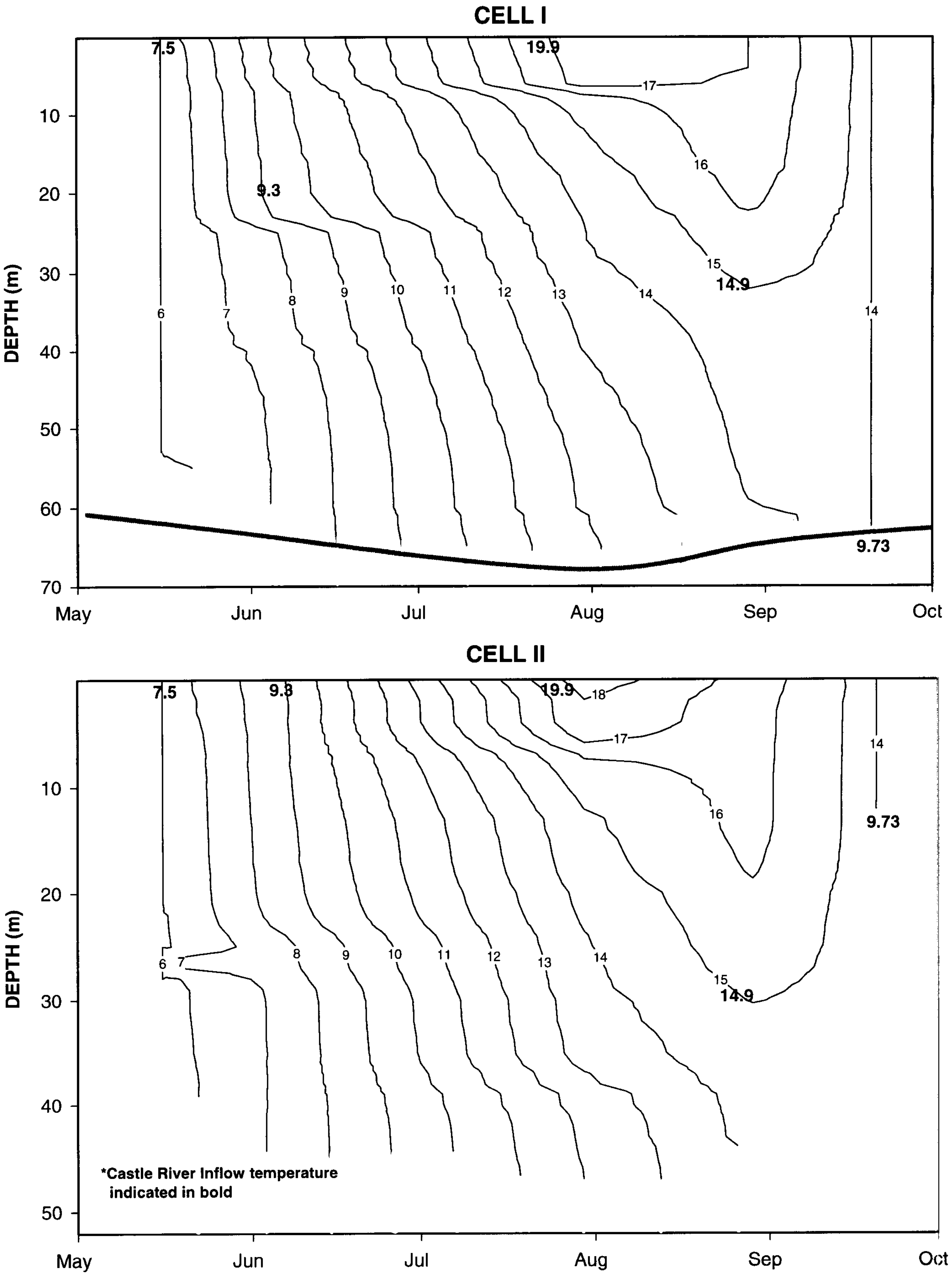


Figure 6e. Time-depth diagrams of temperature in the Oldman Reservoir, Cells I and II, 1996. ***Bold line on Cell I graph indicates depth of water over the diversion tunnel on day of sampling.***

the reservoir, and the inflowing water would remain near the surface (temperature of Castle River inflow water is represented at the appropriate depth on the graphs). If the inflow river water was cooler than the reservoir, it would flow under the warmer water above it; in some cases, it would flow along the bottom to the greatest depth. As the plume of tributary water flows into the reservoir, water in the water column is entrained, and some mixing occurs. These scenarios have implications for reservoir trophic response, depending on whether tributary water enters the euphotic zone or below it.

Over each summer, the temperature at the bottom of the reservoir gradually increased. This was moderated somewhat in Cell II by inflowing river water, so that during 1993, for example, the temperature at the bottom changed very little over a four-week period in June - July. In Cell I, there was an increase in temperature at the bottom during June and into July 1993, but at the end of July, the temperature decreased from 10° C to 9° C. This corresponds to a large inflow of water in the three rivers in mid-July, which was likely cooler than the water at the bottom of the reservoir (river temperature data are not available for 1993). In 1994, temperature patterns are similar for the two cells, and both show weak stratification in August. Note that this area of rapid temperature change is also the temperature of the Castle River inflow on that sampling date, but the monthly data are insufficient to determine how this interflow affected stratification. Temporary stratification occurred in July 1995 as well, and it appears warm river water overflowed cooler water below. By August 22, the next sampling date, the water temperature varied only 2.6° C from the surface to the bottom in Cell I, and somewhat less in Cell II. Wind events would likely mix the water column to considerable depths under these circumstances. In 1996, there was also evidence of thermal stratification near the surface of the reservoir in July, which was reduced by late August.

In contrast to predictions made before the dam was built (Environment Canada 1987), the reservoir does not stratify strongly. Stratification, when it occurs, is temporary and the thermocline tends to be high in the water column. It was observed in three of the five years sampled (excluding 1991), but probably occurred transiently between sampling dates the other years. In July and August, air temperatures are high and surface warming is rapid, leading to establishment of a thermocline. For example, on August 10, 1993, a strong thermal gradient developed at about 13 m in Cell I and a weaker one at the same depth in Cell II. The thermocline was lower in the water column in Cell I two weeks later but had disappeared in Cell II (see also graphs in Figure 8). The reservoir does not stratify strongly because the inflow water volume is high, creating thermal density currents that inhibit stratification. As well, the outflow from the reservoir removes cool, dense bottom water, which also destratifies the water column.

The surface temperature in Cell I was often higher than that of Cell II on the same day, whereas the bottom temperature in Cell I was often lower. As would be expected, the inflow water was usually warmer than the reservoir in spring, but cooler than reservoir water in autumn (Table 5). Caution should be used in interpreting data in this table, because temperature measurements made in the inflow streams were single-point measurements during daylight, and would not represent average temperatures for the rivers on that day. The highest temperature recorded at the bottom of Cell I was 14.26° C, in September 1996. The highest recorded outflow temperature was 15.0° C in September 1995. The large discrepancy between the outflow temperature and the bottom temperature on 8 June 1995 may be attributed to operation of the spillway, which would contribute warm surface water to the outflow.

Although the outflow temperature in this data set was nearly always slightly higher than the temperature at the bottom of the reservoir, the outflow and bottom temperature measurements were rarely made on the same day. The temperature of the outflow and bottom were measured on the same day and time in August 1995; the outflow temperature was 0.7° C higher than the temperature at the approximate elevation of the diversion tunnel within the

Table 5. Temperature (°C) in inflow rivers, bottom of Cells I and II and outflow, 1994-1996. Sampling dates chosen are those where bottom measurement in Cell I is within 3 m of depth of outflow tunnels.

	River Inflows			Cell II		Cell I		Outflow Temp	Air Temp
Date	Oldman Temp	Crowsnest Temp	Castle Temp	Bottom Temp	Depth	Bottom Temp	Depth		
10-Aug-94	16.30	16.49	18.30	13.35	44 m	12.97	63 m	13.57	25
13-Sep-94	13.52	14.13	14.56	14.60	40 m	13.63	62 m		19
10-May-95	7.89	8.12	6.57	4.69	44 m	4.92	62 m	5.16	12
8-Jun-95	7.08	9.84	7.86	5.51	50 m	6.72	68 m	10.69	19
22-Aug-95	16.24	16.40	17.85	14.00	44 m	13.29	63 m	14.00	28
4-Jun-96	7.92	9.42	9.29	7.22	44 m	7.11	60 m	7.56	20
28-Jul-96	19.72	17.90	19.89	12.01	47 m	11.75	65 m	12.47	29
27-Aug-96	14.20	12.73	14.96	14.18	44 m	13.80	61 m	14.45	21
17-Sep-96	8.75	8.98	9.73	14.57	6 m	14.26	62 m	14.74	6

reservoir (13.3° C at bottom, 14°C in outflow). Although this suggests that the outflow is slightly warmer than the water at the bottom of the reservoir, additional data would be needed to confirm this. It is possible that bottom temperatures are somewhat higher near the dam, due to vertical mixing as well as mixing from the shallow areas north of the dam.

The highest outlet temperatures were slightly higher than that predicted by HydroQual (1990). They suggested that the highest outflow temperatures would occur when the water level is lowest. However, there was no statistical relationship between water elevation and outflow temperature ($P>0.5$, n=25) during the study years.

3.1.3 Suspended Solids

The concentration of total suspended solids (TSS) in the main part of the reservoir was fairly low, but was sometimes higher than might be expected for a natural lake with a similar level of productivity. Inflow concentrations were low except in spring. Table 6 summarizes medians and ranges for TSS concentrations in the reservoir and the three major inflow streams. Concentrations were often higher at the three reservoir sites within river arms (III, IV and V) than in the main body of the reservoir, as would be expected. TSS concentrations were highly correlated with flow for the three rivers combined, as well as individually (TSS vs. flow, all rivers, $r^2 = 0.44$, $P<0.0001$, n = 83). Concentrations in inflow streams were very high in spring 1995 and 1996, but this was not reflected in appreciably higher concentrations in Cells I and II. It was not possible to sample the inflow streams during the 1995 flood in early June, but TSS concentrations were likely very high at that time. For example, the Castle River was sampled on June 5, 1995 and the TSS level was 45 mg/L at a flow of 91 m^3/s. On June 7, the flow had increased to a daily mean of 812 m^3/s. Although the TSS concentration on that date cannot be extrapolated from the regression, it was likely over 2000 mg/L. The high TSS concentrations in 1996 in the rivers and the reservoir may be derived from disturbance and settling out along river channels during the previous year's flood, which were resuspended when flows increased. Alternatively, watershed disturbances could have increased suspended materials in runoff.

Concentrations of TSS in the three rivers were fairly similar, but because the flow volume in the Crowsnest River was much lower than in the other two rivers, its TSS load was only 10% of the total TSS load contributed by the rivers. In spite of relatively low TSS

Table 6. Summary of suspended solids (non-filterable residue) data for Oldman Reservoir and inflow streams. Median, range and number of samples, 1991 - 1996. Units in mg/L.

Reservoir				Inflows			
	Median	Range	No. Samples		Median	Range	No. Samples
1991 Cell I	3.9	1.6 - 6.4	8	Oldman 1991	19.0	<0.4 - 171	4
1991 Cell II	3.2	1.6 - 6.0	8	Crowsnest	6.7	1.6 - 45	4
1991 Cell III	6	2.4 - 11	5	Castle	5.8	<0.4 - 28	4
1991 Cell IV	7.8	<0.4 - 18	5	Outflow	10.0	<0.4 - 29	4
1991 Cell V	4.7	<0.4 - 10	5	Oldman 1992	1.4	<0.4 - 12	4
1992 Cell I	1.7	<0.4 - 4.8	10	Crowsnest	7.1	<0.4 - 15	4
1992 Cell II	1.6	<0.4 - 3.6	10	Castle	1.8	<0.4 - 36	4
1992 Cell III	0.95	<0.4 - 3.2	4	Outflow	1.2	<0.4 - 20	4
1992 Cell IV	0.6	<0.4 - 1.6	4	Oldman 1994	5.0	<0.4 - 36	6
1992 Cell V	3	<0.4 - 10	5	Crowsnest	4.7	<0.4 - 15	6
1993 Cell I	2	<0.4 - 3.7	11	Castle	1.2	1 - 5.0	6
1993 Cell II	0.96	<0.4 - 5	11	Outflow	<0.4	<0.4 - 4	5
1993 Cell III	7.7	<0.4 - 57	11	Oldman 1995	5.0	<0.4 - 113	6
1993 Cell IV	16.4	<0.4 - 149	11	Crowsnest	13.6	<0.4 - 34	6
1993 Cell V	3.8	<0.4 - 16	10	Castle	3.0	<0.4 - 56	6
1994 Cell I	2.7	<0.4 - 9	6	Outflow	2.0	<0.4 - 10	7
1994 Cell II	1.5	<0.4 - 5	6	Oldman 1996	0.4	<0.4 - 293	7
1995 Cell I	3.9	<0.4 - 9	5	Crowsnest	17.5	<0.4 - 45	6
1995 Cell II	5	1 - 10	5	Castle	<0.4	<0.4 - 203	7
1996 Cell I	3.2	<0.4 - 8.5	5	Outflow	2	<0.4 - 10	7
1996 Cell II	6.1	<0.4 - 22	5				

concentrations in the reservoir, a very large amount of suspended sediments enters it each year. For the April to October period in 1994-1996 (April-October represented 87% of the total annual inflow volume), an average of 56,500 metric tons of sediment entered the reservoir in the three rivers (Table 7). The highest estimated input occurred in 1996, but much more than this probably entered the reservoir during the June flood in 1995. Even extrapolated to annual, these estimates are somewhat lower than the average annual load measured at Brocket for the period 1966 to 1983 of 266,000 metric tons, although the range was from 7,000 to 1,108,000 metric tons per year (Water Survey of Canada data, reported in Northwest Hydraulic Consultants 1987).

Table 7. Mass of total suspended solids (metric tons) in inflows, outflow and within Oldman Reservoir, 1994-1996. Total inflow and outflow for April-October, and average mass in reservoir for period. Inflow includes Oldman, Crowsnest and Castle rivers only.

	Inflow Rivers	In Reservoir Water Column	Outflow
1994	6910	869	319
1995	59800	1890	1410
1996	103000	1830	845

The latter very high amount (in 1975, a year of high flow rates) likely came from a landslide that occurred on the Oldman River 10 km above its confluence with the Crowsnest River.

It was predicted that most if not all of the inflowing sediment would deposit within the reservoir (Northwest Hydraulic Consultants 1987). This appears to be borne out by the 1994-1996 TSS data. In 1995, over 97% of the TSS entering the reservoir was retained, and this estimate does not include the quantity that entered the reservoir at the peak of the flood or from diffuse runoff and other sources. In 1996, 99% of the sediment entering it remained there. Most of the sediment entering the reservoir falls to the bottom; in 1996, this would have amounted to over 100,000 metric tons. These figures are rough estimates only, because data for other sources of TSS entering the reservoir (including shoreline erosion) were not available. As well, the in-reservoir mass was computed from euphotic zone composite samples, not from the entire water column or from the three river arms. According to Northwest Hydraulic Consultants (1987), the three river arms would retain about 20% of the sediment inflow, and the rest would deposit in the main sections. They estimated that just over half of the total sediment load would be river-borne, and the rest would be derived from shoreline erosion. Northwest Hydraulic Consultants also suggest that after 50 years, there could be a sediment accumulation depth of 15 m against the dam face, but much of this would come from shoreline erosion in the dam area. However, observations in St. Mary Reservoir suggest that this accumulation might be less, and therefore the half-life of the Oldman Reservoir would be longer than anticipated (D. Clark, personal comm., November 2000).

3.1.4 Transparency

The transparency of the reservoir water, as measured with a Secchi disk, was lower than predicted by HydroQual (1990). They suggested that the reservoir would have very clear water, with Secchi depths in excess of 6 m because the reservoir would be so unproductive. In fact, the overall average Secchi depth for the study years, excluding 1991, was 2.4 m and the Secchi depth exceeded 5 m on only two sampling occasions.

Over the six study years, the average Secchi transparency was deeper in Cell II (2.5 m) than in Cell I (2.0 m) ($P<0.01$, n=45). Correspondingly, the average turbidity and total suspended solids concentration was slightly lower in Cell II. However, during 1995-1996, the average vertical extinction coefficient of light (photosynthetically active radiation) was identical in the two cells (average vertical extinction coefficient in ln units = 0.98/m, range 0.38 – 2.33/m). The vertical extinction coefficient was highly correlated with levels of suspended solids in the reservoir ($r^2=0.66$, $P< 0.0001$, n=17), but not with levels of chlorophyll *a*. This suggests that suspended sediment rather than algal cells govern transparency in the Oldman Reservoir.

The year with the clearest water on average was 1993 (Figure 7); Cell II was especially clear. This was a year with above-average runoff, but the level of suspended solids in the inflow streams may have been low, for unknown reasons, or perhaps shoreline erosion was lower than in other years. In 1991 and 1992, the reservoir was filling and probably not representative of typical water clarity for the reservoir. Note the very low transparency in 1995; during the flood (June 8), the Secchi depth reading was 0.6 m in Cell I and 0.3 m in Cell II. Even by the next sampling date, July 11, the transparency was only 0.7 in both cells. For most years, the clearest water occurred in July, after spring runoff was over and suspended sediments in the reservoir had settled to some extent.

3.2 GENERAL WATER CHEMISTRY

3.2.1 Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental requirement for aquatic organisms. Measurement of DO in lakes and reservoirs provides important information on the characteristics and health of the water body. During the six-year study on Oldman Reservoir, dissolved oxygen concentrations were measured throughout the water column on each sampling date during the open-water season. Winter measurements are not available. Typically, dissolved oxygen concentrations in summer decline from the surface of a water body to the bottom; the degree of oxygen depletion is directly related to productivity.

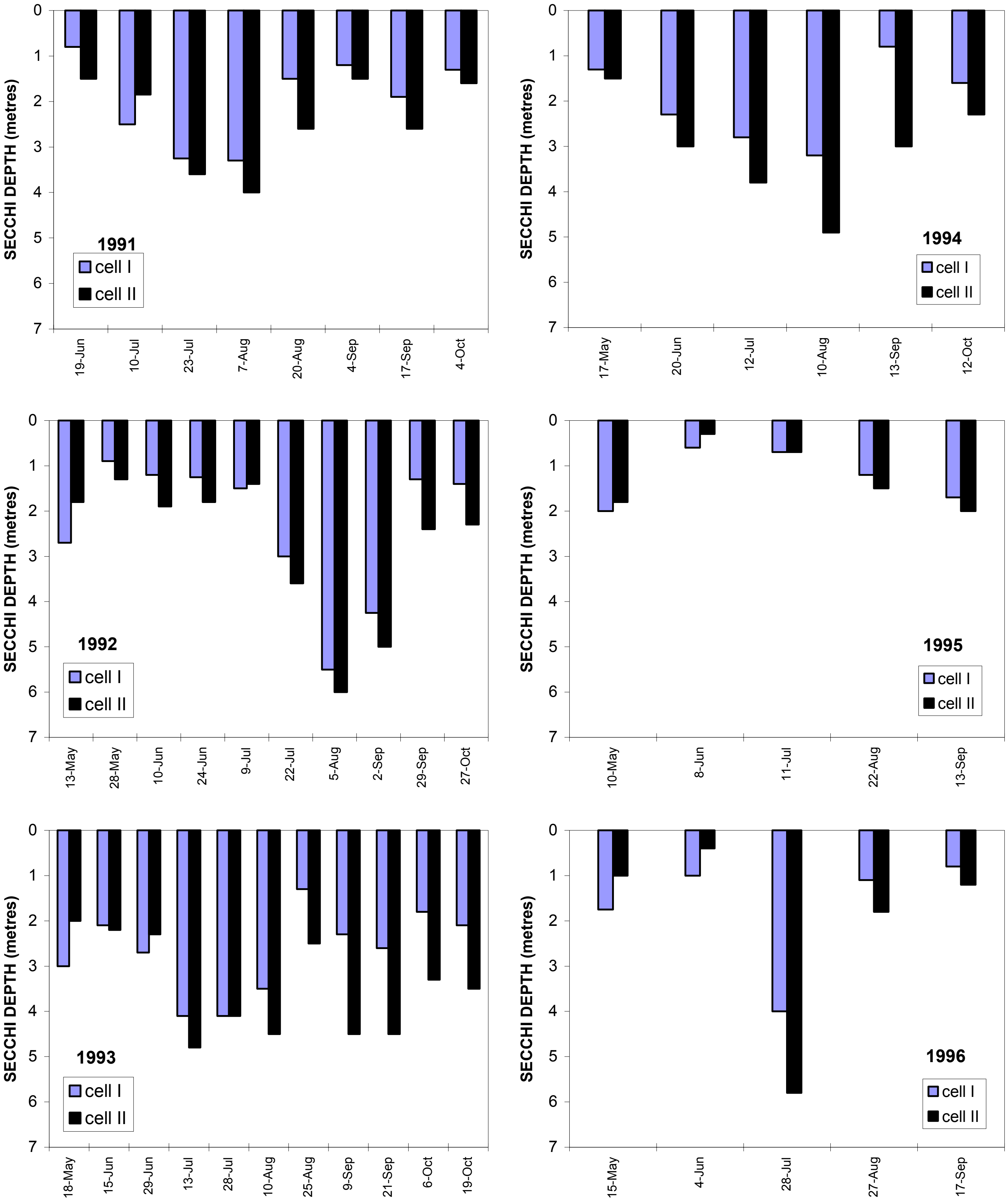


Figure 7. Transparency in the Oldman Reservoir Cells I and II, 1991-1996

Figures 8a and 8b show profiles of dissolved oxygen on mid- to late-summer dates for 1992-1996. Data for 1991 are not included because the reservoir was filling and therefore not typical. The dates graphed were chosen because they are in the open-water period in which oxygen depletion at the bottom is most likely to occur. Temperature profiles are also included on these graphs to indicate stratification if present. Note that stratification is evident on several sampling dates, especially in Cell I. For most sampling dates, the concentration of dissolved oxygen in the reservoir was fairly uniform from the surface to the bottom, and was generally above 70% saturation, even at the bottom.

The lowest recorded DO concentrations were 0.10 to 0.17 mg/L in the bottom 4 m of Cell I on June 8, 1995, just after river inflow to the reservoir peaked during the flood event. At 6 m above the bottom, the DO concentration was 9.2 mg/L. Although there was no temperature gradient at these depths, it is likely that cool, silty river water moved along the bottom, and organic matter in the water created an oxygen demand. Dissolved oxygen was also low in 1994. It was 3.34 mg/L on September 13, 1994, in Cell I (62 m depth). This is equivalent to a saturation level of about 32%. Stratification was very weak on this date in Cell I and not evident in Cell II. The river inflow temperatures suggest that inflow would have moved along the bottom of the reservoir on this date as well, and decomposition reduced the DO level. For all years except 1995, the lowest concentrations at the bottom occurred in late August or early September when water temperatures were highest.

River interflow appears to have affected the DO profile on August 5, 1992 in a different way. In Cell II, the DO concentration increased slightly at about 20 m depth. This is the level that inflow from the Castle River would likely enter the water column in Cell II, based on temperature. Note that the dissolved oxygen concentration also increased in Cell I, at about 29 m depth. These depths are below the thermocline in both cells.

Dissolved oxygen concentrations were also measured in the three inflow rivers and the outflow. As would be expected for unproductive mountain streams, dissolved oxygen concentrations in the inflow rivers were high on all sampling dates. All outflow DO concentrations were above 8.9 mg/L. The outflow was not measured at the dam in September 1994 when reservoir bottom DO was less than 4 mg/L, but at Brocket (several km downstream), the DO concentration was 10.8 mg/L. In 1995, it was measured before the flood; access to the outflow during the flood was not possible.

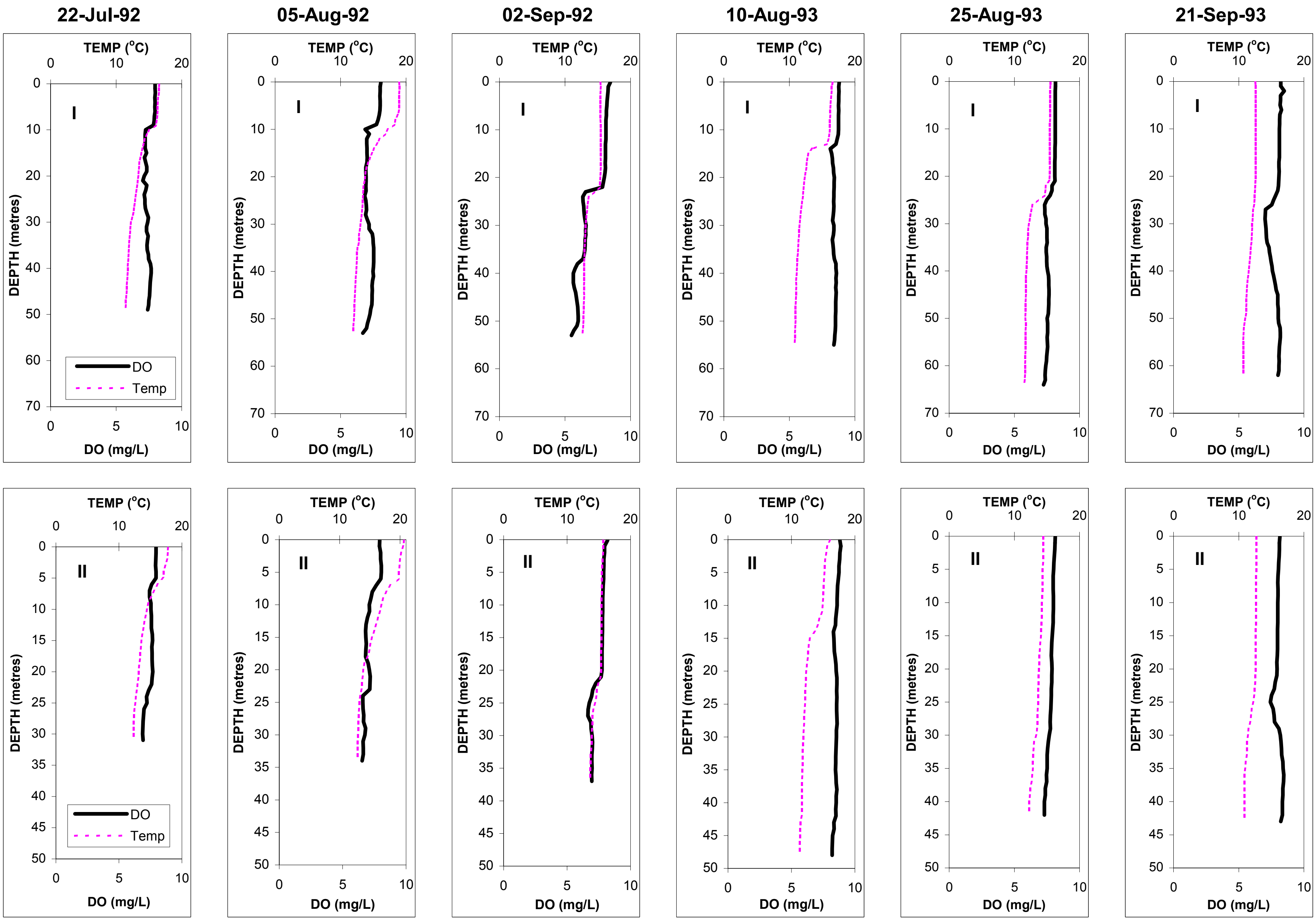


Figure 8a. Dissolved oxygen and temperature profiles in the Oldman Reservoir, 1992 to 1993.

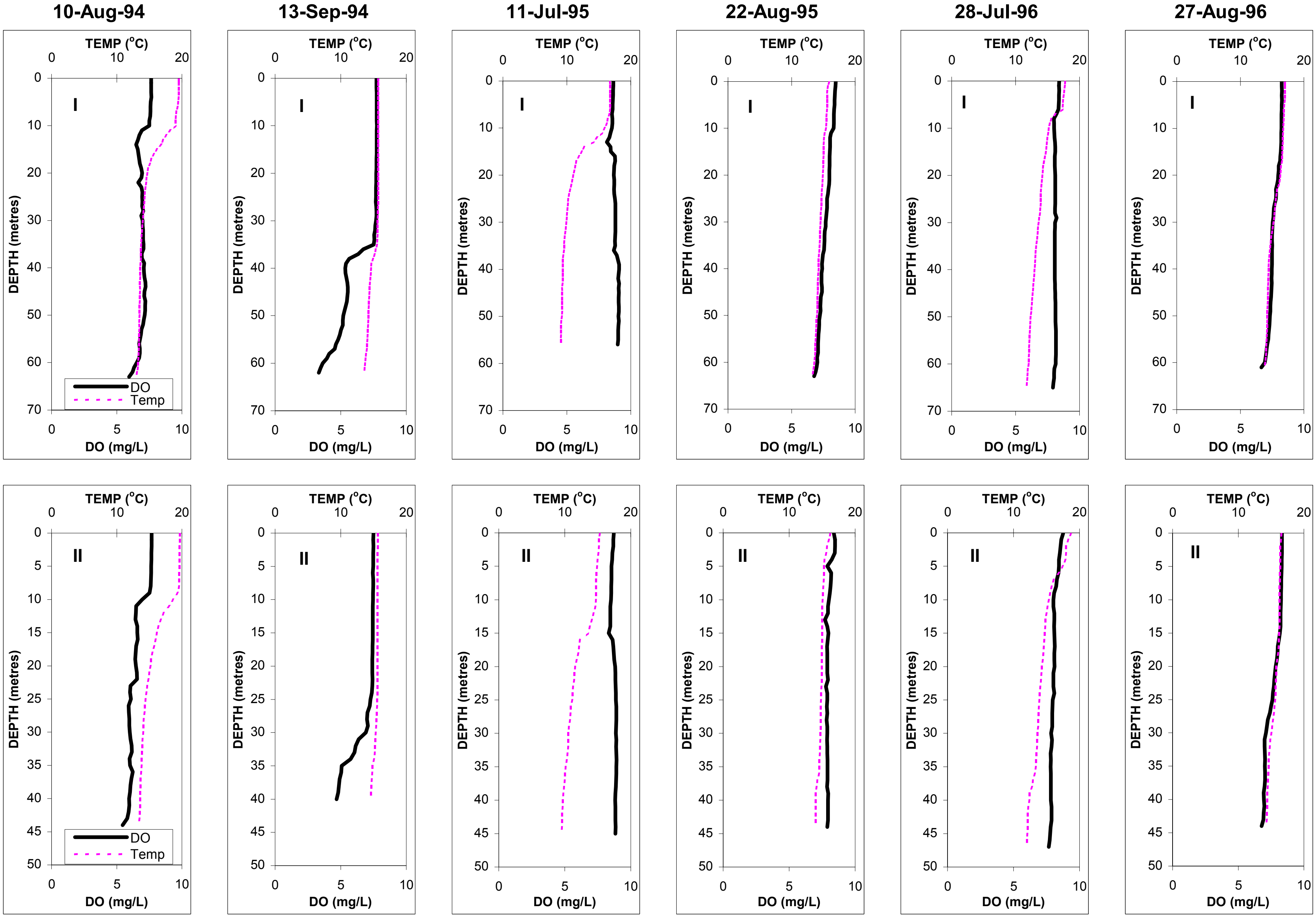


Figure 8b. Dissolved oxygen and temperature profiles in the Oldman Reservoir, 1994 to 1996.

3.2.2 Major Ions and Related Variables

Average reservoir concentrations of major ions, alkalinity, hardness and other variables during each open-water period are listed in Table 8. The water in the reservoir is low in dissolved solids (filterable residue) and moderately hard. The dominant ions are bicarbonate and calcium. Although concentrations fluctuate from year to year, there are no obvious trends. It is likely that reservoir concentrations will be somewhat higher in years with low runoff than in years with high runoff, because there would be less dilution in low-runoff years.

Table 8. Major ions and related variables for Oldman Reservoir. Average of Cells I and II for each open-water period per year. Units are mg/L unless stated otherwise.

	1991	1992	1993	1994	1995	1996
Alkalinity, total as $CaCO_3$	122	120	134	142	133	130
Bicarbonate	148.6	146.4	163.1	173.7	162.2	159.1
Calcium	33.8	36.2	38.7	40.0	40.1	40.8
Carbonate	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chloride	0.8	1.6	1.1	1.4	0.9	0.8
Conductivity, μS/cm	255	267	298	306	287	283
Filterable residue	153	157	191	197	165	186
Fluoride	0.12	0.14	0.16	0.15	0.15	0.15
Hardness, as $CaCO_3$	123	132	144	147	146	147
Magnesium	9.5	10.2	11.4	11.6	11.1	10.8
Non-filterable residue (TSS)	3.5	1.6	1.5	2.1	4.4	4.6
pH (range), units	7.93-8.12	7.78-8.33	7.75-8.21	7.81-8.22	7.79-8.30	8.0-8.19
Phenolic material	0.005	0.003	<0.001	--	--	--
Potassium	0.8	0.8	1.0	1.0	1.1	0.9
Silica, Reactive	5.0	4.0	4.6	4.7	4.9	4.9
Sodium	3.4	3.7	5.1	5.3	5.4	4.8
Sulfate	13.8	19.9	18.7	20.8	19.2	18.2
Turbidity, ntu	4.3	2.4	2.2	4.0	9.8	8.0

The chemistry of the inflow streams is similar to that in the reservoir (Table 9); in fact, the average concentration of many variables in the Oldman and Castle rivers combined is nearly identical to the average concentration in the reservoir. The Crowsnest River generally had the highest concentrations of most of the major ions, and consequently alkalinity, hardness and

Table 9. Major ions and related variables in main inflow streams to Oldman Reservoir and outflow. Average of data for open-water period, all years (1993 excluded). Units are mg/L unless stated otherwise.

	Oldman R.	Crowsnest R.	Castle R.	Outflow
Alkalinity, total as $CaCO_3$	144	160	122	134
Bicarbonate	171.8	190.2	146.9	163.6
Calcium	45.0	55.1	34.3	40.2
Carbonate	1.7	2.7	0.9	<0.5
Chloride	0.75	2.3	0.55	1.0
Conductivity, µS/cm	317	378	249	287
Filterable residue	194	238	155	184
Fluoride	0.21	0.27	0.10	0.17
Hardness, as $CaCO_3$	161	192	130	146
Magnesium	11.9	13.3	10.8	11.3
Non-filterable residue (TSS)	32	15.6	22.9	6.0
pH (range), units	7.80-8.45	7.93-8.49	7.59-8.40	7.77-8.36
Phenolic material	<0.001	<0.001	<0.001	<0.001
Potassium	0.84	0.68	0.66	0.95
Silica, Reactive	5.1	4.1	4.8	4.7
Sodium	5.6	6.5	2.6	4.9
Sulfate	26.9	39.5	12.1	20.9
Turbidity, ntu	22	8.5	16	8.5

filterable residue (total dissolved solids) were also higher. Concentrations in the reservoir outflow were very similar to the average concentrations of these substances in the reservoir, as would be expected. Concentrations of major ions and related variables were somewhat lower when these rivers were sampled in 1984 and 1985. This is probably related to climatic conditions, since we have also observed lower concentrations in lakes in the 1980s, compared with those measured in the 1990s. Such fluctuations are likely within the natural variability of these water bodies.

3.2.3 Metals

Metals were analyzed in water samples collected from the Oldman Reservoir and its inflow streams and outflow during 1991-1994. Mercury was also analyzed in 1995 and 1996. In the Oldman Reservoir, a limited suite of metals was analyzed during 1991-1993 (Mn, Fe, Cu, Zn, Cd, Ba, Hg, Pb), whereas in 1994, a greater range of total and dissolved metals was analyzed. In all samples for which these metals were analyzed (Table 10), levels of arsenic, copper, iron, mercury, molybdenum, selenium and nickel were below water quality guidelines for the protection of freshwater aquatic life (Alberta Environment 1999) in the two cells in the main part of the reservoir. Iron values in the inflow arms exceeded the Alberta guideline once (in July 1993), probably because watershed soils that wash into the rivers would contain iron. Concentrations of most metals without guidelines were very low or near analytical detection

Table 10. Mean concentrations of metals in the water column of Oldman Reservoir, 1991-1996, range of values, water quality guideline and compliance. Concentrations in µg/L. Cells I and II combined. Total (T) and extractable (E) data combined where indicated. D = dissolved. Guideline values from Alberta Environment (1999).

Variable	Mean Value	Range	Guideline Value	% Compliance	Years Sampled	Number of Samples
Aluminum, T	123	5 - 400	100[a]	50%	1994	12
Arsenic, T	0.4	0.1 - 1.1	5[a]	100%	1994	12
Barium, T	107	90 – 130	none	n.a.	1991-1994	46
Beryllium, T	<1	<1 - 2	none	n.a.	1994	12
Cadmium, T	<1	<0.2 - <1	0.047[a]	96%	1991-1994	46
Chromium, T	6	1 – 16	n.a.	n.a.	1994	12
Cobalt, T	<1	<1 – 1.2	none	n.a.	1994	12
Copper, T/E	1	0.5 - 6	7[b]	100%	1991-1994	44
Iron, T/E	80	20 – 300	300[a]	100%	1991-1994	46
Iron, D	8	5 – 20	none	n.a.	1992-1994	13
Lead, T/E	1	0.5 - 5	4[a]	95%	1991-1994	44
Manganese, T/E	6	0.5 - 26	none	n.a.	1991-1994	46
Manganese, D	2	0.5 - 6	none	n.a.	1992-1994	16
Mercury, T	<0.05	<0.04 - <0.05	0.1[a]	100%	1991-1995	56
Mercury, low-level, T	0.0016	<0.00016-<0.0034	0.005[b]	100%	1996	7
Molybdenum,T	<3	1.5 - 5	73[a]	100%	1994	12
Nickel, T	1	0.5 - 3	110[a]	100%	1994	10
Selenium, T	<0. 2	<0.2 - 0.2	1[a]	100%	1994	12
Vanadium, T	<2	<2 - 3	none	n.a.	1994	12
Zinc, T/E	6	0.5 - 51	30[a]	95%	1991-1994	40

[a] CEQG guideline for the protection of aquatic life
[b] Alberta guideline

limits. Aluminum was analyzed only in 1994, when half of the samples collected exceeded the Alberta guideline of 100 µg/L. Total suspended solids in these samples (from Cells I and II) were relatively low, and there was no statistical relationship between aluminum and TSS. There is no obvious explanation for these elevated levels. Total chromium was analyzed in 1994 samples, but values cannot be compared with guidelines for use in Alberta because they refer to tri- or hexavalent chromium. Lead was analyzed on 22 occasions each in Cells I and II; there were two exceedences of the guideline for lead (4 µg/L). Both were in Cell I, in 1992 and 1994, at 5 µg/L. There were also two exceedences of the guideline for zinc (30 µg/L), both in Cell I in 1994 (maximum value 51 µg/L). Copper values were always below the draft Alberta chronic guideline of 7 µg/L. The few exceedences of these metals are unlikely to be a cause for concern. The number of exceedences was greater in Cell I than Cell II, probably because the non-algal turbidity in Cell I was generally higher.

Mercury was always below the analytical detection limit in the early years of the study, so in 1996, samples from near the bottom of the reservoir were analyzed at trace levels (detection limit approximately 0.00016 µg/L). All values in Cells I and II were below the draft Alberta chronic guideline of 0.005 µg/L for total mercury. Wu *et al.* (1997) stated that there were moderate increases in mercury concentrations in fish between 1991 and 1995. The increases were species dependent, and were attributed to the methylation of mercury in soils inundated by reservoir water. In 1997, there appeared to be a decline in levels of mercury in fish (Wu *et al.*1998); for all years, fish mercury data were generally below the Canadian guideline level for safe human consumption.

For the inflow streams, levels of arsenic, cadmium, mercury, molybdenum, nickel and selenium were below water quality guidelines for the protection of freshwater aquatic life (Alberta Environment 1999) in all samples for which these metals were analyzed (Table 11). There were several exceedences of the guideline for aluminum (maximum concentration observed = 690 µg/L in the Oldman River in 1994). There was a strong statistical relationship between non-filterable residue (TSS) and total aluminum (r^2=0.49, *P*=<0.002, n=18), suggesting that the source of aluminum is natural geological materials. Chromium concentrations were occasionally high, but again, they cannot be compared with guideline levels because they were analyzed as total chromium. There were also a few exceedences of the iron guideline in inflow streams. Copper levels were occasionally above the draft Alberta chronic guideline in all inflow rivers and the outflow. The highest values occurred in June 1994 (maximum value observed = 22 µg/L in the Oldman River), when total suspended solids were somewhat elevated. Zinc and lead also exceeded guideline levels occasionally, but concentrations were low (maximum concentrations 120 µg/L and 12 µg/L respectively). As in the reservoir, mercury concentrations for the early years of the study were all below analytical detection limits. A few samples were analyzed at trace levels in 1996, and all were below the draft Alberta guideline for total mercury.

Table 11. Mean concentrations of metals in the Oldman, Castle and Crowsnest rivers, 1991-1996, range of values, water quality guideline and compliance. Concentrations in µg/L. Three rivers combined. Total (T) and extractable (E) data combined where indicated. D = dissolved. Guideline values from Alberta Environment (1999).

Variable	Mean Value	Range	Guideline Value	% Compliance	Years Sampled	Number of Samples
Aluminum, T	161	<10 – 690	100[a]	65%	1994	17
Arsenic, T	0.4	0.2 -1.1	5[a]	100%	1994	18
Barium, T	107	60 – 200	None	n.a.	1991-92,1994	42
Beryllium, T	<1	<1 – 2	None	n.a.	1994	18
Cadmium, T	<1	<0. 2 - <1	0.047[a]	100%	1991-92,1994	42
Chromium, T	7	<2 – 24	n.a.	n.a.	1994	18
Cobalt, T	4	<1 – 34	None	n.a.	1994	15
Copper, T/E	3	<1 – 22	7[b]	85%	1991-92,1994	41
Iron, T/E	155	<10 – 840	300[a]	88%	1991-92,1994	40
Iron, D	9	<10 – 30	None	n.a.	1991-92,1994	18
Lead, T/E	1	0.5 – 12	4[a]	95%	1991-92,1994	42
Manganese, T/E	12	<1 – 107	None	n.a.	1991-92,1994	42
Manganese, D	2	<1 – 6	None	n.a.	1991-92,1994	18
Mercury, T	<0.05	<0.04 – <0.05	0.1[a]	100%	1991-92, 1994-95	71
Mercury, low-level T	0.0015	0.00026-0.0039	0.005[b]	100%	1996	12
Molybdenum,T	<3	<3 – 3	73[a]	100%	1994	18
Nickel, T	2	<1 – 7	110[a]	100%	1994	15
Selenium, T	<0.2	<0.2 - 0.4	1[a]	100%	1994	18
Vanadium, T	<2	<2 – 5	None	n.a.	1994	18
Zinc, T/E	13	<1 –120	30[a]	88%	1991-92,1994	40

[a] CEQG guideline for the protection of aquatic life
[b] Alberta guideline

3.2.4 Pesticides

Pesticide samples were not collected from the inflow streams or reservoir. Between 1985 and 1993, seven pesticide samples were collected on the Oldman River 10 km downstream of the reservoir (Brocket). In July 1993, one value for trifluralin was slightly above the analytical detection limit, for unknown reasons. All other values were below the detection limit.

3.2.5 Suitability for Drinking and Agricultural Use

Water quality guidelines for drinking water supplies refer to treated water, not source water that may be used as a community water supply (CCME 1999). However, if the raw water source, such as the Oldman Reservoir or the Oldman River downstream, meets drinking water guidelines, problems with the treated water are unlikely. Water in the Oldman Reservoir would be excellent as a raw drinking water supply. Of the substances tested, only aluminum may be of concern. It exceeded the guideline for the protection of aquatic life in about half of the reservoir samples tested. At present, there is no Canadian drinking water guideline for aluminum, although it is currently under review (CCME 1999). Removal of suspended solids (turbidity) from the reservoir water would likely reduce levels of aluminum.

Although agricultural use of the Oldman Reservoir water was not a focus of the study, several substances tested can be compared with guidelines for irrigation and livestock watering. All metals and other substances tested were well within guideline levels.

The present study did not include analyses of priority pollutants and other organic substances that may be of concern relative to the suitability of the water for drinking and agricultural use. Recent Canadian research suggests that the long-range atmospheric transport and deposition of trace organic contaminants originating from human activities occurs in the Rocky Mountain snow pack (Blais *et al*. 1998).

3.3 NUTRIENTS

Substances such as phosphorus, nitrogen, silica and carbon are essential nutrients of plants. Levels of these macronutrients (as well as micronutrients) can govern the amount of aquatic plant growth in lakes and reservoirs. Phosphorus is often used as an indicator of the health of a water body, because if phosphorus supplies increase, populations of algae and shoreline vegetation could increase. Water bodies with large amounts of aquatic vegetation have lower recreational values than those that are clear and clean, although limited amounts of aquatic vegetation may increase fish productivity.

3.3.1 Nutrient Concentrations

Figures 9a and 9b show seasonal variation in concentrations of total phosphorus in each cell over the summers of the six study years. Sometimes the differences among the inflow arm cells were fairly large, but the difference in concentration was minimal between Cells I and II. One would expect high spatial variability in nutrient concentrations during reservoir filling (1991 and 1992). In 1993, there was only a slight difference among the five cells except during high runoff inflow in mid-July; inflow and the phosphorus concentration in Cell IV (the Oldman River) were particularly high. During 1994-96, Cell I generally had higher average concentrations than Cell II, but this was not always true for individual sampling dates. This corresponds with slightly greater turbidity in Cell I. There was virtually no difference in levels of TDP between the two cells. The small increases in total phosphorus during the summer appeared to depend on inflow variations rather than increases in algal production as occurs in more productive water bodies. For most years, the highest total phosphorus concentration occurred in June or July after a period of high inflow. Often, but not always, the peak TDP level also occurred at this time.

Average concentrations of phosphorus and nitrogen fractions for the Oldman Reservoir are shown in Table 12. During the reservoir filling in 1991, levels of total (TP) and dissolved phosphorus (TDP) were relatively high, but they stabilized very quickly in subsequent years. Based on the average level of total phosphorus, the reservoir is mesotrophic. However, most of the total phosphorus in the reservoir water is in the particulate form and therefore phosphorus is probably not a good indicator of trophic status (see section on chlorophyll *a*, below).

The measured average reservoir TP concentration in 1996 (an average inflow year) was slightly higher than that predicted by HydroQual (1990) of 6 µg/L TP (also for an average inflow year). For the other years, however, measured average concentrations were similar to those that HydroQual predicted for wet and dry years (14 µg/L and 13 µg/L respectively). HydroQual suggested that annual average concentrations would vary depending on the amount of inflow for a particular year. Although 1995 had the highest average TP concentration and

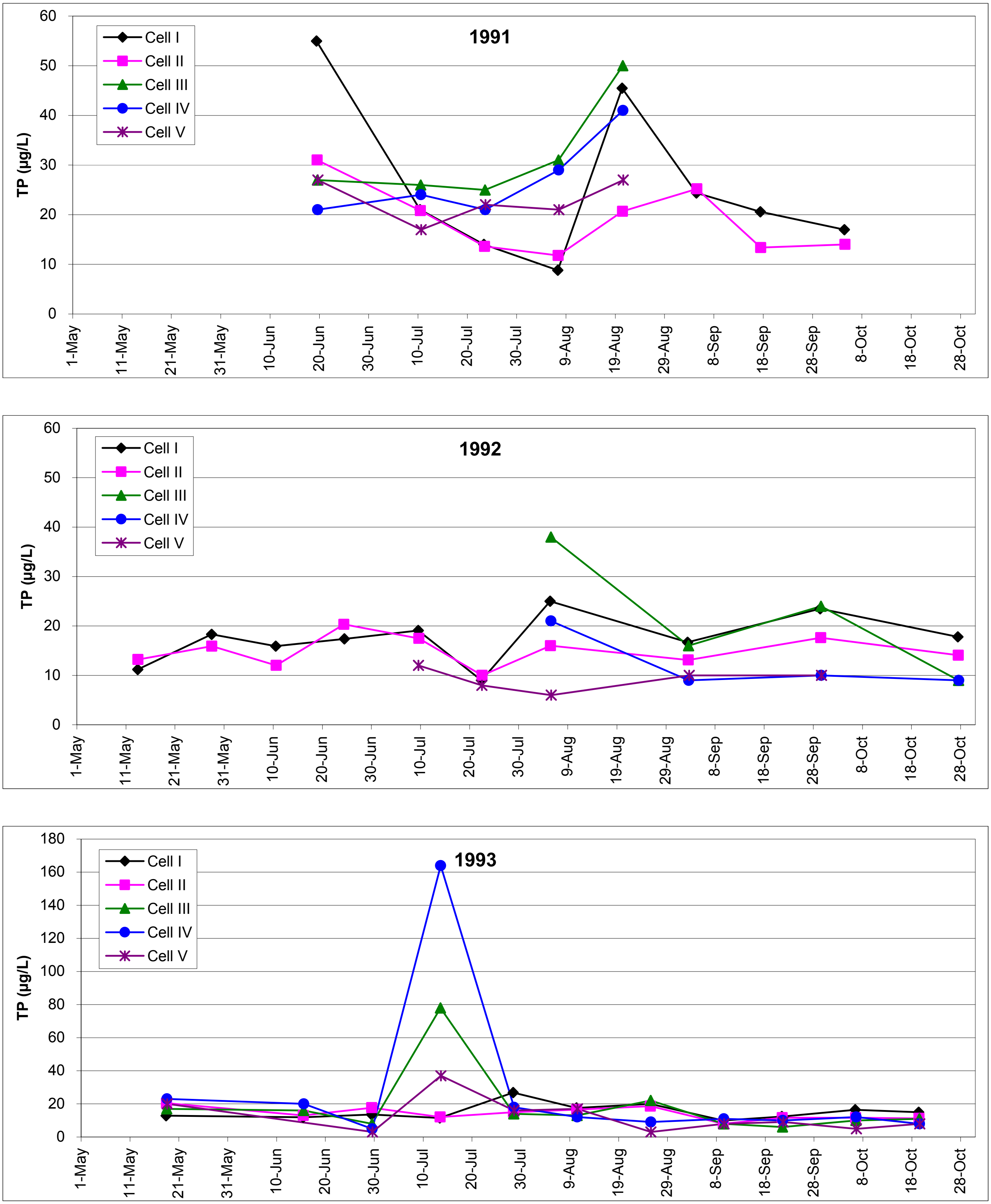


Figure 9a. Concentrations of total phosphorus in five cells in the Oldman Reservoir, 1991-1993.

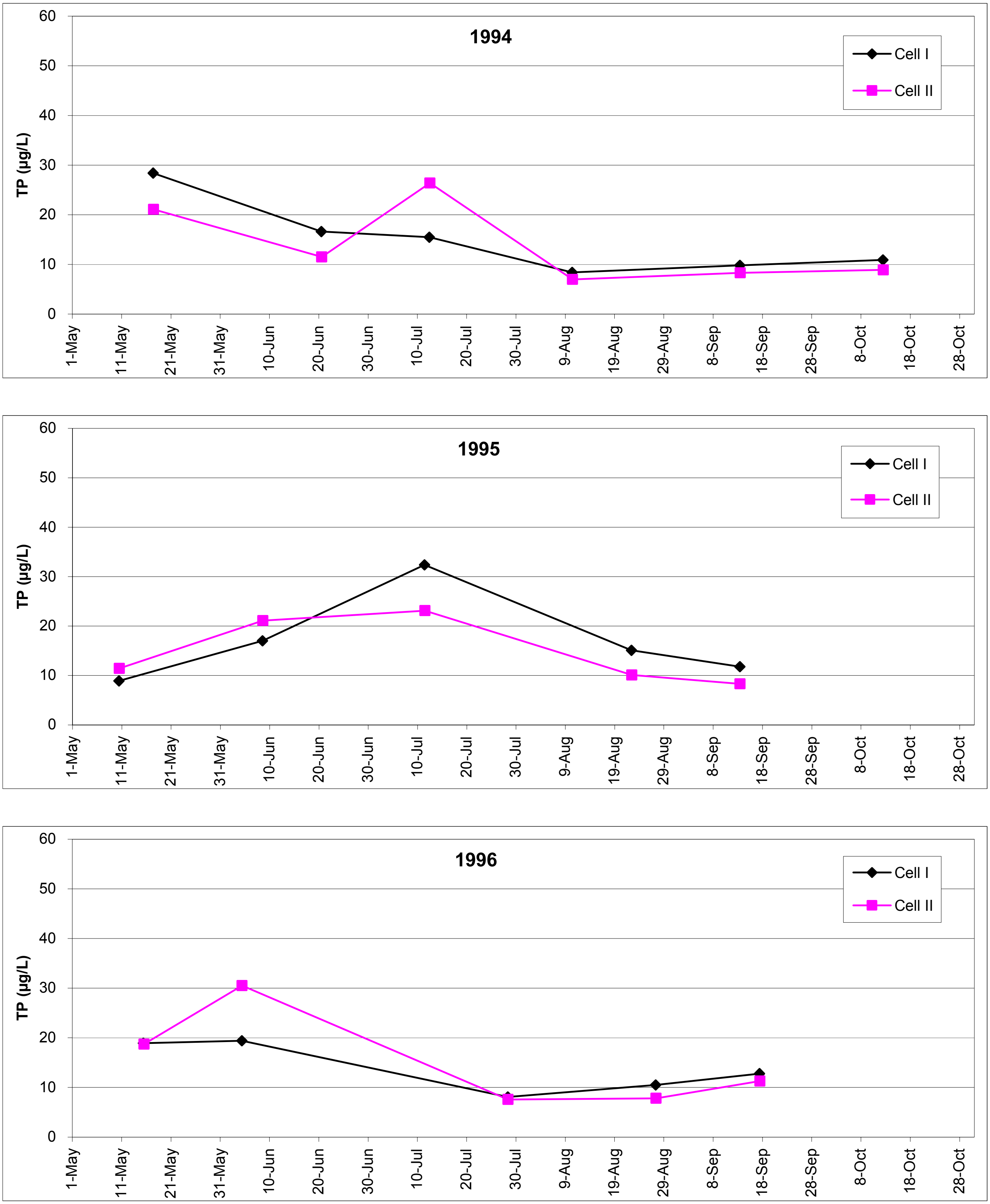


Figure 9b. **Concentrations of total phosphorus in Cells I and II in the Oldman Reservoir, 1994-1996.**

Table 12. Nutrient concentrations, chlorophyll *a* concentrations and Secchi depth in Oldman Reservoir. Average concentration during open-water for Cells I and II. Units are µg/L unless stated otherwise.

	1991	1992	1993	1994	1995	1996
Total phosphorus	22.3	16.2	14.7	14.4	15.9	14.6
Total diss. phos.	9.1	3.1	5.7	4.2	4.1	4.8
Total nitrogen	316	456	337	344	221	181
Total kjeldahl N.	274	423	296	318	146	109
Nitrite+nitrate-N	42	33	43	62	76	72
Ammonia-N	31	10	14	49	9	32
Silica, mg/L	5.0	4.0	4.6	4.7	4.9	4.9
Chlorophyll *a*	2.09	1.34	2.60	1.28	2.04	1.27
Secchi depth, m	2.2	2.5	3.1	2.5	1.25	1.9

inflow volume (excluding 1991), the variation among years was much lower than HydroQual predicted.

Figure 10 shows how similar the TP concentration is from year to year, in spite of very different inflow volumes. In many new reservoirs, the flooding of inundated soils releases nutrients to the water column. This in turn leads to an increase in algal productivity for a few years, after which productivity declines. This is called “trophic upsurge”, and is well documented for new reservoirs in both the United States and Canada (Grimard and Jones 1982). It was expected to occur in the Oldman Reservoir; however, the data over the six study years indicate no evidence of trophic upsurge, probably because topsoil had been removed from the reservoir bottom before it was filled and the reservoir is rapidly flushed. After six years, it is unlikely it would occur.

As Table 12 and Figure 10 show, there was a slight decline in average levels of total nitrogen over the study years, but perhaps a slight increase in nitrite+nitrate-nitrogen levels. The high average concentrations of total nitrogen were biased by occasional very high values for total kjeldahl nitrogen (see Figure 11a and b). Because the water quality in the reservoir was stabilizing the first two or three years of the study, additional years of data would be needed to establish trends. Nitrogen fractions were somewhat more variable than total or dissolved phosphorus. There were no obvious seasonal patterns for total nitrogen or nitrogen fractions. This lack of seasonal variability in nutrients is typical of deep, unproductive water bodies.

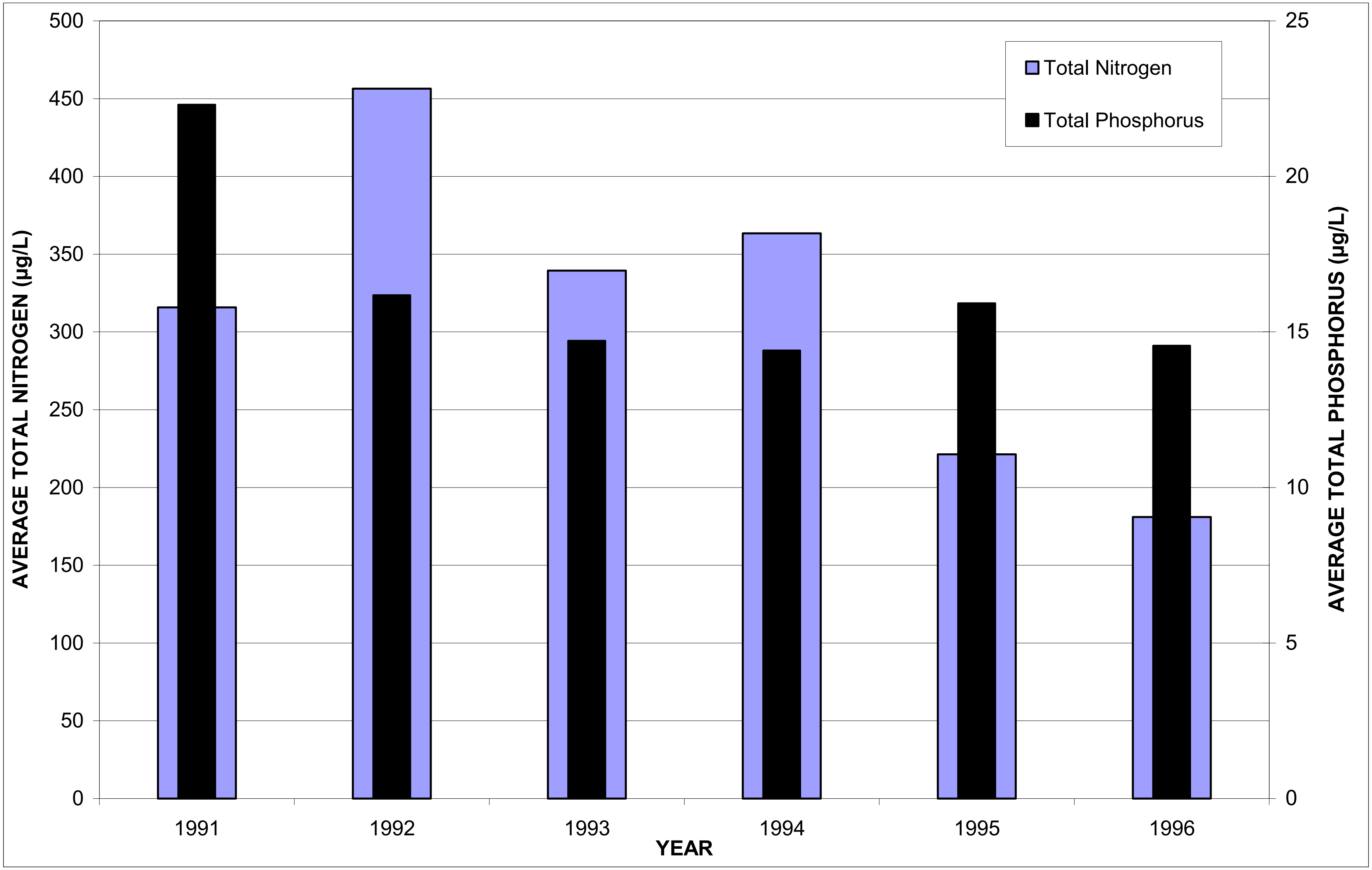


Figure 10. **Annual average concentrations of total nitrogen and total phosphorus in the Oldman Reservoir (average of cells I and II), 1991-1996.**

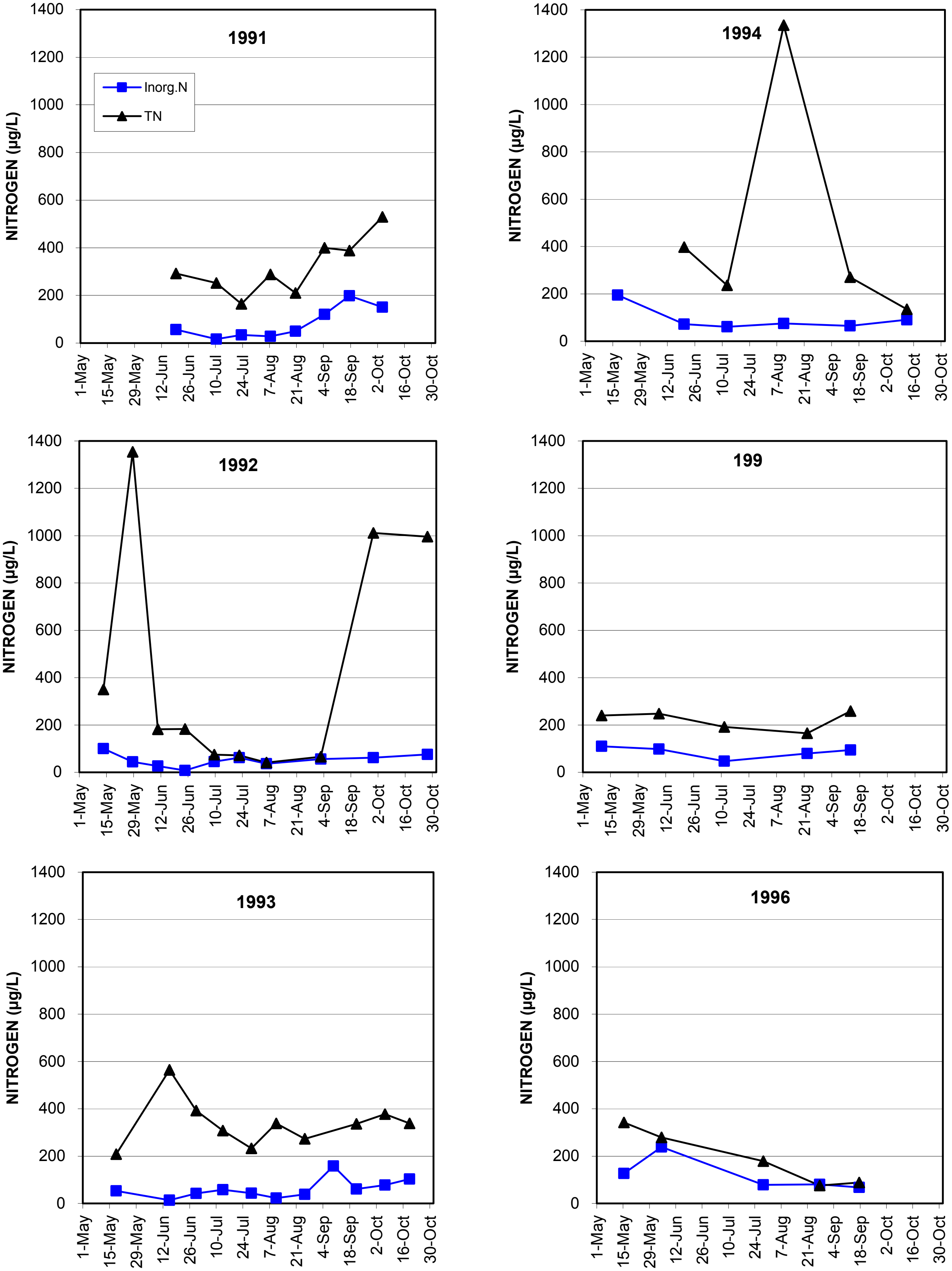


Figure 11a. **Concentrations of total and inorganic nitrogen in the Oldman Reservoir Cell I during the open-water season, 1991-1996**

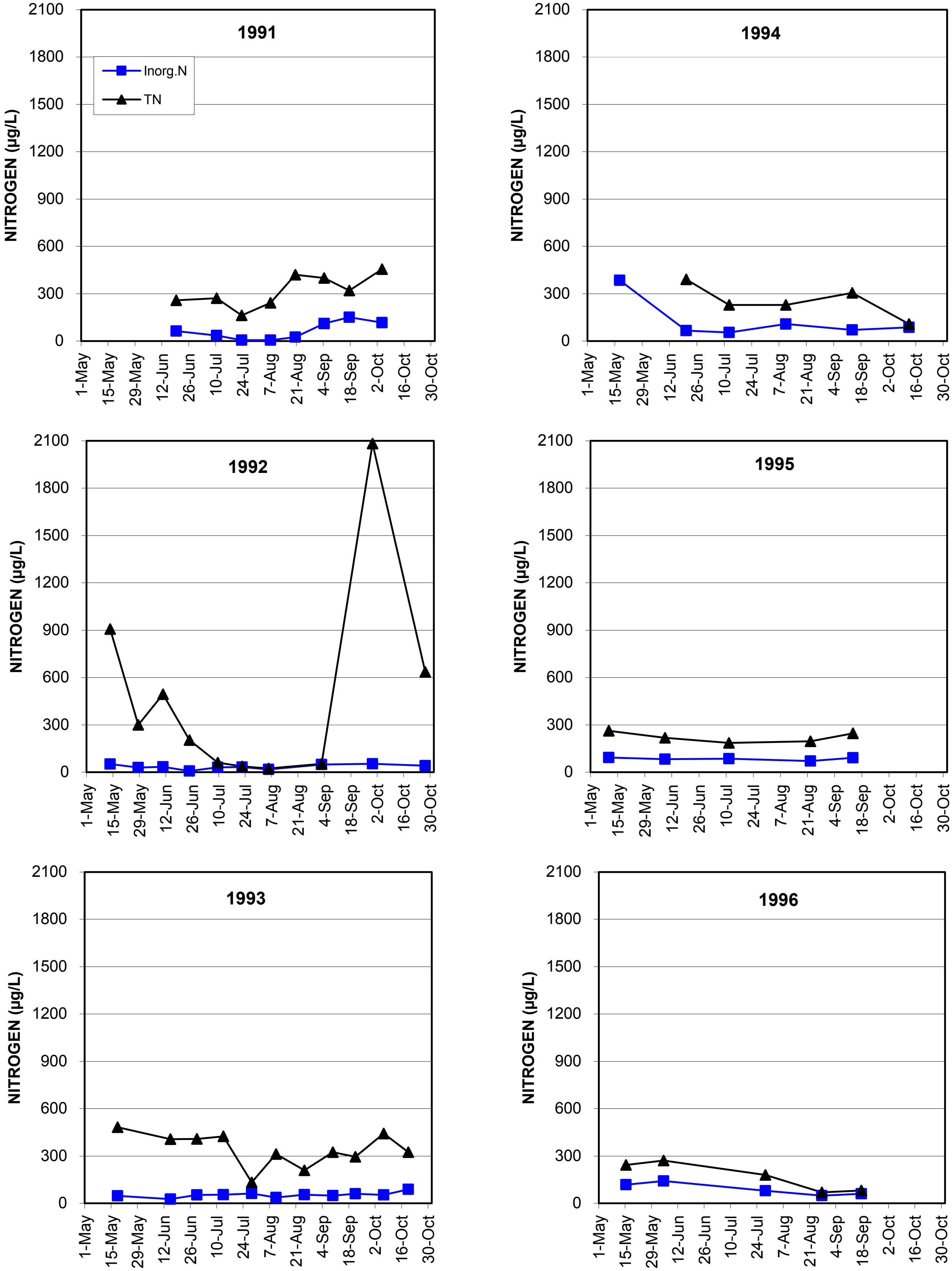


Figure 11b. Concentrations of total and inorganic nitrogen in the Oldman Reservoir Cell II during the open-water season, 1991-1996

Table 13 shows flow-weighted mean concentrations of nutrients in the three main inflow rivers to the reservoir. Average total phosphorus concentrations were generally higher in the major inflow streams than in the reservoir; the exception was 1992, when phosphorus levels in the streams were particularly low. In 1991 and 1992, a different laboratory was used for phosphorus analysis in inflow samples than for the reservoir or for the inflows in later years (see Methods). The stream phosphorus data for that year may not be reliable, although there is no information to suggest this. The highest TP concentrations occurred in 1995 and 1996 when inflow volumes were very high. The effects of the June 1995 flood carried into 1996, with TP concentrations that were the highest measured during the five years of sampling. Because TDP concentrations were not appreciably higher these two years, much of the total phosphorus was in the particulate form as the bed and banks of the rivers eroded.

Table 13. Flow-weighted mean concentrations of nutrients in inflow streams to Oldman Reservoir during the study years, April-October. Units are µg/L.

Oldman River	**1991**	**1992**	**1994**	**1995**	**1996**
Total phosphorus	50	4	39	79	83
Total diss. phos.	15	2	4	8	6
Total nitrogen	242	1029	238	273	288
Total kjeldahl N.	233	1026	223	235	261
Nitrite+nitrate-N	9	3	15	38	27
Ammonia-N	5	49	100	9	27
Crowsnest River	**1991**	**1992**	**1994**	**1995**	**1996**
Total phosphorus	47	17	33	35	63
Total diss. phos.	16	3	5	8	6
Total nitrogen	493	619	245	353	358
Total kjeldahl N.	297	591	161	194	293
Nitrite+nitrate-N	196	28	84	158	145
Ammonia-N	9	9	97	10	20
Castle River	**1991**	**1992**	**1994**	**1995**	**1996**
Total phosphorus	26	9	17	39	96
Total diss. phos.	16	2	3	5	4
Total nitrogen	180	1928	230	219	305
Total kjeldahl N.	149	1909	189	154	234
Nitrite+nitrate-N	31	19	40	65	71
Ammonia-N	5	91	7	8	12

Total nitrogen was particularly high in 1992, especially in the Castle and Oldman rivers. The mean concentrations are biased by high concentrations of total kjeldahl nitrogen during a period of high inflow in June-July. In 1995 during the high inflow period in June, concentrations of nitrogen fractions in the inflows did not increase. Levels of nitrogen fractions were somewhat higher in 1996 than in 1995.

3.3.2 Nutrient Loading

A nutrient budget provides information on sources and the fate of phosphorus and nitrogen. For the Oldman Reservoir, quantifiable sources are:

- The three inflow rivers,
- The remaining watershed, which would include small creeks and diffuse runoff,
- Atmospheric deposition, which includes precipitation and dust falling directly onto the surface of the reservoir.

Shoreline erosion and groundwater inflow are potential sources of nutrients, but neither has been quantified. They are not likely to be major sources. There may be other minor unquantified sources within the basin. Sewage effluent is likely negligible, because shoreline development is minimal. In many Alberta lakes, the bottom sediments are a major source of phosphorus to the water column during the warmest months. However, there was no evidence of "internal" phosphorus loading in the Oldman Reservoir, although phosphorus release from aerobic sediments may occur on occasion.

Tables 14 and 15 show phosphorus and nitrogen loads entering the Oldman Reservoir during the open-water period of the study years (inflows were not sampled in 1993). Note that the year to year variability is high, and that the flood year 1995 had the highest phosphorus and nitrogen loads. The three inflow rivers contribute the greatest amount of these nutrients to the reservoir. Loading from the Crowsnest River is much lower than from either of the other rivers. On average, the Oldman River contributed slightly higher phosphorus loads than the other rivers, but the Castle River contributed slightly higher nitrogen loads.

For most years, the inflow phosphorus load exceeded the outflow TP load, but in 1991, when the reservoir was filling, the inflow and outflow loads were about the same. For all years, but especially in 1991, most of the outflow load was in the particulate form (on average,

Table 14. Total phosphorus budget for Oldman Reservoir, 1991-1992, 1994-1996. Loads in kilograms per April-October period. % = percentage of total loading for season.

INFLOW	1991	%	1992	%	1994	%	1995	%	1996	%
Three rivers	49,463	82	4,706	90	18,079	77	73,916	63	92,304	85
Remaining watershed	10,435	17	342	6	5,026	21	43,095	37	15,407	14
Atmospheric deposition	181	<1	210	4	405	2	390	<1	382	<1
TOTAL	**60,079**	100	**5,258**	100	**23,510**	100	**117,401**	100	**108,093**	100
Water inflow volume, m^3	1467 million		650 million		778 million		1896 million		1265 million	
OUTFLOW	**1991**		**1992**		**1994**		**1995**		**1996**	
P Load, kg	***61,391***		***3,250***		***9,505***		***29,670***		***25,889***	
Water outflow volume, m^3	1413 million		365 million		863 million		1878 million		1302 million	

Table 15. Total nitrogen budget for Oldman Reservoir, 1991-1992, 1994-1996. Loads in kilograms per April-October period. % = percentage of total loading for season.

INFLOW	1991	%	1992	%	1994	%	1995	%	1996	%
Three rivers	318,167	86	785,315	90	152,975	80	344,924	69	330,149	84
Remaining watershed	50,388	13	79,936	9	30,560	16	149,520	30	53,546	14
Atmospheric deposition	3,500	1	4,061	<1	7,831	4	7,541	1	7,387	2
TOTAL	**372,055**	100	**869,312**	100	**191,366**	100	**501,985**	100	**391,082**	100
Water inflow volume, m^3	1467 million		650 million		778 million		1896 million		1265 million	
OUTFLOW	**1991**		**1992**		**1994**		**1995**		**1996**	
N Load, kg	***412,663***		***146,466***		***nd***		***394,258***		***290,846***	
Water outflow volume, m^3	1413 million		365 million		863 million		1878 million		1302 million	

particulate phosphorus made up about 80% of the inflow load and about 66% of the outflow load). Essentially, there was no phosphorus retention in 1991; in 1992 the retention coefficient was 0.38 and it increased each year to 0.76 in 1996. Thus, even with the high flushing rate, most of the phosphorus entering the reservoir stays there, in the form of settled particulate material. The retention of dissolved phosphorus is much lower or non-existent; in 1994 and 1996, slightly more dissolved phosphorus left the reservoir than came in.

As with phosphorus, the inflow and outflow nitrogen loads were similar in 1991. For the other years, outflow loads were lower than inflow loads. In May 1994, there was evidence of an analytical problem with total kjeldahl nitrogen in the outflow sample, and since the outflow volume was highest at that time, extrapolation was not possible. In 1995 and 1996, the nitrogen retention coefficient was about 0.2, suggesting that most of the nitrogen entering the reservoir left it via the outflow.

The total phosphorus and nitrogen mass in the reservoir in 1995-96 averaged 5500 kg and 80,000 kg, respectively. Thus, most of the retained nitrogen was suspended in the water column (probably as dissolved organic nitrogen), whereas most of the phosphorus was no longer in the water column (settled out particulate phosphorus).

3.4 CHLOROPHYLL *a*

Chlorophyll *a* (CHL) analysis of a water sample provides an indication of the size of the phytoplankton population on the particular day of sampling. This in turn indicates the degree of fertility, or trophic status, of the water body. Table 12 shows average concentrations of chlorophyll *a* in the Oldman Reservoir for each study year. These averages, which are for both cells, vary little from year to year. There was no statistical difference in levels of CHL between Cells I and II (P>0.5, n=37). There is no evidence of a trend toward either increasing or decreasing productivity through the study years. As with the phosphorus data, the chlorophyll *a* data suggest that, so far, no trophic upsurge has taken place.

The average annual open-water chlorophyll *a* concentration indicates that the Oldman Reservoir is oligotrophic. CHL is probably a better indicator of the trophic status of the Oldman Reservoir than total phosphorus. Average TP data suggest the reservoir is mesotrophic, but this is mainly because levels of particulate phosphorus are relatively high. The CHL concentrations measured during the study years are slightly lower than the range of average concentrations predicted by HydroQual (1990) of 3 μg/L – 4.5 μg/L. However, these predictions were based on phosphorus-chlorophyll relationships for less turbid systems; the elevated suspended solids concentrations in the Oldman Reservoir appear to suppress algal production, which reduces the overall average. Note that the highest average CHL concentration occurred in 1993, which also had the deepest average Secchi depth. The clearer water allowed marginally higher phytoplankton populations that year. The amount of algae in the reservoir is very low, and the water would look clear and clean most of the time. Phytoplankton data collected from the reservoir in 1992 also indicate it is oligotrophic (Watson 1993). The dominant species were types of nannoplankton, mainly diatoms and cryptophytes. The species composition suggested that the phytoplankton community had not stabilized at that time; many of the taxa noted inhabit riverine systems.

As with nutrients, there were no clear-cut seasonal patterns for CHL concentrations (Figure 12a,b). Some years, the highest concentration occurred in May; other years it was June or July. In this way, it is similar to other southern Alberta reservoirs (Travers, Ghost and Glennifer) and deep unproductive natural lakes (Cold, Ethel, Touchwood), but different from shallow productive lakes, in which the highest CHL generally occurs in July and August. The highest concentration observed in the reservoir during the study occurred in Cell II in June 1993 at 7.4 µg/L; the concentration in Cell I was also high on this date. The water was not particularly clear at that time, perhaps because algae as well as suspended inorganic particles contributed to turbidity. The elevated phytoplankton growth is likely a response to dissolved nutrient inputs during the spring and tempered by the amount of light available to growing algae.

3.5 BACTERIA

Counts of fecal coliform bacteria were generally very low in the inflow stream samples (Table 16). There were no obvious differences among streams or among years, although counts in 1984 and 1985 seem slightly lower than during the study years. Bacteriological samples were only collected one year in the reservoir outflow. Counts were negligible, as would be expected in an outflow from an oligotrophic reservoir.

E. coli counts averaged about half of the fecal coliform counts, suggesting perhaps that many of the coliforms counted were not from warm blooded animals. The Alberta water quality guideline for direct contact recreation (Alberta Environment 1999) states that, for fecal coliforms, the geometric mean should not exceed 200 per 100 mL (this guideline pertains to five samples collected in a 30-day period). None of the individual counts measured during 1994-1996 exceeded this level, so it might be speculated that had sufficient samples been collected, the guideline would have been met.

3.6 SEDIMENTS

Sediment samples were collected from the bottom of the reservoir in four of the six study years, primarily to obtain background information, but also to determine levels of mercury.

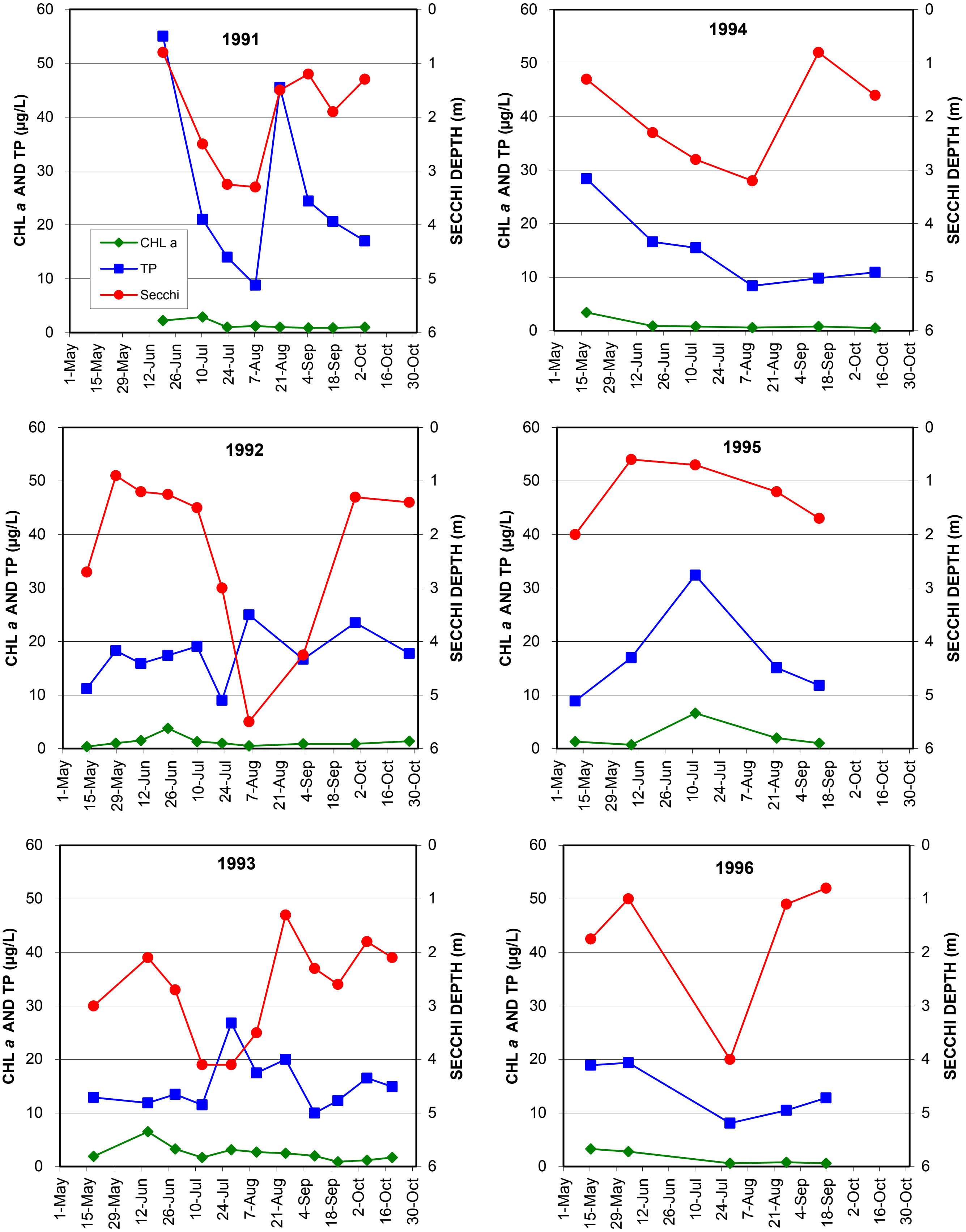


Figure 12a. **Secchi depth and concentrations of chlorophyll *a* and total phosphorus in the Oldman Reservoir Cell I during the open-water season, 1991-1996**

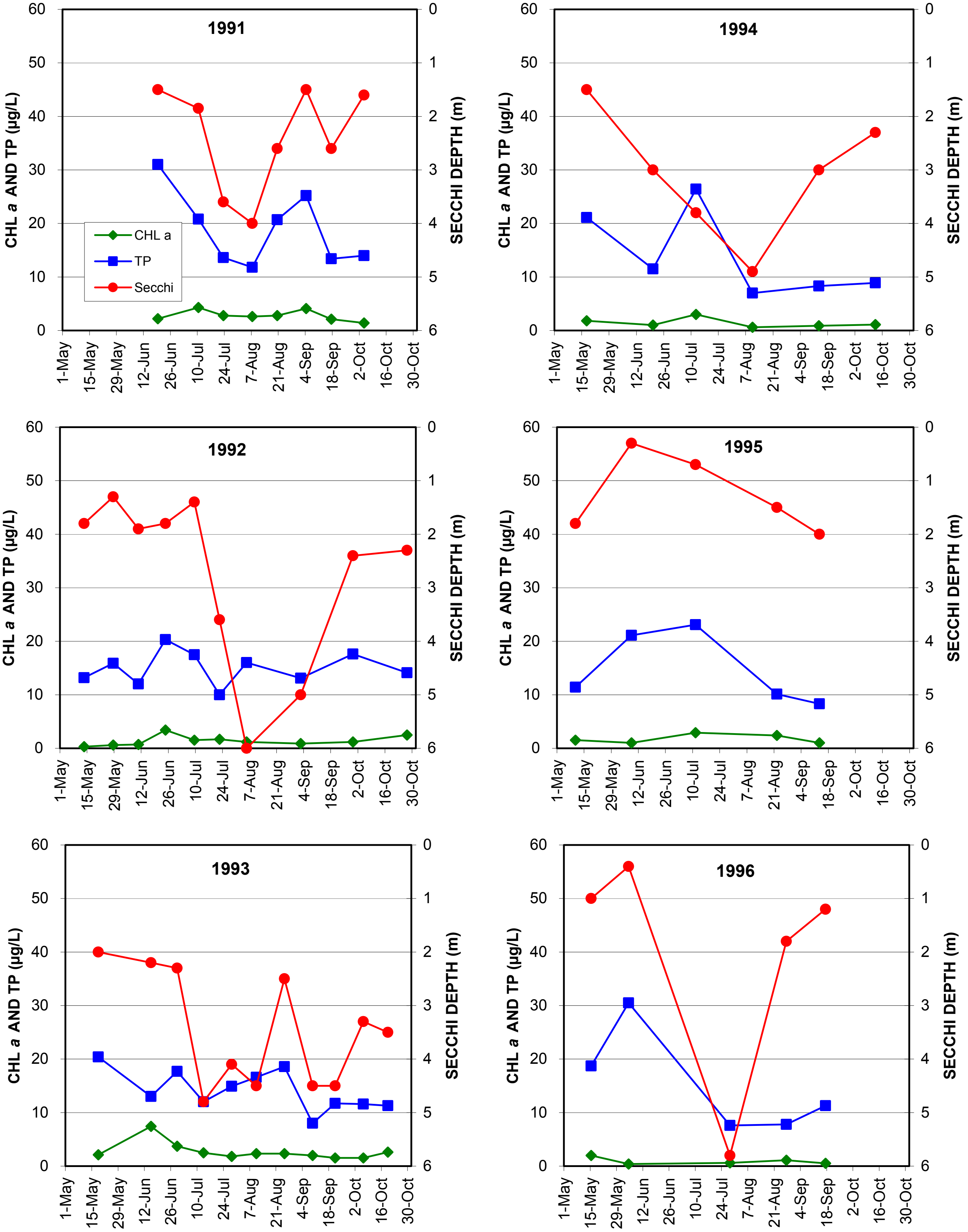


Figure 12b. Secchi depth and concentrations of chlorophyll *a* and total phosphorus in the Oldman Reservoir Cell II during the open-water season, 1991-1996

Table 16. Fecal coliform bacteria in inflow streams to the Oldman Reservoir, 1984-1996. Geometric mean, range and number of samples (n) for year. Counts per 100 mL.

	Sampling Sites	Geometric Mean	Range	n
1984	Castle R. at Hwy 3 Bridge near Cowley	1.9	0 – 9	13
	Crowsnest R. near mouth	2.9	0 – 28	13
	Oldman R. near Waldron's Corner	1.5	0 - 15	13
1985	Castle R. at Hwy 3 Bridge near Cowley	6.8	0 – 100	12
	Crowsnest R. near mouth	22	0 – 100	11
	Oldman R. near Waldron's Corner	7.2	0 – 100	12
	Oldman R. near Olin Creek	19	4 - 300	6
1991	Castle R. at Recreation Area	32	4 – >60	4
	Crowsnest R. upst. Connelly Creek	24	5 – 55	4
	Oldman R. near Waldron's Corner	15	3 – >60	4
1992	Castle R. at Recreation Area	20	8 – 50	4
	Crowsnest R. upst. Connelly Creek	17	10 – 21	4
	Oldman R. near Waldron's Corner	14	7 - 30	4
1994	Castle R. at Recreation Area	18	<2 – 108	6
	Crowsnest R. upst. Connelly Creek	18	6 – 46	6
	Oldman R. near Olin Creek	24	10 – 88	6
	Oldman R. 100 m downstream reservoir	1.2	<1 – 5	5
1995	Castle R. at Recreation Area	7.5	<2 – 40	7
	Crowsnest R. upst. Connelly Creek	17	6 – 146	7
	Oldman R. near Olin Creek	11	2 - 154	7
1996	Castle R. at Recreation Area	24	6 – 64	7
	Crowsnest R. upst. Connelly Creek	25	2 – 150	7
	Oldman R. near Olin Creek	19	2 - 130	7

Table 17 summarizes metals data for reservoir bottom sediment in 1996. Data from 1991 through 1993 are not included in the mean and ranges in the table, because many variables were analyzed using a different method, and also because the reservoir was stabilizing at that time.

The data for most metals for which there are guidelines complied, but most arsenic values were above the sediment quality guideline. However, these levels were all below the probable effects level of 17 µg/g. The toxicity of arsenic depends on its bioavailability; arsenic that is bound within crystalline lattices of clay and other minerals associated with acid-extractable fractions is considered least bioavailable (CCME 1999). It is probable that the source of arsenic for the reservoir is natural geological materials in the watershed, and therefore low in bioavailability. Arsenic levels in the water column above the sediments and in the inflow streams were well below Canadian water quality guidelines.

The only other variable with occasional exceedences of the sediment guidelines was cadmium. As with arsenic, the source is probably natural geological materials. It has a high affinity for negatively charged particle surfaces, and therefore it tends to accumulate in the

Table 17. Mean concentrations of metals in the bottom sediments of Oldman Reservoir, November 1996, range of values, water quality guideline and compliance. Concentrations in µg/g. Cells I - V combined (one sample each from Cells III, IV and V). Guideline values from CCME (1999). Data for samples collected in years other than 1996 not included in mean and range.

Variable	Mean Value	Range	Guideline Value*	% Compliance	Years Sampled	Number of Samples
Aluminum	22,101	11,530 – 29,688			1996	13
Antimony	0.37	0.29 – 0.46			1996	13
Arsenic	7.4	5.6 – 8.8	5.9	7.7%	1996	13
Barium	413	365 – 471			1991-93, 1996	19
Beryllium	1.19	0.6 - 1.47			1996	13
Boron	8.7	6.9 – 10.6			1996	13
Cadmium	0.57	0.32 – 0.70	0.6	69%	1991-93, 1996	19
Chromium	22.5	13.1 – 29	37.3	100%	1996	13
Cobalt	10.4	7.69 – 12.3			1996	13
Copper	24.2	14.6 – 29.4	35.7	100%	1991-93, 1996	19
Iron	21,021	13,094 – 25,750			1991-93, 1996	19
Lead	15.2	9.86 – 18.1	35.0	100%	1991-93, 1996	19
Lithium	20.4	10.9 – 28.2			1996	13
Manganese	569	470 – 717			1991-93, 1996	19
Mercury, tot.	0.04	0.04 – 0.06	0.17	100%	1991-93, 1996	19
Molybdenum	0.70	0.54 – 0.91			1996	13
Nickel	29.2	17.8 – 35			1996	13
Selenium	0.4600	0.1874 – 0.6292			1996	13
Strontium	81.0	64.9 – 93.5			1996	13
Thallium	0.28	0.18 – 0.34			1996	13
Tin	0.76	0.52 – 0.96			1996	13
Uranium	0.97	0.67 – 1.15			1996	13
Vanadium	44.7	25.5 – 56.8			1996	13
Zinc	94.1	52.7 – 117	123	100%	1991-93, 1996	19

* Interim freshwater sediment guideline for the protection of aquatic life.

bottom sediments (CCME 1999). In reservoir water, it was analyzed at below detection limit levels, except for two occasions when it was measured at the detection limit.

Phosphorus fractions and total organic carbon were also measured in the bottom sediments (Table 18). There was no relationship between total phosphorus and organic carbon or the sediment texture variables. Non-apatite inorganic phosphorus (NAIP) was weakly correlated with total organic carbon (r^2=0.21, P<0.05, n=19), but not with any of the sediment texture variables nor with total phosphorus. Total phosphorus levels were similar to those measured in sediments in Lac La Biche (unpublished data, Water Sciences Branch, 1992), but NAIP levels were about five times lower and less spatially variable than those from eutrophic Lac La Biche. Total phosphorus concentrations have not changed appreciably in the sediments of Cells I and II, but NAIP levels appear to have increased after 1991.

Table 18. Texture and concentrations of phosphorus in the bottom sediments of Oldman Reservoir, 1991-1993 and 1996. All samples collected in October or November. Texture and total organic carbon as percent weight, phosphorus as µg/g. Average values for Cells I and II in 1996 (one sample each for remaining data).

	Total Organic Carbon, %	Clay, %	Sand, %	Silt, %	Total Phosphorus, µg/g	Non-apatite Inorganic Phosphorus, µg/g
1991 Cell I	1.36	30	52.3	17.7	588	138
Cell II	1.58	19	52.3	28.7	592	116
1992 Cell I	1	36.7	14.3	49	579	61.8
Cell II	1.2	42.7	20	37.3	625	74.1
1993 Cell I	1.78	45.4	14	40.6	579	95.6
Cell II	0.76	29.4	34	36.6	358	55.5
1996 Cell I	0.96	44.9	37.7	17.4	585	124
Cell II	1.18	43.4	36.7	19.8	610	117
Cell III	0.54	15.6	61	23.4	525	43.2
Cell IV	1.2	24.6	47.1	28.3	604	96.9
Cell V	1.53	49.5	36	14.5	600	291

4.0 CONCLUSIONS

1. Based on available data, water quality in the Oldman River Reservoir is excellent.

Preliminary studies to predict water quality in the Oldman River Reservoir suggested that it would have excellent water quality, because it would be flushed rapidly with river water that is low in nutrients. The six years of data collected during the present study confirm this prediction. The water is suitable for all uses, including raw water supply, irrigation, fisheries and recreation. The reservoir is oligotrophic, based on levels of chlorophyll *a*. Water in the Oldman Reservoir is reasonably clear most of the summer, although suspended solids in the inflow water reduce the water clarity, especially in spring. Water transparency is generally lower than that predicted in preliminary studies. Non-algal turbidity reduces light penetration and as a result, the phytoplankton population is likely light-limited at certain times of the year. The water entering the Oldman River from the reservoir is also excellent, based on variables analyzed during the study.

2. There was no evidence of trophic upsurge during the study years.

Total nitrogen and phosphorus levels were highest as the reservoir was filling, but declined in later years. There was no apparent increase in phosphorus levels in the study years, as would be expected during trophic upsurge. As well, concentrations of chlorophyll *a* varied little from year to year. It is unlikely that trophic upsurge would have occurred after the study years.

3. The reservoir stratifies only weakly, and the hypolimnion remains oxic.

Although dissolved oxygen was barely measurable at the bottom on one sampling date during the study, this appears to be a rare occurrence. On other sampling dates, the dissolved oxygen concentration was nearly uniform from the surface of the water to the bottom. Thus, dissolved oxygen concentrations in the reservoir outflow would be high during the open-water period. Dissolved oxygen was not measured during the winter. The dissolved oxygen levels in the reservoir in the open-water period are sufficient to support aquatic life typical of the area.

4. Water at the bottom of the reservoir remains cool, and therefore the outflow temperature is low.

The highest temperature recorded at the bottom of Cell I was just over 14° C, and the highest outflow temperature recorded was 15° C. The highest outflow temperatures generally occurred in the fall. The lowest temperature in the bottom and the outflow would likely be a few degrees above freezing even during the coldest part of winter.

5. Mercury concentrations are below guideline levels in the water and sediments of the Oldman Reservoir.

Mercury was listed as a potential concern for the reservoir, but levels in the water and bottom sediments, and in the inflow streams, are very low.

5.0 RECOMMENDATIONS FOR FUTURE WORK

Results from sampling that has taken place over the six years following construction of the Oldman Dam indicate that little change occurred in the reservoir's limnological characteristics following the initial filling period. The reservoir was last monitored in 1996. It is therefore recommended that the reservoir and its outflow and inflows be resampled periodically to ensure that the reservoir continues to deliver excellent quality water to the downstream Oldman River.

6.0 LITERATURE CITED

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Appendix 1. Station codes for monitoring stations on Oldman Reservoir and its inflow streams.

OLDMAN RESERVOIR:
Hydrology Station: 05AA032 Oldman Reservoir near Pincher Creek

Water Quality Stations	
Station	Code
Cell I – profile	AB05AB0380
Cell I – composite	AB05AB0370
Cell II – profile	AB05AB0400
Cell II – composite	AB05AB0390
Cell III – profile	AB05AB0420
Cell III – composite	AB05AB0410
Cell IV – profile	AB05AB0440
Cell IV – composite	AB05AB0430
Cell V – profile	AB05AB0460
Cell V – composite	AB05AB0450

Hydrology Stations, Inflow Rivers and Outflow	
Station	Code
Castle River near Beavermines	05AA022
Crowsnest River at Frank	05AA008
Oldman River near Waldron’s Corner	05AA023
Oldman River below Oldman Dam	05AA024

Water Quality Stations, Inflow Rivers and Outflow	
Station	Code
Castle R. at Hwy 3 Bridge near Cowley	AB05AA0410
Castle R. at Recreation Area	AB05AA0400
Crowsnest R. near mouth	AB05AA0270
Crowsnest R. upst. Connelly Creek	AB05AA0220
Oldman R. near Waldron’s Corner	AB05AA0050
Oldman R. near Olin Creek	AB05AA0070
Oldman R. 100 m downstream Reservoir	AB05AB0010

Appendix 2. Physical and hydrological characteristics of Oldman Reservoir for full supply level (elevation 1118.6 m above sea level). *(Sources: Oldman River Dam Operation and Maintenance Manual, 1993; DeBoer 1997)*.

Surface Area	24.20 km^2
Volume	490 million m^3
Maximum Depth	68.6 m
Average Depth	20.2 m
Drainage Basin Area	4390 km^2
Average long-term inflow volume	1298 million m^3
Average inflow volume, 1991-1996	1397 million m^3
Average precipitation onto lake, 1991-96	565.5 mm
Average evaporation from lake, 1991-96	749.3 mm
Average outflow from lake, 1991-96	1342 million m^3
Average hydraulic residence time, 1993 – 1996	0.27 year