Glacial inflows and stratification in a hydroelectric reservoir

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KEYWORDS
Turbidity; glacial fines; plunging inflows; hydroelectric reservoir operations.

EXTENDED ABSTRACT

Introduction

We have been investigating the seasonal variation of turbidity in Carpenter Reservoir located in southwest British Columbia, Canada. Inflows to the reservoir are high in glacial fines, which are slow to settle, and which reduce the depth to which light can penetrate. There is concern that high turbidity from glacial meltwater limits light availability in the reservoir and, in turn, limits biological production. To address these concerns, a two-year field study was conducted in Carpenter Reservoir from May to October in 2015 and 2016.

Carpenter Reservoir (50°50' N, 122°30' W) is a long (50 km) and narrow (~1 km) reservoir situated on the original floodplain of the Bridge River and formed by the construction of Terzaghi Dam in 1960. At full pool (el. 651 mASL), the reservoir has a volume of 10^9 m^3, a surface area of 46 km^2, and a maximum depth of ~50 m. The reservoir has steep valley walls on both sides with mountain peaks reaching nearly 3000 m elevation.

Materials and methods

Field observations included monthly surveys of the reservoir and tributaries, meteorological measurements, and a temperature mooring located in the deepest part of the reservoir. As part of the monthly surveys, profiles of temperature, conductivity and turbidity were collected at 9 stations along the length of the reservoir (Fig. 1).

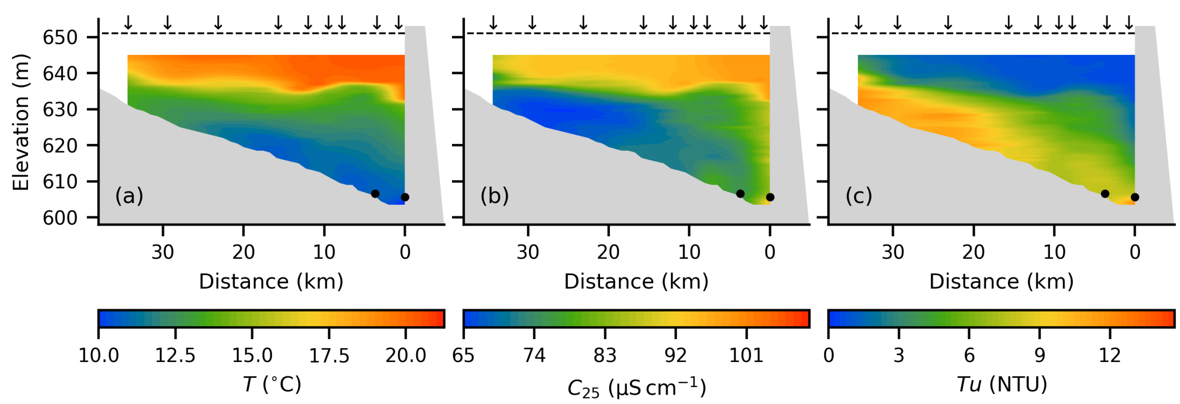

Figure 1. (a) Temperature, (b) conductivity, and (c) turbidity in Carpenter Reservoir, collected on 16 July 2015. The downward arrows mark the location of the CTD casts and the dashed line marks the water level at full pool. The black circles indicate the location of the deep outlets.

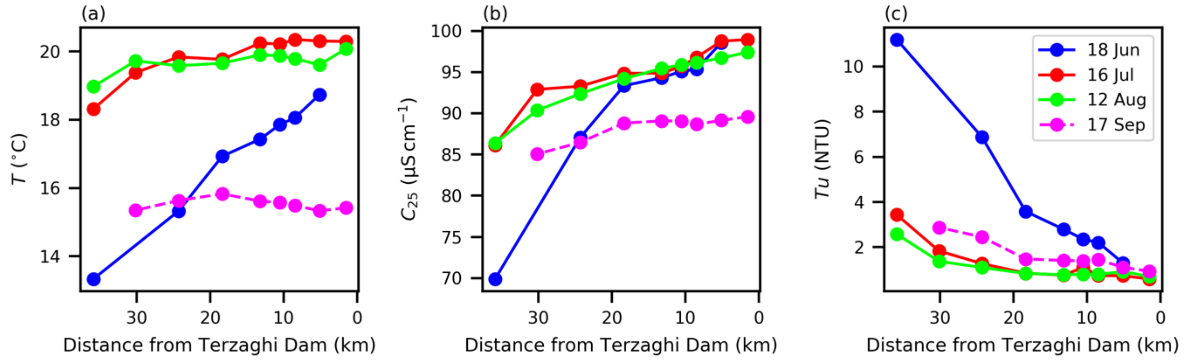

Figure 2. (a) Temperature, (b) conductivity, and (c) turbidity in the epilimnion at the 9 stations along the length of Carpenter Reservoir, 2015. Dashed lines indicate measurements after fall deepening began.

Results and discussion

Based on the field data, thermal stratification in the summer isolated the surface layer from the cold glacial inflows, which passed through the hypolimnion to the deep outlets as illustrated for 16 July 2015 in Fig. 1a. As a result, the surface layer was observed to be relatively clear during the summer, despite the high glacial load into the reservoir (Fig. 1c). Furthermore, the conductivity in the surface layer remained elevated, even with high inflows of lower conductivity glacial meltwater, supporting the hypothesis of an isolated surface layer (Fig. 1b).

The turbidity in the epilimnion varied seasonally, with turbidity high in the spring, decreasing during the summer when the epilimnion was relatively isolated, and rising again as the epilimnion deepened in fall (Fig. 2c). The conductivity in the epilimnion does not change much over the summer (with the exception of the upstream end in June, discussed below). The conductivity of the epilimnion declined in fall as the epilimnion began to deepen, mixing in fresher meltwater from below (Fig. 2b). Note the volume of the epilimnion remained relatively constant until deepening began in the fall.

However, despite this simple picture of an isolated epilimnion, what jumps out from Fig. 2 is the variation in the epilimnion *along* the length of the reservoir. The most notable longitudinal variation was in turbidity which was highest at the upstream end of the epilimnion nearest to the (plunging) glacial inflow, and lowest at the downstream end of the epilimnion near Terzaghi Dam (Fig. 2c). Also observed were longitudinal gradients in the temperature and conductivity of the epilimnion, with the coolest and freshest water at the upstream end (Fig. 2a,b). The longitudinal gradients persisted over the summer, despite a horizontal dispersive time scale of $O(10)$ days. Recall, all outflow is from depth (Fig. 1).

The intriguing persistence of longitudinal gradients in the 'isolated' epilimnion leads us to consider a variety of physical processes. The prevailing down-valley winds result in low Wedderburn numbers with downward tilting of the thermocline toward the dam (W=3, Fig. 1a). Also evident in Fig. 1a are internal waves. The prevailing wind can also give rise to upwelling at the upstream end during low stratification such as in spring. During upwelling, metalimnetic water is entrained into the surface layer providing a source of cooler, fresher, and more turbid water to the epilimnion. This may explain the longitudinal gradients observed in June (Fig. 2) though a smaller gradient continues to persist during summer even when upwelling is not expected.

Note, the majority of the tributary inflow enters Carpenter Reservoir at the upstream end. We speculate that in addition to upwelling, processes in the plunge zone may also result in the addition of cold, fresh and turbid water to the upstream end of the epilimnion which is then dispersed along the length of the reservoir. These processes include detrainment/splitting of the inflow, possibly balanced by entrainment of water from the epilimnion.