Elk Valley Water Quality Plan

Annex I.1

Evaluation of Phosphorus Loads on Upper Lake Koocanusa Trophic Status

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Memo

To:	Marko Adzic	Date:	May 20, 2014
From:	Thomas Gallagher	Re:	Evaluation of Phosphorus Loads on Upper Lake Koocanusa Trophic Status
cc:		Job No:	113-216944-4

Teck Coal Limited (Teck) has constructed a biological treatment system to reduce selenium and nitrate concentrations in runoff water from the Line Creek coal mine. For purposes of the Elk Valley Water Quality Plan, additional active water treatment facilities using similar biological treatment technologies are being considered. These systems are anticipated to reduce total selenium and nitrate concentrations to approximately 20 μg/L and 0.1 mg/L, respectively; but also have the potential to discharge residual total phosphorus (TP) concentrations of 0.3[1] mg/L, with approximately 0.1 mg/L as phosphate (PO_4). This memorandum presents an analysis of the potential for phosphorus discharge from the biological treatment facilities to affect the trophic status of Lake Koocanusa, British Columbia. An estimate was made of phosphorus concentrations in upper Lake Koocanusa, downstream of Elk River, that would result from the treatment of 7,500, 15,000, 22,500 and 30,000 m^3/day of water. These estimates were compared to existing phosphorus concentrations in the upper Lake Koocanusa. The analysis indicates that biological treatment will not change the trophic status of Lake Koocanusa.

Common practice for the evaluation of the potential impact of point source discharges on receiving water quality is to select a low river flow condition when dilution of the point source is minimal. In this analysis, the potential impact of treatment facilities discharges on upper Lake Koocanusa phosphorus levels was computed for a river flow condition representing approximately a one-in-ten-year frequency. The analysis was done for both total phosphorus (organic plus phosphate) and phosphate (PO_4). Although phosphate is the form of phosphorus immediately available for algal growth, organic phosphorus is mineralized to phosphate by bacteria in freshwaters, and is therefore available for algal growth.

[1] Residual total phosphorus concentrations range between 0.3 and 0.1 mg/L. The analysis presented in this document employs a value of 0.3 mg/L. This is a conservative assumption.

Periods used to estimate future phosphorus concentrations in upper Lake Koocanusa were annual average, algal growing season average (June 15th – September 30th), and summer low flow (August 1st – September 30th). Annual average nutrient concentrations, in conjunction with chl-a and Secchi depth, are sometimes used to compute a lake Trophic State Index (TSI). In a phosphorus-limited system like Lake Koocanusa, the growing season average algae (chl-a) concentration is related to the growing season average phosphorus concentration, and summer peak chl-a levels are associated with summer low-flow concentrations.

Current phosphorus concentration in upper Lake Koocanusa was computed based on the Elk River flow (Station 08NK002), measured Elk River phosphorus concentrations (Station BC08NK003), Kootenay River flow (Station 08NG065), and measured Kootenay River phosphorus concentrations (Station BC08NG008). The contribution of phosphorus from the Bull River was estimated by assigning the concentration of the Kootenay River to the measured Bull River flow (Station 8NG002). Locations of these stations are shown on Figure 1.

Phosphorus concentration in upper Lake Koocanusa after discharge of treated effluent water is computed from a mass balance of phosphorus loads entering the lake, and anticipated phosphorus load from the treatment system. Equation 1 presents the conceptual mass balance performed in this analysis. Considering the calculated increase in phosphorus load to upper Lake Koocanusa, inferences are made on the potential effect of the phosphorus loads on Lake Koocanusa's trophic status.

$$C_L = \frac{Q_E \times C_E + Q_K \times C_K + Q_B \times C_B + Q_W \times C_W}{Q_E + Q_K + Q_B + Q_W} \qquad \text{Eq. (1)}$$

Where:

C_L: upper Lake Koocanusa phosphorus concentration (downstream of the Elk River confluence)
Q_E: Elk River flow
Q_K: Kootenay River flow
Q_B: Bull River flow
Q_W: effluent flow
C_E: Elk River phosphorus concentration
C_K: Kootenay River phosphorus concentration
C_B: Bull River phosphorus concentration
C_W: effluent phosphorus concentration

Figures 2 and 3 present river flows and measured total phosphorus/phosphate concentrations for the Elk and Kootenay rivers, respectively, for the periods 1984 through 2012. This period encompasses all available total phosphorus/phosphate river data. Figure 4 plots measured TP and phosphate concentrations against river flow (expressed as cubic meter per second per square kilometer of drainage area) for the Elk and Kootenay Rivers. River flow is normalized by drainage, to facilitate a comparison of phosphorus variability with flow. Although phosphate concentrations do not correspond closely with river flow, there is a strong correlation of increasing river TP concentrations with increasing river flow above 0.01 m^3s/km^2.

Regressions in Figure 4 were used to compute daily Elk and Kootenay TP concentrations for a 43-year period (1970-2012), because computed daily river concentrations provide better average annual, growing season and summer low-flow concentrations than the 5 to 15 TP measurements made each year. This period was selected based on the availability of flow records at all the necessary flow gauges. For phosphate, a constant average concentration of 5 μg/L was used because it represents the average of the Kootenay and Elk River phosphate concentrations of 6 and 4 μg/L, respectively.

Total river flow into upper Lake Koocanusa was analyzed to select a critical low-flow condition, that could be used to calculate the incremental increase in river phosphorus concentration due to several treated water-flow alternatives. From 1970 to 2012, probability distributions of total inflow (Elk, Bull, and Kootenay Rivers) to upper Lake Koocanusa were developed for annual averages, growing-season averages, and low-flow summer average conditions (Figure 5). Total inflow to upper Lake Koocanusa in 1979 (indicated by the red circle on Figure 5) has annual, growing season, and critical summer low flows that are approximately a one-in-ten-year occurrence, and therefore suitable for evaluating the effect of treated water at critical low-flow conditions.

1979 hydrographs for the Elk and Kootenay Rivers are presented in Figure 6. A summary of the annual, growing-season and critical summer average flows for 1979 is presented in Table 1. For comparison purposes, actual one-in-ten-year flow statistics, as derived from the flow probability distribution in Figure 5, are also summarized.

Results of the phosphorus mass balance analysis are summarized in Tables 2 and 3 for total phosphorus and phosphate, respectively. Given the phosphorus versus flow relationships in Figure 4 and the 1979 hydrographs in Figure 6, calculated TP concentrations in upper Lake Koocanusa for the three averaging periods are shown under the column labeled "Calculated Average TP". The next three columns show calculated upper Lake Koocanusa TP concentrations resulting from the treatment of 7,500 m^3/day, 15,000 m^3/day, 22,500 m^3/day, and 30,000 m^3/day of water, and percent increase over existing conditions in parentheses. For example, on an annual average basis and during a critical low-flow year (1979), the phosphorus load resulting from the treatment of 7,500 m^3/day of water (e.g., the West Line Creek Active Water Treatment Facility) could increase upper

Lake Koocanusa concentration from 17.0 μg/L to 17.3 μg/L or 1.7 %. Results from the same analysis for dissolved phosphate are summarized in Table 3.

HydroQual Canada prepared a report titled "Koocanusa Reservoir – State of the Aquatic Environment 1972 – 1988" for the B.C. Ministry of Environment. This report indicates that the trophic status of Lake Koocanusa is oligotrophic to borderline mesotrophic, on the basis of Carlson Trophic State indices for total phosphorus, chl-a, and Secchi depth. Given the small calculated increase (0.6% to 7.6%) in upper Lake Koocanusa TP and phosphate, active water treatment using biological treatment technology and the associated phosphorus discharge will not change the trophic status of Lake Koocanusa.

Sincerely,

HDR Engineering, Inc.

Thomas W. Gallagher

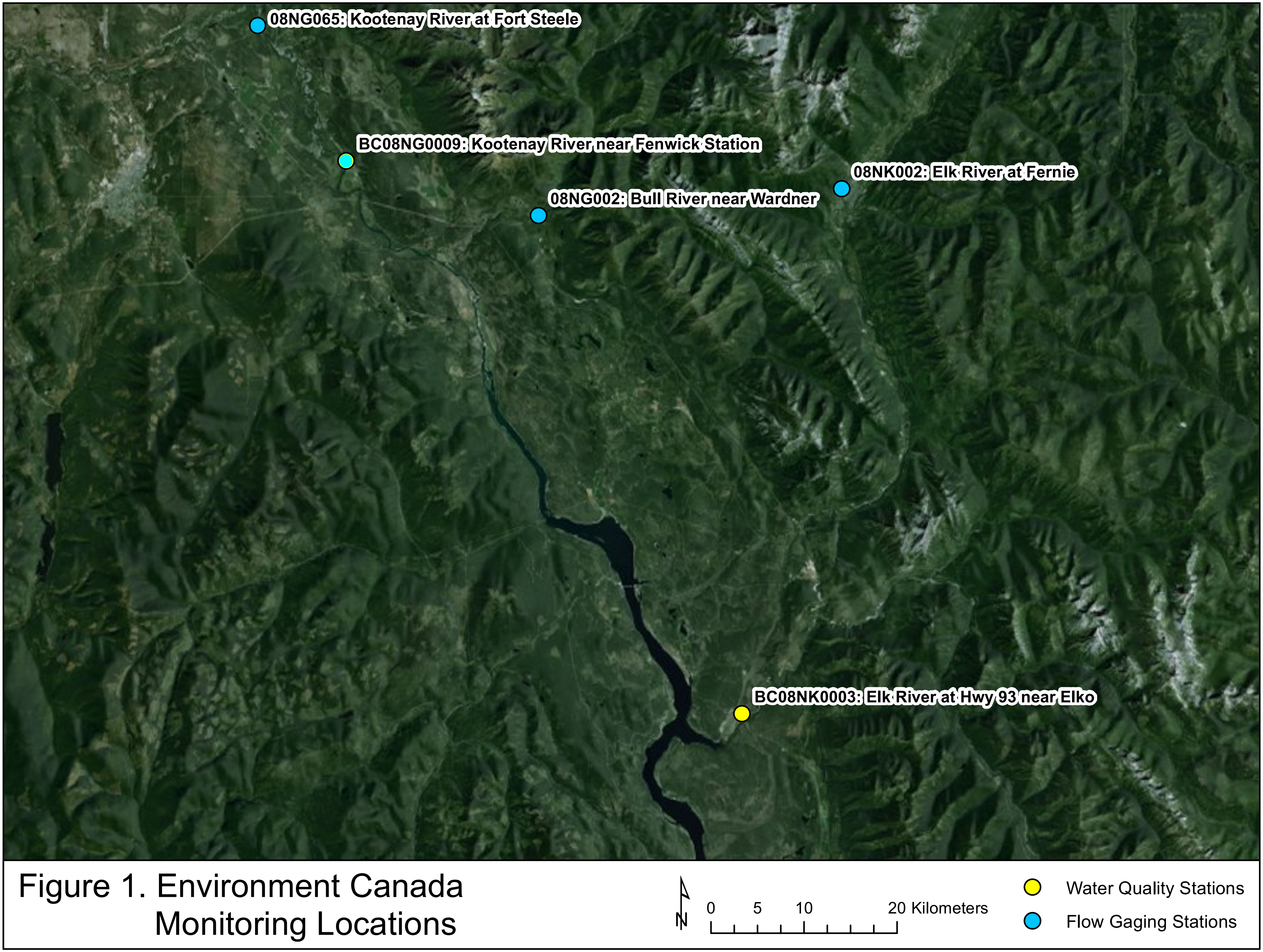

Figure 1. Environment Canada Monitoring Locations

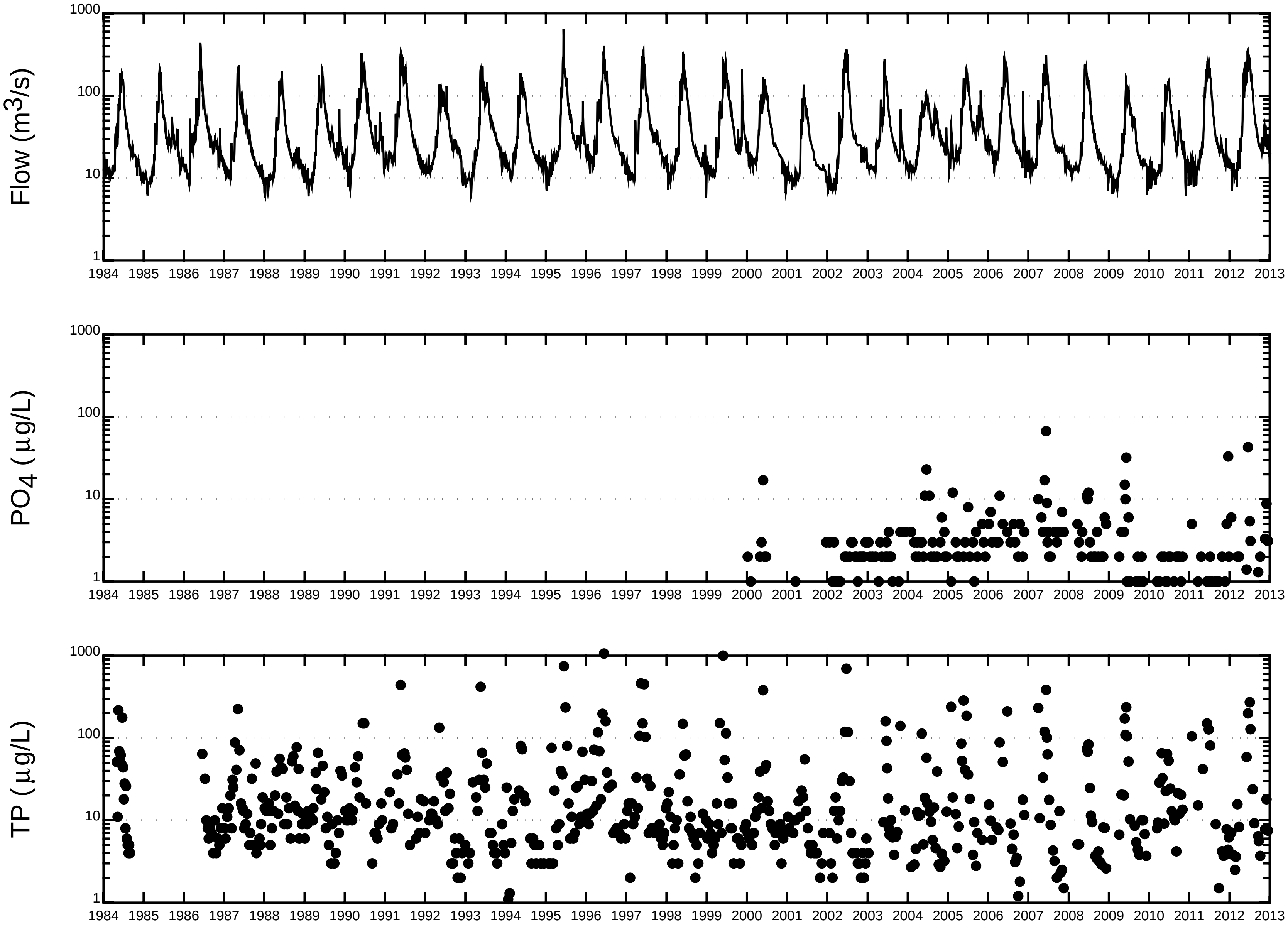

Figure 2. Summary of Available Monitoring Data - Elk River
Flow Station: O8NK002
Water Quality Station: BC08NK003

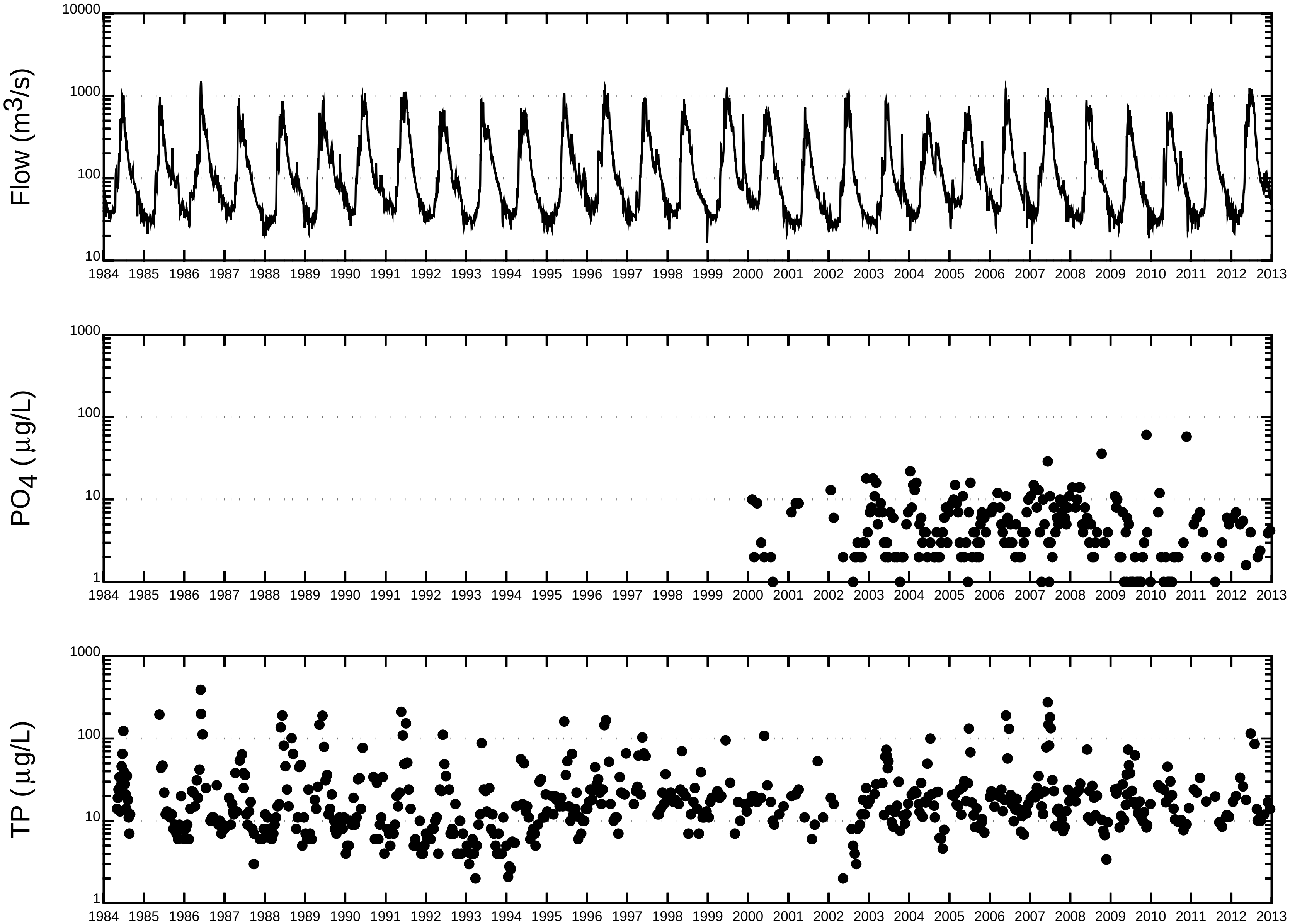

Figure 3. Summary of Available Monitoring Data - Kootenay River

Flow Station: O8NG065

Water Quality Station: BC08NG009

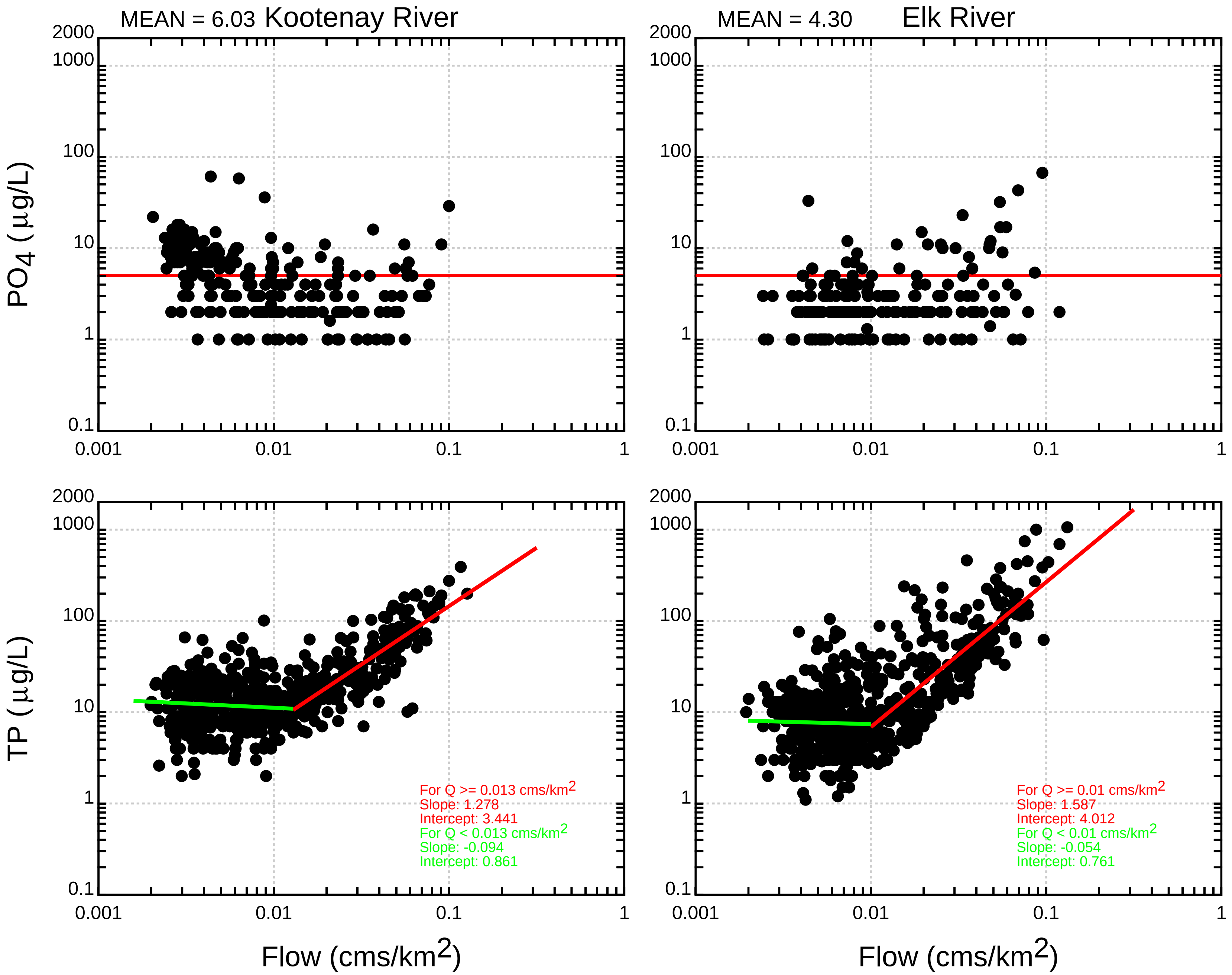

Figure 4. Regression Analysis for Flow and Concentration Relationships

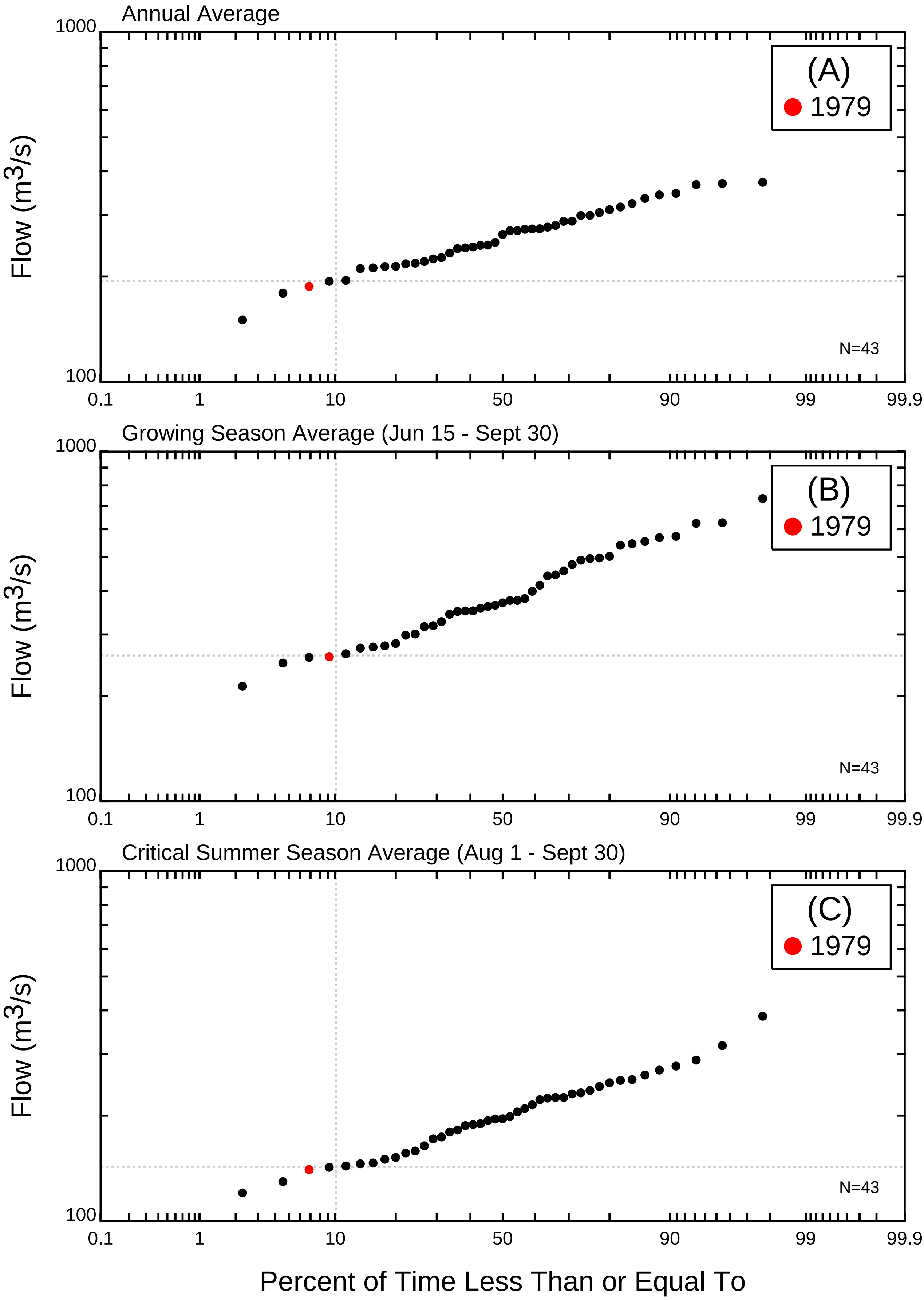

Figure 5. - Distribution of Inflow (Elk, Bull, & Kootenay Rivers) to Upper Lake Koocanusa (1970-2012)

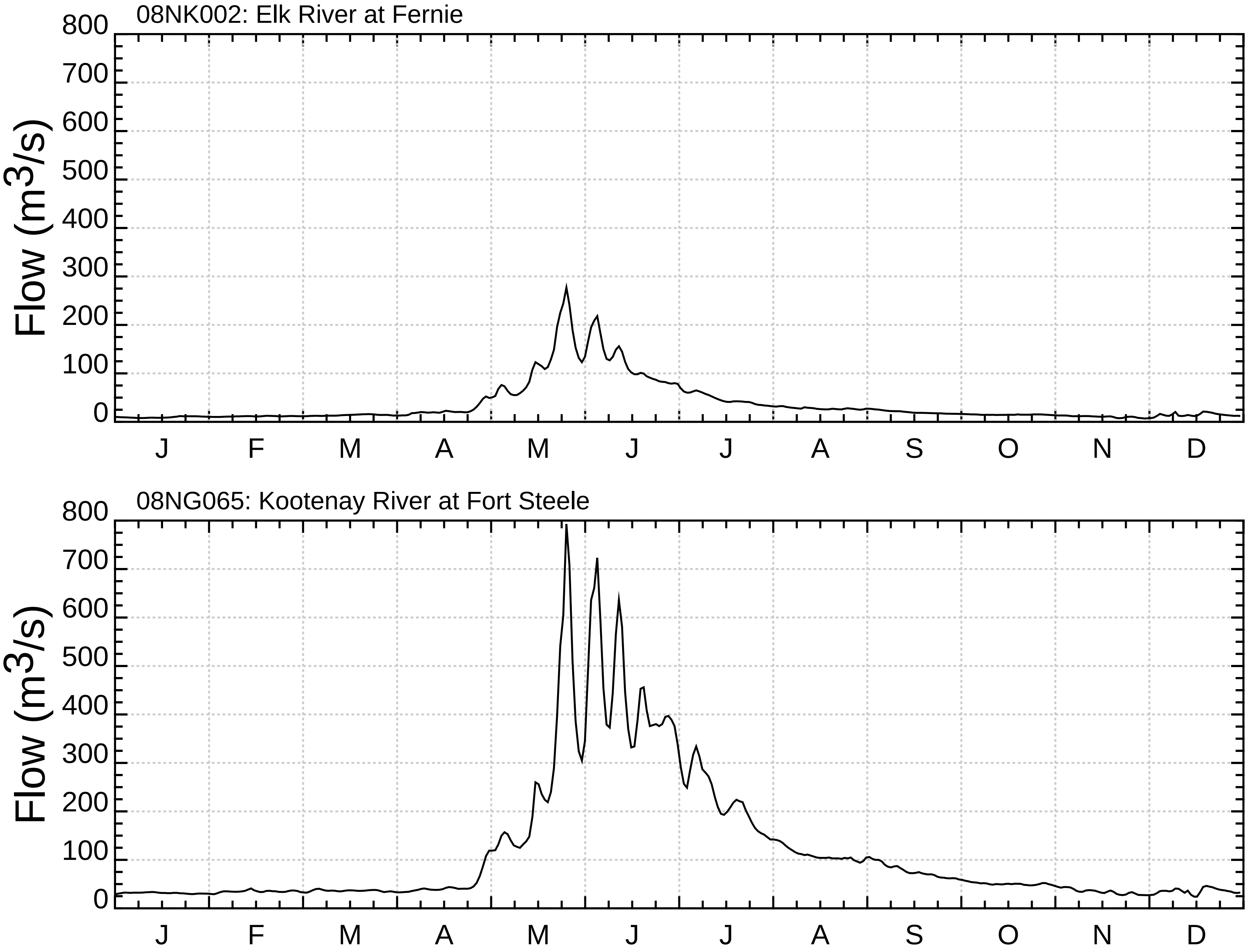

Figure 6. - Critical Low Flow Year (1979) Hydrograph for Inflows to Upper Lake Koocanusa

Table 1. Summary of Critical Low Flow Conditions for Upper Lake Koocanusa

Flow Scenario	Critical Low Flow Year (1979)	Interpolated 1 in 10 Year Low Flow
Annual Average	187	194
Growing Season (Jun 15 - Sept 30)	259	261
Critical Summer Season (Aug 1 - Sept 30)	140	143

Table 2. Summary of Computed Average Increase to Total Phosphorus Concentrations in Upper Lake Koocanusa due to planned Selenium treatment for different river and effluent flow conditions

Flow Scenario	Calculated Average TP (µg/L)	Projected Concentration (% Increase)			
		7,500 m^3/day	15,000 m^3/day	22,500 m^3/day	30,000 m^3/day
Annual Average	17.0	17.3 (1.7%)	17.6 (3.4%)	17.9 (5.0%)	18.2 (7.0%)
Growing Season (Jun 15 - Sept 30)	16.9	17.0 (0.6%)	17.2 (1.7%)	17.3 (2.3%)	17.5 (3.6%)
Critical Summer Season (Aug 1 - Sept 30)	10.5	10.7 (1.9%)	10.9 (3.7%)	11.1 (5.4%)	11.3 (7.6%)

Table 3. Summary of Computed Average Increase to Dissolved PO_4 Concentrations in Upper Lake Koocanusa due to planned Selenium treatment for different river and effluent flow conditions

Flow Scenario	Calculated Average PO_4 (µg/L)	Projected Concentration (% Increase)			
		7,500 m^3/day	15,000 m^3/day	22,500 m^3/day	30,000 m^3/day
Annual Average	5.00	5.10 (2.0%)	5.20 (3.8%)	5.30 (5.7%)	5.40 (8.0%)
Growing Season (Jun 15 - Sept 30)	5.00	5.05 (1.0%)	5.09 (1.8%)	5.14 (2.7%)	5.19 (3.8%)
Critical Summer Season (Aug 1 - Sept 30)	5.00	5.07 (1.4%)	5.13 (2.5%)	5.20 (3.8%)	5.26 (5.2%)

Discharge characteristics for a treatment facility:
Dissolved PO_4 = 0.1 mg/L

Total Phosphorus = 0.3 mg/L