Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison.

BPA_KTOI Project Number 199404900
BPA-KTOI Contract Number 76201
Reporting Period: 06/2017 to 05/2018
Authors: Hassen Yassien, Peter R B Ward,
HAY Engineering Services Ltd., Richmond, B.C.
Canada V7A 4N2

March 2018
Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison
Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison.

Contents
Introduction ........................................................................................................................................... 1
Hydrology and Reservoir Water Levels ................................................................................................. 4
Sampling Procedure ............................................................................................................................... 7
  A. On site measurement ...................................................................................................................... 7
  B. Laboratory analysis ......................................................................................................................... 7
Sampling Locations and Timing ............................................................................................................ 8
Results: Field Measurements and Laboratory Results ........................................................................ 11
  Field Measurements .......................................................................................................................... 11
Laboratory Results: Nutrients and Total Suspended Solids ................................................................. 13
Mass Transport for Nutrients and Reservoir Retention ...................................................................... 18
Comparison with 45-year old data for nutrients, annual data ............................................................. 26
Acknowledgements ............................................................................................................................. 30
REFERENCES ....................................................................................................................................... 30
APPENDIX ............................................................................................................................................ 31

List of Tables

Table 1. Names of sampling sites and catchment areas ....................................................................... 2
Table 2. Inflows and Outflows for the Period 2003 to 2017 for Koocanusa Reservoir. Mean annual flows ± one standard deviation .......................................................... 6
Table 3. Percentage of samples with results below 2 and 3 µg /L limits for TP and TDP ..................... 13
Table 4. Comparison of average values for nutrient annual mass transport values, new data and old data. (± one standard deviation) ...................................................... 29
Table 5. Annual nutrient mass inflows for 1972 to 1975, prior to clean-up of Cominco fertilizer plant at Kimberly, BC ................................................................. 29
Table of Figures

Figure 1. Kootenay (Kootenai) river basin map................................................................. 1
Figure 2. Map of Reservoir, showing Sampling Station Locations................................. 3
Figure 3. 365-day peak flows derived from the sum of the three main tributary flows measured at their gauging stations (Kootenay, Bull and Elk Rivers)4
Figure 4. Mean annual discharge, summed for the three main tributaries at their gauging stations, Koocanusa reservoir.............................................................. 5
Figure 5. Reservoir water surface levels, Koocanusa Reservoir.................................... 6
Figure 6. SAM-1 Smart Aqua Meter used for conductivity, temperature and pH measurements in the field.......................................................... 7
Figure 7. Sampling locations for Koocanusa inflows (top four) and outflows (bottom two) photos........................................................................................................ 9
Figure 8. Sampling Procedures. ...................................................................................... 10
Figure 9. Water quality parameters measured in situ at the sampling stations. 12
Figure 10. TDP and TP values for three inflow stations and one outflow station 14
Figure 11. Nitrogen N (two forms) for Kootenay, Bull and Kootenai downstream. .......................................................... 15
Figure 12. Nitrogen N (DIN and TN) for Elk River......................................................... 16
Figure 13. TSS and VSS values for three inflow stations and one outflow station. 17
Figure 14. Monthly mass transport values for TDP and TP for total inflow for two main streams (Kootenay, Elk and unmeasured catchment) and mass outflow. ........................................................................................................ 19
Figure 15. Monthly mass transport values for DIN and TN for two main inflow streams (Kootenay, Elk and unmeasured catchment) and mass outflow 21
Figure 16. Monthly mass transport values for total suspended solids inflow (Kootenay, Elk and unmeasured catchment) and mass outflow, linear scale (above) and logarithmic scale (below)................................................... 23
Figure 17. Annual mass inflows (Kootenay, Elk and unmeasured catchment) and annual mass outflows of TDP and TP. .................................................. 24
Figure 18. Annual mass inflows (Kootenay, Elk and unmeasured catchment) and mass outflows of DIN and TN. .......................................................... 25
Figure 19. Annual mass inflows (Kootenay, Elk and unmeasured catchment) and mass outflows for total suspended solids.................................................. 25
Figure 20. Koocanusa Reservoir: Annual Nutrient Inflows minus Annual Nutrient Outflows for TP, TN abd DIN.................................................. 26
Figure 21. Annual average water inflows from three streams during present data set (2014-2017) and old data (1976-1978). .................................................. 27
Figure 22. Comparison of 2014 to 2017 annual mass transport data for nutrients with old data (Crozier and Nordin 1981) for three tributary rivers............. 28
Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison.

Introduction

A study of nutrient transport in and out of Koocanusa Reservoir was undertaken for the four run-off seasons 2014, 2015, 2016, and 2017. Koocanusa Reservoir is 90 miles (144 km) long and spans the US-Canada border. The reservoir is situated on the Kootenay (Kootenai) River, between the headwater rivers and Kootenay Lake, see Figure 1. Part of the reservoir is in British Columbia, and part is in Montana.

![Figure 1. Kootenay (Kootenai) river basin map.](image)

At the south end of the reservoir, the Libby dam (Montana) is 422 ft (129m) tall, creating a reservoir with substantial area (18,900 ha) and large storage. The dam was the last of the Columbia River Treaty projects to be constructed, and was completed in 1975.
One of the objectives of the present work was to follow up on studies that were done 40 years earlier, during the time when a cleanup was undertaken of a major industrial water pollution source in Canada. A second objective was to establish about how much mass of total phosphorus (TP) and total dissolved phosphorus (TDP) was being taken up annually by the reservoir, reflected by an effective loss of phosphorus to the river below the Libby dam. The resulting loss of concentration in the flow of the river has been the subject of an environmental remediation (fertilization) project in the Idaho section of the Kootenai River, lead by the Kootenai Tribe of Idaho, underway since 2005. A third objective was to determine if the concentration of total nitrogen (TN) and total dissolved nitrogen (DIN) had changed significantly over the 40-year period.

Three main tributaries supply inflow to the reservoir, namely Kootenay and Bull (entering at the north end) and Elk entering from the east side of the reservoir (see Table 1 and Figure 2. All three rivers are conveniently sampled at road bridge crossings, and these are sufficiently close to Water Survey of Canada gauging stations that the river flows on the days of nutrient sampling were determinable from the published record. An unmeasured catchment area for inflows to Kocanusa reservoir is modest in size, equal to about 22% of the total area of the basin at Libby Dam. Note that Bull River enters the Kootenay River just upstream of the Highway 3/93 bridge. For purposes of comparison with previous reports, the Bull River data were measured and listed in addition to Kootenay and Elk data. For nutrient mass balance calculations, we took care to use inflows from Kootenay and Elk, plus the unmeasured catchment only.

Table 1. Names of sampling sites and catchment areas

<table>
<thead>
<tr>
<th>Stations for water chemistry sampling</th>
<th>Basin Area (km²)</th>
<th>Stations used for measuring river flows</th>
<th>Basin Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LK1, Bull River at Ft Steele-Wardner road bridge</td>
<td>1,520</td>
<td>Bull River near Wardner, WSC 08NG002</td>
<td>1,520</td>
</tr>
<tr>
<td>LK2, Kootenay River at Highway 3/93 bridge (excluding Bull river basin)</td>
<td>12,080</td>
<td>Kootenay River at Fort Steele, WSC 08NG065</td>
<td>11,500</td>
</tr>
<tr>
<td>LK4, Elk River at Highway 93 Phillips Bridge</td>
<td>4,450</td>
<td>Elk River at Fernie, WSC 08NK002</td>
<td>3,090</td>
</tr>
<tr>
<td>Sum of three catchments</td>
<td>18,050</td>
<td>Kootenai River below Libby Dam, Hwy 37 bridge USGS 12301933</td>
<td>16,110</td>
</tr>
<tr>
<td>LK5, Kootenai River below Libby Dam, Hwy 37 bridge</td>
<td>23,000</td>
<td></td>
<td>23,000</td>
</tr>
<tr>
<td>Un-sampled catchment</td>
<td>4,950</td>
<td>Un-gauged catchment</td>
<td>6,890</td>
</tr>
</tbody>
</table>

**Nutrient Transport for Kocanusa Inflows and Outflows: a 45-year Comparison**
Previous work on Koocanusa nutrient transport includes reports by Bonde and Bush (1982), Woods (1982) and Crozier and Nardin (1981), see pages 26-30.

Figure 2. Map of Reservoir, showing Sampling Station Locations
Hydrology and Reservoir Water Levels

Long data sets exist for daily flows in the Kootenay River (at Fort Steele), Bull River (near Wardner) and Elk River (at Fernie). Daily data exist from the date before reservoir filling (1975) to present. Daily flows were summed for the three tributaries, sorted and plotted to show the total flow-rate on the peak day of each year (Figure 3). The largest peak-day events in the 45-year data-set were in 1972, 1974 and 2013. The suspended sediment mass transport may be expected to be very high on these peak day events, For this comparison, data were not corrected for the additional flows from the unmeasured basin areas.

Figure 3. 365-day peak flows derived from the sum of the three main tributary flows measured at their gauging stations (Kootenay, Bull and Elk Rivers)

Daily flows were averaged for each calendar year and plotted as a mean annual discharge, indicating years of unusually high and unusually low runoff, see Figure 4. The largest annual mean events in the 45 year data set were 1972, 1974 and 2012. The period of sampling for the present nutrient work included two high runoff events of about 5 year return period each, and one average runoff event. An earlier report (Crozier and Nordin 1981) on nutrient transport, for the period 1976 to 1978 included one large annual runoff event, 22 percent above the long term mean (about 5 year return period) and one very low runoff event, 32 percent below the long term mean.
Annual runoff data for a 15-year period with a comparison of Koocanusa inflow and outflow show that the unmeasured basin area for the catchment at Libby dam contributes less flow per unit area than the rest of the catchment. This is expected as the unmeasured basin is at low altitude. The unmeasured river flow (see Table 2) contributes only 10.2% additional volume at the dam, a value considerably lower than would be expected from linearly pro-rating on the basis of the fractional basin area.
Table 2. Inflows and Outflows for the Period 2003 to 2017 for Koocanusa Reservoir. Mean annual flows ± one standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Upstream of Koocanusa Reservoir</th>
<th>Sum</th>
<th>Kootenai River below Libby Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bull River near Wardner</td>
<td>32 ± 6</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>Kootenay above Bull confluence</td>
<td>180 ± 31</td>
<td>313 ± 57</td>
</tr>
<tr>
<td></td>
<td>Elk at Phillips Bridge</td>
<td>69 ± 14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estimated Unsampled Catchment</td>
<td>32 ± 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Sum</strong></td>
<td><strong>313</strong></td>
<td><strong>313 ± 57</strong></td>
</tr>
<tr>
<td>Mean annual flows* (m³/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contribution to inflows %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Runoff (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Annual values based on flow records for the period 2003 to 2017.

Data for reservoir water surface levels show that the December 31st target level (2411 feet asl) is met closely in most years. For the four years of interest 2014-2017, the beginning of the first year, 2014, was an exception, and there was more water stored at the end of December than normal, see Figure 5.

Figure 5. Reservoir water surface levels, Koocanusa Reservoir.
Sampling Procedure

River water quality was either measured in situ, or sampled and the samples stored in an insulated container on ice, and sent for analysis. Water samples for TDP were obtained by filtering the river water on-site through a 0.45 micron filter, see photos below, Figure 8. The laboratory analyses were done at Aquatic Research Labs, Seattle, WA.

A. On site measurement:
   1. Total Dissolved solids (TDS)
   2. Conductivity
   3. pH
   4. Water temperature

B. Laboratory analysis:
   1. Total Dissolved Phosphorus (TDP)
   2. Total phosphorus (TP)
   3. NO₃ + NO₂ as N (DIN)
   4. Total Nitrogen (TN)
   5. Total Suspended Solids (TSS)
   6. Volatile Suspended Solids (VSS)

The on-site procedure, see Figure 6, used a Sensorex SAM-1 Aqua Meter (for temperature, pH and conductivity). Calibration was done with a Sensorex solution, strength 167 ppm (229 µS/cm) conductivity, and two buffer solutions for pH, 7.00 and 4.01 at 25°C. The on-site information was recorded as hard copy, and was also downloaded via mobile phone, and the information sent out electronically.

*Figure 6. SAM-1 Smart Aqua Meter used for conductivity, temperature and pH measurements in the field*
The laboratory analyses carried the following detection limits:

- **Total Dissolved Phosphorus (TDP)**: 2 µg/L
- **Total phosphorus (TP)**: 2 µg/L
- **NO₃ + NO₂ as N (DIN)**: 10 µg/L
- **Nitrogen (TN)**: 50 µg/L
- **Total Suspended Solids (TSS)**: 500 µg/L
- **Volatile Suspended Solids (VSS)**: 500 µg/L

**Sampling Locations and Timing**

Access points for inflow sampling (see Figure 7) were where road bridges cross the three major inflow tributaries. These were

1. LK1, Fort Steele to Wardner back-road bridge at Bull River,
2. LK2, Highway 3/93 bridge Kootenay River at Wardner, and
3. LK4, Highway 93 Phillips Bridge at Elk River.

During heavy winter snow conditions, the sampling point for the Elk River was moved (one date only) to the Highway 3 bridge in Fernie. For reservoir outflows, sampling was conducted at just downstream of Libby Dam, Station LK5, near the Highway 37 Kootenay River road bridge. The frequency of sampling was varied to reflect the rapidity of change of the hydrograph, with the highest frequency being during the rising and falling stages of the snowmelt freshet.
Figure 7. Sampling locations for Koocanusa inflows (top four) and outflows (bottom two) photos.
<table>
<thead>
<tr>
<th>Sample collection</th>
<th>Unfiltered sample for TP and TSS analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtering sample, 0.45 micron mesh (TDP)</td>
<td>Examples from filtration at two sites: Solids in filter (top), and none (bottom)</td>
</tr>
<tr>
<td>SAM-1 meter, (pH, conductivity, temp.)</td>
<td>Sample being labeled</td>
</tr>
</tbody>
</table>

*Figure 8. Sampling Procedures.*
Results: Field Measurements and Laboratory Results

Field Measurements

Field measurements for the 4 hydrological years (2014-2017) show that pH values are mainly slightly alkaline, with values in the range approximately 6.9 to 8.6 (Figure 9).

Conductivity values are in the range 130 to 470 µS/cm. A slight downward trend is shown in the last year of the study, for reasons that are unknown.

Water temperatures are in the range 0 to 22°C. As expected for a large reservoir, the outflow temperatures show a different range/timing compared with inflows, because of heat storage and release from the water body.
Figure 9. Water quality parameters measured in situ at the sampling stations
Laboratory Results: Nutrients and Total Suspended Solids

Water samples were sent away for analysis for measurement of two forms of nitrogen, TN and \((\text{NO}_3 + \text{NO}_2)\) -N, two forms of phosphorus, TDP and TP, total suspended solids and volatile suspended solids.

TDP values are close to, or below the detection limit (2 µg/L) for a substantial fraction of the samples (see Table 3) for stations LK1 and LK5. We assume that the TDP concentration was 1 µg /L for these. For these stations (Bull river and Kootenai downstream of the dam), this causes uncertainty in values for a large part of each year.

Table 3. Percentage of samples with results below 2 and 3 µg /L limits for TP and TDP

<table>
<thead>
<tr>
<th></th>
<th>Total Phosphorus</th>
<th>Total Dissolved Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;2 µg/L</td>
<td>&lt;3 µg/L</td>
</tr>
<tr>
<td>LK1</td>
<td>23%</td>
<td>33%</td>
</tr>
<tr>
<td>LK2</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>LK4</td>
<td>3%</td>
<td>12%</td>
</tr>
<tr>
<td>LK5</td>
<td>3%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Detection limit is 2 µg /L

TP values for inflows (see Figure 10) show a spike in concentration during freshet periods, with peak annual values in the range 100 to 700 µg/L. These peaks are associated with peak suspended sediment transport, with the phosphorus attached to clay and silt sized particles. Year 2017 was the largest year in the 4-year series for TP inflow concentrations. Outflow concentrations (LK5) were low (<2 µg/L) for the majority of the time.

We tested for correlation between TP values for Bull River and Kootenay River, since these catchments are adjacent to one another. There was a high correlation (80%) in the values. DIN and TN values for the two stations were also highly correlated (91% and 84% respectively).
Results for nitrogen N for Kootenay, Bull and Kootenai (below Dam) rivers are plotted together, see Figure 11. NO$_3$ + NO$_2$ nitrogen for Kootenay and Bull rivers shows a double concentration peak during the year for all years, one in winter with peaks of about 150 µg/L, and one during freshet conditions (early summer) with peaks of about 220 µg/L.
Figure 11. Nitrogen N (two forms) for Kootenay, Bull and Kootenai downstream.

Results for N for Elk river are plotted separately, Figure 12, because the range of values is much higher than for other stations. For NO$_2$ + NO$_3$ as N for example, the inflow concentration values for Elk river were about an order of magnitude larger than inflow values for Kootenay river. High values of NO$_2$ + NO$_3$ as N in the outflow at LK5 are attributed to the effect of the Elk nutrient inflows to the reservoir.
Suspended solids concentrations (see Figure 13) showed timing that closely corresponded with freshet flow conditions, with TSS peak annual values in the range 120,000 to 420,000 µg/L for Kootenay, Bull and Elk rivers. During the winter months, TSS concentrations were low, <10,000 µg/L most of the time.

Figure 12. Nitrogen N (DIN and TN) for Elk River.
Figure 13. TSS and VSS values for three inflow stations and one outflow station
Mass Transport for Nutrients and Reservoir Retention

Mass inflows and mass outflows were computed for each (24 h) sampling date for the four-year period, starting on 1\textsuperscript{st} January 2014, and finishing on 31\textsuperscript{st} December 2017. The mass transport at each station per day (in kg) was taken from the product of 86.4 times the daily water flow rate (Q m\textsuperscript{3}/s) times the nutrient concentration (g/m\textsuperscript{3}). For the period before startup of sampling in April 2014, values were computed from the product of daily river flow values times a value of concentration obtained from January to April data for 2015, 2016, 2017. For the period from termination of sampling in August 2017, values were computed from the product of daily river flow values times a value of concentration obtained from August to December data for 2014, 2015, 2016.

Daily mass transports were computed at two inflow stations (Kootenay and Elk) and one outflow station (see description below) by multiplying the daily river flow rate by nutrient concentrations interpolated from the periodic sampling dates. Allowance was made for inflow from the unmeasured catchment area, mainly along the sides of the reservoir.

\textit{Kootenay River}: Daily volumetric flow rate pro-rated from the gauging station at Fort Steele to the location of the Wardner (Hwy 3/93) bridge sampling site, times the daily concentrations calculated by interpolating the Kootenay values obtained from sampling. The sampling station is downstream of the Bull River confluence, and flows at this location include Bull river flows.

\textit{Elk River}: Daily volumetric flow rate pro-rated from the WSC Fernie gauging station to the location of the Phillips (Hwy 93) bridge sampling site, times the daily concentrations calculated by interpolating the values obtained from sampling.

\textit{Unmeasured catchment}: Mass transport as computed for Kootenay River, pro-rated by a factor of 10.2\% (see Table 2 above).

\textit{Kootenai River downstream}: Daily volumetric flow rate from the USGS gauge times the daily concentration computed by interpolating the values obtained from sampling at the Hwy 37 bridge site.

Daily values of mass transport were then integrated to provide monthly values for nutrients and for solids. Monthly mass transports for phosphorus as TP (Figure 14), show values for outflows are smaller by about an order of magnitude than monthly inflows. This large difference may be because phosphorus is attached to sediment particles, and these show inflow/outflow differences that are very large indeed, associated with settlement in the reservoir. Monthly mass transport for TDP for May 2014 is extremely high, influenced by concentration values for TDP on 18\textsuperscript{th} May 2014 for Kootenay and Elk rivers that are one to two orders of magnitude larger than
normal for freschet conditions. Monthly mass transport for TDP for the outflows during the period September to March are uncertain, because during this period the majority of samples provided concentrations that are below, or very close to, the detection limit, see Table 3.

Figure 14. Monthly mass transport values for TDP and TP for total inflow for two main streams (Kootenay, Elk and unmeasured catchment) and mass outflow.
Monthly values for DIN and TN mass flows for the outflow below Libby Dam (Figure 15), show two peaks per year, one in summer and one in winter. These peaks are mainly determined by the timing of the water releases from the reservoir, affected by hydro-power generation, as scheduled by the dam operator. November and December flows are frequently high, and this causes high mass transport values for DIN and TN during these months.

Note that for the 2014 calendar year, these values are affected by a gain of 715 Mm$^3$ of the downstream annual volume for water released from the reservoir, providing slightly more outflow of nutrients compared with years with balanced storage. This was because the reservoir surface level was at higher elevation at the beginning of the 2014 year than normal, Figure 5.

For 2015, 2016 and 2017 the water balance for the reservoir is neutral, as the reservoir was at the same level on the starting and finishing dates (1$^{st}$ January and 31$^{st}$ December).
Figure 15. Monthly mass transport values for DIN and TN for two main inflow streams (Kootenay, Elk and unmeasured catchment) and mass outflow
Total suspended solids mass transport values (Figure 16) show a wide range, with maximum monthly values for inflow of about 600,000 tonnes at the peak freshet month in both 2014 and 2017. Values outside the (3) months of the summer freshet are negligible. Monthly outflow values are negligible, less than 5,000 tonnes/month during the freshet period, constituting a difference of about 2 orders of magnitude compared with inflows. Clearly a very significant sediment settling effect is caused by the presence of the reservoir.
Figure 16. Monthly mass transport values for total suspended solids inflow (Kootenay, Elk and unmeasured catchment) and mass outflow, linear scale (above) and logarithmic scale (below).
Annual mass transport values were computed from daily values for nutrient inflows and outflows for TDP, TP, DIN and TN for the four year period.

TDP annual inflow (Figure 17) averaged about 45 tonnes annually. TDP average outflow was hard to quantify, because results of the majority of samples were just above or below the detection limit (see Table 3). Assuming an approximate amount of outflow of 21 tonnes annually, the retention of TDP in the reservoir was 24 tonnes annually for the 4-year period. The year 2014 was the highest of the 4 years for inflow of TDP, but not for TP. This very high value is associated with very high concentration values on one date in May 2014.

TP retention in the reservoir was very high, with outflow values averaging about 7% to 20% of inflow values (93% to 80% retention).

![Figure 17. Annual mass inflows (Kootenay, Elk and unmeasured catchment) and annual mass outflows of TDP and TP.](image)

*Note: Confidence in TDP outflow values is low, because a large proportion of samples had values of concentration at, or just above the detection limit.*

Annual DIN values for outflow were about 84% to 93% of DIN values for inflow for all years except 2015 (69%). Annual TN values for outflow were in the range 66% to 85% of annual inflow values (Figure 18).
Figure 18. Annual mass inflows (Kootenay, Elk and unmeasured catchment) and mass outflows of DIN and TN.

Annual mass transport of total suspended solids for inflows were about 2 orders of magnitude larger than outflows, Figure 19. The trapping efficiency of the reservoir is high, with values about 97.5% to 99% during the freshet period. Annual differences between inflow and outflow of total suspended solids is in the range 300,000 to 1,100,000 tonnes, implying a massive loss of solids in the reservoir.

Figure 19. Annual mass inflows (Kootenay, Elk and unmeasured catchment) and mass outflows for total suspended solids.
Amounts of nutrient mass trapped annually in the reservoir range from values of several hundred to over one thousand tonnes (for TP, DIN and TN, Figure 20).

Note that the annual mean TDP and TP amounts trapped in Koocanusa reservoir (24 and 585 tonnes) for the 4 years 2014 to 2017 is much larger than the amount of P added by fertilization at the KTOI nutrient dosing site at Leonia (Idaho-Montana border). This averaged approximately 10.5 tonnes (P) during the summer seasons (2006 to 2017) of operation.

![Figure 20. Koocanusa Reservoir: Annual Nutrient Inflows minus Annual Nutrient Outflows for TP, TN and DIN.](image)

**Comparison with 45-year old data for nutrients, annual data**

*Crozier and Nordin, 1981,* reported on annual loads for nutrient data, TDP, TP, DIN and TN for Koocanusa reservoir (Kootenay, Bull and Elk rivers) for years 1972 to 1978. This period included years post filling conditions (1972 onwards) for the reservoir, and post clean-up (1975 onwards) of the Kimberley fertilizer plant. The plant had historically contributed very large amounts of TP and TDP to a tributary creek (Mark Creek and St. Mary river) of the Kootenay river.
Kootenay River inflows for 2014-2017 (see Figure 21) were calculated upstream of the Bull River confluence for comparison with the Crozier and Nordin data set (1976-1978) post clean-up years.

The period of sampling for the present nutrient work included two high runoff events of about 5 year return period each, and one average runoff event (Figure 21). The earlier report (Crozier and Nordin 1981) on nutrient transport, for the period 1976 to 1978 included one large runoff event of about 5 year return period and one very low runoff event (see long hydrological data series, Figure 4).

**Figure 21. Annual average water inflows from three streams during present data set (2014-2017) and old data (1976-1978).**

Annual mass transport values for the Kootenay river (see Figure 22) were computed by using daily concentrations from the Wardner sampling station, and multiplying by daily Kootenay river flows upstream of the Bull river confluence. Bull river values and Elk river values were computed from daily values, as described in Section “**Mass Transport**”, and determining annual values from these. Note that Bull river data for 1978 for TP were affected by a very large (>10 x normal) concentration of phosphorus on a single sampling date in June 1978.
Figure 22. Comparison of 2014 to 2017 annual mass transport data for nutrients with old data (Crozier and Nordin 1981) for three tributary rivers.

The main changes in nutrient transport over the multi-decade period (see Table 4) are as follows:

**For TDP**
- Kootenay River: Mean of recent data about \( \frac{1}{2} \) mean value of old data
- Bull and Elk Rivers: Mean of recent data similar to mean of old data
- Total: Mean of recent data about \( \frac{2}{3} \) of mean of old data

**For TP**
- Kootenay River: Mean of recent data similar to mean of old data.
- Bull River: Mean of recent data about \( \frac{1}{3} \) of mean of old data, see comment, page 27 last sentence.
- Elk River: Mean of recent data 70% more than mean of old data
- Total: Mean of data similar to mean of old data (old data total affected by unusually high value for Bull River)

**For DIN**
- Kootenay and Bull Rivers: Mean of recent data similar to mean of old data
- Elk River: Mean of recent data exceeds mean of old data by factor of 8.
- Total: Mean of recent data exceeds mean of old data by factor of 3.

**For TN:**
- Kootenay and Bull Rivers: Mean of recent data similar to mean of old data.
- Elk River: Mean of recent data exceeds mean of old data by factor of 3.
- Total: Mean of recent data exceeds mean of old data by 81%.
Table 4. Comparison of average values for nutrient annual mass transport values, new data and old data. (± one standard deviation).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bull River</td>
<td>1976-1978</td>
<td>3 ± 1</td>
<td>90 ± 108</td>
<td>123 ± 15</td>
<td>219 ± 45</td>
</tr>
<tr>
<td></td>
<td>2014-2017</td>
<td>3 ± 1</td>
<td>27 ± 27</td>
<td>121 ± 22</td>
<td>228 ± 31</td>
</tr>
<tr>
<td>Kootenay River</td>
<td>1976-1978</td>
<td>44 ± 14</td>
<td>278 ± 18</td>
<td>580 ± 90</td>
<td>1,257 ± 348</td>
</tr>
<tr>
<td></td>
<td>2014-2017</td>
<td>20 ± 9</td>
<td>331 ± 291</td>
<td>599 ± 94</td>
<td>1,338 ± 190</td>
</tr>
<tr>
<td>Elk River</td>
<td>1976-1978</td>
<td>13 ± 5</td>
<td>111 ± 98</td>
<td>253 ± 144</td>
<td>817 ± 380</td>
</tr>
<tr>
<td></td>
<td>2014-2017</td>
<td>16 ± 16</td>
<td>189 ± 158</td>
<td>2,068 ± 273</td>
<td>2,578 ± 316</td>
</tr>
<tr>
<td>Sum of 3 streams</td>
<td>1976-1978</td>
<td>60 ± 10</td>
<td>478 ± 141</td>
<td>956 ± 212</td>
<td>2,293 ± 767</td>
</tr>
<tr>
<td></td>
<td>2014-2017</td>
<td>39 ± 26</td>
<td>547 ± 420</td>
<td>2,788 ± 351</td>
<td>4,144 ± 382</td>
</tr>
</tbody>
</table>

Prior to clean-up of procedures in the Cominco Kimberly fertilizer plant, values for TDP and TP for inflows to the reservoir were much higher than post clean-up conditions, see Table 5, data from Crozier and Nordin 1981.

Table 5. Annual nutrient mass inflows for 1972 to 1975, prior to clean-up of Cominco fertilizer plant at Kimberly, BC.

<table>
<thead>
<tr>
<th>Year</th>
<th>TDP [tonne]</th>
<th>TP [tonne]</th>
<th>DIN [tonne]</th>
<th>TN [tonne]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>333</td>
<td>839</td>
<td>923</td>
<td>1,907</td>
</tr>
<tr>
<td>1973</td>
<td>771</td>
<td>1,481</td>
<td>679</td>
<td>2,117</td>
</tr>
<tr>
<td>1974</td>
<td>507</td>
<td>1,456</td>
<td>865</td>
<td>2,353</td>
</tr>
<tr>
<td>1975</td>
<td>708</td>
<td>1,693</td>
<td>890</td>
<td>2,866</td>
</tr>
<tr>
<td>Average</td>
<td>580</td>
<td>1,367</td>
<td>839</td>
<td>2,311</td>
</tr>
<tr>
<td>Std. deviation</td>
<td>199</td>
<td>368</td>
<td>109</td>
<td>413</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>34%</td>
<td>27%</td>
<td>13%</td>
<td>18%</td>
</tr>
<tr>
<td>Kootenay River Contribution</td>
<td>93%</td>
<td>87%</td>
<td>65%</td>
<td>63%</td>
</tr>
</tbody>
</table>

*Crozier and Nordin, 1982
During this 1972-1975 pre clean-up period, total TDP values from the 3 rivers were an order of magnitude higher than after clean up, and TP values were about 3 times higher than after clean-up. DIN and TN values were about the same during the 1972-1975 period as they were during the period 1976-1978.

Acknowledgements.

The work was funded by Bonnville Power Corporation through multiple contracts starting in 2014 (#s: 65368, 68921, 72784, and 76201) with Kootenai Tribe of Idaho. Charlie Holderman (KTOI) supervised and supported the project. Cory Laude (R & D Consulting) and Nora Kedish provided reliable and thorough support in the field with the sampling program. Greg Hoffman (USACE) provided us with information about Koocanusa reservoir surface levels and volumes.

REFERENCES


Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison

APPENDIX

Tables from Woods (1982), Table from Nordin (1981).

NUTRIENT LOADINGS

The nutrient transport from the Lake Koocanusa inflows and outflows were estimated by Bonde and Bush (1975) in a manner similar to equation 3. Nutrient loading from the 12,036 km² of drainage area that was engaged was estimated by the method of watershed-export coefficients of Reckhow, Beauch, and Simpson (1980). Sufficient data were available from the Bull, Elk, and Tobacco Rivers to permit calculating loadings per unit area. Streamflow and water-quality data for 1975-77 were input to equation 3 and the results were summed to derive annual loadings of total phosphorus and total nitrogen. The annual loadings for each stream were divided by their gaged drainage area. The median value of the derived watershed-export coefficients for the three streams was 0.014 kg·ha⁻¹·a⁻¹ (range = 0.002 to 0.196, number of samples = 13) for total phosphorus and 1.55 kg·ha⁻¹·a⁻¹ (range = 0.52 to 1.75, number of samples = 14) for total nitrogen. These two median watershed-export coefficients were multiplied by the engaged drainage area of 1,209,502 ha to obtain annual loadings of total phosphorus and total nitrogen in kilograms. These values then were multiplied by 0.001 to convert them into megagrams.

Atmospheric deposition of total phosphorus and total nitrogen received by the surface of Lake Koocanusa was estimated using the product of the reservoir's mean annual surface area in hectares, a forest-atmospheric input coefficient in kilograms per hectare per year, and a 0.001 factor which yielded annual loading in megagrams. Forest-atmospheric input coefficients were 0.27 kg·ha⁻¹·a⁻¹ for total phosphorus and 0.99 kg·ha⁻¹·a⁻¹ for total nitrogen—the only values cited in Reckhow, Beauch, and Simpson (1980) that were judged by this author as geographically applicable to the study area. Mean annual surface area, in hectares, was derived from statistical analysis of daily measurements of surface altitude. Mean annual reservoir surface altitude was converted to surface area using area-capacity curves for Lake Koocanusa.

Loadings of total phosphorus and total nitrogen from the sewage-treatment plant at Eureka, Montana (fig. 1), were obtained from the U.S. Environmental Protection Agency (1977). Annual loadings of 1.8 Mg of total phosphorus and 9.1 Mg of total nitrogen were measured during 1975 at the Eureka plant.

Variations in annual loadings of total phosphorus and total nitrogen were due, in part, to variations in annual streamflow. To remove this effect, each annual loading was divided by its respective annual streamflow to obtain a loading rate per unit volume of streamflow, expressed as megagrams per cubic kilometer of streamflow.

The relationship between influent loadings of total phosphorus and total nitrogen and the loadings of these two nutrients discharged through Libby Dam was quantified with a nutrient-retention coefficient (Dillon and Rigler 1974), calculated thusly:

$$ C = 1.0 - \frac{E}{I} $$

where

- $C$ is a nutrient-retention coefficient;
- $E$ is the mass of nutrient, in megagrams, discharged from the reservoir in a year; and
- $I$ is the mass of nutrient, in megagrams, that entered the reservoir in a year.

INFLUENT LOADINGS

Listed in tables 4 and 5 for total phosphorus and total nitrogen are the annual loadings and loading rates per unit volume of streamflow that entered Lake Koocanusa via gaged streamflow, ungaged drainage areas, atmospheric deposition, and the Eureka sewage-treatment plant. From 1972 through 1975, the influent loading of total phosphorus ranged from 1,488 to 1,626 Mg. A large reduction occurred in 1976; the 1976 loading of total phosphorus was 39.4 percent of that estimated for 1975. For 1977-80, the loading of total phosphorus varied from 362 to 498 Mg. The loading rate per unit volume of streamflow for total phosphorus generally followed the same trend as the annual loadings of total phosphorus. The changes in total loading of total phosphorus primarily resulted from changes in loadings from

<table>
<thead>
<tr>
<th>Year</th>
<th>Loadings</th>
<th>Loading rate, kg·m⁻³·a⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1,375</td>
<td>2.3</td>
</tr>
<tr>
<td>1974</td>
<td>1,060</td>
<td>1.9</td>
</tr>
<tr>
<td>1975</td>
<td>1,240</td>
<td>2.3</td>
</tr>
<tr>
<td>1976</td>
<td>1,230</td>
<td>2.3</td>
</tr>
<tr>
<td>1977</td>
<td>1,250</td>
<td>2.3</td>
</tr>
<tr>
<td>1978</td>
<td>1,260</td>
<td>2.3</td>
</tr>
<tr>
<td>1979</td>
<td>1,250</td>
<td>2.3</td>
</tr>
<tr>
<td>1980</td>
<td>1,250</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Loadings</th>
<th>Loading rate, kg·m⁻³·a⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1,375</td>
<td>2.3</td>
</tr>
<tr>
<td>1974</td>
<td>1,060</td>
<td>1.9</td>
</tr>
<tr>
<td>1975</td>
<td>1,240</td>
<td>2.3</td>
</tr>
<tr>
<td>1976</td>
<td>1,230</td>
<td>2.3</td>
</tr>
<tr>
<td>1977</td>
<td>1,250</td>
<td>2.3</td>
</tr>
<tr>
<td>1978</td>
<td>1,260</td>
<td>2.3</td>
</tr>
<tr>
<td>1979</td>
<td>1,250</td>
<td>2.3</td>
</tr>
<tr>
<td>1980</td>
<td>1,250</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Two nutrients discharged through Libby Dam were quantified with a nutrient-retention coefficient (Dillon and Rigler 1974), calculated thusly:

$$ C = 1.0 - \frac{E}{I} $$

where

- $C$ is a nutrient-retention coefficient;
- $E$ is the mass of nutrient, in megagrams, discharged from the reservoir in a year; and
- $I$ is the mass of nutrient, in megagrams, that entered the reservoir in a year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Loadings</th>
<th>Loading rate, kg·m⁻³·a⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1,375</td>
<td>2.3</td>
</tr>
<tr>
<td>1974</td>
<td>1,060</td>
<td>1.9</td>
</tr>
<tr>
<td>1975</td>
<td>1,240</td>
<td>2.3</td>
</tr>
<tr>
<td>1976</td>
<td>1,230</td>
<td>2.3</td>
</tr>
<tr>
<td>1977</td>
<td>1,250</td>
<td>2.3</td>
</tr>
<tr>
<td>1978</td>
<td>1,260</td>
<td>2.3</td>
</tr>
<tr>
<td>1979</td>
<td>1,250</td>
<td>2.3</td>
</tr>
<tr>
<td>1980</td>
<td>1,250</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison

### Table 1. Nutrient Loadings, Productivity, and Trophic State of Lake Koocanusa, 1976-80

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Gaged</th>
<th>Ungaged</th>
<th>Loadings, in 1,000s of metric tonnes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>2,452</td>
<td>2,452</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>2,457</td>
<td>2,457</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>2,679</td>
<td>2,679</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>2,678</td>
<td>2,678</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>2,809</td>
<td>2,809</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Total loadings for 1973-80 include annual loadings of 7,411 megagrams from ungaged inflows and 3,671 megagrams from upstream sewage-treatment plant.

### Table 2. Comparison of 1977-78 Loadings of Total Phosphorus (PP) and total nitrogen (TN) at two stations on the St. Mary River, one upstream and one downstream from the fertilizer plant at Kimberley, British Columbia

<table>
<thead>
<tr>
<th>Year</th>
<th>Upstream station</th>
<th>Downstream station</th>
<th>Percentage upstream loading as of downstream loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>6.4</td>
<td>17.9</td>
<td>37.2</td>
</tr>
<tr>
<td>1974</td>
<td>21.5</td>
<td>18.1</td>
<td>119.8</td>
</tr>
<tr>
<td>1975</td>
<td>2.8</td>
<td>10.1</td>
<td>15.6</td>
</tr>
<tr>
<td>1976</td>
<td>10.5</td>
<td>18.4</td>
<td>104.7</td>
</tr>
<tr>
<td>1977</td>
<td>3.8</td>
<td>15.0</td>
<td>187.8</td>
</tr>
<tr>
<td>1978</td>
<td>8.9</td>
<td>11.4</td>
<td>114.1</td>
</tr>
</tbody>
</table>

*Loadings from Iue et al., U.S. Army Corps of Engineers, without comment. (1982).*

The declining trend in total loading that was readily apparent for total phosphorus did not occur for loadings of total nitrogen. During 1976-80, influent loadings of total nitrogen ranged from 2.461 to 4.679 megagrams nitrogen loading was not largely reduced in 1976 (table 8) as was total phosphorus loading. Variations in the loading of total nitrogen were primarily due to variations in loadings of total nitrogen in gaged inflow, because ungaged inflow was estimated as a constant proportion of loadings from the upstream sewage-treatment plant and atmospheric deposition were too small to significantly affect total loading. The loading rate per unit volume of streamflow for total nitrogen showed no definite trend (table 8). Water-pollution-control measures instituted at the fertilizer plant apparently had little effect on the amount of total nitrogen carried per unit volume of streamflow, because loadings of total nitrogen upstream and downstream from the fertilizer plant did not substantially change during 1976-78 (table 8).
INFLOW  TP 314 tonnes/yr   TDP  60 tonnes/yr
INFLOW  TN  2293 tonnes/yr  DIN  1159 tonnes/yr

---

_Nutrient Transport for Koocanusa Inflows and Outflows: a 45-year Comparison_