# Libby Dam Hydro-electric Project Mitigation: Efforts for Downstream Ecosystem Restoration

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## ABSTRACT

Construction of Libby Dam, a large hydropower and flood control dam was completed on the Kootenai River, near Libby, Montana in the Northwestern United States in 1972. Downstream river discharge, thermal regimes, nutrient availability, and dependent habitat conditions and ecological functions have been significantly altered by dam construction and operation. In response to ultraoligotrophic conditions downstream from Libby Dam, experimental additions of phosphate fertilizer solution (ammonium polyphosphate, 10-34-0) at in-river target concentrations of 1.5 an 3 μg/L along with N/P ratios > 15:1 were implemented. A solar-powered nutrient addition system was custom built to dose small releases of dissolved nutrients at rates from 10 to 40 L/hour, depending on river discharge, averaging several hundred $m^3/s$. Positive responses in nutrient availability, primary, and secondary productivity, including biomass, abundance, and species richness were observed following nutrient addition. Data collection and analysis will be ongoing through 2009.

## INTRODUCTION

Libby Dam, the only large project on the upper Kootenay River system, was completed in the United States part of the river, near Libby, Montana in 1972. Current peak power production at the dam is about 525 MW. The Kootenai River, a 5th order river, crosses the Canada/USA border twice on its 776 km route to the Pacific Ocean (Figure 1). The river basin is sufficiently far north that there is a distinct and fairly short growing season for the aquatic food chain. Live reservoir storage is substantial, with water residence time of about 5½ months (based on mean annual discharge of about 440 $m^3/s$). Hydrologic and hydraulic factors that affect the downstream aquatic and floodplain ecology have changed significantly during the post impoundment period.

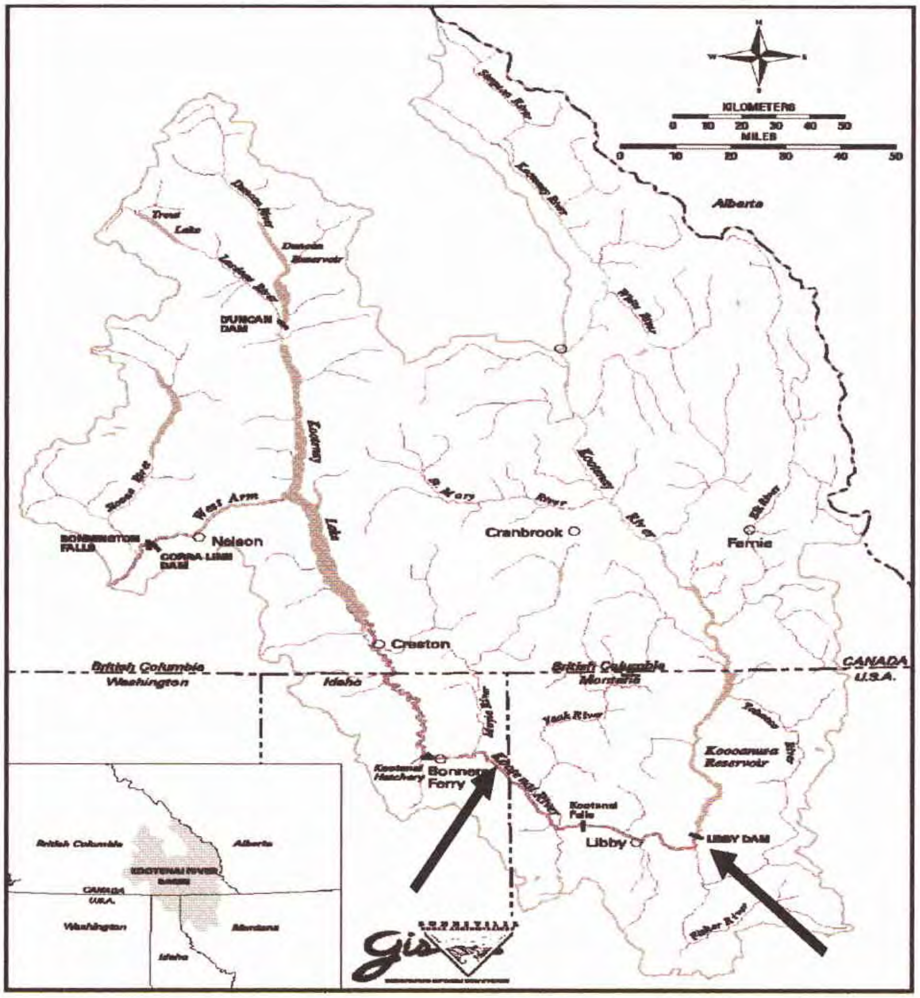

Figure 1. Map of the Kootenai River watershed. Libby Dam and location of reach for fertilization are shown, each with an arrow. Nutrient addition occurs at the Montana/Idaho border.

Highly valued native fish populations in the Kootenai River, including white sturgeon (*Acipenser transmontanus)*, burbot (*Lota lota*), bull trout (*Salvelinus confluentus*) and kokanee salmon (*Oncorhynchus nerka*), and their supporting ecological conditions, have deteriorated during post-dam years. Population declines have been attributed to post-dam hydrograph and thermograph changes, deterioration and loss of in-channel and off-channel habitats, and reduced water quality and nutrient availability.

In response to ultraoligotrophic conditions downstream form Libby Dam, a pilot (mesocosm) project was undertaken in 2002-2003 to evaluate the effects of controlled phosphorus (P) and nitrate (N) addition treatments on primary productivity, and to assess the feasibility of larger-scale experimental river fertilization. Consistent with other ongoing regional nutrient addition programs, additions of P at concentrations in the 3 to 5 µg/L range, along with N/P ratios > 15:1, were very effective at increasing primary productivity. Based on these results the largest experimental river fertilization project to date was initiated in the Kootenai River at the Montana-Idaho border.

## DOWNSTREAM SITUATION POST LIBBY DAM PROJECT

Damming of rivers represents a cataclysmic event for large river-floodplain ecosystems. Impounding large rivers creates a myriad of ecological change across trophic levels. Dams interrupt a river's essential ecological processes by altering the timing, magnitude, and duration of the hydrograph, and sediment, and nutrient dynamics in the river's downstream aquatic, riparian, floodplain, with linkage to surrounding terrestrial environments.

*Physical effects* - Physical effects of Libby Dam on the downstream environment include significant reductions in the largest (flood) flows, increases in low season (winter) discharges, and rapid changes in flow associated with turbine loads at the dam. Although a program of guidelines for ramping flows for turbine shut-downs and turbine start-ups was in place and was enforced, this program was over-ridden sometimes during emergencies. An example of river flows in at a gauging station in the treatment reach (USGS Kootenai River at Leonia) during a pre-impoundment year, and a post impoundment year, both for average snow pack conditions, is shown (Figure 2). The reduction in peak discharge, with a post-impoundment condition about 50% of the pre-impoundment condition, and several-fold increases in winter flows is ecologically dramatic.

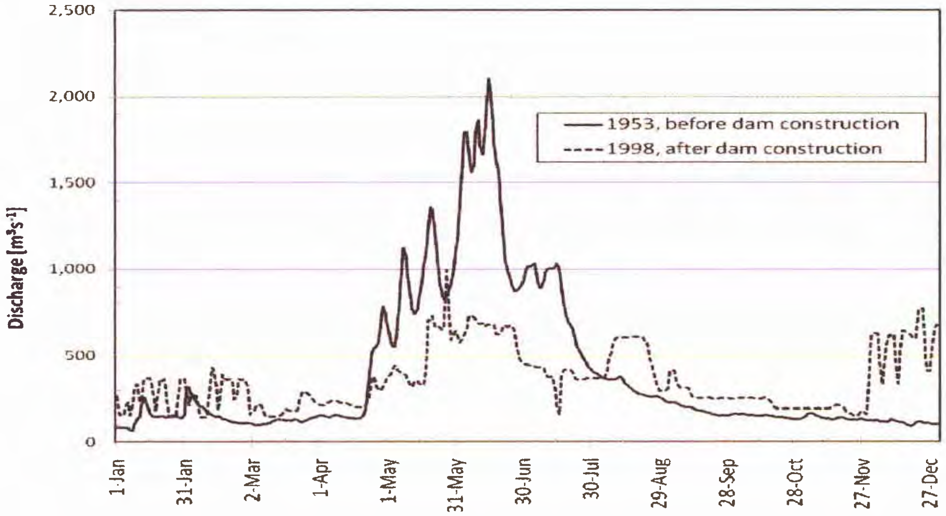

Figure 2. Pre- and post-dam Kootenai River hydrographs in the treatment reach.

Post-dam sediment transport has also been significantly reduced in the river downstream from the dam. The suspended load upstream of the impoundment consists of a wide range of materials, from glacial flour sized material, to all sizes of sand and gravel. The reservoir behind the dam (Lake Koocanusa) is sufficiently long, about 80 km, so that no significant amounts of even the smallest sizes of suspended material appear at the dam outflows. In the study reach downstream from the dam and the Montana/Idaho border, a flow of about 1400 m$^3$/s is required to mobilize gravel on the bed of the river. A flood flow discharge of this magnitude has only occurred once during the 35 year period since dam completion.

*Biological effects* - Lake Koocanusa acts as a nutrient sink, trapping an estimated 63% of total incoming phosphorus (P) and 25% of total incoming nitrogen (N) (Woods 1982). Due to very low current velocities behind the reservoir, these nutrients bind to sediments and fall out of solution (Snyder and Minshall 1996) making them unavailable to organisms in the downstream river. Consequently, the Kootenai River downstream from the dam is now considered "nutrient poor" (ultraoligotrophic) and P-limited (Snyder and Minshall 1996). Lower nutrients render a reduction in food production, which is thought to be a major contributor to poor sportfish production over the past two decades (Snyder and Minshall 1996).

Additional biological effects of Libby Dam construction and operation include reductions in condition and abundance of many native fish and wildlife populations. A recent ecological assessment (KRSBP 2006) estimated that the abundance and productivity of bull trout *(Salvelinus confluentus)* is currently at about 60 percent of what it was historically. The abundance and productivity of Westslope cutthroat trout is currently at about 20 percent of what it was historically. The abundance of Columbia River redband trout is estimated at 10 percent of historic, while kokanee (*Oncorhynchus nerka*) are at about 40 to 50 percent of historic. White sturgeon (*Acipenser transmontanus*) and burbot (*Lota lota*) are both estimated to be at about 0 to 10% of historic.

Numerous factors contributing to fish population declines have been identified, including hydrograph changes, elimination of side channel slough habitats, water temperature changes, water quality for nutrients, and alteration of overall biological productivity (Anders et al. 2002; KRSBP 2006). A very low (ultraoligotrophic) concentration of dissolved phosphorus in the river downstream from Libby Dam was identified as a critical factor limiting primary production and overall ecosystem health.

## NUTRIENT ADDITION

Several ongoing initiatives were implemented during the past decade to improve the ecological condition of the Kootenai River downstream from Libby Dam. Successful increases in primary production have been achieved with the addition of inorganic P and N as a means of restoring altered aquatic ecosystems (Ashley et al. 1999). A large scale nutrient enhancement program was implemented in the North Arm of Kootenay Lake, BC in 1992 to assist the recovery of declining kokanee populations and a collapsing ecosystem. The results of this implementation were significantly increased production at all levels of the food web (Ashley et al. 1999).

A decision was made to initiate the largest experimental river fertilization project to date. The river reach selected for treatment was immediately downstream from the Montana-Idaho border. The reach included an established government gauging station. Pre-treatment aquatic bio-monitoring began in 2001; post-treatment monitoring began in 2005.

Various engineering technologies for nutrient dosing systems at remote sites have been tested in the past (e.g. Ward et al. 1997). For the Kootenai River, a solar-powered nutrient addition system was designed and custom built to consistently dose small releases of dissolved nutrients at low rates, from 10 to 40 L/hour, depending on river discharge. The system (Figures 3 and 4) consisted of nine large storage tanks, about 8000 liters each, spill protected by a heavy duty plastic membrane, a coarse filter, an industrial performance diaphragm pump, a backpressure sustaining valve set at 1.5 bar, an electromagnetic flow monitoring system, a data logger, and a PVC pipeline to the river's edge. The diaphragm pump was selected for its reliability, its flow consistency, and because of extremely low power consumption of only 23 watts at maximum flow. The pump and the flow monitoring system were both solar powered using small solar arrays of peak power 260 W and 130 W respectively, with energy storage in lead acid batteries providing 7 to 10 days of standby power. The flow indicated by the flow monitoring system was independently calibrated using a standard flask, and shown to be within 2% agreement with the actual flow.

Figure 3. Storage Tanks and Protective Berm-Liner for Ammonium PolyPhosphate Nutrient

Figure 4. Assembly of diaphragm pumps and backpressure valves

Dosing of ammonium polyphosphate solution (10-34-0) was scheduled annually for the summer growth period from June 1st to September 30th. The amount was regulated by a U.S. Environmental Protection Agency Permit that specified factors such as the necessary minimum dilution. Daily adjustments by the site operator were made to the dosing flow, following the river hydrograph, in order to keep the in-river dilution at the required value. Information was recorded by the operator concerning the battery state of charge, the flow rates of the river and the dosing flow, and the temperature. Samples of the 10-34-0 solution were sent for analysis periodically, to confirm that the concentration of phosphorus was close to reported specification. The flow information from the data logger showed that the pumped dosing flow was consistent, and stayed within ± 1.5 % of the set daily values for the whole season.

Target in-river P concentrations downstream from the zone of complete mixing were 1.5 µg/L during the first summer season of operation. During subsequent summer periods a P concentration of 3 µg/L was sustained, using a volume of about 50 to 70 thousand liters of 10-34-0 fertilizer, depending on the seasonal run-off.

## MONITORING PROGRAM AND PRELIMINARY RESULTS

Primary productivity and algal accrual rates, along with invertebrate and fish community metrics and conditions, were consistently measured annually, before and after experimental fertilization. Experimental nutrient addition and biomonitoring are expected to continue for an initial 5 year experimental period (2005-2009). Biomonitoring is ongoing and involves periphyton sampling on the river bottom from growth plates, water chemistry analyses, and invertebrate and fish community assessments. Initial results following fertilization showed sharp increases in primary productivity, invertebrate density and richness, and increased fish biomass and condition immediately downstream from the nutrient addition site.

*Nutrients, Algae, Aquatic Insects*— Pre-treatment nutrient concentrations in the Kootenai River were extremely low relative to similar sized rivers. Phosphorus levels (TP) were typically less than 10 µg/L during the growing season, and soluble reactive P (SRP) was usually less than 1 µg/L (Table 1). These values indicate ultra low concentrations unable to support significant biological growth in higher trophic levels of the food web. Nitrogen levels, though low, were adequate for good biological growth.

After the addition of 10-34-0 to achieve a target concentration of 1.5 in 2005 and 3.0 µg/L in 2006 and 2007, neither TP or SRP increased significantly after fertilization. However, total chlorophyll concentration did increase significantly, especially in 2006 and 2007, see Table 1. This indicates that phosphorus was being taken from the water column rapidly by a growing algae community on the substrate of the river. Chlorophyll concentrations (a measure of algae growth, see Figure 5) within the treatment reach increased from a pre-treatment range of 1-5 mg/m$^2$ to 5-12 mg/m$^2$ in the first year of P addition. Chlorophyll then increased to approximately 30 mg/m$^2$ after the fertilization target for P was raised from 1.5 to 3.0 µg/L in 2006. Chlorophyll *a* remained around 30 mg/m$^2$ during the 2007 fertilization effort, with a couple locations peaking over 100 during the height of in-river growing conditions in mid July.

Table 1. Summary of biological and chemical parameters monitored in the Kootenai River, Idaho. Results are from sites within the nutrient addition reach. Fertilizer additions began in 2005.

| | 2004 (Pre) | 2005 | 2006 | 2007 |
|---|---|---|---|---|
| Phosphorus Concentration (ug P/L) | TP: 5-10<br>SRP: < 1 | TP: 6-10<br>SRP: < 1 | TP: 7-10<br>SRP: ~ 1 | TP: 7-10<br>SRP: ~ 1 |
| Chlorophyll Concentration (mg/m$^2$) | 1-5 | 5-12 | 20-40 | 25-40 |
| Aquatic Insects Density (#/m$^2$) | 1000-2000 | 3000-5000 | 7,000-10,000 | 7,000-12,000 |

Aquatic insects responded positively and quickly to phosphorus additions in the Kootenai River (Figure 6). Pre-treatment insect densities typically ranged between one and two thousand individuals per square meter of river bottom, values well below what one would expect for a river of this order. Three months after P additions began in 2005, aquatic insects had increased to nearly 5,000 individuals per square meter, and increased further during 2006 and 2007 to nearly 12,000 per $m^2$ downstream of the nutrient additions.

In summary, the rapid uptake of supplemental phosphorus and corresponding growth in algae and aquatic invertebrates indicated a positive cascade of energy has developed by adding a relatively small amount of nutrient to the Kootenai River. Future phosphorus additions will be needed to ensure biological growth on par for an unimpounded 5th order river at comparable latitudes.

Figure 5. Dried out algal mat shown as a white coloration, following flow reduction

Figure 6. Aquatic insects (stonefly larvae) found under a stone in the Kootenai River.

*Fish Community Assessment*- Up to two-fold increases in total fish density and biomass were observed following fertilization at locations directly downstream from the nutrient addition site. Similar results have been seen in other aquatic inorganic fertilization programs (Slaney et al. 1993; Slavik et al. 2004). A Mountain whitefish (*Prosopium williamsonii*), accounted for nearly all the response, suggesting that insects in their diet are also benefiting from nutrient additions.

In addition to density, mean relative weights (*Wr*) increased for mountain whitefish (from 4.5 to 6%) and largescale suckers (from 10 to12%) in the treated reaches during 2006 and 2007. This is felt to be one of the primary modes of increased fish densities because significant positive correlations between the percentage of mature eggs and fish biomass-Wr have been reported in numerous studies. Mean total length at capture for each age class was higher in treated than untreated reaches during post treatment years (Figure 7). Increased density of mountain whitefish of each sampled age group was highest in treatment locations as compared to the non-treatment sites, suggesting further benefits of nutrient addition. Age 4 whitefish density increased 4-fold at one site following nutrient addition. Although not to this magnitude, an increase in this age class was expected, since this was the first size group fully recruited to the sampling gear (boat electrofishing) following the start of the treatment (2005).

Density of indicator species such as mountain whitefish is expected to increase even more in the future as was seen in the Mesilinka River (200-400 $m^3/s$; Slavik et al. 2004), where a 5 fold increase in resident whitefish populations following several years of nutrient additions was reported.

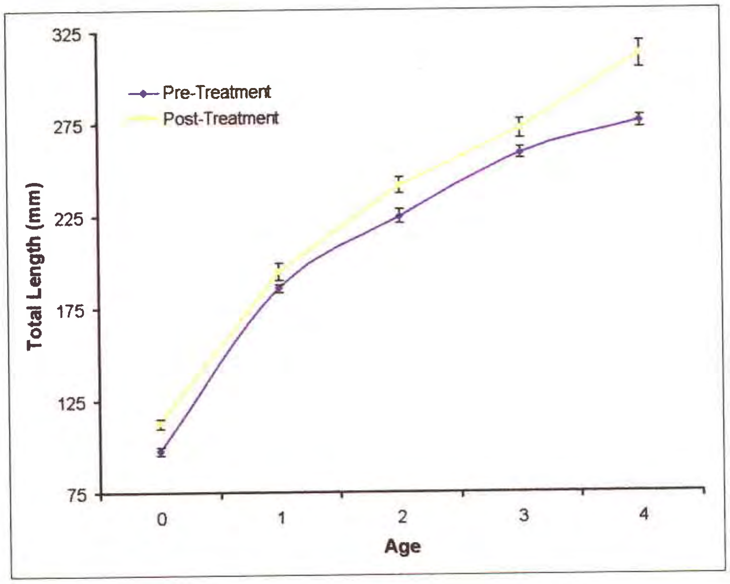

Figure 7. Pre (2002-03) and Post-Treatment (2006-2007) Mountain whitefish total length at capture (September of each year) in the Kootenai River 20 rkm below treatment site.

Although not fully analyzed and still in its initial experimental years, this largest river fertilization program to date is showing promising signs of success as a hydropower mitigation restoration approach. Additional analysis and subsequent treatment is expected to produce additional positive results of larger magnitude.

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