LONG-TERM INFLUENCE OF LIBBY DAM OPERATION ON THE ECOLOGY OF MACROZOOBENTHOS OF THE KOOTENAI RIVER, MONTANA AND IDAHO

REPORT TO

Montana Department of Fish, Wildlife & Parks
Helena, MT

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INTRODUCTION

Background

During the past two decades, the ecological effects of river regulation have received extensive scientific investigation. The theoretical predictions of the Serial Discontinuity Concept (see Ward and Stanford 1983) of regulated rivers have consistently been supported by ecological field studies (Hauer and Stanford 1982, Armitage 1984, Perry et al. 1986, Garcia de Jalon et al. 1988, Rader and Ward 1988, Stanford et al. 1988, Hauer et al. 1989, Hauer and Stanford 1991 and many others). The SDC hypothesizes either upstream or downstream shifts in physical, chemical and biological attributes of a river as functional resets of the River Continuum (sensu Vannote et al. 1980). Studies of regulated rivers have demonstrated changes in riverine algae, aquatic insects and fishes as a result of hydropower on large river systems. Large high-head dams on large rivers, such as Libby Dam on the Kootenai River, significantly alter flow regimes, diel channel flow, current speeds, substrata, nutrients, organic matter resources, and the dynamics of these variables in time and space. Unlike many large dams that have hypolimnial release, Libby Dam has a selective withdrawal system which allows dam operators to mimic the natural annual temperature regime in the dam discharge.

The ecological consequences of these biophysical alterations are manifold; affecting virtually all aspects of the river’s biota. Usually, hydropower regulation creates a broad expanse of river channel between maximum and minimum dam discharge that often may experience diel or day to day inundation and dewatering. This area, called the variational zone (see Stanford and Ward 1992), is dependent on local river channel morphometry and dam discharge flows and schedules (Jourdonnais and Hauer 1993). Frequently, the variational zone of 5th to 6th order regulated rivers may be as narrow as 5 - 10 m along steep sided banks and >100 m in less confined reaches.
Zoobenthos in dam tail waters can only inhabit that portion of the channel that has remained inundated for the past 3-5 weeks. Studies of colonization rates show that typically several weeks are required for benthic organisms to invade newly wetted habitat and approach an equilibrium of community composition (Thorp et al. 1985, Fuchs and Statzner 1990). Thus, the varial zone of regulated rivers is often devoid of benthic organisms, particularly when there has been frequent flow fluctuation. There may also be significant mortality of zoobenthic organisms because of stranding if flows have remained high in dam tail water for an extended period, permitting colonization, followed by rapid decrease in discharge (Corrarino and Brusven 1983, Fisher and LaVoy 1972, Perry and Perry 1986).

Water arrives in a catchment with the potential to do work. It carves across bedrock and carries material downstream. The resistance to being moved downstream is a function of the shape, size and mass of the object that is being encountered by the force of the water. As flow increases and decreases with change in flow, both the velocity of the water and its ability to move material or organisms residing in the river also changes. The ability of the water to move material is measured as force which is proportional to the mass of the object being moved and the acceleration of that object. The force moving material parallel to the bed surface is referred to as shear force.

Water does not flow uniformly, either across a stream channel or at different depths over the stream bed. For example, velocity of the water is greater several feet above the stream bed than directly on the stream bed. This is the result of the viscous properties of water and the dynamics of fluid flow over a solid surface. Viscous properties of water establish a boundary layer near the object that is stationary forming a microenvironment that is inhabited by the macroinvertebrates that are the focus of this study. The patterns of flow within the microenvironment of the boundary layer are an important component of the physical habitat. Dead-water zones are created on the
downstream sides of cobble and boulders. Likewise, flow patterns on exposed surfaces can influence the behavior of benthic organisms clinging to those surfaces (e.g., blackflies; Craig and Galloway 1987).

It was long believed that the body shapes of lotic zoobenthos were well adapted to minimize forces of flow (Hynes 1975). However, more recent studies in stream ecology have demonstrated the important role of stream hydraulics in the distribution and abundance of lotic organisms (Statzner et al. 1988). The hydraulic environment constrains and influences benthic insects through various stresses like turbulence and near-bottom shear stress. Changing flow regimes and current velocities have long been known to affect rates of zoobenthos drift (Perry 1984); however, discharge patterns, that vary dramatically in regulated streams, also result in rapidly varying hydraulic forces and change in spatial distribution of microhabitat. Frequent changes in hydraulic shear stress at the microhabitat level has been shown to negatively influence zoobenthos populations (see Statzner et al. 1988 for review).

River regulation by high-head hydroelectric dams exert profound perturbative forces on the downstream riverine environment. These influences manifest throughout the riverine zoobenthic community affecting spatial and temporal distributions, behavior, productivity, reproductive success, and many other important population variables. Thus, it is clear that regulated river systems and their associated ecological problems must be approached from a holistic, ecosystem perspective (Stanford and Hauer 1992) to affect long-term management solutions.

Rationale for Research below Libby Dam

Discharge patterns of dams throughout the Columbia River Basin have changed significantly as the total storage capacity in the Columbia hydropower dams have increased in number during the past 80 years (see Stanford and Hauer 1992 and Stanford et al. 1996). Along with other factors related to the interconnected
electrical energy network of the Northwest Power Pool (see Jourdonnais and Hauer 1993), increased storage capacity in US and Canadian reservoirs has directly affected the annual cycle and variable discharge patterns from Libby Dam. More recently, flows designed to mitigate the losses of salmon in the Lower Columbia have also affected the timing of annual discharge. These factors have a direct bearing on tail water benthic insects and thus food web support of fish populations in the Kootenai River below Libby Dam.

A recent synthesis of river regulation in the Flathead Basin illustrated the stochastic nature of discharge patterns from hydroelectric dams and the resulting significant ecological impact on riverine fauna (Stanford and Hauer 1992). Likewise, Perry (1984) reported that rapid fluctuations in discharge from Libby Dam resulted in significant changes in the rates of drift and stranding of zoobenthic organisms. Similar observations have been made by other researchers working on hydroelectric facilities throughout the Northern Rockies (e.g., Hungry Horse, Dworshak).

Although detailed analyses of the effects of river regulation due to Libby Dam on selected biophysical variables of the Kootenai River were completed in the early 1980s (Perry and Huston 1983, Perry 1984, Perry and Perry 1986, Perry et al 1986), we do not know what the long-term effects of Libby Dam operations have been as tail water populations reach a quasi-equilibrium in the face of short-term annual disparities in flow regimes. Likewise, there remains uncertainty regarding effects of recent changes in flow regimes compared with those occurring during the studies by Perry (see Appendix A to compare Kootenai River flows in 1979-80 and 1994-95).

The purpose of this study was two fold: 1) to determine the effect of seasonal variation in hydropower operations on the zoobenthos of the Kootenai River, and 2) to directly compare, where possible, changes in benthic species diversity and density that may have occurred between an earlier study (1979-80) and contemporary conditions (1994-95).
Study Area

The Kootenai River at the Montana-Idaho border drains approximately 11,740 sq. mi. (30,419 km²) of the Rocky Mountains in British Columbia and Montana and has an average annual discharge of 13,900 cfs (394 cms). Glaciation and the porous nature of the sedimentary bedrock have greatly influenced basin and channel morphology. The headwaters of the Kootenai River in British Columbia consist primarily of the main fork of the Kootenai River and the Elk River. The landscape in each of these major drainages is dominated by coniferous vegetation. The entire flow of the Kootenai River is impounded by Libby Dam, located approximately 5.7 km [3.4 mi] upstream of the Fisher River and =25 km [15 mi] upstream of the town of Libby, MT. Additional side tributaries of the Kootenai River in Montana below Libby Dam include the Fisher River (838 sq. mi. [2171 km²]; 485 average cfs [13.7 cms]) and the Yaak River (766 sq. mi. [1985 km²]; 888 average cfs [25 cms]).

Five sampling sites were located along the longitudinal gradient of the river system from Libby Dam to Bonners Ferry, Idaho (Figure 1). Sampling Station 1 (DUN) was =3 km [=2 mi.] downstream of the dam at the Dunn Creek river access site. Sampling Station 2 (ELK) was near the Elkhorn RV campground and resort, =18km [=11mi.] downstream of Libby Dam. The third sampling location (PIP) was down river from the town of Libby, and just upstream of the mouth of Pipe Creek, =35km [=21 mi.] downstream of the dam. Each of these sites were approximately the same sampling locations used in a study conducted by Montana Fish, Wildlife and Parks (MFWP) in 1979-80 (see Perry and Huston 1983, Perry 1984, and Perry et al 1986). Station 4 (KOA) was =30 km [18 mi] down river from Station 3 and immediately upstream of the US Highway 2 bridge that crosses the Kootenai River =5km [3 mi] downstream of Troy MT at a KOA campground. Finally, Station 5 (CPT) was =50 km [30 mi] down river
Figure 1. Map of the Kootenai River between Libby Dam and Bonners Ferry showing the locations of major tributary streams and the five study sites.
from Station 4 and =5km [3 mi] upstream from Bonners Ferry ID, near the area known locally as Crossport.

Study Design

In cooperation with the Libby Field Station of the MFWP, we selected 3 sampling dates that corresponded to three distinctly different flow fluctuation types. During late spring and early summer 1994, the Kootenai River was maintained at a discharge of =20,000 cfs as part of experimental flow augmentation for endangered Kootenai River white sturgeon (D. Skarr and S. Dalby pers. comm.). At the end of the "sturgeon flow" period in July, Libby Dam was ramped down to =12,000 cfs and then a few days later to =4,000 cfs. We sampled for stranding of benthic organisms and drift along the longitudinal gradient of the river over a 36 hr period (94/VII/10 and 94/VII/11) as the 4,000 cfs discharge reached each site. Because of the very high density of stranded insects, the extended time necessary to sample each site, and the necessity to sample stranded and drifting insects at each site as 4000 cfs discharge was achieved in the river, after collecting samples of stranded benthic insects and benthic drift at all stations, we returned to each site (94/VII/15) and sampled zoobenthos.

During late-July, August and most of September the discharge from Libby Dam was regulated at a constant 4,000 cfs. In late September, hydropower operations initiated a four-month-long period of flow fluctuation in which discharge varied between 4,000 and 20,000 cfs. Flow fluctuations occurred abruptly, both with increasing and decreasing flow. We sampled in mid-October 1994 (94/X/15 and 94/X/16) after two high to low discharge cycles. As in July, we sampled when the discharge declined to =4,000 cfs at each site. However, unlike July when we sampled stranded insects and benthic drift at each site and then returned to sample channel zoobenthos, in October we were able to collect channel benthic samples along with the stranding and drift samples as we progressed along the river gradient. We were
able to complete all sampling within the two days because of far fewer stranded insects and thus less time needed for their sampling.

The next sampling date in mid-April 1995 (95/IV/6) corresponded to a lengthy period of stable flow at 4,000 cfs. This stable flow period in late winter and early spring followed a period of extensive flow fluctuation in fall and early winter. We completed all sampling at each site in one day because of no stranding.

River Discharge and Calculations of Shear Stress

River discharge data were obtained from USGS records for the Kootenai River at Libby, MT (USGS Station Number 12303000) and the Kootenai River below Libby Dam (USGS Station Number 12301933). Data are expressed as daily average river discharge in cubic feet per second (cfs).

Data for calculating change in bottom shear-stress were derived from channel cross-section and velocity data provided by the MFWP. The velocity profile pattern of a fluid moving above a solid surface is a function of the universal velocity-distribution law. The equation describing this law is of the form:

\[ \frac{v}{V^*} = \frac{1}{k} \ln \left( \frac{yV^*}{v} \right) + B \]  

(1)

where \( v \) is the velocity (m/s) as it varies with distance \( y \) (m) away from a solid surface. \( V^* \) is the shear velocity (m/s), which is the square root of the shear stress divided by fluid density. Thus, the velocity profile permits the calculation of shear velocity (\( V^* \)) at the boundary layer based on water velocity and depth of water flowing above the bed surface. Based on shear velocity estimates one can calculate shear stress (\( \tau_0 \)) acting on the surface of the bed sediments and benthic organisms (N/m²), where \( N = \) newtons, employing the following formula:
\[ \tau_0 = \rho (V^*)^2 \]  
\[ (2) \]

where \( \rho \) is the density of the water and

\[ V^* = \frac{b}{5.75} \]  
\[ (3) \]

and where \( b \) is equal to the slope of the regression line fitted to the relationship between velocity and \( \log \) (depth).

Shear stress can also be estimated for the entire channel at different discharge levels. At different discharges the critical shear stress \( (\tau_c) \) is given as:

\[ \tau_c = \rho gRS \]  
\[ (4) \]

where \( \rho \) is the density of the water, \( g \) is equal to the acceleration due to gravity, \( R \) is the hydraulic radius of the river channel at the given discharge and \( S \) is the slope of the river channel.

In deriving an equation for critical shear stress it is assumed that when a particle is about to move out of the bed sediments the shear force acting to overturn it is balanced with the submerged weight of the particle, which holds it in place (Gordon et al 1993). By equating the two forces at the threshold of movement, an equation for critical shear stress necessary to move particles of various sizes can be obtained:

\[ \tau_c = \Theta_c gd (\rho_s - \rho) \]  
\[ (5) \]

where \( d \) is the particle size in meters, \( \rho_s \) and \( \rho \) are particle and water densities, respectively, \( g \) is equal to the acceleration due to gravity, and \( \Theta_c \) is a dimensionless constant that is a function of particle shape, fluid properties, and the arrangement of
the particles. In this study we used a $\Theta_c$ equal to 0.04 which is standard for mixed bed sediments that are settled in a fairly random grain arrangement. Thus, it was possible to estimate the size of particles which would be entrained at different flow regimes based on the calculation of $d$ in formula (5) if critical shear stress ($T_c$) is calculated as given in formula (4).

**Field and Laboratory Methods**

Benthic macroinvertebrates were sampled at each of the sampling sites on three dates corresponding to the distinctly different seasons and hydrographic regimes from hydropower operations. Sampling was initiated for each sample date at Station 1 within 1-2 hrs after 4,000 cfs had been achieved at the dam. This permitted the low flow discharge to reach equilibrium at the site. We sequenced our sampling to begin at Site 1 and finish at Site 5 and to arrive at each site, as near as possible, as to the time of achieving low flow discharge. Benthic macroinvertebrates were sampled in riffle areas at each site using a modified kick-net technique developed by Hauer (1980), and also used by Perry (1984) on both the Flathead and Kootenai Rivers. By using the same sampling technique and gear made it possible to make direct comparison of abundance data collected in the 1979 - 1981 study with results from this study.

Five replicate 0.36 m$^2$ plots were sampled at each site. Samples were field preserved in 95 percent ethanol. Upon return to the laboratory, samples were rinsed onto a metal mesh sieve with a mesh size $\leq$150 µm. Samples were fractionated to appropriate subsample sizes dependent on macroinvertebrate density. All picked and sorted organisms were identified to the lowest practical taxon, usually the species level except for Chironomidae and Simuliidae, which were identified to the family level. Organisms were examined using Wild M5 dissecting microscopes at 6X to 50X magnification. Taxonomic keys by Merritt and Cummins (1984), Jensen (1966),
Stewart and Stark (1988), and Wiggins (1977), as well as several other original manuscripts where necessary (e.g., Jensen 1966, Morihara and McCafferty 1979), were used for identification.

Insect drift samples were collected at each sample site and date. Drift was collected with two nets measuring 30cm x 49.5cm across the opening. These were the same nets used by Perry and Perry (1986). The drift nets were constructed of nitex measuring 3550 µm per 10 meshes with a nominal mesh size opening of 125 µm. Drift nets were placed perpendicular to the river flow. Nets were allowed to continuously sample for 30 to 70 minutes depending on flow regime and rate of drift material accumulated. Current velocity was measured for a 1 minute interval with a standard Gurley meter. The total volume of water sampled by the drift nets was calculated as CV x A x T = V; where

- \( CV \) = current velocity
- \( A \) = area of the drift net opening
- \( T \) = total time the drift net was deployed
- \( V \) = total volume of water sampled

Drift samples were placed in separate containers, preserved with 95% ETOH to an approximate final concentration of 70%, and returned to the laboratory. Organisms collected in the drift nets were enumerated and identified using the same laboratory techniques as previously described for benthic samples.

Stranded organisms were collected by using a 50cm x 50cm grid placed on the channel substratum of the recently dewatered varial zone. The varial zone was separated into 3 equal sections from the recent high-water edge to the current water edge. Subzones were labeled A, B and C going from farthest from the river to nearest to the river. Five samples were collected from each subzone. Stranded organisms
were collected directly into vials containing 70% ETOH. All stranded organisms were later enumerated and identified using the same laboratory techniques as previously described for benthic and drift samples.

**RESULTS**

*Hydrologic Regime*

Discharge in the Kootenai River below Libby Dam has been significantly altered by hydropower operations since 1972. The natural pattern of discharge in streams and rivers of southeastern British Columbia and northwestern Montana has been referred to as Rocky Mountain snow melt dominated (Poff and Ward 1989). The large, unregulated rivers of western Montana tend to achieve a maximum annual discharge during May and June that may exceed 10 to 100X mean low flow; although most extreme flooding events during the past century have occurred during late May and early June as a consequence of "rain on snow" events (Hauer 1991). In Appendix A, daily mean discharge is presented for the Kootenai River at Libby (Water Years 1952 through 1971) and the Kootenai River below Libby Dam (Water Years 1972 through 1995).

We analyzed the flow regimes for these two contrasting periods; WY 1952 through 1971 representing the pre-dam natural flows and WY 1975 through 1995 as the post-dam flow regime. We did not include WY 1972 through 1974 as the reservoir was filling. In Figures 2 through 6, we illustrate the significant changes that have occurred in the flow regime of the Kootenai River that are a direct result of river regulation. Prior to 1972 the average annual discharge pattern (Figure 2A) had a typical Rocky Mountain snow melt dominated hydrographic pattern. However, as is
Figure 2. Mean daily discharge (± 1 std dev) of the Kootenai River at Libby MT. Water Year 1952 through 1971 (Panel A) and below Libby Dam from Water Year 1975 through 1995 (Panel B).
apparent in Figure 2B, since 1975 both the annual pattern of discharge and the
variability in discharge has been significantly altered. No longer does the Kootenai
River have an annual snow melt runoff pattern. Mean daily discharge generally
remained less than 20,000 cfs throughout each year with lowest discharge in April,
May, June and July; the time period of highest flow prior to dam operation. Libby Dam
operations have also resulted in significant alteration in the annual pattern of day-to-
day changes in mean daily flow (Figure 3). Prior to Libby Dam mean daily change in
river discharge varied little from early August through March of each year (Figure 3A).
Beginning in April of each year (see illustrations in Appendix A) discharge generally
increased into May and June. River discharge then generally decreased during late
June and into July. Mean daily change in discharge of as much as 3,000 to 4,000 cfs
on the rising limb of the hydrograph and decrease of 2,000 cfs on the falling limb were
typical (Figure 3A). However since 1975, the mean daily change in discharge has
become far more widely scattered (Figure 3B). Note that the width in the pattern of this
variable is most diverse and unpredictable from August through February, virtually the
opposite of the natural regime.

The significant alteration in the pattern of discharge as a result of Libby Dam
operation is also dramatically seen in comparison of the range in daily change for
each date over the pre-dam and post-dam comparison years. Prior to dam operation
the range in daily change in discharge was narrow from August through March with
increased range of change during runoff (Figure 4A). However, after the construction
of Libby Dam the range of daily change in discharge has been extremely wide
throughout the entire year with the exception of during the time period when it is
natural for the river to be experiencing greatest change (Figure 4B: e.g., April, May and
June).

Alteration from the natural discharge pattern in the Kootenai River can also be
seen through analysis of the mean daily percent change in discharge. This variable is
Figure 3. Mean daily change in discharge of the Kootenai River from Water Year 1952 through 1971 (Panel A) and below Libby Dam from Water Year 1975 through 1995 (Panel B).
Figure 4. Range in daily change in discharge of the Kootenai River from Water Year 1952 through 1971 (Panel A) and below Libby Dam from Water Year 1975 through 1995 (Panel B).
a measure of the percent change in discharge from one day to the next with the prior day as the discharge of reference. For example, if the river has a discharge on Day 1 of 10,000 cfs and then increases to 20,000 cfs on Day 2, this represents a 100% increase in discharge. However, if the river on Day 3 returns to 10,000 cfs, this represents a 50% decrease in discharge. Thus, with the first day as the reference on may observe a positive percent change >100%, but a river can only decrease by <100%.

Prior to dam operation the twenty year mean daily percent change in discharge remained less than ± 10% throughout the year (Figure 5A), even during runoff. Although the value of change may have been high, this generally occurred when discharge was already high, thus the percent change would remain relatively low. However since dam operations, the mean daily percent change has been widely scattered throughout the year, but particularly from October through March (Figure 5B), with a range from = 40% to = -20%. This is even more dramatically seen in comparison of the range in the daily % change in discharge (Figure 6). During the twenty years prior to dam operation the daily change in discharge never changed on any two consecutive dates by more than 100% (Figure 6A). However, during the past twenty years the maximum positive change in discharge for consecutive dates was frequently more than 300% (Figure 6B). Likewise, the negative range in daily percent change in discharge was never more than 40% and generally <10% prior to dam operation. However, during the past twenty years negative range in daily percent change in discharge frequently approaches 80% throughout the year.

Although these analysis provide a clear contrast between pre- and post-dam Kootenai River hydrographic patterns, examination of the daily variance and range in discharge illustrates how radically the Kootenai is fluctuated (Figure 7). Generally, USGS data are only available for mean daily discharge; however, hourly means are available for a short time after the water year ends. We obtained hourly mean
Figure 5. Mean daily percent change in discharge of the Kootenai River from Water Year 1952 through 1971 (Panel A) and below Libby Dam from Water Year 1975 through 1995 (Panel B).
Figure 6. Range in daily percent change in discharge of the Kootenai River from Water Year 1952 through 1971 (Panel A) and below Libby Dam from Water Year 1975 through 1995 (Panel B).
Figure 7. Daily range (Panel A) in discharge and variance (Panel B) of hourly mean discharge (cfs) in the Kootenai River below Libby Dam during Water Year 1995.
discharge data for Water Year 1995. These data clearly demonstrate that during any one year the Kootenai River has been subject not only to wide day-to-day change in discharge, but to changes of as much as 16,000 cfs from one time of day to another. This is particularly significant since generally this occurred as discharge fluctuated between 20,000 and 4,000 cfs.

*Change in River Discharge and Effects on Shear Stress*

As river discharge changes the fluid mechanics and tractive forces acting as shear stress on bed sediments and benthic organisms also changes. We calculated the change in shear stress at or near the thalweg and across the river channel using data provided by MFWP. These data contained four cross sectional profiles just down stream from our Study Site 1. Cross sectional data (XS582, XS1638, XS3209, and XS4426) included profile position and depth at position. Data for each cross section included current velocities at four discharge levels; 4000 cfs, 9000 cfs, 15000 cfs and 30000 cfs (Figures 8, 9, 10 and 11).

Table 1 shows the change in estimated shear velocity ($V^*$) and shear stress ($\tau_0$) at different discharge regimes and thalweg velocities. As discharge increases from 4000 cfs to 30000 cfs there is a significant increase in thalweg and shear velocity. These increased velocities result in $\approx 10X$ increase in shear stress or this range in discharge. Likewise, whole channel calculation of critical shear stress ($\tau_c$) shows an increase between 4000 and 30,000 cfs (Table 2) of $\approx 2X$ and a similar increase in the threshold size of particles that would be either moved (sizes below threshold) or entrained (sizes larger than threshold). Data presented in both tables illustrate the significant change in shear stress associated with change in discharge across a range typical of diel discharge flux in the Kootenai River below Libby Dam. Note that whole channel critical shear stress given in Table 2 is based on the average channel slope.
Figure 8. Cross section profile (Top Panel) and current velocities (Lower Panel) at four different discharges at cross section 582 on the Kootenai River below Libby Dam. Data provided by Montana Department of Fish Wildlife and Parks.
Figure 9. Cross section profile (Top Panel) and current velocities (Lower Panel) at four different discharges at cross section 1639 on the Kootenai River below Libby Dam. Data provided by Montana Department of Fish Wildlife and Parks.
Figure 10. Cross section profile (Top Panel) and current velocities (Lower Panel) at four different discharges at cross section 3209 on the Kootenai River below Libby Dam. Data provided by Montana Department of Fish Wildlife and Parks.
Figure 11. Cross section profile (Top Panel) and current velocities (Lower Panel) at four different discharges at cross section 4426 on the Kootenai River below Libby Dam. Data provided by Montana Department of Fish Wildlife and Parks.
Table 1. Shear velocity ($V^*$) and shear stress ($\tau_0$) near the river thalweg associated with changes in discharge in the Kootenai River below Libby Dam, Montana.

<table>
<thead>
<tr>
<th>River Discharge</th>
<th>Thalweg Vel. (m/s)</th>
<th>Velocity profile slope</th>
<th>$V^*$ (m/s)</th>
<th>$\tau_0$ (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>XS 582</td>
<td></td>
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<td></td>
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<tr>
<td>4000 cfs</td>
<td>1.8</td>
<td>0.249</td>
<td>0.043</td>
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<td>9000 cfs</td>
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<td>0.394</td>
<td>0.069</td>
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<td>0.130</td>
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<td>XS 1638</td>
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<td>0.062</td>
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<td>XS 4426</td>
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<tr>
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<td>6.8</td>
<td>0.905</td>
<td>0.157</td>
<td>24.75</td>
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Table 2. Whole channel width estimated change in critical shear stress ($\tau_c$) and size of particle entrainment (diameter in mm) associated with changes in discharge in the Kootenai River below Libby Dam, Montana.

<table>
<thead>
<tr>
<th>Cross section</th>
<th>4000 cfs</th>
<th>9000 cfs</th>
<th>15000 cfs</th>
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between Libby Dam and Libby MT, USGS Gauging Stations 12301933 and 12303000 (Δ elevation 17.8m [58.5ft]; distance 26.9km [16.7 miles]). We measured channel slope at Stations 1, 2 and 3 with a laser level (Lieca TC600 Total Station) to verify this as an approximate Kootenai River channel slope. Our results agreed closely with those of the USGS. Surface bed sediments in the Kootenai River are generally between 100 and 300 mm. Thus, typical discharge from Libby Dam is not capable of moving the typical particle sizes encountered in the river.

River Channel Zoobenthos

The macrozoobenthic community was dominated at each sampling site by the aquatic insect orders Ephemeroptera, Plecoptera, Trichoptera, and Diptera. However, response to river regulation within these aquatic insect orders was very species-specific.

Ephemeroptera

Several species of mayflies were common in the Kootenai River downstream of Libby Dam, each responding to river regulation in distinctive species-specific ways. The most commonly occurring mayfly species were *Baetis tricaudatus*, and the three ephemerellids, *Drunella flavilinea, Serratella tibialis*, and *Ephemerella inermis* (Figure 12). Baetids are small fast swimming larvae that move rapidly between resting surfaces. In the Kootenai River these resting surfaces are primarily on and between the large cobble substrata. These larvae are known to be primarily collector/gatherers (sensu Merritt and Cummins 1996) that feed on detritus and diatoms. *Baetis* nymphs were most abundant at Station 1 (DUN) in July and April, when > 6,000 and > 3000 individuals m⁻² were collected, respectively. Many of the *Baetis* nymphs were very small in July. Perry and Huston (1983), sampling with nearly monthly frequency, concluded that *Baetis tricaudatus* was most likely multivoltine (i.e., more than one
Figure 12. Density of four dominant species of mayfly nymphs (*Baetis tricaudatus*, *Drunella flavilinea*, *Serratella tibialis*, and *Ephemerella inermis*) in the Kootenai River below Libby Dam at each of the study sample sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOA), and Site 5 (CPT).
generation per year) in the Kootenai River. We agree with their conclusion that the multivoltine life history of *Baetis* may, at least partially, account for the relatively high density of this species and its apparent ability to adapt to the most rapidly fluctuating flow regimes (Site 1) found nearest the dam.

*Drunella flavilinea* are relatively robust nymphs that feed by scraping rock surfaces for diatoms and other components of the biofilm. *Drunella* nymphs rarely swim, but rather generally cling to the substratum and crawl from one boulder to another as they feed. *Drunella*, like other ephemerellids, in the large rubble bottom rivers of the northern Rocky Mountains are found most prevalently within the interstitial spaces of the substratum where individual cobble are >10cm diameter and there is little fine material, such as sand and small gravel, filling the space between rocks. *D. flavilinea* nymphs were collected all five sampling sites, but were most abundant at Stations 2, 3, and 4, where densities were typically between 200 - 400 m⁻² (Figure 12) except during the autumn collection. During October we did not collect any *Drunella* nymphs from any site; however, the absence of nymphs was almost certainly the result of the life history of the species in which adults emerge in the mid to late summer and nymphs do not reappear in the river until winter.

*Serratella tibialis* nymphs were very abundant at Stations 2, 3, 4, and 5 where densities ranged from 700 - 1800 m⁻². However, note that *Serratella* were only present during the summer (Figure 12). As in the case of *Drunella, S. tibialis* were not present other times of the year because of their life history cycles. We found *Ephemerella inermis* to be relatively abundant in the Kootenai River; densities were often >500 m⁻² and even > 1600 m⁻² during April at Station 1 (Figure 12). Both *Serratella* and *Ephemerella* nymphs are lighter bodied than *Drunella*; however, like *Drunella*, they primarily exist as clingers to rock surfaces, are dependent on interstitial space within the substratum, and feed as collector/gatherers on algae and detritus (Merritt and Cummins 1996).
Plecoptera

Stoneflies are an exceedingly important part of the benthic communities of most unregulated streams and rivers of the Northern Rocky Mountains. Over 42 species occur in the mainstem Flathead River in spite of its being partially regulated by Hungry Horse Dam on the South Fork. (Stanford 1975). Stoneflies also tend to compose a significant portion of zoobenthic biomass and species frequency distributions. For example, in the unregulated segments of the Flathead River system, Plecoptera nymphs often compose > 30% of the total numbers of insect larvae and up to 50% of the biomass (Stanford 1975, Hauer et al. 1994). All stonefly species tended to be least abundant at Site 1.

The most commonly occurring stonefly species during this study on the Kootenai River were Pteronacys californica, Taenionema pacificum, Classenia sabulosa, and Hesperperla pacifica (Figure 13). Interestingly, Sweltsa coloradensis was the most commonly occurring stonefly nymph collected by Perry (1984), although density was generally <20 m⁻². In contrast, although we did collect Sweltsa nymphs from each site on at least one of the sampling dates, most samples contained no Sweltsa nymphs. The highest sample mean for any site on any date was 8 m⁻² at Site 5 in July.

Although Pteronarcys nymphs were not collected during any season at Site 1 (DUN), yet they were relatively common (15 - 30 m⁻²) at the other four sampling sites during July and October (Figure 13). Density of Pteronarcys nymphs during April, however, was very low, <2 m⁻² at all sites. Pteronacys californica is one of the largest stonefly nymphs with a semi-voltine life history (i.e. requiring more than one year to complete a life cycle). The nymphs are primarily detritivores, feeding extensively as shredders on leaf litter (Merritt and Cummins 1996), but also known to feed on large particles of sloughed algae that may be trapped in the interstitial spaces of the rubble substratum. In many Rocky Mountain streams Pteronacys californica nymphs and
Figure 13. Density of four dominant species of stonefly nymphs (*Pteronarcyis californica*, *Taenionema pacificum*, *Claassenia sabulosa*, and *Hesperoperla pacifica*) in the Kootenai River below Libby Dam at each of the study sample sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOA), and Site 5 (CPT).
adults (locally known as salmon flies) are extremely important components of trophic support for trout fisheries.  

*Taenionema* nymphs are much smaller than *Pteronarcys*, and similarly were not collected at Station 1 on the Kootenai River (Figure 13). Also *Taenionema* nymphs were only collected during the autumn and spring, corresponding to their life history in which they appear as early instar nymphs in the fall, grow throughout the winter and spring months and emerge as adults from the river during late spring as river temperatures warm (Stanford 1975). The density of *Taenionema* nymphs was highest at Station 4 (KOA) and Station 5 (CPT) during the fall where densities reached nearly 80 m\(^{-2}\) and 40 m\(^{-2}\) at the two sites, respectively. *Taenionema* generally feed as collector/gatherers of detritus or sloughed algal matter rather than as grazers of periphyton (Merritt and Cummins 1996). Sloughed algae may be more abundant at the lower sampling sites as predicted by the SDC (Ward and Stanford 1983); although we did not attempt to quantify sloughed algae as a potential food source in the river.

Both *Classenia* and *Hesperoperla* are very large, semi-voltine nymphs that are predators primarily on mayfly nymphs and dipteran larvae. *Classenia* nymphs were far more abundant than *Hesperoperla*, however, neither were very abundant at Stations 1 or 2. Furthermore, density of both perlids only exceeded 10 m\(^{-2}\) during the July and October samplings (Figure 13).

**Trichoptera**

Three taxa of caddisfly larvae were very common in the Kootenai River below Libby Dam during this study; *Hydropsyche occidentalis*, *Hydropsyche cockerelli*, and *Cheumatopsyche spp.* Hydropsychid larvae build a small retreat made of pieces of vegetation and gravel glued together with silk. The retreat is permanently attached to the surface of the rubble substratum making the larvae relatively sessile. At the
opening of the retreat the larvae also spins a silk capture net that has a very specific size and net-mesh. Hydropsyche cockerelli tends to spin a slightly larger net than H. occidentalis, which in turn spins a slightly larger mesh net than Cheumatopsyche. The different size nets, as well as different responses to both temperature regimes and effects of hydropower regulation, result in significantly different patterns of distribution and abundance along the longitudinal gradient of the river from Libby Dam to Bonners Ferry. Similar large-scale distribution patterns have been observed elsewhere in western Montana (Hauer and Stanford 1982, Stanford et al. 1988).

H. cockerelli larvae generally appeared in highest density and across all sampling dates at Station 1 (DUN). Larval density during summer, fall and early spring just below the dam remained high (> 400 m⁻², see Figure 14). H. occidentalis larvae were most abundant at Stations 2, 3, and 4 during the summer and fall, while Cheumatopsyche sp. larvae were most abundant at Stations 4 and 5, again during the summer and fall. The very low density of Hydropsychid larvae during the spring likely relates to the flow regime as a consequence of hydropower operations and is addressed below in the discussion section.

Although the Hydropsychids were numerically the dominant caddisfly group in the Kootenai River throughout this study, other species occurred at densities that make them a significant component of the benthic community. Brachycentrus sp. larvae occurred commonly during the July and October sampling dates at all sites, but were most abundant at Site 3 (PIP). We also collected Hydroptila sp. larvae (microcaddis), most frequently at Sites 1 and 2. Hydroptila generally feed by piercing cells of attached filamentous green algae (Merritt and Cummins 1996), which was common on rock surfaces at these sites. Ceraclea sp. larvae, like Hydroptila generally feed on periphyton, but are dissimilar since they are primarily grazers. Ceraclea larvae were most abundant during October at Sites 2 and 3 where mean densities were 92 and 52 m⁻², respectively. Rhyacophila spp. larvae are a common predator in unregulated
Figure 14. Density of three dominant species of net-spinning caddisfly larvae (*Hydropsyche cockerelli, Hydropsyche occidentalis, and Chaumatopsycha sp.*) in the Kootenai River below Libby Dam at each of the study sample sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOA), and Site 5 (CPT).
large rivers of western Montana (e.g., upper Flathead Rivers; Hauer 1980). *Rhyacophila* were relatively common at Site 4 in July and October (74 and 24 m⁻², respectively). During April, *Rhyacophila* larvae were most abundant at Site 3, although densities were < 5 m⁻². Only two individuals throughout the study were collected at Site 1 (DUN).

Although they did not appear in the benthic samples, limnephilid larvae were particularly common at Stations 1 and 2. We regularly observed larvae in the genus *Dicosmoecus* crawling along the edge of the river and exposed in the varial zone immediately after reduction in river discharge. Adult *Dicosmoecus* were also very common in October and were observed frequently flying and landing on riverside vegetation.

**Diptera and Non-insect Zoobenthos**

Lotic Diptera are taxonomically very complicated; just in the family Chironomidae for example, there are over 2000 species in the Nearctic Region (Coffman and Ferrington 1996). Furthermore, most larvae in this order cannot be taxonomically distinguished much beyond the tribe level of identification without extensive and tedious microscopy. Therefore, for the purpose of this study, we identified Diptera to the family level of resolution with the understanding that there are distinct, species level responses to river regulation. However, this approach is also justified by the knowledge that within the various families, trophic relationships and ecological position with respect to the lotic food web, is fairly consistent (Merritt and Cummins 1996).

Chironomid larvae were the most abundant taxa in the Kootenai River throughout this study (Figure 15). Mean densities of Chironomidae were often more than several thousand individuals per square meter. For example, highest were achieved at Site 1 during July when the density was >10,000 m⁻². Densities at all the
Figure 15. Density of two dominant taxa of Diptera larvae (Chironomidae and Simuliidae) in the Kootenai River below Libby Dam at each of the study sample sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOA), and Site 5 (CPT).
sample sites during the summer and spring were relatively high (4000 - 12,000 m\(^{-2}\)). Density at all sites was lowest during the October sampling. Based on comparative data with other insect taxa, the low October density may be due primarily as a result of life history cycles. The overall high densities of chironomids occurred primarily because of the abundance of attached algae which provided both trophic support and stable microhabitat. Chironomid larvae were most frequently observed in direct association with either the stalked diatom *Gomphonema* or within the gelatinous structure of a filamentous green algae, probably *Ulothrix*.

Larvae of the dipteran family *Simuliidae* were very abundant at Site 1 (Figure 15). Blackfly larvae, which feed by filtering very small particles from the seston, were generally observed in clumped distributions in smooth water flow microhabitats. Simuliiids also appeared most abundantly during mid-summer in conjunction with warmer temperatures. The lower larval density at Stations 2 - 5 are discussed below.

Oligochaetes (aquatic worms) and snails also occurred frequently in benthic samples. Oligochaetes were found to be most abundant at Site 5 during July and October when densities were as high as 78 and 64 m\(^{-2}\), respectively. At sites 2, 3 and 4 densities were generally 20 -30 m\(^{-2}\). We also collected snails; both *Physa* sp. and *Limnea* sp.. However, many samples contained no snails; and those that did frequently only had one or two individuals. The highest density of snails collected in any one sample was during October at Site 2 (ELK), in which a single sample had 25 m\(^{-2}\). Interestingly, both snails and oligochaetes were absent from Site 1.

**Comparison of Zoobenthos Density 1979-80 vs 1994-95**

During 1979 and 1980 MFWP conducted a detailed study of the zoobenthos of the Kootenai and Fisher Rivers (Perry and Huston 1983, Perry 1984, Perry and Perry 1986, Perry et al. 1986). This study was restricted to Sampling Sites 1, 2, and 3 of this
study on the Kootenai River. We used identical sampling techniques and equipment (modified kick-net and drift nets), and thus we were able to directly compare seasonal data among dominant species between 1979-80 and 1994-95 at these three sampling locations.

Among the mayflies, *Baetis tricaudatus* and *Ephemerella inermis* nymphs were consistently the most abundant at the three sampling sites common to both studies and across sampling dates (Figure 16). At Station 1 (DUN), comparison of *Baetis* nymphal density was nearly the same between studies during July; in October >1000 m⁻² in 1980 vs <200 m⁻² in 1994, but in April <800 m⁻² in 1980 vs >3000 m⁻² in 1994. In contrast, *Baetis* at both Station 2 (ELK) and 3 (PIP) were less abundant on all sampling dates in 1994-95 compared to 1979-80, and frequently the decline in *Baetis* density exceeded an order of magnitude. For example, in April and 3 *Baetis* nymphal density was >5000 m⁻² in 1980 vs <300 m⁻² in 1995 at Station 2 and >6000 m⁻² in 1980 vs <300 m⁻² in 1995 at Station 3.

A somewhat different spatial pattern was observed for *Ephemerella inermis* nymphs (Figure 16). Density of *Ephemerella* was lower in 1994-95 at Stations 1 and 2 than 1979-80 on all sampling dates. The decrease in nymphal density was most pronounced in October when the number of individuals was >10,000 m⁻² in 1979 vs <400 m⁻² in 1994 at Station 1 and >2,000 m⁻² in 1979 vs <200 m⁻² in 1994 at Station 2. At Station 3 density was fairly similar across years and dates, although only ≈10 m⁻² were present in 1980 and ≈100 m⁻² in 1994.

Among the net-spinning caddisfly larvae, we observed several interesting changes in species composition and shifts in distributional patterns (Figure 17). Perry and Huston (1983) and Perry (1984) reported *Hydropsyche oslari* as a dominant species of net-spinning caddisfly in the Kootenai River. However, in 1994-95, we found no *H. oslari* and large numbers of *Hydropsyche cockerelli*. We have verified that Perry's larval identifications were correct. Thus, we must conclude that *Hydropsyche*
Figure 16. Density of two mayfly species (Baetis tricaudatus and Ephemerella inermis) at Site 1 (near Dunn Creek), Site 2 (near Elkhorn) and Site 3 (near Pipe Creek) in the Kootenai River, comparing data from 1979-80 (open bar) and data from 1994-95 (stippled bar) during each of three different seasons and flow regimes.
Figure 17. Density of three caddisfly species as well as early instars of all three species combined (Hydropsyche cockerelli, Hydropsyche occidentalis, and Cheumatopsyche sp.) at Site 1 (near Dunn Creek), Site 2 (near Elkhorn) and Site 3 (near Pipe Creek) in the Kootenai River, comparing data from 1979-80 (open bar) and data from 1994-95 (stippled bar) during each of three different seasons and flow regimes.
oslari has largely been eliminated from the river and replaced by *Hydropsyche cockerelli*.

In addition to this species replacement, we also observe a distinct upstream extension of hydropsychid larvae. We found *H. cockerelli* larvae at relatively high densities at Site 1 during all sampling dates. Densities were consistently 500 - 1,300 m\(^{-2}\) at Station 1 (DUN) among all instar *H. cockerelli*.

At Station 2 (ELK) *H. cockerelli* larval density decreased, but *H. occidentalis* density significantly increased. In July 1994, we observed large numbers of *H. occidentalis* larvae; however, later in the year density of caddisfly larvae were significantly reduced at this site, particularly by April. This general pattern was also observed at Station 3, with significant reduction in net-spinning larvae of all species comparing 1979-80 to 1994-95 (Figure 17).

Particularly interesting distribution and abundance patterns were also observed among the Diptera larvae (Figure 18). Blackfly larvae (Simuliidae) are similar to net-spinning caddisfly larvae in that they both feed on suspended particles in the water, although blackflies are known to feed on extremely small material (i.e. <10 μm). Like *H. cockerelli* larvae, the number of blackfly larvae were significantly greater at Station 1 in 1994-95 than in 1979-80. However, the number of blackfly larvae at Stations 2 and 3 were significantly lower, often by more than an order of magnitude, in 1994-95 vs 1979-80. Among the Chironomidae, larval density was much lower in 1994-95 vs 1979-80 across all sampling dates and stations (Figure 18).

**Insect Drift and Stranding**

Larvae from five insect families comprised over 95% of drift in collections in this study; the mayfly families Baetidae and Ephemerellidae, the caddisfly family Hydropsychidae, and the two Diptera families Chironomidae and Simuliidae. Drifting baetid nymphs were consistently ~50/100 m\(^3\) during each of the sampling dates at
Figure 18. Density of two Dipteran taxa (Chironomidae and Simuliidae) at Site 1 (near Dunn Creek), Site 2 (near Elkhorn) and Site 3 (near Pipe Creek) in the Kootenai River, comparing data from 1979-80 (open bar) and data from 1994-95 (stippled bar) during each of three different seasons and flow regimes.
Station 1 (DUN) and 70/100 m$^3$ at Station 3 (PIP) during October (Figure 19). At other locations and dates baetid drift densities were much lower. Among the ephemerellid nymphs drift density was highest at Station 2 (ELK) and Station 4 (KOA) during April. During July the only Ephemereellidae nymphs collected were at Stations 1 (DUN) and 2 (ELK). Among the hydropsychids, generally we observed drifting larvae at Stations 2 - 5 during July, but not at Station 1. During summer, maximum drift density of hydropsychids was observed at Station 4. During October and April, hydropsychid drift was only seen at Stations 1 and 3. However, there was significant disparity between the drift at these two sites; Station 3 drift density being $>10X$ that of Station 1 on both dates (Figure 19).

Chironomid and simuliiid larvae were an important part of the drift at all sites and across all sampling dates. Among the chironomids, larval density was generally highest during the July sampling with the exception of Station 2 (ELK). Although Station 2 also consistently had one of the lowest drift densities among all stations (Figure 20). Among the blackfly larvae, drift density was consistently highest at Station 1 (DUN), but across all stations the highest drift density occurred during October. Furthermore, during October drift density between stations was remarkably similar, particularly in view of the significant differences in blackfly larval density between stations observed in the benthic collections (see Figures 15 and 18).

Perry and Perry (1986) also sampled near shore insect drift in association with a sudden decrease in river discharge. They expressed drift density as a function of total insect drift rather than by specific taxa. Comparing 1979-80 drift data to drift of this study; at Site 1 (DUN) they collected an insect drift density among all species of 1742 /100 m$^3$ in July and 3047 /100 m$^3$ in January. This compares to 195, 134, and 38/100 m$^3$ during July, October and April, respectively, of this study at the same river location (Figure 21).
Figure 19. Density of insect drift of three dominant family taxa (Baetidae, Ephemerellidae and Hydropsychidae) in the Kootenai River below Libby Dam at each of the study sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOA), and Site 5 (CPT).
Figure 20. Density of insect drift of two dominant dipteran taxa (Chironomidae and Simuliidae) in the Kootenai River below Libby Dam at each of the study sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOÁ), and Site 5 (CPT).
Figure 21. Density of insect drift of all taxa in the Kootenai River below Libby Dam at each of the study sites; Site 1 (DUN), Site 2 (ELK), Site 3 (PIP), Site 4 (KOA), and Site 5 (CPT).
Stranding collections were made along the shoreline immediately after low flows were achieved at each of the sampling sites in both July and October (Figure 22). Although we sampled the shoreline on the April sampling date we did not expect, nor did we observe, any evidence of insect stranding in the spring for the simple reason that we sampled in April after an extended period of consistent low flow from Libby Dam. However, particularly during July there was considerable evidence of invertebrate stranding after reduction of flow. At Station 1 (DUN) the most abundant organisms stranded were blackfly larvae and pupae, *Ephemera inermis* larvae, and *Hydropsyche cockerelli* larvae. At Station 2 (ELK) most standing occurred in July among snails (Lymnaea) and *E. inermis*. At Station 3 (PIP) we observed stranding across a wide range of benthic organisms including Chironomid larvae, snails, *E. inermis*, *Serratella tibialis*, *Drunella flavilinea*, *H. occidentalis*, and *H. cockerelli*. We observed as many as 30 larval fishes m⁻². Stations 4 (KOA) and 5 (CPT) generally had mostly mayfly nymphs and a few hydropsychid larvae, particularly Station 4, during July.

In general, across all sites and seasons, the highest density and highest diversity of stranding occurred during the summer when the varial zone was exposed after an extended period of being within the wetted perimeter of the river channel. We also observed many larvae drying quickly in the sun during the July sampling. Perry and Perry (1986) also reported large numbers (>20,000 m⁻²) of insects stranded at Sites 1 and 3. Corrarino and Brusven (1983) found highest stranding of *Baetis tricaudatus* nymphs during the fall when temperatures were warm and dewatered substratum dried quickly. Similarly, Perry and Perry (1986) observed high stranding and mortality associated with rapid decrease in discharge, especially during summer when warm temperatures and direct exposure to high sunlight caused rapid desiccation.
Figure 22. Density of dominant macroinvertebrate taxa (and larval fish) stranded in the varial zone at each of the five sampling sites on the Kootenai River during July (solid black bar) and October (stippled bar). No organisms were found stranded in April. The varial zone was divided into three areas in distance from the channel (Area A farthest, Area B in middle, and Area C closest to the channel).
We observed distinct effects of hydropower on the zoobenthos of the Kootenai River. The effects were different between species, seasons, dam operations and sites along the river continuum from dam tail waters to down-river sampling stations. Species-specific differences can be attributed to different morphologies, life histories, habits, habitat preferences, and trophic relations. There were four dominant mayfly species. *Baetis tricaudatus* and *Ephemerella inermis* nymphs were very abundant at Stations 1 through 4, particularly *Baetis* at Station 1 (DUN) during April. *Drunella flavillinea* and *Serratella tibialis* were most abundant at Stations 2, 3 and 4; however, *Drunella* were absent from the river in October while *Serratella* were absent in the fall and spring collections. Their absence from benthic samples during those seasons were due to specific life history traits. *Ephemerella*, *Drunella*, and *Serratella* are all in the family Ephemerellidae. Each shows a similar pattern of response to river regulation in that they were generally most abundant at Stations 2, 3 and 4 regardless of life history sequence traits. Thus, as a general pattern, the very small but highly motile *Baetis tricaudatus* nymphs tended to be most abundant close to the dam while the larger and less active ephemereellids were most abundant among the central reach sampling sites. The rate of change in shear stress (see Table 1), which in turn is the result of change in discharge and current velocity, may play an important role in the more motile, fast swimming species being favored upstream near the dam and the slower, crawling species at the more downstream sites.

A comparison of 1979-80 data with collections made in 1994-95 revealed very interesting changes in species-specific distribution and abundance. With the exception of very high abundance in April at Station 1, *Baetis* density was lower during each season and sampling location in 1994-95 than in 1979-80. In many cases, the difference in nymphal abundance was more than an order of magnitude
lower in 1994-95. For example at Station 2 (ELK) in October, the 1979-80 study reported >3000 *Baetis* nymphs m⁻², but in 1994 we observed <100 m⁻². *Ephemera* inermis abundance, in general, was also lower in 1994-95 than in 1979-80, particularly at Stations 1 and 2 (Figure 15). For example, at Station 1 in October 1980 Perry and Huston (1983) found >10,000 *Ephemera* nymphs m⁻², but in 1994 we collected <100 m⁻².

The net-spinning caddisflies (Hydropsychidae) have a predictable longitudinal species replacement among many of the river continua in western Montana (Hauer and Stanford 1982, Stanford et al. 1988). The sequential pattern from small, 1st order creeks to the large, 6th - 7th order rivers begins with *Parapsyche elsis* in the headwaters, replaced by *Arctopsyche grandis* in 3rd - 4th order streams; *Hydropsyche cockerelli* and *H. oslari* in 4th, 5th and 6th order rivers; and *Hydropsyche occidentalis* and *Cheumatopsyche* sp. in 6th to 7th order rivers. The Kootenai River below Libby Dam is down river of the *P. elsis* stream continuum segments. We collected only three specimens of *A. grandis* larvae among all sites and sample dates. Perry and Huston (1983) reported them as being infrequently collected at Sites 2 and 3 (<10/m²/yr). *H. cockerelli* was the dominant net-spinning larvae at Station 1 but was found in generally lower density at all of the downstream sampling sites, although was particularly abundant at Station 3 in October. *H. cockerelli* was largely replaced by *H. occidentalis* at Stations 2 through 4, while *Cheumatopsyche* sp. were most abundant at Stations 4 and 5. Thus, the hydropsychid caddisflies followed an expected pattern of distribution. However, we did not expect the extremely low density among all hydropsychids at Stations 2 - 5 during spring 1995. Rather, based on previous studies on the Flathead River and earlier study on the Kootenai River, we expected the density of net-spinning caddis larvae to be 400 to 800 m⁻² at Stations 2 and 3. At Station 1, density of *H. cockerelli* was very similar between sampling dates, but at each of the 4 lower sampling stations (Sites 2 - 5) larvae of all three species were virtually absent.
during spring 1995 (Figure 14). Interestingly, drift of hydropsychid larvae during spring was actually highest at Station 3, even though density on the substratum was >100X greater at Station 1.

A similar pattern was observed among the Diptera larvae, particularly when comparing functionally similar trophic guilds. The Simuliidae larvae, like the net-spinning caddisflies, are sessile filter-feeders that capture drifting seston particles. Similarly to *H. cockerelli*, the density of simuliids was greatest immediately below the dam (see Figure 15) all three sampling dates.

The general distributional pattern among the Chironomidae was less pronounced than that of the simuliids, however midge larvae tended to be most abundant at Station 1, decrease in abundance at Stations 2 and 3, then slightly increase in density at Station 4. Interestingly, when we compared 1994-95 data with that of 1979-80 simuliid larval density had increased dramatically at Station 1 (DUN), but had also decreased significantly at Stations 2 and 3 in all seasons. For example, in October at Station 2 simuliid density in 1979-80 there were > 15,000 larvae m\(^{-2}\), but we collected <500 m\(^{-2}\). In April the 1979-80 study collected > 25,000 larvae m\(^{-2}\), we collected < 1000 m\(^{-2}\). Similar differences were observed among the Chironomid larvae except that their density was higher during the 1979-80 study at all sites and on all dates than in this study. These differences were most pronounced at Station 2 where on all three sampling dates midge larval densities reported in the earlier study were > 10X higher than what we observed.

Plecoptera diversity and density in the Kootenai River was reported by Perry (1984) to be particularly low in comparison to either the Flathead River or the Fisher River. She attributed the low stonefly populations to river regulation, however, she was uncertain as to the cause since thermal regimes in the Kootenai River were largely maintained near natural because of selective withdrawal capability of the dam and thus thermal control of the dam discharge. Likewise, we found far fewer stonefly
nymphs and in lower diversity than in a recent study of the Flathead River (Hauer et al., 1994). Thus, it appears that the Plecoptera continue to be impacted by Libby Dam operations.

Although Perry (1984) hypothesized that low dissolved O$_2$ or the lack of winter icing conditions in the tail waters may play a role in low plecopteran densities, it seems unlikely to us that these are the primary constraining factors on plecopteran species. Rather, we believe that the low stonefly density and diversity with continued loss of species in the Kootenai River below the dam is because of (1) rapid and frequent flow fluctuation and (2) change in substratum character that results from elimination of stream power associated with high flow events. Flow fluctuation has been shown elsewhere (Stanford 1975, Hauer et al. 1988) to have a particularly strong effect on stoneflies because of their habit of massing at the river margins prior to emergence. If emergence of a species coincides with a rapid reduction in dam discharge, nymphs are particularly susceptible to desiccation in summer or freezing in winter. Stoneflies also appear to be particularly sensitive to loss of stream bed scour. Periodic high flows and the movement of sediment, particularly large gravel and cobble plays an important role in maintaining interstitial space within the substratum. The distribution of sediment sizes along and across the river channel directly influences the distribution of organisms. Shifting sands or the imbedding with fine sediments within the cobble substratum reduces species abundance and richness. As illustrated in Table 2, the diameter of particles entrained even at 30,000 cfs is much smaller than the typical cobble size of the river. Because high discharge that occurs during spring snowmelt is now captured in Lake Koocanusa (Libby Reservoir), the river is now incapable of moving and redistributing the cobble bed-sediments even at dam-controlled, high discharge. Thus, the large cobble alluvium of the Kootenai River is not moved, sorted and redistributed.
Armoring (i.e., infilling of interstitial space with fines) of the substratum may also interfere with hydraulic connectivity between the channel and the subsurface hyporheic zone (sensu Stanford and Ward 1993) of the river. In the Flathead River near Kalispell, hyporheic stoneflies comprise an important part of the riverine biota, often among the most abundant mature nymphs emerging from the river during the spring (Stanford 1975). [Note: that segment of the Flathead River has received effects of both flow fluctuation and thermal modification from Hungry Horse Dam.] However, a major difference between the Flathead River near Kalispell and the Kootenai River is the effect of substratum redistribution during high discharge from spring runoff of the North and Middle Forks.

During July 1994, stranding of benthic organisms was a significant problem, particularly among sessile or slow moving species. We collected large numbers of caddis and dipteran larvae, mayfly nymphs, snails, and occasionally larval fish stranded on the shoreline. The Kootenai River varial zone was rapidly dewatered after nearly two months of relatively stable, high-flow discharge (see Appendix A). The relatively stable flow during June and early July permitted colonization of the varial zone by benthic fauna. The rapid decline in discharge from 20,000 to 12,000, then to 4,000 cfs left a broad expanse of river bottom exposed. Although some benthic species move rapidly, such as *Baetis*, many are sessile or move slowly and are easily trapped as the regulated discharge water recedes to the low flow channel. Thus, as in July 1994, whenever the river has high steady flow for several weeks, the inundated river channel is colonized. If the flow is then rapidly dropped (e.g., 8,000 cfs in < 1hr) benthic fauna are trapped on the dewatered varial zone. This was observed to a much lesser degree in October because of the frequent flow fluctuation continuously restricted colonization. And, it was not seen at all in April because of the long-term low steady flow.


**CONCLUSIONS**

There are numerous questions that arise from the data collected in this study. Some of the answers to these questions are easily concluded, others are more obscure, and still others merely lead to more questions. The answer to the question regarding stranding is not complicated. That portion of the river channel that is wetted by the river continuously for several weeks is colonized by benthic organisms. If the discharge in the river is reduced rapidly and sufficiently to expose portions of the channel wetted perimeter, a significant portion of the benthos occupying the varial zone is stranded and dies. The ecologically sound solution to this can be achieved through slow rather than rapid reduction in dam discharge. Current dam operations permit rapid fluctuation in dam discharge that frequently results in daily fluctuation in river discharge between 4,000 and 20,000 cfs (see Figures 3 - 7). However, an analysis of the rate of decline in river discharge prior to dam construction reveals a typical rate of fall on the hydrograph from 20,000 to 10,000 cfs to occur over a 15 - 30 day time period, depending on the water year.

An additional complicating factor as dam operations rapidly fluctuate river discharge (e.g., 4,000 and 20,000 cfs per day) is hydraulic variability and shear stress in the thalweg (channel center) and its affect on the benthic community (see Tables 1 and 2). As river discharge is rapidly and frequently fluctuated, so too are the microhabitats that are affected by flows over the cobble substratum where the benthic invertebrates reside. Many of these organisms are sessile and as such not capable or rapid movement as microhabitat characteristics change. For example, both hydropsychid and blackfly larvae are very flow-sensitive. This means they are restricted to microhabitat environments that have a fairly narrow range of acceptable current velocities. Rapidly changing flow regimes produce changes in flow and shear
stress over the substratum at the microhabitat spatial scale. Under natural discharge regimes these organisms change the location of their individual-specific spatial niche accompanying the slow change in discharge. However, under current dam operation regimes the rate of change in discharge is beyond the ability of these organisms to compensate by moving to a new, appropriate microhabitat. Those individuals that do remain in the river are restricted to microhabitats that are least subject to current speed and sheer stress change with changing discharge. This results in fewer appropriate microhabitats capable of supporting benthic fauna and thus overall a much lower density.

Fish behavior may also be significantly affected by frequent flow fluctuation. Juvenile fish, particularly young-of-the-year must remain near shore where there is generally more cover, less predation, and slower current velocities. However, under a frequently changing discharge regime juvenile fish not only must move long distances to remain near the shore, but during high discharge are forced to reside in a portion of the river without benthic organisms (i.e., food). Likewise, adult fish behavior may be directly affected by the recurring change in discharge as dominant individuals attempt to occupy an ever shifting microhabitat spatial structure (Bachman 1983).

It is important to keep in mind that even a single reduction in flow establishes a new boundary for the benthic community. For example, 6 weeks of steady flow at 16,000 cfs followed by a single day of 4,000 cfs will result in stranding of those organisms that had colonized the wetted channel that is exposed between 4000 and 16,000 cfs. Thus, as the river is lowered to the 4,000 cfs channel the benthos in the varial zone between 16,000 cfs and 4,000 cfs is eliminated. Benthic organisms can only recolonize the varial zone as the river discharge remains relatively stable. This requires several weeks or months, but reaches a quasi-equilibrium appropriate for that season within the long-term wetted channel.
Within the benthic community, there are many changes that have occurred in the Kootenai River since the early 1980's. Surprisingly, Station 1 has experienced an increase in abundance of seston feeding organisms. Both net-spinning caddisflies and blackfly larvae were far more numerous in 1994-95 than in 1979-80. Also surprising, particularly in comparison to the other sample sites, the density of filter feeders remained relatively consistent across seasons, and thus flow fluctuation regimes. This is likely the result of trophic change within the reservoir or mixing of different water strata from the reservoir to achieve the desired thermal regime. It was beyond the scope of this study to identify changes in Lake Koocanusa or thermal stratification and mixing at the dam; however, this would be of both scientific and management interest for future investigation. Likewise, we do not know why Hydropsyche oslari was entirely replaced by Hydropsyche cockerelli, between the 1979-80 and 1994-95 studies. Both species are commonly collected in large rivers, like the Kootenai, throughout western Montana and Idaho. We can only speculate that the species-specific effects that resulted in the upstream shift in filter-feeder productivity, also resulted in the observed species replacement.

Although Site 1 experienced increased filter-feeder production, hydropsychids and simuloids had significantly reduced abundance at Stations 2 and 3 during October and particularly April, compared to the 1979-80 study. Indeed, at both Sites 2 and 3 caddisfly and blackfly larvae were nearly absent in April 1995. The reason for this is obscure since dam discharge was essentially constant at 4,000 cfs for two months prior to sampling in April. Although a definitive answer would have required multiple sampling dates from November 1994 through January 1995 to observe the decline, it is highly likely that the frequent flow fluctuations in October through January (see Appendix A) had a profound effect on these organisms. Thus, the low density observed in April was likely the result of effects that had occurred months earlier. The lack of recovery by April, even after several months of stable flow, can be explained by
an absence of reproduction by these organisms during winter. One can expect a more rapid recovery from a deleterious effect among benthic organisms if those affects occur during a time that is also marked by high reproduction.

Although, verification of this hypothesis would require a very specific experimental design of similar flow manipulations in the winter, as well as during summer, based on observations in other regulated river systems flow fluctuation during the winter is the likely cause of the very low density at Stations 2, 3, 4 and 5 the following spring (Stanford 1975, Hauer and Stanford 1981, 1982). What is less clear is why this did not also affect those populations at Station 1, unless the earlier discussed sestonic changes had an over-riding positive effect.

The effects of hydropower and flow fluctuation seen among the caddisfly and blackfly larvae were also observed among the mayflies. It is interesting that in comparing both *Baetis tricaudatus* and *Ephemerella inermis* across sampling sites and seasons the general pattern is that there were fewer of these organisms in 1994-95 than in 1979-80. This was particularly true comparing Stations 2 and 3 in April. At Station 2 *Baetis* density was >5,000 m⁻² in the 1979-80 study, but < 200 m⁻² in this study. At Station 3 *Baetis* density was > 6,000 m⁻² in the 1979-80 study, but < 300 m⁻² in this study. Although the pattern was similar for *Ephemerella* nymphs, these differences were less dramatic. Nonetheless, the declines in abundance among extremely important benthic organisms that support fish production in the Kootenai River since the 1979-80 study are significant.

Likewise, based on comparison to other rivers in western Montana and Idaho, and the study by Perry (1984), the Kootenai River continues to have a significantly reduced plecopteran community. This is likely due to the long-term patterns of hydropower operation that include changes in the hydrographic pattern and frequent flow fluctuation. It may also be the result of significant changes in substratum condition.
(i.e., the armoring and filling of cobble and interstitial space), which is in turn related to discharge and sediment supply and redistribution.

**Implications of the Data and Possible Mitigation Solutions**

River regulation by Libby Dam has had numerous deleterious effects on river zoobenthos. With the exception of density of net-spinning caddisflies and blackflies in the dam tail waters, most species have reduced abundance when either comparing long-term trends, such as this study with the 1979-80 study, or between rivers in the region. The river downstream of the dam has an expansive varial zone that is essentially devoid of zoobenthos whenever the dam is operated with dramatic flow fluctuation. Dominant species present are those that emerge as adults off the surface of the water column (e.g., trichoptera, diptera), rather than crawling out on the lateral margins of the river (e.g., plecoptera), where they must deal with the vagaries of the varial zone as a consequence of Libby Dam operations.

The data presented herein, particularly in light of the 1979-80 study, clearly demonstrate that radical and rapid flow fluctuation has a major affect on zoobenthos (Hauer et al. 1989, Stanford and Hauer 1992, Jourdonnais and Hauer 1993). Stanford and Hauer (1992) after analysis of natural flow regimes and daily flow fluctuation is concluded that a smoothing out of the annual hydropower discharge pattern would be necessary to restore benthic production and achieve a more natural fishery. They suggested that the rising limb of the hydrograph not exceed 10% change per day and that the falling limb not exceed 5% change per day.

The implications of the data from this study for river restoration and management suggest two fundamental changes in operations for Libby Dam on the Kootenai River. 1) Restore peak flows during the spring runoff period to coincide with maximum flows from smaller side tributary basins entering the river below the dam (e.g., Fisher River). Such flows are necessary to move and redistribute the substratum
and prevent armoring and filling of interstitial substratum space. 2) Restrict daily rate of change in discharge to no more than 10% per day. To accomplish these restoration goals, system operators would need to be cognizant of long-term discharge trends to anticipate needs to fill the reservoir, provide down river water requirements, or to be responsive to hydropower operations throughout the Columbia Basin.

Finally, regardless of the mitigation actions that are taken to reduce the effect of flow fluctuation in the Kootenai River, whatever is proposed and implemented should be evaluated. Too often ecosystem mitigation efforts are implemented without consideration of long-term effects or to determine if the actions taken were effective (Stanford and Poole 1996). Thus, an adaptive management plan should be carefully considered that allows performance evaluation and the redirection of mitigation actions or funds. As concluded by Stanford and Hauer (1992); "given the cost of mitigation, and the sensitivity and intricate linkages that characterize the ecosystem, adaptive management in an ecosystem context should be viewed as essential to the mitigation process".

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LITERATURE CITED


APPENDIX A. Discharge in the Kootenai River at Libby, MT (Water Years 1952 - 1971) and below Libby Dam (Water Years 1972 - 1995). Discharge is given in cubic feet per second (cfs). Data are from the USGS at Station Numbers 12303000 and 12301933, respectively.
WATER YEAR 1973

WATER YEAR 1974

WATER YEAR 1975