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MITIGATION, COMPENSATION, AND FUTURE PROTECTION FOR FISH POPULATIONS AFFECTED BY HYDROPOWER DEVELOPMENT IN THE UPPER COLUMBIA SYSTEM, MONTANA, U.S.A.

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ABSTRACT

Pursuant to the Northwest Power Planning Council's Fish and Wildlife Program for the Columbia River system, we estimated losses in fish populations and developed mitigation, compensation, and protection alternatives for reservoirs and downstream river reaches affected by hydropower development in the Flathead and Kootenai River systems in northwest Montana, U.S.A. The construction of Hungry Horse Dam has resulted in estimated annual losses of 65 500 migratory juvenile westslope cutthroat and 1965 adult migratory bull trout from the Flathead Lake and River system. In addition, operations of Hungry Horse and Kerr dams caused annual losses conservatively estimated at 96 300 river-spawning and 131 000 lakeshore-spawning kokanee adults. Water level fluctuations caused by dam operations at Libby and Hungry Horse reservoirs result in: (1) altered thermal stratification, (2) indirect losses in phytoplankton and zooplankton production, (3) direct washout of phytoplankton and zooplankton through dam penstocks, (4) reductions in standing crop of benthic organisms and of insects on the water surface, and (5) reduced fish growth in the late summer and fall. Mitigative measures include: (1) 99·2 and 113·3 $m^3 s^{-1}$ minimum flows in the Flathead and Kootenai rivers respectively, to protect salmonid eggs and juveniles, (2) improvement of fish passage to restore migrations between the Flathead and Swan systems, and (3) biological rule curves for operations at Libby and Hungry Horse reservoirs. To compensate for fisheries losses, we recommend enhancement of spawning and rearing habitat, introductions of hatchery juveniles, and spawning channels. We recommend protection from further hydropower development for 100 stream reaches (1386 km) for fish species of special concern, and for outstanding sport fisheries. These and other measures will be considered by various agencies in developing an overall fisheries restoration plan which should be flexible, and employ principles of adaptive management. Effectiveness of the plan may be limited by heavy reliance on hatchery fish. Although mitigation efforts may not restore fish populations to pre-dam levels, substantial benefits should be realized.

KEY WORDS Columbia River system Montana, U.S.A. Hydropower development Migratory fish losses Mitigation Compensation Protection alternatives Reservoir level fluctuations Dam operation rule curves Minimum river flows Fisheries recovery plan Adaptive management

INTRODUCTION

From 1933 to 1975, 28 federal dams were built on the Columbia River system in states of northwest U.S.A. Construction and operation of these dams, and of privately operated facilities, resulted in a sharp decline in anadromous salmon and steelhead populations, and in damage to resident (freshwater) fish and to wildlife in Oregon, Washington, Idaho, and Montana (Northwest Power Planning Council, 1987). In 1980, the U.S. Congress passed the Pacific Northwest Electric Power Planning and Conservation Act (the Act), designed in part to balance hydropower development and other natural resources in the Columbia system. The Act formed the Northwest Power Planning Council (the Council) and directed the Council to 'promptly develop and adopt...a program to protect, mitigate and enhance fish and wildlife...on the Columbia River and its tributaries.' The Act also specified that (1) the Columbia should be treated as a system (thus including resident fish in upstream reaches), and (2) the Bonneville Power Administration

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(BPA), acting in behalf of ratepayers, would be required to use revenue and legal authority to protect and mitigate impacts on natural resources to the extent that they have been influenced by federal hydroelectric operations.

In Montana, four dams were built on the Kootenai and Flathead rivers, including two federal projects (Libby and Hungry Horse dams), and two privately operated facilities (Kerr and Bigfork dams) (Fraley, 1986). These dams blocked fish migration corridors, removing access to historic spawning and rearing areas for migratory fish species such as westslope cutthroat trout and bull trout. Dam operations caused large fluctuations in downstream waters and seasonal drawdown of reservoirs. The changes had serious consequences for riverine and reservoir fish.

To address these fisheries losses, the Montana Department of Fish, Wildlife and Parks (MDFWP) implemented (with BPA funding) measures of the Council's fish and wildlife program to: (1) quantify hydropower-related fisheries losses, (2) recommend operational constraints at the hydropower facilities, (3) recommend measures to compensate for fisheries losses when changes in operations would not be practicable, and (4) recommend important stream reaches that could be protected from further hydropower development. BPA provided funding for the Confederated Salish and Kootenai Tribes to conduct a similar effort on tribal lands in the south end of Flathead Lake and the Flathead River below Kerr Dam (Darling *et al.*, 1984).

In this paper, we report the results of MDFWP investigations on riverine and reservoir environments in the Flathead and Kootenai systems and propose options for mitigating impacts on the fishery, compensating for past losses, and protecting fish habitat and fish populations from future impacts.

STUDY AREA

The Flathead and Kootenai river systems in northwest Montana are the northeasternmost drainages of the Columbia River basin (Figure 1). Flathead Lake is the largest natural lake in the western United States with a maximum length of 43·9 km and a surface area of 50990 ha. Its mean depth is 32·5 m; maximum depth is 113 m (Potter, 1978). The largest tributary to the lake is the Flathead River with an average annual flow of 276·3 $m^3 s^{-1}$. The North, Middle and the South forks of the Flathead River drain large tracts of public lands including the Flathead National Forest and Glacier National Park.

Twenty-five fish species reside in the Flathead Lake and River system; ten are native. Principal native game fish species include westslope cutthroat trout (*Salmo clarki lewisi*), bull trout (*Salvelinus confluentus*), and mountain whitefish (*Prosopium williamsoni*). Non-native species include lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*) and kokanee (*Onchorhynchus nerka*). All of the above species except the lake trout are migratory, using the river and its tributaries for spawning and rearing. After maturing in the lake, bull trout spawn in the fall, and cutthroat spawn in the spring, in headwater tributaries. Juveniles of these species grow in tributaries for one to three years before emigrating to Flathead Lake. Some cutthroat reside only in the river or in tributaries.

Kokanee spawn in the river system and along the lakeshore in the fall. Emergent fry enter the lake the following spring (Fraley and Clancey, 1988). Recently, kokanee populations in Flathead Lake have declined dramatically. The decline has been related to hydropower impacts, an increase in *Mysis* shrimp densities and other factors (Fraley and Decker-Hess, 1987; Beattie *et al.*, 1988).

The Flathead River and two tributaries, the South Fork of the Flathead River and Swan River, and Flathead Lake are presently affected by dams. Kerr Dam was completed in 1938 and has a nameplate generating capacity of 168 megawatts. The dam, operated by the Montana Power Company, is located 7 km downstream of the natural lake outlet (Figure 1). The Flathead River flows for 72 miles below Kerr Dam to join the Clark Fork of the Columbia River. Prior to impoundment, the water level of Flathead Lake remained relatively constant near 879 m (mean sea level) msl from September to mid April. Spring runoff typically increased the lake elevation to the annual maximum (881·8 m) in May and June. Since impoundment, the lake has been held near full pool from June 15 into September. Drawdown usually begins in mid September and minimum pool is reached in March. Flood control and recreational constraints on the project affect the lake levels from April to October.

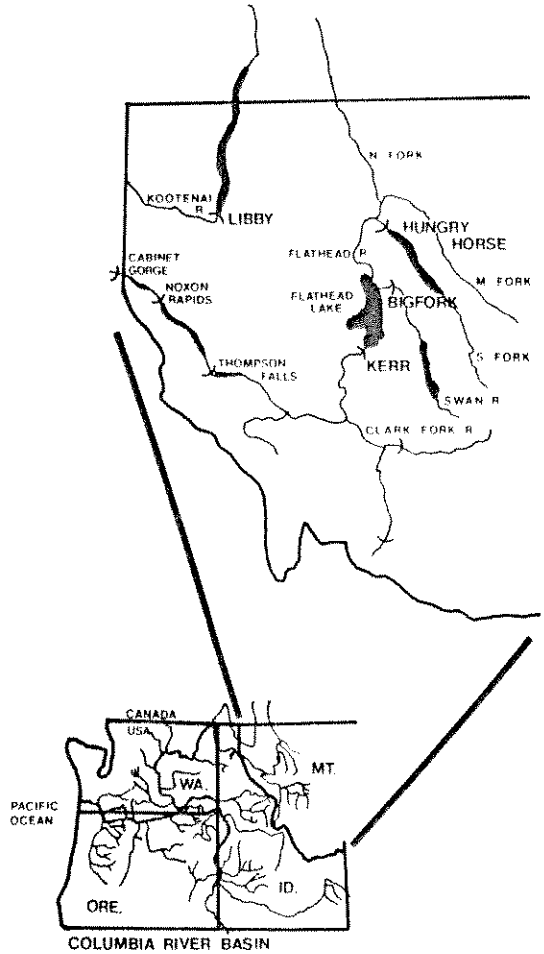

Figure 1. The upper Columbia River system in Montana

Hungry Horse Dam was completed in 1952 and the reservoir reached full pool elevation of 1085·4 m msl in July 1953. The dam impounded the South Fork of the Flathead River eight km upstream from its confluence with the Flathead River. Hungry Horse is a 56 km long storage reservoir with a surface area of 9632 ha at full pool and is operated by the Bureau of Reclamation. The primary benefits of the project are flood control and power production at downstream projects. Water passes through 19 downstream projects, generating approximately 4·6 billion kilowatt hours of energy annually as compared to 1·0 billion at the Hungry Horse project. Hungry Horse and Kerr dams are regulated in concert with the complex network of electrical energy producing systems, water consumption needs, and flood control requirements throughout the Pacific Northwest. Neither Kerr nor Hungry Horse dams are equipped with fish passage facilities.

The Swan River flows for approximately 90 km before entering Swan Lake, then meanders for 20 km until its entry to Flathead Lake. Bigfork Dam is located 1·6 km above the mouth of the Swan River entering Flathead Lake; it was built in 1902 and has a generating capacity of 4·1 megawatts. A fish ladder was constructed in the 1930s and modified in the late 1960s to enable Flathead Lake migratory salmonid populations to pass over the 12-foot high dam. However, because of the design flaws in the ladder, fish migration upstream into the Swan drainage is very limited (Zubik and Fraley, 1987).

The Kootenai River is the second largest tributary of the Columbia River with an average annual flow of 341·9 m^2 s^{-1} (Chisholm and Fraley, 1986) (Figure 1). Its drainage basin has an area of about

49 987 km^2 and includes parts of southeastern British Columbia, northern Idaho, and northwestern Montana. Eighteen fish species are present in the Kootenai River system. Major game fish species in the river and Libby Reservoir are westslope cutthroat, kokanee, bull trout, rainbow trout (*Salmo gairdneri*), and burbot (*Lota lota*). Kokanee were introduced in the Canadian portion of the drainage in 1978. Kokanee populations in Libby Reservoir have increased dramatically in recent years.

Libby Dam, operated by the U.S. Army Corps of Engineers, was constructed from 1966 to 1972 with a generating capacity of 420 megawatts. Libby Reservoir is 145 km long and has a surface area of 18 801 ha at full pool. The reservoir is operated for flood control and power generation, and serves as a major upstream storage reservoir for the Columbia system. Water released from Libby Dam passes through 16 downstream hydroelectric projects enroute to the Pacific Ocean. An international treaty regarding the operation of the reservoir was signed between the United States and Canada since the upper 67 km of the reservoir are located in British Columbia.

METHODS

Determination of fisheries losses in the Flathead system

We calculated losses of migratory westslope cutthroat in the Flathead system caused by the construction of Hungry Horse Dam and blocking of fish migration using a habitat-based approach (Zubik and Fraley, 1987). Stream order and gradient were found to be significantly related to juvenile westslope cutthroat densities in tributary reaches in the upper Flathead basin (Fraley and Graham, 1982). Using this relationship, we calculated the rearing potential in tributaries of the South Fork Flathead River which were inundated or isolated from the Flathead system by Hungry Horse Dam. We assumed that streams with gradients of six per cent or less were populated by migratory cutthroat juveniles, while resident cutthroat occupied tributary sections with gradients greater than six per cent. To calculate potential losses of rearing westslope cutthroat in the portion of the South Fork Flathead River which was inundated, we estimated cutthroat densities in representative reaches of the South Fork above the reservoir (Zubik and Fraley, 1988) and applied these densities to the portion of the river inundated by the reservoir. In these analyses, we assumed that inundated stream reaches were at the same level of carrying capacity as reaches not under the reservoir.

We estimated losses of migratory bull trout caused by the construction of Hungry Horse Dam (and blocking of the South Fork Flathead River) based on the proportion of drainage area that the South Fork comprised in relation to the North and Middle forks. Assuming that bull trout escapement was proportional to drainage area, we estimated the historic spawning run in the South Fork based on the average known spawning runs of bull trout in the North and Middle forks from 1980–1986.

Impacts of the operation of Kerr and Hungry Horse dams on kokanee reproduction in the Flathead River and Flathead lakeshore were documented by various methods of determining egg and pre-emergent fry mortality (Decker-Hess and McMullin, 1983; Fraley and McMullin, 1983). We documented emergent fry survival using emergence traps places over spawning areas in regulated and unregulated portions of the system (Fraley *et al.*, 1986b). We also analyzed the historic relationship between operations of Kerr and Hungry Horse dams and kokanee year-class strength (Fraley and Decker-Hess, 1987; Fraley *et al.*, 1986a).

The loss of adult kokanee in the Flathead system caused by hydroelectric operations was estimated by comparing historic and recent spawning escapements (Beattie *et al.*, 1988). Limited data existed upon which to base estimates of historic escapements. Estimates of historic escapements in the main stem Flathead River were based on the proportion of spawning areas (35 per cent) influenced by groundwater springs. These areas were less subject to the water level fluctuations caused by hydroelectric operations at Hungry Horse Dam. In the mid 1970s, escapements in the main stem exceeded 330 000 kokanee (Beattie *et al.*, 1988). These high escapements were partly attributed to favourable dam operations in the early 1970s. Escapement to the spring-influenced sites (35 per cent × 330 000 = 115 500) was considered to be a good estimation of escapement to the main stem river before the construction of Hungry Horse Dam.

Table I. Physical and biological samples collected at Libby and Hungry Horse reservoirs 1983–1987

Sample type	Total number of samples Hungry Horse	Libby
Water Column Profiles (water temperature, dissolved oxygen, pH, conductivity, solar input)	225	230
Zooplankton (30 m vertical tows, Schindler trap)		
Zooplankton	725	744
Loss through outlet	77	30
Surface insects (1 × 0·33 m surface tow)	1144	819
Benthos (Peterson dredge)	573	755
Emergence (1 m^2 surface traps)	423	376
Fisheries		
Horizontal experimental gill nets	1355	1882
Vertical experimental gill nets	—	872
Hydroacoustic surveys	—	4
Stomach analyses	1160	2446

Historic escapement along the Flathead Lake shoreline was conservatively estimated to equal the number of mature kokanee caught in the fall fishery of 1962 and 1963. Recent escapements were estimated by counting either spawning fish or redds (Fraley and Decker-Hess, 1987).

Quantitative biological models and biological rule curves for Libby and Hungry Horse Reservoirs

We constructed hydrologic/biological models for both reservoirs and used them to produce dam operation guidelines (rule curves) for optimizing biological production. Physical and biological characteristics of Libby and Hungry Horse reservoirs were assessed from 1983 through 1987 (Table I). Three localities were examined in each basin to detect longitudinal variation in physical and biological characteristics (Chisholm and Fraley, 1986; May *et al.*, 1988). Field data through 1986 (Table I) were used to construct the models specific to each reservoir, the fifth year was used for preliminary model testing. Model components were validated after construction. A three- to five-year model refinement phase was planned, beginning in 1988.

The biological model is comprised of four components: physical environment, primary production, secondary production and fish community. Calculations in the higher trophic level model components receive input from the preceding trophic submodel(s), much as energy is transferred through a biological system. Submodels were calibrated to field measurements individually to avoid unrealistic predictions of dam operation effects on reservoir biology.

The physical environment model was a digitized three-dimensional representation of the reservoir topography and volume, by which the daily hydrologic balance in inflow, reservoir surface elevation, and dam discharge were calculated. The superimposed thermal structure was modelled on 11 years of daily climatological records (U.S. Weather Service, Kalispell, Montana) adjusted to measured thermal conditions at the study reservoirs, long-term inflowing tributary temperatures, the physical properties of water, and basin topography. The model accommodates both the selective withdrawal system at Libby Reservoir and the fixed withdrawal system at Hungry Horse Reservoir.

The vertical distribution of primary production was quantified by light and dark bottle ^{14}C liquid scintillation techniques. Associated light attenuation was measured with a photometer at each sampling depth (0, 1, 3, 5, 10, 15, 20 and 25 m). Nutrients were measured by the U.S. Geological Survey during primary production assays. A least-squares linear regression used to empirically model primary production within the tolerance limits of light and temperature removed about 70 per cent of the raw variance. The theoretical response of a phytoplankton community to existing nutrient levels was incorporated into the model. The model outputs an annual schedule of total production, minus phytoplankton production lost through the dam outlet.

We predicted secondary production by correlating zooplankton density and distribution, benthic biomass, emergence of aquatic insects and terrestrial insect deposition with environmental parameters. Zooplankton data were linked to primary production by measured carbon transfer efficiencies and theoretical community models (Ulanowicz and Platt, 1985). Benthic production was calculated from a linear regression of standing stock of aquatic Diptera larvae by reservoir bottom elevation (permanently wetted, occasionally dewatered and frequently dewatered), and dipteran emergence per unit biomass based on emergent insect capture. Terrestrial insect deposition was treated separately for nearshore (≤100 m) and offshore areas. Capture rate was assumed to equal measured standing stocks for each species in surface tows. Estimates of species biomass and size distributions were included in fish food availability calculations.

The effects of dam operation on primary and secondary production were examined by model simulations of one year. We used results of successive trials using different dam operation scenarios to optimize biological production during low, medium, and high water years, and to develop dam operation rule curves. We have assumed at this stage of the model that optimizing primary and secondary production will lead to optimizing fish growth and biomass. The predicted effects of violating the recommended rule curves (seasonal reservoir operation guidelines) will be used to assess mitigation needs and strategies. The fisheries models will be refined and tested over the next several years to arrive at final seasonal operation guidelines for fisheries.

Protection of stream reaches from future hydropower development

Under the Council's Pacific Northwest Rivers Study, we assessed resident fisheries and wildlife values and recreational, natural, and cultural features in and along rivers and streams of the Columbia drainage in Montana (Decker-Hess *et al.*, 1988). We assigned a rating of Class I for outstanding values or unique features, Class II for substantial value, Class III for moderate value, and Class IV for limited value for each reach assessed in each resource area. Streams were rated for habitat, species, and sport fishery value. Habitat and species values were based on accumulated points for quality of habitat and genetic verification of fish species of special concern to Montana (native fish found in limited number and/or restricted in distribution). Sport fishery value was based on recreational importance as indicated by game fish abundance and size, stream aesthetics and angling use.

Criteria for assigning protected status to a stream were (1) Class I stream reaches which contain habitats critical for sustaining Montana's fish species of special concern (where genetic purity has been established through electrophoresis) and no substantial populations of contaminating species are present, or (2) streams with outstanding recreational fisheries or essential spawning habitats for outstanding recreational fisheries.

RESULTS AND DISCUSSION

Fisheries losses and impacts

Fisheries losses in Flathead Lake and River. Hungry Horse Reservoir inundated 58·3 km of tributary habitat with gradients of less than 6·0 per cent. In addition, 527 km of tributary habitat in the upper South Fork drainage with gradients less than 6 per cent were blocked to migratory cutthroat in the Flathead system by Hungry Horse Dam. Based on stream order and gradient relationships, the total loss of 585 km of tributary habitat represents an annual loss to the Flathead Lake and River system of approximately 175 500 migratory juveniles aged I–III (Table II). In addition, we calculated that habitat supporting 11 600 migratory cutthroat juveniles was lost to the Flathead Lake and River system when Hungry Horse Reservoir inundated 57 km of the South Fork Flathead River. In summary, we calculated that 65 500 juvenile migratory cutthroat were lost annually from Flathead Lake populations, based on the average

Table II. Estimated number of adfluvial cutthroat juveniles lost by stream order and gradient categories (for gradients less than six per cent) in tributary reaches of Hungry Horse Reservoir

Stream order	Gradients (%)	Number of reaches	Length (m)	Number of cutthroat per 100 m (mean)	Total calculated loss (number of fish)
Reaches inundated by Hungry Horse Reservoir					
2	0·4–1·8	4	4 770	22·7	1 083
2	2·2–2·6	2	4 004	56·9	2 278
2	2·8–3·6	5	5 370	77·6	4 167
2	4·0–5·8	8	5 108	31·6	1 614
3	0·6–0·6	1	8 692	22·3	1 938
3	2·6–3·8	9	9 384	25·4	2 384
3	4·3–5·9	5	4 096	43·4	1 778
4	0·9–0·9	1	3 956	5·2	206
4	2·0–3·5	4	12 874	13·5	1 738
	Total	39	58 254		17 186
Reaches above full pool (includes upper South Fork drainage)					
2	1·5–1·5	1	877	22·7	199
2	2·2–2·3	4	9 739	56·9	5 541
2	2·8–3·8	7	13 905	77·6	10 790
2	3·9–5·9	32	79 047	31·6	24 979
3	0·7–1·0	2	10 916	22·3	2 434
3	1·1–1·4	2	9 898	38·9	3 850
3	1·7–2·2	8	51 918	62·9	32 656
3	2·6–4·0	20	86 468	25·4	21 963
3	4·1–5·9	20	62 865	43·4	27 283
4	0·3–0·6	8	38 963	5·2	2 026
4	1·1–1·3	5	40 337	24·0	9 681
4	1·7–4·8	13	68 778	13·5	9 285
5	0·6–0·8	3	53 220	14·3	7 610
	Total	125	526 931		158 297
				Grand total	175 483

age–class distribution and migration rates of each age class of cutthroat from previous studies (Zubik and Fraley, 1987). Based on the proportion of drainage area and average spawning runs in the North and Middle forks, we calculated that approximately 1965 bull trout spawners were lost from the Flathead Lake population when Hungry Horse Dam was constructed. This would translate to a loss of two or three times that number of adults in Flathead Lake because only one-half to one-third of the adult population spawn each year.

We conservatively estimated the annual loss of main stem river-spawning kokanee to be 96 300 adult fish (Beattie *et al.*, 1988). This figure does not include escapement to the North, South and Middle forks of the Flathead River. A creel survey in 1975 estimated that main stem escapement exceeded 330 000 kokanee. Subsequent spawning surveys (Fraley and McMullin, 1983) indicate that 65 per cent of these fish derived from unusually successful spawning in the upper main stem in 1971 to 1972 when hydro operations at Hungry Horse Dam were favourable. The remaining 35 per cent (115 500) derived from reproduction in spring influenced spawning areas. We believe that this lower figure (115 500) approximates historic main stem spawning escapement. Between 1980 and 1984, after a previous period of unfavourable operation at Hungry Horse Dam had impacted spawning success in the main stem, (but before *Mysis* had reached sufficient levels to affect kokanee in Flathead Lake) spawning escapement averaged 19 200 fish. The loss attributable to hydro operation is the difference between 115 500 and 19 200, or 96 300 fish. If mitigation responsibility included the enhanced level of the main stem run, the loss would be the difference between 330 000 and 19 200, or 310 800 fish.

Agricultural and domestic development along the river banks, angler harvest and increased abundance of predatory fish could also have influenced kokanee spawning success and recruitment since Hungry Horse Dam was built. But we believe that the cumulative impacts of hydro operations were far more significant in reducing kokanee production. There appears to be no relationshhip between numbers of hatchery fry planted sporadically in Flathead Lake in the 1960s and 1970s and subsequent numbers of adult fish. *Mysis* were first discovered in Flathead Lake in 1981 and should not have affected kokanee populations during our historic analysis period.

Flathead Lake water level fluctuations associated with the operation of Kerr Dam have negatively impacted the reproductive success of lakeshore spawning kokanee. Since the mid 1970s, the increasing demand for electrical energy in the fall and winter has prompted Montana Power Company to draft the lake more rapidly in the fall and hold the lake near minimum pool for a longer period in the winter. As the lake level recedes in the fall, kokanee redds above the minimum pool elevation are exposed. Unless the incubating eggs are wetted by groundwater seeps, high mortality is incurred within a few days after exposure (Decker-Hess and McMullin, 1983).

Even where favourable groundwater discharge maintains viable eggs, successful emergence is prevented because emergent alevins are isolated from the lake. High egg mortality has reduced the lakeshore-spawning 'stock' to 2–4 per cent of the total escapement in the Flathead system. Surveys in the early 1950s documented 30 spawning areas on the east and west shores of the lake. By the early 1980s, only 12 areas, including only one site on the west shore, attracted spawning runs. A creel survey of the popular lakeshore fishery for spawning kokanee in the fall of 1962 estimated that 134 000 fish were harvested. Because the total lakeshore run averaged about 3000 fish from 1980–1985 (Fraley and Decker-Hess, 1987), at least 131 000 adults have been lost annually because of dam operations. A different interpretation of the relative magnitude of sport harvest and escapement of shoreline spawners (i.e. anglers harvested only half the total run) suggest that the annual loss is 262 000 fish.

Impacts on the biota in Libby and Hungry Horse Reservoirs. Model simulations and the results of the trophic level investigations were used to assess the effects of various dam operating scenarios on abiotic factors and reservoir biota. From 1972 through 1986, the hydraulic residence time of Libby Reservoir averaged 0·64 years (monthly values ranged from 0·1 to 2·66). Rapid replacement of reservoir water weakens thermocline stability. At Hungry Horse Reservoir, water residence averaged 2·76 years during the same period (monthly range 0·21 to 26·21) and a stronger thermal stability was typical.

Primary production peaked between June and August and was two to three times greater at Libby Reservoir than at Hungry Horse Reservoir (Table III). Nutrient concentrations at Libby Reservoir were artificially elevated by effluent from a phosphate mine in British Columbia, Canada. In 1987, mining was discontinued. Additional sampling began in 1988 to detect changes in the phytoplankton community. Model output of annual totals (metric tons of carbon fixed) was more sensitive to reservoir elevations during July and August than to the depth of maximum withdrawal during late winter and early spring. Failure to refill the reservoirs resulted in decreased water volume of optimal temperatures for biological productivity. Production decreased at an accelerated rate as surface elevation deviated from full pool. Direct loss of primary production through the dam was greatest when surface elevation approached the depth of withdrawal and when discharge volume was maximized.

Prediction of zooplankton production responded to simulated dam operation in the same manner as phytoplankton (Table III) and the annual production schedule was nearly the same shape. Loss of zooplankton biomass was significant when the reservoir was isothermal (May and Fraley, 1986) and when surface elevation approached the outflow depth. Predicted loss of zooplankton production was more sensitive to the latter.

Benthic biomass was least ($P \leq 0{\cdot}05$) in the frequently dewatered layer of both reservoirs and varied inversely with the frequency of dewatering (Chisholm and Fraley, 1986; May *et al.*, 1988). Captures of emergent insects indicated decreased production per unit dipteran biomass with increased depth,

Table III. Simulated effects of dam operation on primary and secondary production as related to maximum drawdown elevation at Libby and Hungry Horse reservoirs. Average annual inflow of 9·979 km^3 (8·09 mega acre feet) at Libby Reservoir and 3·351 km^3 (2·717 maf) at Hungry Horse were assumed

	Maximum drawdown (m below full pool)		Primary production (metric tons C)	Zooplankton production (metric tons C)	Per cent loss terrestrial insect deposition	Per cent loss benthic production
Libby	Shallow*	18·7	13 157	1510	8·0	31·5
	Medium*	36·6	11 848	1360	17·4	49·4
	Deep*	46·6	8 870	1018	36·6	79·1
Hungry Horse	Shallow†	12·2	4 337	502	4·9	3·5
	Medium‡	25·9	4 316	495	10·4	5·3
	Deep§	57·9	3 277	376	36·7	20·3

*Drawdown curves from U.S. Army Corps of Engineers, Libby Dam Operations Manual.
†Hungry Horse Reservoir Dry Year Refill Curve.
‡Simulated drawdown based on 25·9-m pre-study recommended drawdown limit.
§1988 drawdown.

however, attesting to the importance of frequently dewatered shallow areas for fish food production. The model showed that failure to refill the reservoirs during late summer had a negative impact on benthic production. Greatest loss of benthic production was caused by dewatering substrate near full pool elevation during peak insect emergence (Grimas, 1961; Fillion, 1967).

Insects on the water surface, important food organisms for cutthroat trout, were mainly dipteran adults during spring and terrestrial insects were most abundant during fall at Libby Reservoir and Hungry Horse Reservoir. Terrestrial deposition was patchy. Average densities in nearshore samples were greater than densities in offshore samples, but did not differ statistically ($P > 0{\cdot}05$). Terrestrial deposition was proportional to reservoir surface area. Simulated drawdown schedules that remain at full pool during periods of insect activity show no loss of potential insect deposition. Conversely, schedules that deviate from full pool result in lost potential; the loss increases with reduced surface area.

Fish species of greatest concern at Libby and Hungry Horse reservoirs are kokanee and westslope cutthroat trout, respectively. Stomach analysis revealed that zooplankton (almost exclusively *Daphnia* spp. <1·5 mm carapace length) was the major food source of kokanee (97 per cent). Aquatic and terrestrial insects constitute the largest percentage of cutthroat food items from spring through fall. As in Libby Reservoir, cutthroat in Hungry Horse Reservoir rely heavily on zooplankton, mainly *Daphnia pulex* >1·5 mm long, during late fall and winter. Fish biomass increased rapidly during late summer and fall at both reservoirs and was greatest when reservoir surface elevation reached full pool by July and remained full through October. Therefore, drawdowns during the September and October period could reduce fish growth substantially.

Measures to mitigate, compensate and protect fisheries in the basin

Mitigation of impacts

Flows to protect fish. Maintaining minimum streamflows in the Flathead and Kootenai rivers would protect riverine fish populations from further damage by hydropower operations. The wetted perimeter method was used to determine minimum flows needed to maintain invertebrate and fish populations in the Kootenai and Flathead rivers below the Hungry Horse and Libby dams. The inflection point on the wetted perimeter–discharge relationship for the Flathead River below the confluence with the South Fork occurred at 99·2 m^3 s^{-1}. Below this flow, the amount of wetted streambed declined rapidly. To maintain this minimum flow in an average water year, discharges from Hungry Horse Dam are required from August through March. Flows from the North and Middle forks alone are sufficient to meet the

99·2 m^3 s^{-1} minimum flow in the Flathead River from April through July in an average water year. Maintaining the minimum flow in the Flathead River would protect benthic insect production, incubating salmonid eggs, and rearing salmonid juveniles. The minimum flow restraint resulted in greatly increased survival of kokanee eggs in the Flathead River in 1985 and 1986 (Beattie *et al.*, 1988).

A maximum flow of 127·5 m^3 s^{-1} in the Flathead River is in place on an interim basis during the kokanee spawning period (October 15–December 15; Fraley *et al.*, 1986a). This flow guideline was designed to prevent kokanee from spawning high on the river margin in areas that would later be dewatered. The guideline will be removed if kokanee do not recover in the system.

The wetted perimeter inflection point for the Kootenai River below Libby Dam occurred between 113·3 and 141·6 m^3 s^{-1}. A minimum flow of 113·3 m^3 s^{-1} would ensure sufficient wetted streambed for aquatic insect production, mountain whitefish spawning and juvenile salmonid rearing.

Flathead Lake level manipulation. To provide significant benefit for kokanee reproduction on the Flathead Lake shoreline, Kerr Dam operations should be changed. These changes may not be compatible with other biological and recreational concerns. Two strategies are possible. The lake could be drafted earlier, so that shallow spawning would occur primarily in the lower half of the drawdown zone. Alternately, the length of time the lake is held at minimum pool could be reduced, so that egg mortality in the lower half of the drawdown zone would be minimized. Refilling the lake to 1 m above minimum pool by March 1 would, under both strategies, minimize exposure mortality and facilitate the emergence of fry. Exposure of the lower half of the drawdown zone was relatively short in the 1960s and early 1970s (Decker-Hess and Clancey, 1984). Favourable operations allowed relatively strong lakeshore spawning runs to persist through the 1960s. But these operational changes at Kerr Dam compromise wildlife populations in the lower Flathead River, reduce the capacity of the dam for flood control and reduce electric power production potential in the fall and winter.

Improved fish passage and operations at Bigfork Dam. With modifications and/or redesign, the fish ladder at Bigfork Dam could pass salmonids migrating upstream from Flathead Lake. Fish passage at this facility would make available 1813 km^2 of drainage area in the Swan system that was blocked when the dam was constructed in 1902. Cutthroat and bull trout could again access spawning and rearing habitat in the Swan River and its tributaries. Rehabilitation of some tributary streams in the Swan drainage may be required since brook trout (*Salvelinus fontinalis*) have become established in many of the lower gradient tributary reaches in the drainage. Removal or substantial reduction of this exotic species would increase the availability of spawning and rearing habitat for cutthroat and bull trout in the drainage.

After ascending Bigfork Dam, kokanee could spawn in the Swan River and along the shoreline of Swan Lake. The number of juvenile kokanee that migrate downstream of Flathead Lake and contribute to the Flathead fishery could be substantially increased.

Mortality of cutthroat adults, juvenile cutthroat, bull trout, and kokanee fry moving downstream over Bigfork Dam from the Swan drainage may not be high because most of the water passes over the spillway, a three to seven m drop, during their migration period from March through the end of July. Adult bull trout survival may be adversely impacted because they migrate downstream to Flathead Lake in the fall (September through October). During this time period, most or all of the flow is diverted through the penstock conduit while a minimum flow of 1·13 m^3 s^{-1} remains in the river channel. Installing screens across the diversion intake would minimize fish entrainment.

Biological rule curves (seasonal reservoir operating guidelines) for Libby and Hungry Horse Reservoirs. Reducing impacts on fishery production by recommending modifications of dam operation is limited by the physical nature of the impoundment and dam structure. The 1938 International Treaty between the U.S.A. and Canada requires 2·467 km^3 (2 million acre-feet) of flood storage in Libby Reservoir by January 1. At extremely low inflows ($<$5·617 km^3 yr^{-1} at Libby Reservoir), it is physically impossible to refill the reservoir within the annual cycle if downstream flows are maintained to sustain the river fishery. Extremely high inflows require additional water storage capacity to contain flood waters and avoid overfilling Libby Reservoir. For this reason, preliminary dam operation rule curves for the period from January 1 through June 30 are incremental based on April 1 through June 30 inflow forecasts (Figure 2). An April–August inflow of 4·089 km^3 (3·314 maf) is required to refill the reservoir from the January 1 mandatory drawdown.

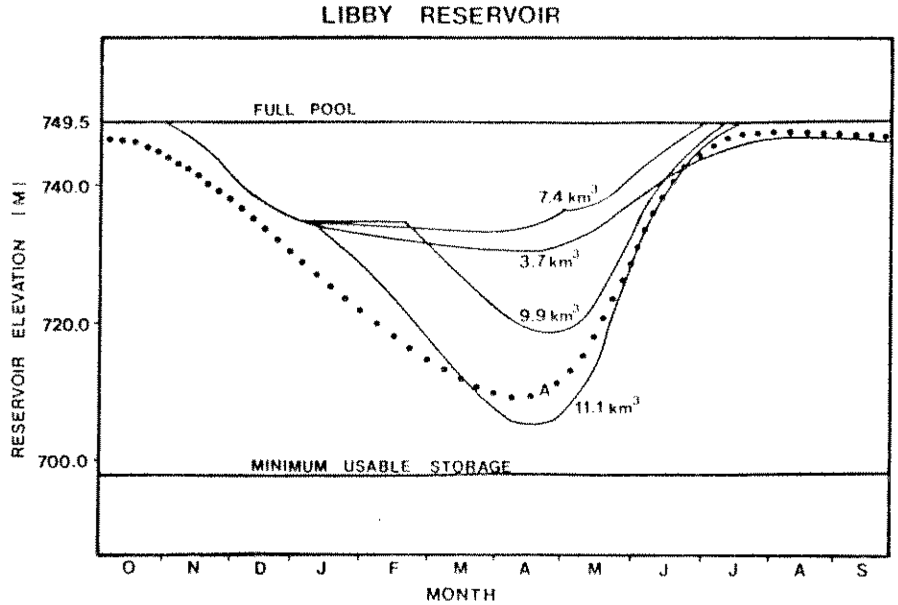

Figure 2. Proposed biological rule curves (seasonal water level guidelines) for dam operation at Libby Reservoir. The rule curve is constant from early July through December 31. A mandatory 2·467 km³ storage capacity is required by January 1 (elevation 734·9 m). The remainder of the water year is incremental based on the April 1 through June 30 inflow forecasts in km³. The numbered curves define maximum drawdown and the rate of drafting and refilling at selected inflow volumes (km³). An April–August inflow ≥4·088 km³ is required to refill the reservoir from the mandatory January 1 drawdown. The dotted line 'A' represents the historical average annual drawdown schedule

Discharge from Hungry Horse Reservoir is regulated to achieve a recommended maximum flow of 127·5 $m^3 s^{-1}$ in the Flathead River at Columbia Falls from October 15 through December 15 for successful kokanee spawning. This restricts the rate at which the reservoir may be drafted. A 40-foot drawdown by January 1 was allowed for flood storage. Preliminary biological rule curves are incremental for the period from January 1 through June 30 based on April 1 to June 30 inflow forecasts (Figure 3). An April to August inflow ≥1·005 km^3 (0·815 maf) is required to refill the reservoir from the January 1 drawdown.

Prior to the present study, interim reservoir drawdown limits were recommended for irrigation or power production (33·5 m at Libby Reservoir and 25·9 m at Hungry Horse Reservoir). The model shows that these limits can be met to maintain reservoir habitat for biological production during winter isothermal conditions and to enhance the probability of refilling the reservoirs. However, the limits cannot be met during April–August flood events >10·107 km^3 (8·194 maf) at Libby Reservoir and >4·134 km^3 (3·352 maf) at Hungry Horse Reservoir. Reservoir drafting should be conservative until the first inflow forecast is available in January, then adjusted monthly as runoff predictions are updated. Early reservoir refill and maximum duration at full pool are important for fish production.

Preliminary biological rule curves are constant from July 1 through December 30 (Figures 2 and 3). After the first of the year, a variable biological rule curve is selected based on the April–August inflow volume forecast. The combined rule curves are maximum drawdown guidelines for irrigation and power production. Compensation levels will be quantified, in part, based on percentage loss of biological production (biomass) calculated by the models when the recommended biological rule curves are violated for purposes other than emergency flood control.

Compensation for losses. Methods not involving changes in hydroelectric operating regimes are the most practicable means of compensating for historic losses to the Flathead kokanee population. These methods include improving of spawning habitat in selected tributary streams, construction of spawning channel(s) on the lakeshore, and supplementing recruitment in the lake by planting hatchery-reared kokanee fry. Formerly productive, spring-fed side channels of the Flathead River would benefit from

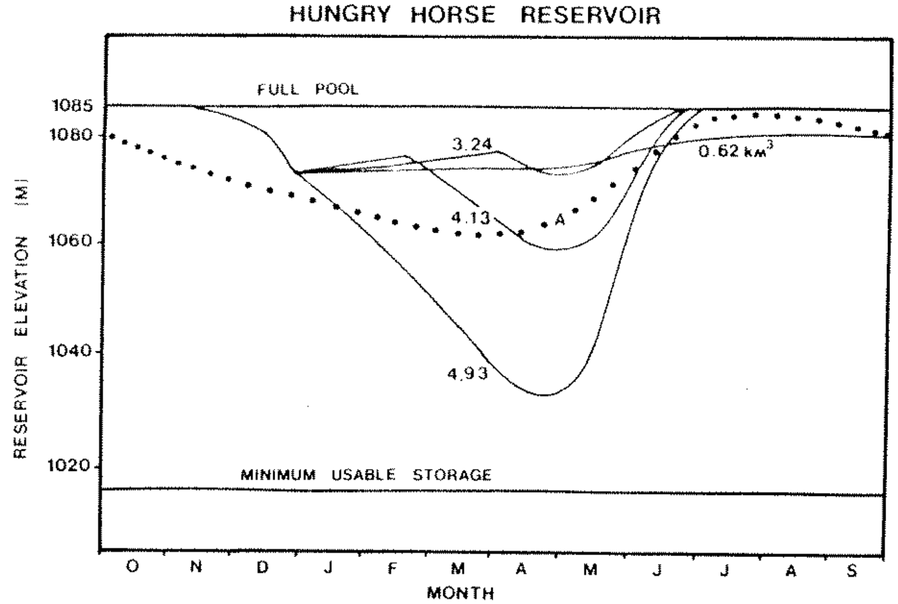

Figure 3. Proposed biological rule curves for dam operation at Hungry Horse Reservoir. The rule curve is constant from early July through December 31 and allows for a 12·19 m drawdown by January 1 for flood water storage. The remainder of the water year is incremental based on the April 1 through June 30 inflow forecasts in km³. The numbered curves define maximum drawdown and the rate of drafting and refilling. An April–August inflow ≥ 1·005 km³ is reguired to refill the reservoir from the January 1 drawdown. The dotted line 'A' represents the historical averge drawdown schedule

removal of fine sediment from the substrate and streambank stabilization. It may be possible to rehabilitate kokanee spawning runs in these areas by planting eggs and/or early alevins.

Spawning channels on the lakeshore, fed by small tributary streams, would also provide high-quality habitat that is not influenced by water level fluctuation. Once the initial construction and development is complete, the operational costs of channels and tributary enhancement are low in comparison with those of a full-scale hatchery.

Production of kokanee fry in a hatchery for direct planting into Flathead Lake has been successful since the 1930s, and could be scaled to meet specific harvest or compensation goals. The survival of hatchery-produced kokanee fry may exceed that of naturally-produced fry (Rieman and Bowler, 1980). Their release may be timed to coincide with peaks in zooplankton in the lake. This is particularly advantageous in systems, such as Flathead Lake, where exotic planktivores, such as the opossum shrimp (*Mysis relicta*) have been introduced. Mysid shrimp compete with planktivorous fish, and may bring about fundamental changes in secondary production, including changes in zooplankton species composition and their temporal and spatial distribution (Morgan *et al.*, 1978; Beattie *et al.*, 1988). Where the viability of small fry, that enter the lake in May, is compromised by competition with mysid shrimp, delayed release of artificially-produced fry is seen as the only means of increasing recruitment. Large-scale hatchery programs depend on the availability of brood stock. The costs of constructing and operating a hatchery facility are high.

Assuming fry-to-adult survival to be two percent (Fraley *et al.*, 1986), replacing the 131 000 adult kokanee lost annually because of Kerr Dam would require planting 6·55 million fry. The introduction of 4·8 million fry would be required to replace the 96 300 kokanee lost annually in the Flathead River because of Hungry Horse operations. Survival of fry could be lower than the levels stated here if the effect of mysids chould not be overcome.

Non-operational means of mitigation appear to be the most feasible way to replace cutthroat losses caused by the construction of Hungry Horse Dam. Correcting fish passage problems at tributaries in the North and Middle Fork drainages would reopen spawning and rearing habitat formerly available to migratory bull and cutthroat trout from Flathead Lake. Plants of hatchery fry could then be made to reestablish migratory salmonid runs. Correction of fish passage problems at road culverts around Hungry Horse Reservoir would benefit migratory cutthroat populations in the reservoir, but would not compensate for losses of migratory populations in Flathead Lake. Degraded habitat in other tributaries on the Flathead system could be improved to increase spawning and rearing area for migratory cutthroat and bull trout in Flathead Lake. Plants of hatchery fry could hasten the establishment of migratory salmonids in these tributaries.

Direct introduction of hatchery-reared cutthroat into Flathead Lake could compensate for some of the fisheries losses incurred when Hungry Horse Dam was constructed. Careful choice of hatchery stocks would avoid genetic contamination of the native westslope cutthroat. Compensation for westslope cutthroat losses would require the introduction of 65 500 fish 200–250 mm in length into the lake annually. Hatchery rearing and introduction of juvenile bull trout may not be practical. There are no records of successful hatchery-rearing of bull trout juveniles to an adequate size (150–250 mm) necessary to introduce into Flathead Lake. Spawning channels for production of migratory cutthroat and bull trout juveniles probably is not a viable means of increasing populations in Flathead Lake because both species have instream rearing requirements of one to three years.

Measures to increase spawning and rearing habitat probably could compensate for only 20 per cent of the loss of cutthroat (based on drainage area). Approximately 80 per cent of the compensation, therefore, would have to be accomplished by direct plants of juveniles into the lake.

Protection from future hydropower development

A total of 100 stream reaches (1386 km) in western Montana met the fisheries criteria and were recommended for protection from future hydroelectric development to the Council (Table IV). Twenty-four per cent of the stream lengths were recommended for the presence of fish species of special concern, including westslope cutthroat trout, bull trout, native rainbow trout and white sturgeon (*Acipenser transmontanus*); 19·2 per cent were outstanding sport fisheries including those of the upper Flathead and Kootenai rivers; and 56·8 per cent were essential spawning habitat for outstanding sport fisheries. Of the 14 proposed hydropower sites in the licensing process in western Montana, the protected areas recommendations would prohibit the development on only one proposed site located on the Kootenai River 16 km below Libby Dam.

The recommended streams constitute resources where hydroelectric development would have significant adverse effects which cannot be adequately mitigated or compensated. Protected area designations ensure that ratepayers' investments in fish and wildlife rehabilitation under the Northwest Power Act are not undermined by new development. Also, protected areas designation will give further developers a clearer message on the value of fish and wildlife resources and provide the Federal Energy Regulatory Commission with information to make hydropower decisions that better reflect the environmental protection being encouraged in the Columbia River basin.

RECOMMENDATIONS

Construction and operation of hydroelectric facilities in the Flathead and Kootenai drainages have caused very significant losses in fish populations and continue to affect both riverine and reservoir fisheries. We recommend consideration of the following alternatives to mitigate harmful effects, compensate for fisheries losses, and provide future protection for fish populations.

1. Protect existing riverine fisheries and mitigate further damage by maintaining a 99·2 $m^3 s^{-1}$ minimum flow in the Flathead River, and a 113 $m^3 s^{-1}$ minimum flow in the Kootenai River. Maintain the 127·5 $m^3 s^{-1}$ maximum flow in the Flathead River below Columbia Falls if spawning runs of kokanee are observed ascending the river.
2. Mitigate impacts to the fisheries in Libby and Hungry Horse reservoirs by following proposed biological rule curves (seasonal guidelines) for the operation of the facilities; compensate for losses of

Table IV. Stream kilometres by drainage and criteria recommended for protection from future hydroelectric development in western Montana

Drainage	Essential spawning habitat	Species of special concern	Class I Sport fishery	Totals
Swan				
# reaches	4	0	0	4
# km	34	0	0	34
Flathead				
# reaches	22	19	1	42
# km	246	139	80	465
Kootenai				
# reaches	16	4	1	21
# km	3396	53	43	432
Clark Fork				
# reaches	8	15	1	24
# km	118	109	80	307
Blackfoot				
# reaches	5	0	1	6
# km	32	0	53	805
Bitterroot				
# reaches	0	3	0	3
# km	0	63	0	63
Total				
# reaches	55	41	4	100
# km	766	364	256	1386

production predicted by the biological models by enhancing the reservoir fisheries or by off-site compensation.

3. Compensate for the loss of westslope cutthroat juveniles to the Flathead system caused by the construction of Hungry Horse Dam by: (1) improving fish passage at Bigfork Dam and planting migrating juvenile cutthroat in streams in the Swan drainage from which brook trout have been removed, (2) rehabilitating habitat in the lower Flathead River tributaries and planting juvenile cutthroat, and (3) introducing 200–250 mm juvenile cutthroat directly into Flathead Lake.
4. Partially compensate for the loss to the Flathead system of bull trout adults by improving fish passage at Bigfork Dam, thus restoring interchange between the Swan and Flathead populations. Further study is needed before artificial enhancement of bull trout in the system could be undertaken.
5. Compensate for the loss of river spawning kokanee and lakeshore spawning kokanee by introducing to Flathead Lake 11·35 million kokanee fry. Half of these fry could be raised in a hatchery and introduced to the lake after being reared in pens. A spawning channel along the Flathead lakeshore or improvement of habitat in spawning areas could provide the remaining half of the fry. If kokanee are not found not to be viable because of the effects of *Mysis*, shift compensation to another species (e.g. westslope cutthroat).
6. Protect important drainages from future development by adopting protected area designations.

These recommendations will be considered by the Montana Department of Fish, Wildlife and Parks and Confederated Salish Kootenai Tribes in cooperation with other agencies in developing a mitigation plan for the Flathead system. This plan will be presented to the Northwest Power Planning Council in

1989 for amendment into their Fish and Wildlife Program. The details of the mitigation plan will depend on fisheries co-management objectives currently being prepared by the Confederated Salish and Kootenai Tiribes and Montana Department of Fish, Wildlife and Parks.

Because of the long-term nature of ecological change after regulation (Petts, 1980) and the biological uncertainty associated with these aquatic systems and the models used to assess them, the recommendations should be flexible and employ principles of adaptive management or 'learning by doing' (Holling, 1978; Lee and Lawrence, 1986; Northwest Power Planning Council, 1987; Walters, 1986). This interactive approach will enable managers to improve on mitigation and management programs as changes occur and new knowledge is gained. Some recommendations may prove to be ineffective, but if a long-term restoration and monitoring effort is part of the plan, the approach should lead to eventual success (Lee and Lawrence, 1986).

Successful implementation of these measures will achieve partial mitigation and compensation for affected fisheries. There are several factors, however, which will limit recovery. First, because of establishment of *Mysis* in Flathead Lake, it may not be possible to maintain reproducing populations of kokanee. Second, technology is not presently available to develop spawning and rearing channels to compensate for losses of bull trout and cutthroat trout. Third, most compensation measures involve introductions of hatchery-reared fish; these could lead to competition with or genetic changes in native populations. Hatchery production is a marginal alternative to losses of natural reproduction. Finally, major changes in water level management and power system design would be required to follow the proposed biological rule curves in Libby and Hungry Horse reservoirs.

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