# FISH FRIENDLY HYDROELECTRIC PROJECT DEVELOPMENT, AN ALASKAN SUCCESS STORY

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## ABSTRACT

Five existing Alaskan hydroelectric projects have proven to be environmentally benign. Siting these projects at high elevations, above productive lowland terrestrial habitat and in basins with perched lakes, where fish are confined to areas well downstream of the dam: 1.) reduces the area, and quality of land inundated, and, 2.) ameliorates project impacts on fish. Mitigation in the form of replacement spawning habitat or application of scientifically justified minimum flow regimes in the downstream, fish bearing stream reaches further reduce impacts and may even benefit salmon use of the regulated stream. Regulated flows benefit fish by reducing the frequency of extreme high flow events that can wash out eggs and young fish and by eliminating low winter flow events that can desiccate or freeze incubating eggs and fish.

## INTRODUCTION

Development of hydroelectric projects has become increasingly difficult recently, due to the negative environmental consequences, both real and perceived, often associated with dams and reservoirs. The current debate in the Pacific Northwest over the effects of Columbia and Snake River projects on salmon and the recent World Commission on Dam's report on Dams and Development (WCD, 2000) are two examples of the controversy surrounding the hydroelectric industry. Negative effects commonly associated with hydroelectric projects include:

- inundation of productive wildlife habitat or agricultural land,
- blockage of migratory routes for fish,
- destruction of spawning and rearing habitat for fish,
- alteration of downstream water quality and quantity,
- inundation of culturally significant resources, and,
- displacement of economically marginal populations.

These effects are most often associated with large, main-stem river projects, particularly projects located in the lower, biologically more productive portions of large watersheds.

Alaska, by nature of climate, topography and population density, presents the opportunity to develop and operate numerous small, environmentally benign hydroelectric projects. Potential sites typically are located in drainage basins with high perched lake systems that

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entirely lack, or have only limited fish resources in the upper basin. Around ten such projects are currently in operation in Alaska and dozens of additional sites are known (Locher Interests Ltd., 1998). While many of the undeveloped sites present real development challenges, largely related to the high up-front development costs of hydro and the environmental constraints of transmission line siting, they represent a valuable potential resource for meeting future energy needs in a rational, environmentally sound manner. This paper describes five existing projects, with an emphasis on their environmental records to date. All are owned by the State and operated by local utilities.

## GENERAL DESCRIPTION OF THE PROJECTS

From the early 1980's through 1991, the State of Alaska, Alaska Power Authority (now the Alaska Energy Authority), working with local utilities, participated in the development of, and acquired ownership of five hydroelectric projects. Table 1 below summarizes the pertinent features of these projects.

**Table 1. Selected features of the five AEA owned hydroelectric projects.**

| Project | Bradley | Solomon | Swan | Terror[1.] | Tyee |
|---|---|---|---|---|---|
| **Location** | Kachemak Bay 21 miles WNW of Homer | South shore of Valdez Bay, 4 miles SE of Valdez | Revillagigedo Island , 22 Miles NW of Ketchikan | Kodiak island, 25 miles SW of Kodiak | 40 Miles SW of Wrangell |
| **Communities Served** | Railbelt Communties[2.] | Valdez and Glenallan | Ketchikan | Kodiak and Port Lions | Wrangell and Petersburg |
| **Initial operation** | 9/1/91 | 7/1/82 | 6/7/84 | 4/1/85 | 5/9/84 |
| **Installed Capacity** | 119.5 MW | 12.0 MW | 22.0 MW | 22.5 MW | 22.5 MW |
| **Type of Dam** | Rockfill concrete facing | Rockfill, asphalitic-facing | Concrete arch | Rockfill, concrete facing | Lake tap |
| **Normal Maximum Pool Elevation** | 1,180 ft, msl | 685 ft, msl | 330.5 ft, msl | 1,420 ft, msl | 1,396 ft. msl |
| **Maximum Active Storage** | 280,000 af | 31, 500 af | 86,000 af | 112,000 af | 52,400 af |
| **Pre-impoundment lake surface area** | 1,242 ac | 100 ac | 1,050 ac | 280 ac | 434 ac |
| **Post-impoundment lake surface area** | 3,820 | 615 | 1,500 | 1,020 | 434 |
| **Additional area Inundated** | 2,578 ac | 515 | 450 | 740 ac | 0[3.] ac |

1. Terror Lake is unique in that it is a trans-basin project. It consisits of a dam on the outlet of Terror Lake and a tunnel diverting water from the lake to a powerhouse located on the nearby Kizhuyak River.
2. Those communities interconnected by transmission systems between Homer, Anchorage and Fairbanks.
3. Tyee Lake is a lake tap project and has no dam.

## PROJECT CHARACTERISTICS CONTRIBUTING TO REDUCED ENVIRONMENTAL EFFECTS

The above projects have certain common characteristics that contribute to their overall low level of environmental impact. None are large, main-stem dam facilities that disrupt the migratory routes of fish or physically impact biologically productive lower river floodplain habitats. Thus, many of the major environmental effects associated with hydropower were completely avoided by virtue of project siting.

Except for Tyee Lake, all were formed by damming the outlet of an existing, perched lake. Tyee Lake, also a perched lake, was not dammed. In all cases the reservoirs are located above waterfalls and/or extremely steep stream sections, biologically isolating them from the lower basin. Three of the projects had no pre-impoundment fish populations in the reservoir or in the river reaches immediately below the dams. One project, Swan Lake, had a small, natural, pre-impoundment population of fish (landlocked kokanee and Dolly Varden char) in the reservoir and Tyee Lake had a population of artificially stocked Arctic grayling. Cold, oligothrophic, high elevation perched lakes in Alaska commonly lack fish entirely or support only small populations of stunted fish.

In addition to the lack of fish resources in the reservoirs, the terrestrial areas inundated were of limited value to wildlife. This was due to the combined effects of steep topography, high elevation and northern latitude. Commonly, lower elevation flood plain and coastal zone habitats are more diverse and biologically productive than higher elevation areas, where climate extremes act to limit biological productivity and diversity. Thus, the inundated areas, particularly at Terror and Bradley, were steep sloped, without extensive zones of productive wetlands and lacking high wildlife value. Further, they were primarily vegetated with species such as dwarf willow and alder and no pre-impoundment clearing was required. The Swan Lake reservoir, located at the lowest elevation and most southerly latitude of the five projects had a biologically more productive inundation zone (temperate rainforest) and pre-impoundment logging was required. However, the Swan Lake reservoir perimeter was mostly steep side slope habitat with relatively low biological diversity.

Finally, given the relatively low productivity and lack of fish populations in and around the reservoirs, cultural resources were essentially absent in the inundation zones (i.e. Pre-historic peoples generally spent little time in areas of low biological productivity).

## COMPARISON TO HYDROELECTRIC DEVELOPMENTS WORLDWIDE

As a means of characterizing the environmental cost of hydroelectric projects worldwide, Goodland (1997) compared the total area of land inundated and the number of people requiring resettlement to the total installed capacity, in Megawatts (MW). The 32 projects evaluated by Goodland averaged 176 hectares (ha) of land inundated and 73 people requiring resettlement per MW of installed capacity (range; 0 – 1,426 ha and 0 – 1,000 people). In contrast, the Alaskan projects inundate an average of only 9.4 ha of land per MW (range; 0 – 17 ha) and none required either resettlement of people or salvage of structures.

Given Alaska's low population density and the high elevation siting of the projects it is not surprising that the number of people requiring resettlement was zero. However, the Alaskan projects also rank well on the basis of total area inundated. This is true even though the total installed capacity of the Alaskan projects is relatively small (40 MW average as compared to 2,914 MW for Goodland's list). One might expect the ratio of inundated lands to installed capacity to be higher for smaller projects. However, by using existing lakes as storage reservoirs, the amount of land inundated was minimized (for the Tyee lake tap project, no land was inundated).

## AQUATIC HABITAT ISSUES

Although the projects can be characterized as relatively benign environmentally, there were definite concerns identified during their planning and construction. Not unexpectedly, most involved fish. Nine species of fish are present at one or more of the five projects. They are listed in Table 2. Table 3 summarizes the use these fish make of area waters.

**Table 2. Common and scientific names of fish found at the five projects.**

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| Chinook (king) salmon | *Oncorhynchus tsawytscha* |
| Coho (silver) salmon | *O. kisutch* |
| Chum (dog) salmon | *O. keta* |
| Sockeye/Kokanee salmon[1.] | *O. nerka* |
| Pink (humpback)salmon | *O. gorbuscha* |
| Cutthroat trout | *Salmo gairgneri* |
| Rainbow trout | *S. clarki* |
| Dolly Varden char | *Salvelinus malma* |
| Arctic grayling | *Thymallus arcticus* |

[1.]Commonly the name kokanee is applied to the landlocked populations such as the one found in Swan Lake while sockeye (or red) salmon is used for ocean going populations.

**Table 3. Fish use of project waters, by project and species (main species or habitat use[1.] delineated by bold type).**

| Species | Bradley | Solomon | Swan | Terror | Tyee |
|---|---|---|---|---|---|
| Chinook | **SS, SI, SR** | | | | |
| Coho | SS, SI, SR | | | SS,SI,SR | SR |
| Chum | SS, SI | SS, SI | | **SS,SI** | |
| Sockeye | SS, SI, SR | | | | |
| Kokanee | | | **RR**[1.] | | |
| Pink | **SS,SI** | **SS, SI** | | **SS,SI** | **SS,SI** |
| Cutthroat trout | | | | | SR |
| Rainbow trout | | | | | SS?,SR |
| Dolly Varden | | | RR | SS | SR |
| Arctic grayling | | | | | RR |

[1.]SS = Stream Spawning, SI = Stream Incubation, SR = Stream Rearing, RR = Reservoir Resident

As shown in Table 3 and in Table 4, four of the project river systems support anadromous salmon in their downstream reaches. At Solomon and Tyee, use is restricted to tidewater and short stretches of stream above tidewater. However at both Bradley and Terror substantially larger areas of the stream support salmon. In addition, at Terror, the lower 1.5 miles of the Kizhuyak River, which receives the outflow from the project powerhouse (and thus is subject to project effects on discharge) also supports salmon spawning and rearing.

**Table 4. Stream distance between tidewater and the project dams compared to distance from tidewater to the upper limits of fish use.**

| Stream Distance | Bradley Lake | Solomon Gulch | Swan Lake | Terror Lake | Tyee Lake |
|---|---|---|---|---|---|
| Tidewater to dam | 10 miles | 5,000 ft | 2,790 ft | 8.5 miles | 1.9 miles |
| Upper limit. salmon use | 6.0 miles | 1,000 ft | 0 | 4.5 miles | 1,000 ft |

In all four projects supporting anadromous salmon, the most numerous species is pink salmon. Thus, pinks were used as the primary indicator species, against which project impacts were evaluated and for which mitigation was planned.

At Bradley, chinook and coho salmon also utilize the lower river for spawning, incubation and rearing (Morsell, 1995, 2000). In addition, the lower river also supports some chum and a few red salmon (Morsell, 1995, 2000). The Terror River supports a large run of chum as well as a small population of coho salmon. (Blackett, 1992). At Tyee, chinook, chum and coho salmon "occasionally" spawn and rear in the stream and rainbow trout, cutthroat trout and Dolly Varden char reportedly use lower Tyee Creek for rearing (Kelly, 1987). Finally, Tyee Lake supports an introduced population of Arctic Grayling (FERC, 1981).

In contrast to the other projects, there was no pre-project anadromous salmon use of Falls Creek (the Swan Lake outlet stream), even in the short section below the isolating waterfalls. However, Swan Lake did support a small pre-impoundment population of land locked kokanee salmon, along with Dolly Varden char (Hoopes, 1978).

## Project Specific Concerns

None of the projects supported significant fisheries above the dams. Further, no migratory routes were blocked by the dams, limiting fisheries impacts to the lower stream reaches. Nevertheless, fisheries issues were of primary concern at all the projects. Concerns centered on operational effects on downstream water quality and quantity. Specific issues included:

- reduced and/or seasonally altered flows in the spawning areas,
- reduced frequency of flushing flows with resultant habitat deterioration due to sedimentation, and,

- changed water quality including altered thermal regimes effecting the rate of egg and alevin development.

The primary concern at both Terror and Bradley was the potential impact of altered flows on downstream spawning, incubation and rearing of salmon. At Tyee, in addition to the impact of altered flows on salmon use of Tyee Creek, increased seasonal draw down of Tyee Lake and resultant isolation of Arctic grayling from tributary stream spawning habitat were concerns. At Swan, the concern was for loss of kokanee and Dolly Varden char spawning habitat, due to inundation of shoreline and/or tributary stream habitat.

**Fisheries Evaluation and Mitigation Programs**

Both pre- and post-operational studies were carried out at all the projects. Neither the pre-operational analyses nor the post-operational monitoring studies found any evidence of significant water quality effects from the projects. In contrast, post-operational changes to downstream flow regimes were recognized by all parties as having the potential for impacting fish. As a result, each of the five project licenses contains one or more special conditions intended to ensure the protection of the fish resources.

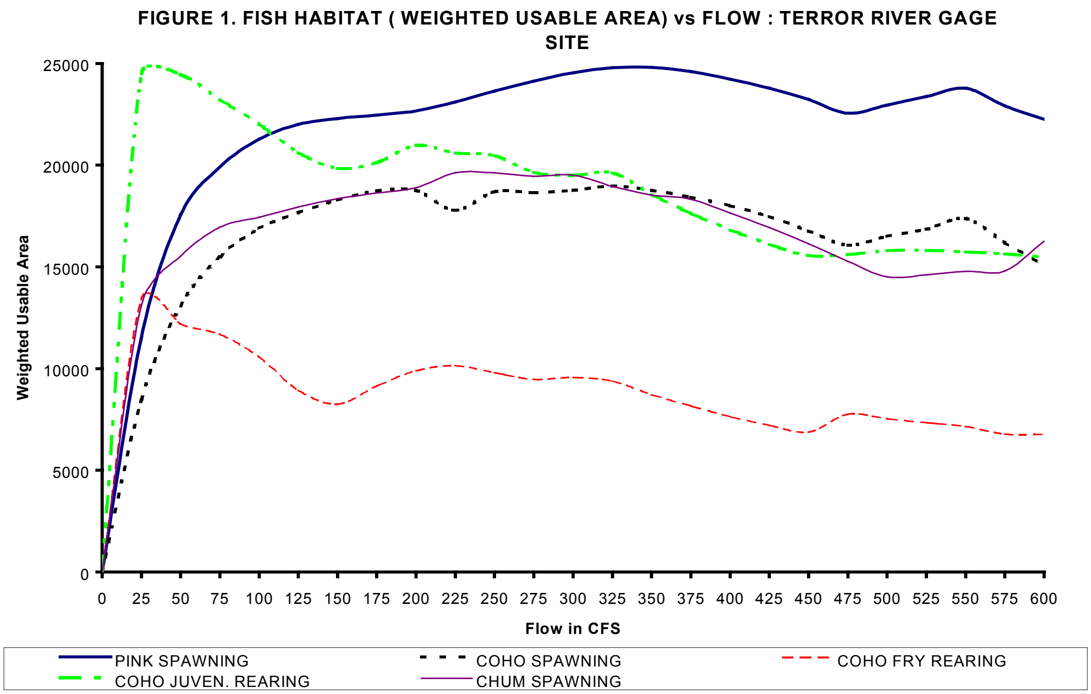
At both Bradley and Terror the U. S. Fish and Wildlife Service's Incremental Instream Flow Methodology (IFIM) was used to establish post-impoundment minimum flow requirements. IFIM work was supported by multi-year fish monitoring and the collection of other basic habitat information. For the other projects pre- and post-operational studies focused on quantifying fish usage.

Three projects, Bradley, Terror, and Solomon Gulch have minimum flow requirements, designed to provide adequate downstream habitat at all times of the year. Minimum flow at Solomon Gulch is set at two cubic feet per second (cfs) year round. More complex minimum flow requirements were established for Terror and Bradley, as detailed in Table 5, below.

**Table 5. Minimum flow regimes for the Bradley Lake and Terror Lake projects**

| **Bradley Lake** | | **Terror Lake** | |
|---|---|---|---|
| **Dates** | **Discharge** | **Dates** | **Discharge** |
| May 12 – Sep 14 | 100 cfs | Jan – Mar | 60 |
| Sep 15 – Sep 23 | Decrease at 5 cfs/day | Apr | 100 |
| Sep 24 – Oct 31 | 50 cfs | May – Oct | 150 |
| Nov 1 – Nov 2 | Decrease at 5 cfs/day | Nov 16 – Nov 30 | 100 |
| Nov 3 – Apr 30 | 40 cfs | Dec | 60 |
| May 1 – May 11 | Increase at 5 cfs/day | | |

Figure 1 below presents the IFIM derived relationship between flow and fish habitat developed for Terror Lake (Arctic Environmental Information and Data Center, 1981). This information was used to develop the Terror Lake minimum flow requirements shown above. Similar IFIM information was used to develop the Bradley Lake flow requirements.




No minimum flows were required at Tyee Lake. Without a dam and outlet works, release of flow into Tyee Creek would be difficult. However, to offset anticipated habitat loss due to decreased flow in Tyee Creek, 950 lineal feet (28, 500 square feet) of the project tailrace was supplied with gravel, to create replacement spawning habitat.

At Swan Lake, with no downstream fish use, minimum flows were not required. However, it is a post licensing requirement that the licensee consult annually with both the U. S. Fish and Wildlife Service and the Alaska Department of Fish and Game as to the status of reservoir fish populations. The purpose of this consultation is to determine if evidence has been found of any deterioration of the fish populations in the reservoir. Should such evidence be detected, the licensee is required to conduct more detailed studies to determine the cause, and, presumably to develop a plan to address the cause.

## EVALUATION OF PROJECT EFFECTS ON THE FISH RESOURCES

### Tyee Lake

Only two of the three turbine generator units planned for Tyee have been installed. Further, loads have been less than anticipated and the project has operated at a reduced level from that assumed during licensing. As a result, neither the extreme seasonal draw down of Tyee Lake nor the reduction in flow in Tyee Creek has occurred as anticipated.

With no lake draw down, the issue of impacts to Arctic grayling disappeared. As reported by Kelly (1987), salmon spawn successfully in the new tailrace habitat. Moreover, with only minimum reduction in Tyee Creek flow, this habitat continues to be available and the total amount of available spawning habitat has increased since project completion. Concern that the tailrace spawning gravel would become unsuitable for spawning due to sand deposition and embedding have not been borne out. A recent analysis (Harza, 1995) concluded that gravel composition is comparable to the original material, placed at the time of construction. Operations staff observations that substantial numbers of pink salmon spawn, both in the tailrace and Tyee Creek, supporting a conclusion that mitigation was successful and that the project has not harmed area fish.

An inter-tie between the Tyee Lake project and Ketchikan is being planned. Should this project proceed and a third unit be installed Tyee likely will be operated at or near capacity. In such a case fisheries issues will require re-evaluation as some level of increased impact is likely.

**<u>Swan Lake</u>**

Studies of the fish populations of Swan Lake do not indicate that reservoir fish have suffered. As shown in Table 6, while post-impoundment capture numbers are somewhat lower than those reported from pre-impoundment studies, the overall resource conditions appear to be generally unchanged. As summarized by Kelly (1998):

> *"Past studies (R. W. Beck and Associates. 1987) have shown Swan lake to contain a small (both in number and size) population of kokanee along with an even smaller population of Dolly Varden. Data collected during the 1998 Swan lake study indicate that the fish populations have continued to reproduce and grow in a manner similar to that of the pre-impoundment and post-impoundment populations, as shown in previous monitoring studies."*

This is in agreement with Hoopes (1978) who reported that while pre-impoundment catch rates and average lengths of fish taken varied considerably from year to year none of the data could be characterized as evidence of anything other than a relatively small population of stunted individuals. Post-impoundment data indicate that Swan Lake continues to support a small population of fish, similar to that present before project completion. This is the expected case given the isolated, oligotrophic character of Swan Lake, both in its pre- impoundment state and as it exists today.

**Table 6. Pre- and post-impoundment sampling results from Swan Lake.**

| Year | Age Class | Number Taken | Average Length (mm) |
|---|---|---|---|
| **Pre-impoundment** | | | |
| 1980 | 0 | 0 | -- |
| | I | 35 | 141 |
| | II | 43 | 183 |
| 1982 | O | 0 | -- |
| | I | 31 | 140 |
| | II | 46 | 184 |
| 1984* | 0 | 16 | 67 |
| | I | 21 | 188 |
| | II | 56 | 222 |
| **Post-impoundment** | | | |
| 1985* | 0 | 41 | 70 |
| | I | 1 | 180 |
| | II | 24 | 230 |
| 1987* | 0 | 12 | 68 |
| | I | 3 | 171 |
| | II | 17 | 205 |
| 1998** | 0 | 0 | -- |
| | I | 6 | 135 |
| | II | 17 | 201 |

*R. W. Beck, 1987, **Kelly, 1998

Moreover, even if the operation of Swan Lake were to result in a reduction or elimination of fish from the impoundment, it is almost certain that the populations would be restored. Lost Lake, a small natural lake located upstream from Swan Lake supports both kokanee and Dolly Varden char and is a natural source of recruitment for the reservoir.

## Solomon Gulch

The Solomon Gulch project continues to support substantial numbers of pink salmon spawning in both the lower section of Solomon Gulch Creek and in the project tailrace. However, project effects on fish have been obscured by the construction of a hatchery at the mouth of Solomon Gulch Creek. Hatchery returns have overwhelmed the small population of wild pink salmon and little can be deduced as to project effects on the artificially enhanced population that now utilizes the area. Nevertheless, there is no evidence that the project adversely effects fish that are use the area.

## Terror Lake

While there was initial concern that the Terror project had the potential to negatively effect fish in the lower Terror River, it also was anticipated that a minimum flow release regime tailored to the system would provide adequate mitigation. As detailed below, this seems to have been the case. Among the predicted effects of the minimum flow regime at Terror Lake were benefits due to decreased frequency of the extreme high flows that scour redds (spawning nests constructed in the river gravel) and elimination of extreme low flow events during winter that de-water redds or freeze out incubating fish. In addition, there was concern that the lack of occasional high flow events might result in a deterioration of spawning habitat due to stream aggradation. In the Kizhuyak River augmented winter flow, from powerhouse discharge was predicted to provide limited fisheries benefits.

Post-project monitoring studies, (Blackett, 1992) as summarized by Railsback and Trihey (1992) confirm that the project had no discernable negative impact on the salmon use of the two effected streams (see Table 7, below). In fact, Trihey and Railsback (1992) concluded that evidence of an overall benefit could be seen, at least in the Terror River.

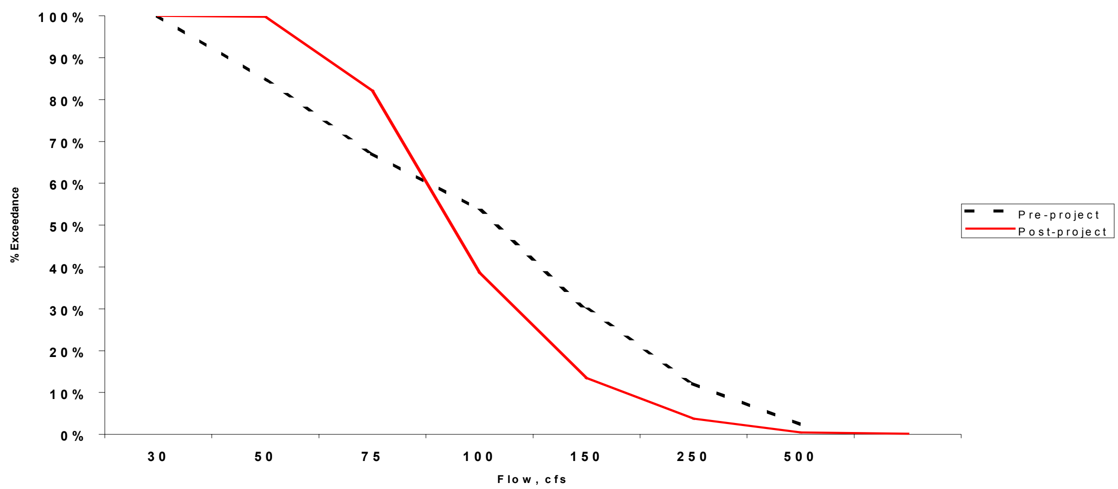
**Table 7. Pre- (1982-85) and post-impoundment (1986-88, 1990) escapement and return data for the Terror River, Kizhuyak River and two nearby reference streams.**

| | **Average Escapement** | | **Average Return[1.]** | | **Ratio[2.]** |
|---|---|---|---|---|---|
| | Pre-project | Post-project | Pre-project | Post-project | |
| **Terror** | | | | | |
| Pink | 62,000 | 113,000 | 193,000 | 313,000 | 1:1.62 |
| Chum | 9,000 | 11,250 | 22,750 | 24,750 | 1:1.09 |
| **Kizhuyak** | | | | | |
| Pink | 28,500 | 62,250 | 90,750 | 99,750 | 1:1.10 |
| Chum | 7,750 | 25,250 | 15,500 | 36,250 | 1:2.34 |
| **Reference[3]** | | | | | |
| Pink | 208,750 | 246,250 | 748,500 | 1,133,500 | 1:1.51 |
| Chum | 33,250 | 64,000 | 97,250 | 115,725 | 1:1.19 |

1. Estimated escapement plus estimated commercial harvest for the statistical area.
2. Ratio of pre-project returns to post-project returns.
3. Combined numbers for the Uganik and Uyak rivers

That the post-operation flow regime provides significantly improved winter flow conditions is evidenced in Figure 2 and Table 8 below. Post-operational experience shows that the Terror River receives substantial input from the drainage area below the dam, in addition to that released from the dam. As a result, discharge at the USGS gage near the mouth of the river, where flow is monitored, commonly exceeds the required minimum. Further, high flow events, capable of moving gravel downstream through the system, have and will likely continue to occur. In fact, the maximum average daily discharge recorded to date, 4,610 cfs, occurred in the post project period. This maximum was related to a September 1995 storm event that caused widespread flooding throughout south central Alaska.

**Figure 2. Terror River gage, pre- and post-project winter exceedence curves (Jan – Mar)[1.]**




[1.] Pre-impoundment flows 1982 – 84, Post-impoundment flows 1985 – 1999.

**Table 8. Pre- and post-impoundment discharge data (based on average daily discharge in cfs), Terror River gage, mouth of Terror River.**

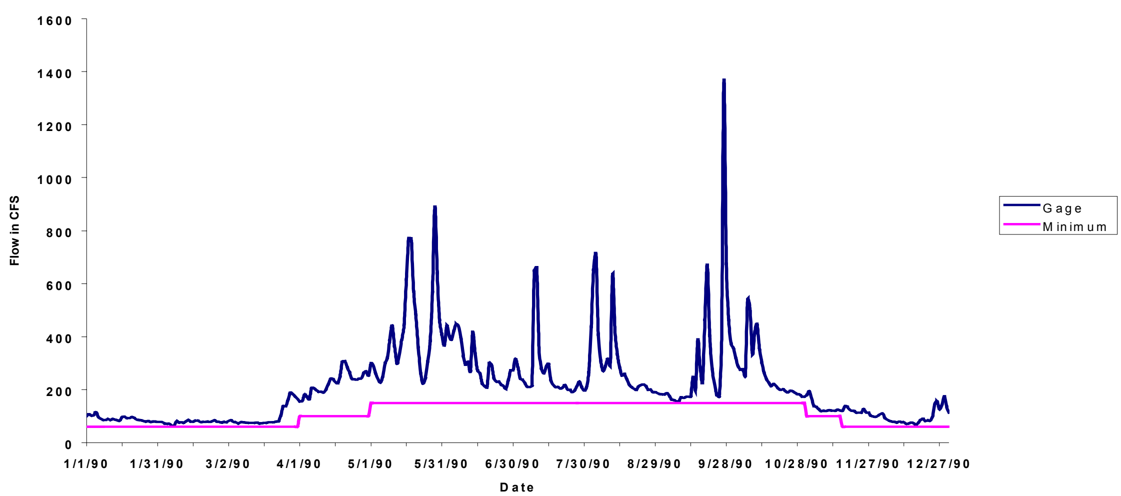
| | Pre-project | | | Post-project | | |
|---|---|---|---|---|---|---|
| Month | Minimum | Maximum | Average | Minimum | Maximum | Average |
| Jan | 24 | 734 | 100 | 51 | 983 | 127 |
| Feb | 19 | 400 | 82 | 49 | 1120 | 111 |
| Mar | 19 | 599 | 94 | 50 | 432 | 100 |
| Apr | 24 | 357 | 94 | 47 | 880 | 173 |
| May | 60 | 1430 | 394 | 112 | 1230 | 328 |
| Jun | 290 | 2110 | 816 | 179 | 1760 | 502 |
| Jul | 96 | 2000 | 577 | 161 | 2100 | 375 |
| Aug | 85 | 2010 | 330 | 155 | 1380 | 294 |
| Sep | 92 | 2500 | 375 | 137 | 4610 | 302 |
| Oct | 75 | 2600 | 243 | 142 | 2540 | 279 |
| Nov | 47 | 2210 | 214 | 31 | 2010 | 183 |
| Dec | 34 | 1100 | 156 | 26 | 1290 | 143 |

Thus, while the Terror Lake Project has changed downstream flows, the effect has not been deleterious to the fish and may be beneficial. To understand why this is so, it is important to note that the distance between the point of release of fish flows at the dam and the point of compliance monitoring is about eight river miles. Moreover, of the total drainage area of the basin, (46.3sq. mi.), 67 percent or 31.2 sq. mi is below the dam. Thus, natural inflow from below the dam contributes heavily to total discharge at the gage, where the project is monitored. This means that the river maintains a more natural flow regime in the downstream, fish bearing areas than might be expected. Due to the long lag time between release of water at the dam and its arrival at the gage (up to six hours), project operators must utilize a conservative approach to maintaining minimum discharge. That is, they release more water than required, to guard against violations should a sudden cold snap or other event in the basin below the dam cause a sudden decrease in natural inflow below the dam. This is necessary because the minimum flow requirement is enforced as an instantaneous flow and even a short departure from the required value is considered as a potential violation of the license condition.

As a result, post-project flows regularly are higher than the required minimum. In some cases this is solely due to the contribution of the downstream basin. In June, for example, the project almost never releases water from the dam. Between 1985 and 1999, average daily discharge in June due exclusively to natural inflow below the dam is 500 cfs. The minimum average daily discharge recorded for June during that same period is 156 cfs. At other times of year, particularly in winter, conservative operation result in flows at the gage that are generally higher than required and are well above the periodic low winter events that commonly occurred before project completion. In March, historically the month of lowest stream discharge, the minimum average daily flow for the 1985-1999 post-operational period was 50 cfs, as compared to a minimum of 19 cfs under pre-project conditions.

Figure 3 shows a typical annual discharge record at the lower river gage, as compared to the required minimum flow for fisheries. As seen, in the summer the intervening flows from the basin below the dam provide more than is required while in winter conservative operation results in discharges significantly above the mandated 60 cfs.

**Figure 3. Average daily discharge at Terror River Gage site compared to license mandated minimum discharge, calendar year 1990**




## <u>Bradley Lake</u>

Table 9 summarizes pre-and post-impoundment escapement estimates for Bradley River pink salmon, the principal species using the river. Table 10 provides data on chum, coho, sockeye and chinook salmon, as trap net catch-per-hour, for the same period.

**Table 9. Estimated Bradley River pink salmon escapement, 1986 1998.**

| Pre-impoundment | | Post-impoundment | |
|---|---|---|---|
| Year | Estimated Escapement | Year | Estimated Escapement |
| 1986 | 4,700 | 1991 | 8,370 |
| 1987 | 4,050 | 1992 | 600 |
| 1988[1.] | 300 | 1993 | 24,500 |
| 1989[2.] | 46,500 | 1994 | 3,980 |
| 1990 | 1,900 | 1995 | 48,000 |
| | | 1996 | 1,520 |
| | | 1997 | 32,5 00 |
| | | 1998 | 875 |

[1.] Even year returns of pink salmon in the Bradley River have been poor since 1986, when heavy flooding likely washed out spawning habitat in the lower river.
[2.] Closure of commercial fisheries following Exxon Valdez oil spill may have contributed to abundance of pink salmon in 1989.

**Table 10. Pre- and post-impoundment trap net catch-per-hour data for Bradley River chum, coho, sockeye and chinook salmon.**

| Species | chum | coho | sockeye | chinook |
|---|---|---|---|---|
| **Pre-impoundment** | | | | |
| **1986** | 0.15 | 0.050 | 0.003 | 0.019 |
| **1987** | 0.02 | 0.017 | 0.002 | 0.013 |
| **1988** | 0.02 | 0.028 | 0.020 | 0.028 |
| **1989** | 0.27 | 0.060 | 0.040 | 0.010 |
| **1990** | 0.11 | 0.037 | 0.077 | 0.019 |
| **Post-impoundment** | | | | |
| **1991** | 0.03 | 0.080 | 0.056 | 0.018 |
| **1992** | 0.01 | 0.028 | 0.027 | 0.019 |
| **1993** | 0.05 | 0.005 | 0.040 | 0.039 |
| **1994** | 0.04 | 0.088 | 0.073 | 0.024 |
| **1995** | 0.08 | 0.0452 | 0.020 | 0.045 |
| **1996** | 0.06 | 0.0853 | 0.112 | 0.046 |
| **1997** | 0.07 | 0.026 | 0.077 | 0.078 |
| **1998** | 0.01 | 0.012 | 0.045 | 0.051 |

Morsell (1995,2000) summarizes the results of the monitoring studies done in the Bradley River as follows:

- Odd year pink salmon have done well under regulated flow, as evidenced by the large 1993, 1995 and 1997 runs.
- Even year pink escapements continue to be poor, as has been the case since 1986, when severe flooding significantly changed the most heavily used pink salmon spawning area.
- Chum salmon may have been adversely affected by regulated flow, possibly by decreased availability of upwelling groundwater. However, area wide chum returns were poor during 1990 –98 and the Bradley results may reflect area trends.
- Chinook salmon returns have increased in size since flow regulation, with the highest returns occurring in the last four years of the study (1995-98). Qualitative

observations indicate that the amount of spawning and rearing habitat for chinook may have expanded under project regulated flows.

As in the Terror River, regulated flow in the Bradley River has reduced the frequency and severity of high flow events while providing more stable winter flows (Table 11). As in the case for the Terror project, low flow events in winter have been largely eliminated by the project while overall average flows and peak flow events have decreased. This has produced habitat changes that effect the fish in a variety of ways.

**Table 11. Pre- and post-project discharge data (as monthly averages cfs), Bradley River Gage, mouth of Bradley River.**

| | Pre-project | | | Post-project | | |
|---|---|---|---|---|---|---|
| Month | Minimum | Maximum | Average | Minimum | Maximum | Average |
| Jan | 32 | 777 | 159 | 40 | 174 | 58 |
| Feb | 37 | 343 | 91 | 46 | 356 | 71 |
| Mar | 38 | 350 | 83 | 44 | 129 | 53 |
| Apr | 30 | 195 | 67 | 40 | 193 | 66 |
| May | 51 | 1930 | 452 | 82 | 396 | 169 |
| Jun | 464 | 2820 | 1050 | 97 | 365 | 168 |
| Jul | 892 | 2650 | 1392 | 98 | 205 | 143 |
| Aug | 585 | 3820 | 1286 | 107 | 262 | 140 |
| Sep | 365 | 2510 | 836 | 58 | 954 | 141 |
| Oct | 97 | 10000 | 808 | 58 | 231 | 86 |
| Nov | 53 | 2400 | 224 | 46 | 725 | 84 |
| Dec | 19 | 3610 | 198 | 40 | 421 | 61 |

As a result of this regulated flow regime, depth, width and velocity have been reduced in the lower Bradley River. In the lower, tidal reaches siltation has increased, decreasing habitat value for salmon. However, upstream sections that previously were deep, fast and lacking in suitable substrate have become usable for spawning through the deposition of suitable substrate. Thus, spawning activity has moved upstream in the river and it appears that there has been a net increase in pink salmon spawning habitat since the project went on-line (Morsell, 1995, 2000). This expansion of spawning habitat to upstream areas has been especially important to chinook salmon, as they are better able to utilize the faster, deeper portions of this habitat.

Finally, a dramatic, if unanticipated change noted following completion of the Bradley Project was the increase in observed use of the lower Bradley River by wildlife. With reduced flows and continued use by salmon for spawning, the river provides more access to salmon carcasses than was the case in the past, when strong currents tended to rapidly flush them away. Black bear, fox, mink, eagles, gulls, ravens and magpies have been observed feeding on salmon. In addition, lower summer flows, shallower water and reduced current velocities have made the river a travel corridor for wildlife rather than a barrier, as it once was.. During the post-project fisheries monitoring studies, moose and black bear were observed to routinely travel across the river and river otter and mink were seen using the area more frequently.

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