Spada Lake Biological Assessment and Sport Fishery Evaluation

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Executive Summary

Spada Reservoir, 1870 acres when full, is by far the largest freshwater lake in Snohomish County. It is the only lake of its nature in the greater Seattle-Everett area with vehicular and trailered boat access. The mountainous reservoir environs create a locally unique angling opportunity for wild, naturally–produced trout. The fishery, when coupled with modern, well–maintained access, picnic, and viewing areas, is a recreational gem sitting on the doorstep of the Puget Sound urban corridor.

Periodic creel surveys have been conducted on Spada Lake since 1985 to monitor the trout fishery, and assure its maintenance on a natural–production basis. An important objective of this study was to evaluate the success (or failure) of its maintenance since enlargement of the reservoir in 1984.

Trout fishing on Spada Lake in the mid 1980s was superb, as documented by periodic whole–season creel surveys. Unfortunately, the fishery has deteriorated over the past decade. By 1995, harvest rates had dropped to nearly zero, and angler effort was the lowest on record, even lower than that seen before reservoir enlargement in 1984. Most Spada Lake anglers in 1995 were fishing it for the first time, indicating many former users had abandoned the fishery due to displeasure with the low harvest rates. There was a very high non–compliance rate (nearly 58%) on the 12" minimum size regulation as anglers seemed compelled to retain fish just shy of the legal length.

On–lake studies in 1996-97 were focused on the biology of the trout, and an assessment of the lake's zooplankton food resources. Attention was paid to those factors which may be limiting trout growth and survival, particularly the infection dynamics of *Diphyllobothrium*, a trout cestode parasite. Other elements of the study were a first–ever summary of the operational characteristics of the reservoir, a compilation of its physical and chemical characteristics, and an evaluation of its fish production potential.

All available information on the fishery through 1997 was analyzed and evaluated in terms of its attainment of the Goals and Objectives of the Washington Wildlife Commission. From this review, further critical research was identified, as well as management and regulations changes that can be made immediately which will result in improved fishing.

Spada Lake is a rapidly flushing reservoir (ca. three times/yr) with remarkably low nutrient levels. Its heat budget in 1995 showed it to be a relatively cool lake, below both median and mean values for lakes of similar size, elevation, and latitude. Based on these edaphic factors, its fish production potential (hence, fishery yield) is also quite low. In addition, the lake is quite turbid in the spring, further depressing productivity and limiting angling success.

Zooplankton food resources are not abundant, and are reflective of a relatively sterile, oligotrophic system. Low phytoplankton production is the ultimate cause of zooplankton (and benthos) food shortages. This is aggravated by a probable high density of brown bullheads and juvenile trout. The zooplankton community showed evidence of excessive planktivory (overwhelming abundance of inedible *Holopedium* and near–absence of *Daphnia*). Without supplemental fertilization, the reservoir is expected to remain a cool, unproductive system since nutrients added by flooded soils in the mid 1980s (which fueled the best fisheries) have probably been exhausted.

Preliminary data on the benthic invertebrate community shows the classic distribution of species in a reservoir where much of the littoral zone is annually exposed. Larger macroinvertebrate species such as snails, dragonfly and damselfly nymphs, and leeches are largely absent, both in the lake and in the trout diet. Chironomid larvae and oligochaetes were relatively abundant, but the latter were not eaten by trout. Midge larvae are an important part of the trout diet, but are clearly insufficient to maintain trout condition.

The overall trout population in the reservoir is about one half rainbow, about one third cutthroat, and about one fifth hybrids of these two. A preliminary, indirect estimate of trout fry recruitment ranged from 0.56 to 2.5 trout/acre, very low values. A more definitive assessment is needed, based on mark–recapture or tributary fry trapping methods. Annual mortality (fishing + natural) for all trout combined was estimated as 45 percent in 1997. A first–ever trout population estimate based on two differing approaches ranged from 2269 to 10,162. The latter is more reasonable, but still represents a very low density of 5.4 trout/acre.

Length frequencies of the trout collected correlated closely with length–at–age data. Most trout were Age 1 to 3, with older trout being relatively scarce. Trout larger than 32 cm (12.5") were rare, which explains the low harvest rate seen in the 1995 creel survey. There was no evidence from vertical gillnetting that larger, older trout preferred deeper water.

Total trout standing stock was estimated as a little less than 1.0 lb/acre. Based on Spada's water chemistry and morphometry, and models from other reservoirs, standing stock should be closer to 40 lbs/acre. The difference is probably due to an erroneous population estimate, and/or the lack of an estimate of brown bullhead biomass. Rectifying both data deficiencies is a high priority for additional research.

Trout age and growth data were analyzed from samples collected in earlier years, both pre– and post reservoir enlargement. Annual incremental growth of trout Age 3 or older was significantly lower in 1997 than in 1992, the most recent sampling period. Trout growth rates in Spada are lower than most other area reservoir trout populations. Most trout legally harvestable (≥ 12") are at least Age 3, mostly Age 4 or older. Annual growth increments for trout Age 3 or older in Spada were well below that seen in other area reservoir trout populations. Since these other reservoirs have similar potential productivity (morphoedaphic factors), the abundance of brown bullheads in Spada may be a significant factor affecting trout growth rates.

Overall, trout were in poor condition in Spada Lake in 1997. Relative weights of both rainbow and cutthroat were almost always below the median, or "good" value of 100 established for this index. Only rainbow showed a slight increase in relative weight over the summer. The 1997 trout samples showed a sharp decline in both relative weight and relative condition after 11 to 12 years of reservoir aging. Ninety three percent of all trout sampled in 1997 had little or no internal fat, and 55 percent of all trout entering the winter had little or no internal fat. Fat content and relative weight were correlated with trout parasite levels, and indirectly, with mortality.

Although almost all trout were obtaining some food between early April and mid–October, internal fat levels were extremely low, as was relative weight for most age groups. About six percent of all stomachs were judged to be full; a running biweekly mean of degree of fullness was always less than 50 percent. The trout diet is currently predominantly midge pupae or larvae, supplemented with terrestrial insects and stone– or caddisfly nymphs that wash in from the tributaries. Zooplankton (cladocerans) is less important throughout the year. Preferred cladoceran species (*Daphnia*) are only suitably abundant and large to elicit a trout feeding response for a few weeks of the year.

Rainbow, cutthroat, and their hybrids were found to be infected with *Diphyllobothrium ditremum*. Prevalence of the tapeworm parasite varied seasonally in all three trouts, ranging from 10 to 100 percent overall, but was between 50 and 100 percent in mid–November, going into the stressful winter period. Infection intensity varied greatly, with plerocercoid counts ranging from 0 to 185 in individual trout. The trout spend one or two years in the tributaries before entering the reservoir. First–year reservoir residents built infections to a mean mid–summer peak of 27 plerocercoids/fish, but declined to a fall level of 4/fish. Patterns of intensity over the sampling period varied between the trout life history groups, with first–year reservoir residents potentially suffering greatest mortality.

Infection intensities observed are sufficient to cause mortality, particularly for trout in poor condition. Observed declines in cestode prevalence within a single species and age group over the summer was interpreted as mortality.

Cutthroat tended to exhibit lower infection intensities than either rainbow or hybrid trout. When considered on a seasonal basis, this difference may also indicate a greater susceptibility to mortality.

Elimination or direct control of the parasite in Spada Lake is virtually impossible. Options with the most promise for indirect control include a change in the fish species mix to one which includes species that are either more resistant to the parasite, or have a diet which does not include copepods (the parasite vector). Lake fertilization or other enhancement of the invertebrate prey base which would effect a trout dietary shift away from copepods would also probably help, but would require further research to determine costs and feasibility. It's also possible that a dietary shift may be facilitated by control of brown bullheads if they are shown to be a major competitor for relatively scarce food resources.

Estimated fishery yield (annual weight of trout harvested/unit area) nearly tripled when the reservoir was enlarged, but then declined to 3.2 percent of the level seen in 1979-80 (pre–enlargement), and in 1995 was 1.1 percent of that seen in 1985. Current reservoir water chemistry and morphology suggest a sustainable annual yield of 1.15 kg/ha (1.03 lbs/ac). This represents an estimated 24 percent reduction from Stage I on a per unit area basis, but reservoir enlargement in Stage II increased overall potential yield 76 percent from Stage I. Unfortunately, attainment of 1.15 kg/ha in the fishery is nearly impossible under the current 12" minimum size regulation. Harvest of smaller, younger trout age classes will allow an increase in yield, but the negative impact on spawning escapement cannot be assessed without a more accurate trout population estimate, and/or additional trout life history information to allow modeling of various fishery strategies.

A preliminary estimate of harvestable trout suggests that between 6200 and 6450 fish, ranging from Age 2 to Age 5, may be taken and remain below the theoretical maximum sustainable yield level. If an average harvest of 2.0 trout/angler is set as a goal, effort (number of angler trips) may need to be capped at about 3225 trips/yr to avoid overfishing the stocks. Supplemental stocking of catchable trout would boost the number of trips and/or the mean harvest/angler beyond that supported by natural production alone. Under any scenario, additional trout life history information is needed to enable fishery modeling, and help assure that escapement levels are not reduced to an unacceptable level.

Of 12 Washington Wildlife Commission Goals and Objectives examined, only two were attained at Spada Lake in 1995-97. Most probably can be met to greater or lesser degrees through adaptive management. Some additional research and exploratory enhancement will be required. The current regulations and resultant reservoir trout community are not effective mitigation for the lost wild trout stream fishery, nor even the initial reservoir fishery (Stage I).

In order to move toward attainment of Wildlife Commission goals and the management objectives for the fishery, a combination of additional research and immediate management actions are recommended. Additional research should focus on brown bullhead control, lake fertilization, trout life history, trout/bullhead dietary interactions, and new species introductions (both fish and invertebrate). Immediate management actions include a switch from a 12" minimum size to a 12" maximum regulation, with no more than two trout over 10" being retained and a five fish harvest limit; supplementation with a wild cutthroat donor stock; stocking of marked trout to estimate trout abundance and recruitment; and evaluation of the growth and parasite resistance of a cutthroat donor stock.

Background

Project History and Mitigation Terms ("Stage II")

In 1961 the Federal Power Commission ("FERC") granted license to the City of Everett, Washington, and Snohomish County Public Utility No. 1 ("PUD") to construct and operate a water supply and hydroelectric development on the Sultan River. Prior to this, a smaller dam had been constructed on the Sultan at RM 9.7 in 1916 to divert water to Lake Chaplain, and thence to the City of Everett for municipal and industrial use.

Spada Lake is a multiple–use reservoir located on the Sultan River 16.5 miles from its confluence with the Skykomish River, located at 47° 58' N, 121° 39' W, at an elevation of 442 m (Figure 1). The impoundment and associated hydroelectric facilities are collectively known as the Henry M. Jackson Hydroelectric Project ("Jackson Project"), and are operated by the PUD in cooperation with the City of Everett. Spada Lake supplies drinking water for the City of Everett through an intertie with the Everett Water Department's Lake Chaplain reservoir (Figure 1).

Culmback Dam and its resultant reservoir, Spada Lake, was constructed in two stages. Original construction of Culmback Dam using rock and earthen materials (Stage I) was completed in 1965, with initial reservoir filling in April of that year. The Stage I reservoir occupied 770 acres (312 ha) at full pool (1,360' msl), with 8.8 miles of shoreline, and a volume of 34,500 acre-feet. The dam was raised from 202 to 262 feet above streambed, and the morning glory spillway crest was raised to elevation 1,450' (Stage II) in 1982-83, which increased the maximum allowable reservoir surface elevation by 90 feet. Reservoir raising occurred between November 1983 and April 1984. Spada Lake now occupies 1,870 acres (757 ha) at full pool, with 17 miles of shoreline, and a volume of 153,260 acre-feet.

Water is diverted from the Sultan River at Culmback Dam, and flows to a powerhouse located on the Sultan River at RM 4.5 via an eight mile conduit consisting of four miles of tunnel and four miles of pipeline. Water leaving the powerhouse may re–enter the river, or be returned upstream through a second pipeline using head generated in the descent from Culmback Dam. Water in this upstream return pipeline is directed either to Lake Chaplain, or back to the lower river diversion dam at RM 9.7 where it re–enters the river (Figure 1).

Spada Lake supports an historically popular sport fishery for resident rainbow (*Oncorhynchus mykiss*) and cutthroat trout (*O. clarki*), and hybrids of these two species. While supplemental stocking of trout fingerlings occurred between 1965 and 1979 (Appendix Table 1), the fishery has been managed solely on the basis of trout natural reproduction since 1979. Special regulations are in effect to assure an adequate spawning escapement (Appendix Table 2).

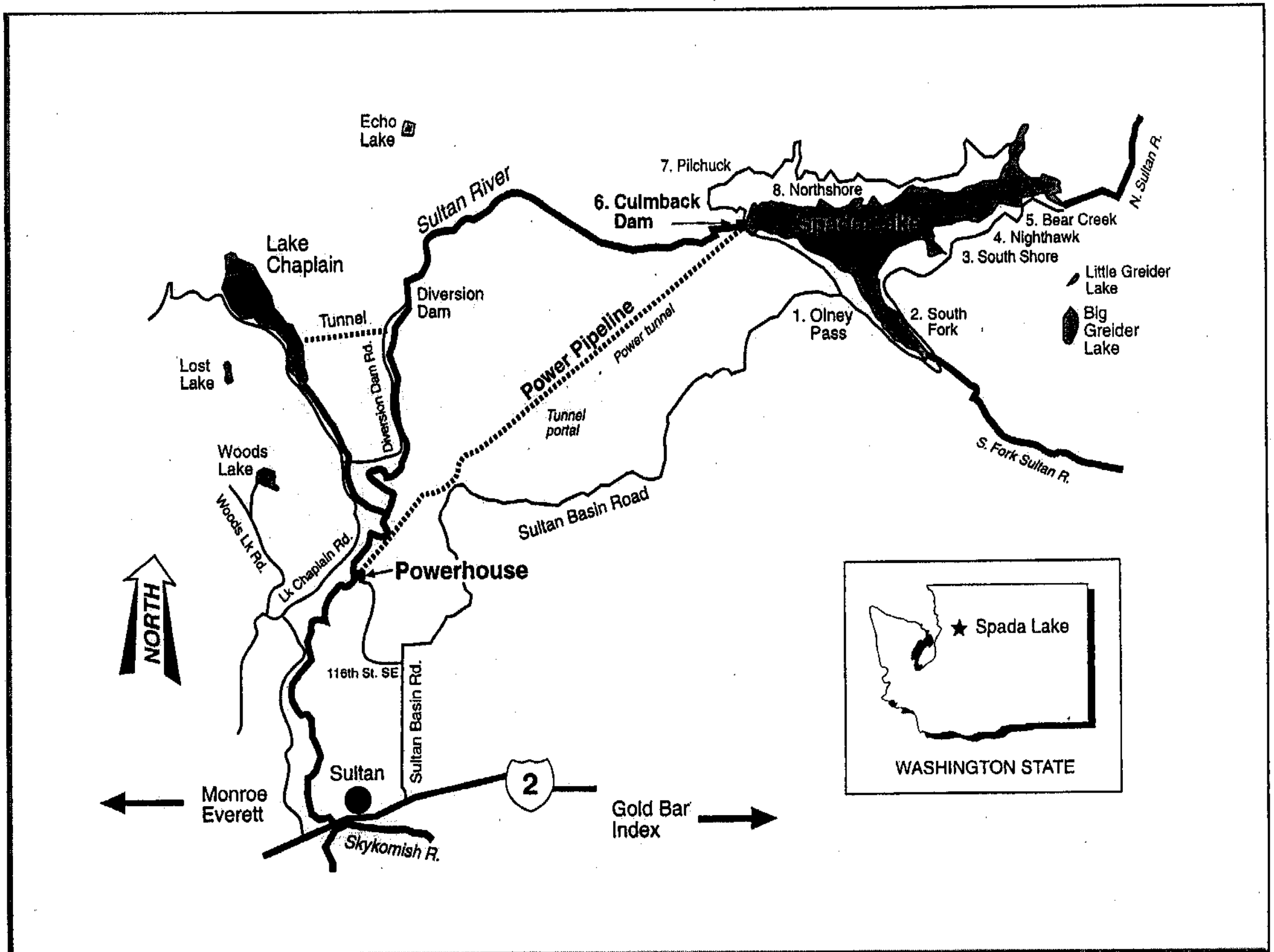

Figure 1. Jackson Hydroelectric Project (access areas are named and numbered).

Terms of the FERC license for Stage II included monitoring the effects of the raising on the reservoir sport fishery, and supplemental trout stocking, if needed. Up to ten creel surveys on Spada Lake were authorized over a 14–year monitoring period (1984 through 1998). Results of these surveys would form the basis for determining whether or not the goal of a self–sustaining wild population of trout and resulting fishery had been achieved (FERC Project No. 2157, Revised Exhibit S, January 1983).

Mitigation terms were renegotiated with the PUD and Everett Water between 1995 and 1996 to allow for an updating creel survey on Spada Lake in 1995, and biological studies on the reservoir in 1996-97. The principal purpose of the 1996-97 studies was to obtain specific trout life history information needed to fully evaluate the raising of Culmback Dam, and to refine long–term management objectives for the trout fishery. A final creel survey one to two years following any regulation changes or initiation of supplemental trout stocking was also agreed to. The biological studies, a final creel survey (if any), and possible regulation of the number, size, and species of fish stocked would constitute the final component of mitigation of the effects of Stage II.

Creel Surveys and Fishery Performance

Six creel surveys were conducted by the PUD on the Spada Lake fishery in the years 1985 through 1989, 1992, and 1995 (Thiesfeld *et al.* 1985; Shapiro and Associates and University of Washington 1987, 1988, 1989, 1990; Pentec Environmental 1993). These surveys were reviewed and summarized by the Washington Department of Fish and Wildlife in 1995 (Pfeifer 1995). Following the 1995 review and consultation with the PUD, an updating creel survey was conducted in 1995 (Pfeifer 1996a). The following sections highlight the principal statistics and findings from these surveys.

Total Harvest

Total fish harvest increased five– or six–fold after Stage II, but decreased an order of magnitude in 1988, then dropped to an extremely low level in 1995 (Table 1). The drop in harvest from 11 to 20,000 in 1985-87 to about 1500 in 1988-89 was largely caused by imposition of special regulations (notably a 12" minimum length and a bait ban) in 1988. However, the additional 78 percent reduction in harvest between 1989 and 1995, had other cause/s since regulations have been constant since 1988.

A sharp reduction in harvest rates manifested itself as early as the 1989 season. Shapiro and Associates and University of Washington (1990) ascribed much of the harvest reduction to a relative scarcity of legal–sized fish. Effort itself was reduced as the bait prohibition removed one entire group of anglers. "Displeasure with the continued low CPUE appears to have discouraged other anglers, resulting in less fishing effort and lower harvest than in most other years since lake enlargement" (Shapiro and Associates and University of Washington 1990).

Table 1. Estimated total fish harvest from Spada Lake, 1979 through 1995, based on season–long creel survey. Special regulations were in effect since 1988.

Year	Rainbow	Cutthroat	Hybrid	Coho	Bullhead	Combined
1979	1,268	1,842	-----	0	6	3,116
1980	478	1,912	-----	0	0	2,390
1985	8,927	11,215	-----	90	0	20,243
1986	3,828	6,259	1,372	67	6	11,536
1987	5,450	5,681	819	0	18	11,968
1988	502	664	144	0	0	1,310
1989	544	1,164	188	0	0	1,896
1992	163	210	111	0	0	484
1995	108	140	174	0	0	422

(Coho (*Oncorhynchus kisutch*) caught in 1985 and 1986 were the result of a one–time illegal introduction to the reservoir, and have not reappeared. Brown bullhead (*Ictalurus nebulosus*) were also illegally introduced to basin waters, but are not caught or harvested in any significant numbers due to angler disinterest in this species, and the bait ban. Hybrids of rainbow and cutthroat were not accounted for in the years prior to 1986, but have been comprising an increasing fraction of the trout catch since 1989.)

Catch Rate and Catch Success

While harvest per angler has dropped steadily from 1.14 fish/angler in 1986 to 0.125 in 1995, total catch has increased from about 1.6 fish/angler in 1985-86 to 2.3 in 1988 through 1995 (Table 2). Catch rates have mirrored catch success, with harvest per unit effort declining from around 0.40 fish/hr to 0.03 in 1995. The total catch rate, which includes fish released, has been relatively constant, ranging from 0.52 to 0.61 fish/hr between 1988 and 1995 (Table 2). In summary, trout are being caught at about the same rate, but the number being retained (harvested) has dropped dramatically.

Table 2. Trout catch and harvest rates from Spada Lake, 1979 through 1995. Catch consists of fish harvested plus fish released. Numbers released were not accounted for in 1979-80 or 1985.

Year	Number Released	Harvest per Angler	Catch per Angler	Harvest per Hour	Catch per Hour
1979	-----	-----	1.54	0.40	-----
1980	-----	-----	1.09	0.29	-----
1985	-----	-----	1.56	0.42	-----
1986	4,457	1.14	1.59	0.27	0.38
1987	2,400	1.77	2.12	0.41	0.49
1988	7,969	0.34	2.42	0.09	0.61
1989	8,136	0.41	2.17	0.10	0.54
1992	7,046	0.135	2.10	0.03	0.52
1995	4,402	0.125	2.32	0.03	0.60

The drop in harvest rate could be caused by either a reduction in the number of trout ≥ 12" in the population, a change in angler attitudes, or both. One possible change in angler attitude would be a greater number of anglers willing to voluntarily release all fish caught, whether or not the fish were legal to retain. Support for reduced numbers of trout ≥ 12" appears in discussion of the 1992 creel survey (Pentec 1993): "These data indicate a relatively stable catch rate since 1986, but in recent years more fish have been released than retained. The decline in CPUE in 1992, while RPUE remained high, suggests that the average size of trout in the lake may be decreasing."

Total Angler Effort

Season–long angler effort (hours) on Spada Lake has declined almost continuously since 1985 (Table 3). The estimated total effort in 1995 was the lowest on record, even lower than that documented prior to Stage II.

Table 3. Angler trips and effort levels on Spada Lake, 1979 through 1995.

Year	Angler Hours	Total Trips	Trips / acre
1979	7,845	2,017	2.62
1980	8,261	2,199	2.86
1985	47,770	12,994	6.95
1986	42,430	10,079	5.39
1987	29,375	6,769	3.62
1988	15,235	3,835	2.05
1989	18,686	4,619	2.47
1992	14,574	3,584	1.92
1995	7,785	2,002	1.07

Conversion of angler hours into completed trips showed exactly the same trend as raw effort (Table 3). When expressed in terms of trips per surface acre, the 1995 level is even more remarkable, since it was well below half that seen in Stage I (prior to 1985).

Fishery Yield

Potential yield from reservoir fisheries can be estimated based on reservoir morphometry and water chemistry (Ryder 1965, 1982; Jenkins 1967, 1982; Oglesby 1977; Schlesinger and Regier 1982; Stables *et al.* 1990). See Tertiary Production—Fish Harvest (Yield) and Recreational Use Level for estimates of potential yield for Spada Lake for Stage I and Stage II.

Although reservoirs commonly experience a period of enhanced productivity following enlargement, and then decline to some basal or lower level (Baxter 1977; Ostrofsky and Duthie 1980; Benson 1982; Bryan 1982; Ploskey 1983; Kimmel and Groeger 1986), the sharp drop in estimated annual fishery yield (kg/ha) between 1987 and 1995 was unexpected, and alarming (Table 4). The estimated total yield of 52 kg in 1995 is only 6 percent of Spada's modeled sustainable annual yield (Tertiary Production—Fish Harvest (Yield) and Recreational Use Level, and Jenkins 1982).

Table 4. Estimated annual yield of the Spada Lake sport fishery, 1979 through 1995.

	STAGE I		STAGE II	
Year	**Kg**	**Kg / ha**	**Kg**	**Kg / ha**
1979	754	2.42		
1980	616	1.98		
1985			4899	6.47
1986			2596	3.42
1987			2513	3.32
1988			402	0.53
1989			533	0.71
1992			258	0.34
1995			52	0.07

The apparent increasing shortfall in the fishery's productivity prompted the 1996-97 examination of biological conditions in the lake, as well as trout growth, mortality, and relative abundance. Finally, anglers were surveyed in 1995 to look for any important changes in their fishing methods or attitudes toward retention of fish caught.

The importance of angler attitudes or knowledge of posted regulations was underscored by the large increase in non–compliance with the 12" minimum size documented during the creel surveys:

1988:	17.0%
1989:	18.2%
1992:	19.2%
1995:	57.8%

Relationships to Current Fishery Management Goals and Objectives

Specific fishery management goals and objectives for Spada lake were prepared following the review of past studies (Pfeifer 1995) and completion of the updating 1995 creel survey (Pfeifer 1996a). The Goals, Policies and Objectives of the Washington Fish and Wildlife Commission (Wash. Dept. Wildlife 1991; WDFW 1995) were of paramount importance in the development of management objectives for Spada Lake. Various elements of the WDFW Wild Salmonid Policy (WDFW 1997) also bear directly on the management of wild trout stocks in Spada Lake. The following study elements were identified as a result of the management objective–setting process:

G1. Management Goal: *Maintain abundant wild fish for consumption.*

R1. Research Need: Determine cause/s of putative lack of harvestable trout. Determine whether harvest is, or has been excessive on older age classes, or whether mortality is largely due to parasitism, or some other source. Assess the adequacy of natural trout fry recruitment.

G2. Management Goal: *Maintain diversity and reasonable abundance (of wildlife).*

R2. Research Need: Monitor the degree of hybridization between the rainbow and cutthroat stocks. As resources become available, evaluate the integrity and uniqueness of the stocks through genetic stock identification procedures.

G3. Management Goal: *Emphasize native species and natural production, but stocking is permissible.*

R3. Research Need: Evaluate and revise the current regulations and minimum size limit to achieve harvest and catch rate objectives on the basis of natural production. Evaluate mortality sources and the feasibility of meeting the objective of a naturally–sustained fishery. Evaluate the need for supplemental trout stocking, and impacts of same, as well as means to evaluate its success.

G4. Management Goal: *Manage for optimum species diversity.*

R4. Research Need: Evaluate the need for, and ecological consequences of stocking new fish species into Spada Lake to better achieve catch or harvest rate objectives.

O1. Management Objective: *Maintain consistent presence of all age classes.*

R5. Research Need: Table the relative abundance of age groups in past surveys, and 1997 samples of the whole–lake population. Estimate trout annual mortality, both natural and due to angling.

O2. Management Objective: *Prevent long–term reduction in average fish length at age or growth rate.*

R6. Research Need: Evaluate current age–at–length conditions; relate to reservoir rearing habitat conditions. Assess the degree to which angling may be affecting length at age. Assess the potential impact of supplemental stocking on growth of the native trout.

O3. Management Objective: *Prevent long–term reduction in trout relative condition or mean age at maturity.*

R7. Research Need: Evaluate the degree to which management can affect these attributes in this population. Evaluate the historic changes in these measures in Spada Lake trout.

O4. Management Objective: *Provide a catch rate of at least 1.0 fish/hour for trout of any size.*

R8. Research Need: Assess whether regulation changes and/or supplementation will achieve this objective.

O5. Management Objective: *Provide a harvest rate of 0.5 fish/trip for trout 12" or larger.*

R9. Research Need: Determine the relative abundance of trout ≥ 12" in the lake population. Evaluate length at age and mortality, and the feasibility of meeting this objective.

O6. Management Objective: *Regulate the fishery for a maximum yield of 1 kg/ha/yr.*

R10. Research Need: Using past fishery and limnological data, assess the feasibility of meeting this objective. Relate the yield goal to the fish population age and size structure in terms of harvestable numbers, and permissible harvest rates/angler.

O7. Management Objective: *Increase the "quality" aspects of the fishery by assuring maintenance of some older age classes of trout (age 4 or older).*

R11. Research Need: Evaluate annual mortality; ascribe to harvest or natural causes insofar as possible.

O8. Management Objective: *Maintain fishery attractiveness such that annual angler use is at least 2.75 trips/acre (ca. 5,150 trips/yr).*

R12. Research Need: Identify (and recreate, if possible) those fishery attributes that attracted this level of angler interest in earlier years.

1995-97 Study Objectives

Field activities and office research were conducted to address as many of the previous twelve research needs as possible. All will be dealt with to greater or lesser degrees in the balance of this report. Comments on specific goals and objectives will appear in pertinent Results and Discussion sections, as appropriate. A synthesis of opinion, findings, and attainment of proposed management objectives appears as Summary of Findings and Fishery Management Recommendations and Attainment of Management Objectives.

Description of the Study Area

Basin Geologic, Vegetative, and Development History

Washington Department of Game and Snohomish County P.U.D. No. 1 (WDG 1982) provide setting information for the Sultan River basin as a whole; these remarks are specific to the sub–basin above Culmback Dam. The reservoir basin is characterized by high relief, being bounded on the east by high Cascade Range peaks equivalent in elevation to the Cascade Crest; on the north and south by lateral ridges and peaks extending westward; and on the west by lower foothills of the Cascades. Elevations in the sub–basin range from the 6,617 ft (2017 m) summit of Del Campo Peak to 1,470 ft (448 m) at the top of Culmback Dam. The area of the sub–basin draining to the reservoir is 44,294 acres (Laura Vaugious, pers. comm. 1998). The geomorphic processes that shaped the area include alpine and continental glaciation, as well as fluvial and gravitational processes associated with stream dissection and structural faulting.

From Culmback Dam, the Sultan River trends west, then southwesterly in a 13.5 mile gorge. At the terminus of the gorge, the river travels through three miles of floodplain until reaching its confluence with the Skykomish River at the Town of Sultan.

In the vicinity of Culmback Dam, the Sultan River flows through a narrow rock gorge into which it was diverted from its former course down the Pilchuck River drainage by the glacial material of the so–called Pilchuck Plug. Recession of the Puget Lobe of the Cordilleran ice sheet occurred about 14,000 years ago (Booth 1987).

A thick deposit of glacial silt, clay, and gravel now constitutes part of the right abutment and northwest rim of Spada Lake. Considerable portions of the tributary valleys (Elk Creek, SF Sultan, etc.) are overlain with glacial outwash soils of various types. Major soil categories in the basin include shallow to moderate residual soils (2 to 5 feet deep); deep residual soils; and deep glacial soils (12 feet deep).

Bedrock in the basin is variable. Schists dominate the Williamson Creek drainage; most of the rest of the basin is composed of meta–sedimentary and meta–volcanics, or granitics (igneous intrusives).

Franklin and Dyrness (1973) defined several vegetation zones in the western Cascades. From sea level to 2,000 feet (600 m) they described a band of forested vegetation termed the Western Hemlock Zone. Characteristic trees include western hemlock, Douglas–fir, and western red cedar. After a disturbance such as fire or logging, plant community development in this zone follows a predictable pattern. Under natural conditions, the plant community sequence is first an herb and shrub stage, then Douglas–fir regenerates under the shrubs. Eventually, these trees grow taller than the shrubs and form a closed canopy, shading out some of the early shrub and herb species. At a later stage, a mix of western hemlock and red cedar seeds under the Douglas–fir, resulting in an all–aged hemlock and cedar forest, forming a fairly closed canopy with a few very large Douglas–fir stems emerging above the canopy. These latter conditions currently prevail in the North Fork Sultan River valley above the lake, while many years of incremental logging have left a patchwork of varying–aged stands of predominantly Douglas–fir on the sideslopes surrounding the reservoir proper.

Above 2,000 feet Franklin and Dyrness (1973) described the Silver Fir Zone. At lower elevations within this zone, natural species replacement after disturbance begins with a shrub-herb community into which western hemlock regenerates. Pacific silver fir then seeds under the canopy of western hemlock and slowly becomes the dominant species in all strata. At higher elevations, Pacific silver fir regenerates in the shrub stage, and western hemlock does not occur at any step in the sequence.

Elements of both Western Hemlock and Silver Fir Zones occur in the Spada Lake sub–basin, affected predominantly by intense forestry management in the general vicinity of the reservoir. Substantial areas of undisturbed silver fir and associated species occur at the higher elevations, particularly in the Williamson Creek, North Fork Sultan River, and Elk Creek basins.

(Road mileage constructed for timber management has been extensive, and in recent years substantial areas have deteriorated significantly due to landslides or bridge removal which have prevented maintenance access. Road sideslope failures have resulted in mass soil and woody debris movements directly into the reservoir or tributaries in a number of locations.)

Forestry, mining, and recreation (hunting, fishing, appreciative wildlife viewing, hiking, and boating) are the historic uses of the Sultan basin.

Timber harvest has been practiced in the sub–basin since the 1940s. The rate of cut has diminished significantly in recent years, and there are no current sales planned for the area. Much of the Williamson Creek, North Fork Sultan, and Elk Creek sub–basins are being proposed as a Natural Resource Conservation Area under Washington State law, with no timber harvest or road construction. Spotted owl and marbled murrelet management issues affect the area as well (Al McGuire, pers. comm. 1998).

Hard rock mining in the sub–basin preceded large–scale timber harvest by many years. While many active mines and test adits are documented in the sub–basin, the principal workings were the 45 Mine in the headwaters of Williamson Creek; the Bren–Mac, Iowa, Florence Rae, and Sultan Queen Mines in the North Fork Sultan drainage; and the Kromona Mine in the South Fork Sultan drainage. None of these mines are currently supporting important commercial activity, nor do any currently pose significant threats to water quality in the reservoir.

Hunting has been popular in the sub–basin since the late 19th century, but few improvements have been specifically made for this form of recreation. Road construction that preceded timber harvest abetted hunter use levels.

Significant recreational development followed turn–of–the–century mining, logging, and hunting by many years. Resident trout fishing in the upper Sultan River and its forks was popular from the early 1900s until the construction of Culmback Dam in 1965. Several of the larger high lakes in the sub–basin (Upper and Lower Greider) were first stocked in 1953, with Copper and Boulder following in the mid–1960s. Trails to the Greiders and Boulder were formalized and hardened by the Washington Department of Natural Resources in the early 1970s. Launch ramps were located at various points around the reservoir in both Stage I and II, however, they were much more elaborate in Stage II, and included extensive paved parking areas, public restrooms, scenic vista site developments, picnic areas, and interpretive signage.

No reliable estimates are available for resident trout fishing in the upper Sultan River prior to Stage I development in 1965. Year–round creel survey was conducted on Spada Lake in 1979-80 (Stage I; WDG 1982). There were about 2,100 angler trips to Spada Lake in both 1979 and 1980.

Basin Climate Data

See WDG (1982) for a more detailed discussion of climate in the Sultan River, and Snohomish River basins. With respect to the operating characteristics of Spada Lake, we note that the Sultan Basin has the highest runoff per unit area (11.0 cfs/square mile) compared to any other major gauging site in the Puget Sound area. This characteristic is reflected in the remarkable range in monthly total precipitation documented at Culmback Dam (Figure 2). The nearly 52 inches (132 cm) of rainfall in November 1990 preceded the largest spill volumes on record through the Morning Glory spillway.

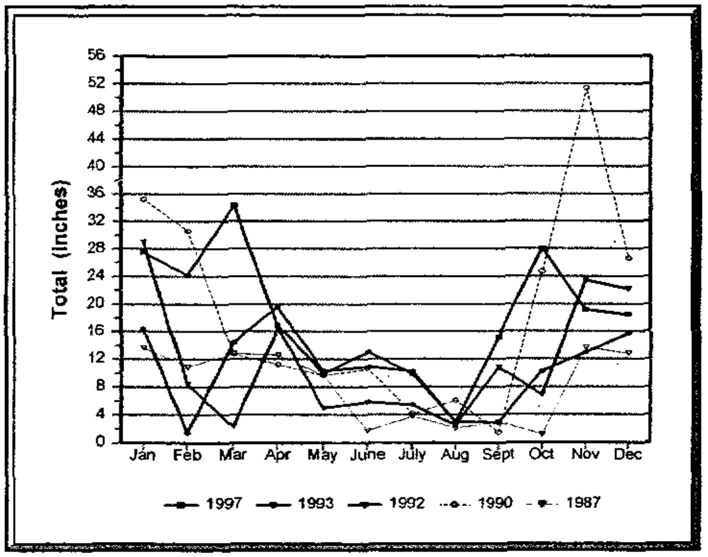

Figure 2. Total monthly rainfall at Culmback Dam for the years 1987, 1990, 1992, 1993, and 1997.

Monthly rainfall in the two highest reservoir inflow years (1990, 1997), the two lowest (1987, 1992), and a median inflow year (1993) from 1987 through 1997 are plotted in Figure 2. Precipitation rates are clearly extremely variable in the October through April period, but tend to be more consistent in the months of May through September. Note that (unfortunately) 1997 monthly rainfall values were among the highest in this 11–year period, particularly in March, June, and September. The heavy June 1997 rainfall preceded the only July spill in the 33–year history of the Jackson Project.

Reservoir Morphology and Operation

Spada Lake is a headwater storage project managed primarily for power and municipal supply purposes. The Snohomish County P.U.D. No. 1 brings it to near full pool in June-July, and drafts to a minimum level in December-January. Flood control is not a primary function due to limited storage volume relative to inflow potential. A slide valve located at the base of the dam (invert elevation 1,240 ft msl) could be used, if necessary, to completely drain the reservoir and restore a free–flowing stream. There is no dead storage *per se*. If, under extreme drought conditions the reservoir reached 1,385 feet, then all withdrawal via the power tunnel intake would cease, and flow would be provided down the natural Sultan River channel (by opening a Howell–Bunger valve) to supply municipal water to the City of Everett (Dan Miles, pers. comm. 1998).

Morphometry

At full pool, the reservoir extends easterly 5.25 miles (8.4 km) into the Cascades foothills (Table 5). Full pool shoreline length (22 miles) and development (3.63) are relatively high due to numerous embayments and tributary mouths. Maximum depth in the old river channel upstream of the dam is 210 feet (64.0 m), and the mean depth at full pool is 82 feet (25 m).

Table 5. Morphometric and operational data for Spada Lake.

Drainage area (sq. miles)	69.21 (179.25 sq. km)
Drainage area:surface area	23.68 : 1
Average annual discharge (acre-feet; 1987 through 1997)	526,338
Surface elevations (ft msl)	
Full pool	1,450 (442 m)
Average annual drawdown (1987 through 1997)	1,414 (431 m)
Minimum operational pool	1,410 (430 m)
Maximum drawdown on record (Stage II)	1,395.5 (425 m)
Surface area	
Full pool (acres)	1,870 (757 ha)
Average days/yr at full pool	6.1
Average days/yr ≥ 1445.0 ft	32.8
Average annual drawdown (acres)	1,436 (581 ha)
Minimum operational pool	1,386 (561 ha)

Table 5. Continued.

Volume (acre-feet)	
Full pool	153,260 (0.189 km^3)
Average annual drawdown	93,549 (0.115 km^3)
Minimum operational pool	87,765 (0.108 km^3)
Maximum length (miles; reservoir centerline)	5.00 (8.0 km)
Old riverbed thalweg	5.25 (8.4 km)
Shoreline length (miles)	
Full pool	21.98 (35.4 km)
Average annual drawdown	15.20 (24.5 km)
Shoreline development	
Full pool	3.63
Average annual drawdown	2.86
Maximum depth (ft)	210 (64.0 m)
Mean depth (full pool)	82 (25 m)
Storage ratio (vol./average inflow)	0.291 : 1
Lake Filling Time (V/I; years)	0.474
Lake Flushing Time (V/O; years)	0.287

Reservoir gradient, and the area:volume relationship are provided in Figures 3 and 4. In the range of normal project operation, the relationships between surface elevation, lake volume, lake area, and bottom gradient are nearly linear.

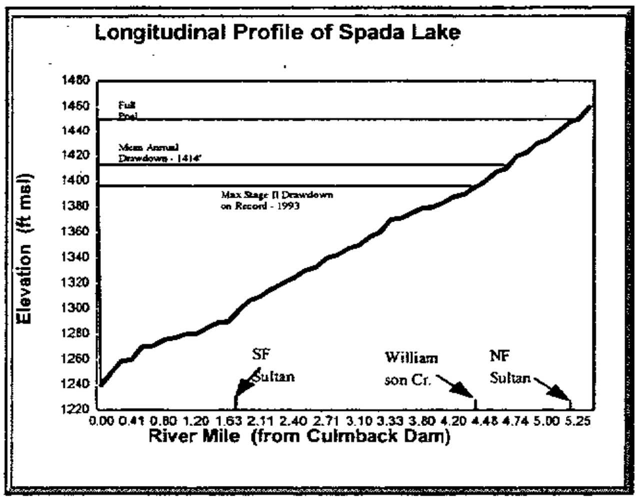

Figure 3. Longitudinal profile of Spada Lake.

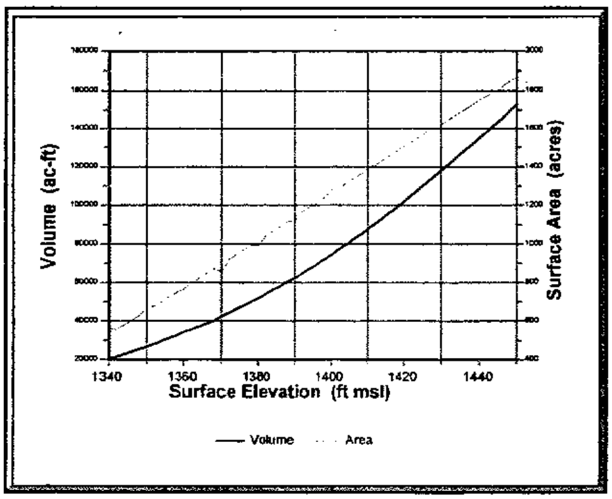

Figure 4. Spada Lake hypsographic curves.

Inflow/Outflow Relationships

Monthly lake–filling and flushing times were calculated using the following formulas (Woods 1982).

$$LFT = V/I \times .0833 \quad \text{and} \quad HRT = V/O \times .0833$$

where

LFT = lake–filling time in years
HRT = hydraulic–residence time in years
V = mean monthly reservoir volume in acre-feet
I = monthly inflow in acre-feet
O = monthly outflow in acre-feet
.0833 = conversion of months to years

Lake filling time represents the time required to replace the volume of a reservoir at a given inflow, whereas flushing (hydraulic–residence) time represents the time required to replace the reservoir volume at a given outflow. Straskraba (1973) considered lake–fill (retention) time to be a major key to understanding reservoir limnology. Retention time affects thermal structure, water currents and nutrients, and therefore, the degree of eutrophy (Dillon 1975) and primary production in a reservoir (Dickman 1969; St. John et al. 1976; Woods 1979). Reservoirs with short retention often have weakly developed thermal structure, which is the case with Spada Lake (Results and Discussion of Water Quality).

Hydraulic residence time may have an important influence on zooplankton production (Mayhew 1977). He found that residence times of less than one year were associated with reduced zooplankton populations. Spada Lake has a very high turnover rate when compared with other area reservoirs:

Reservoir	Retention Time	Flushing Time	Trophic Status
Hungry Horse (MT)	2.85	2.65	ultraoligotrophic
Libby (MT)	0.75	0.62	oligotrophic
Koocanusa (MT/BC)	0.67	0.53	oligotrophic
Ross Lake (WA)	0.58	0.52	oligotrophic
Spada Lake (WA)	0.47	0.29	oligotrophic

The storage ratio of Spada Lake is remarkably low, with turnover averaging just over three times per year (1/.291 = 3.44). This compares with 1.84 for Ross Lake in the north Cascades in Washington.

Lake fill times are greatest in July, August, and September when inflow is least and reservoir volume is greatest (Figure 5); flushing is highest (fill times lowest) in the wet months of November through February or March when the reservoir volume is least (Figure 6). Nevertheless, due to the relatively low inflow: volume ratio, monthly retention and flushing times are almost always less than one half year (Table 6).

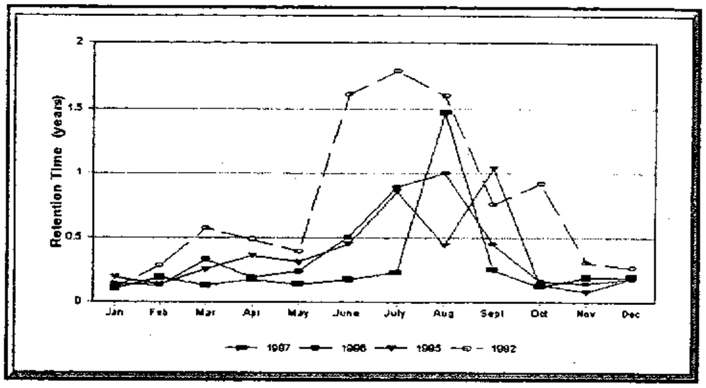

Figure 5. Monthly filling time (vol/flow) of Spada Lake in 1992 and 1995-97.

The monthly relationship between inflow and outflow is shown in Figure 7 for the highest inflow year between 1987 and 1997 (1997), the median inflow (1993), and the low water year (1992). While power generation (outflow) generally keeps pace with inflow, unusual floods in recent years have resulted in major spills, notably in November-December of 1990 (not shown). In November of that year inflow was 186,068 acre-feet, roughly double the highest values plotted in Figure 7.

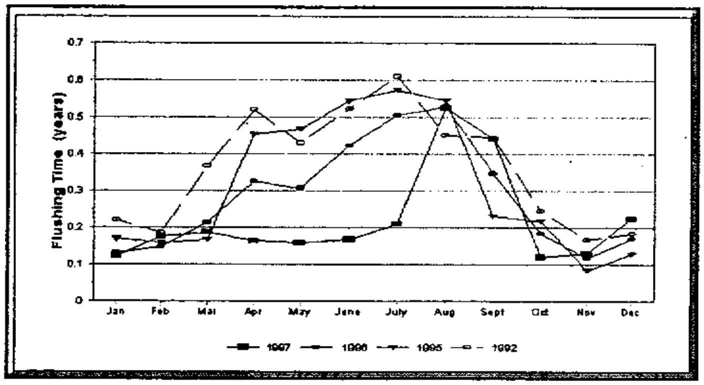

Figure 6. Monthly hydraulic residence (vol/outflow) of Spada Lake in 1992 and 1995-97.

The unusually high inflows in 1997 show clearly in Figures 5 and 6, with most 1997 retention or flushing times being less than that seen in recent years, particularly in the spring and early summer months. Retention/flushing times did not return to a more typical value until August.

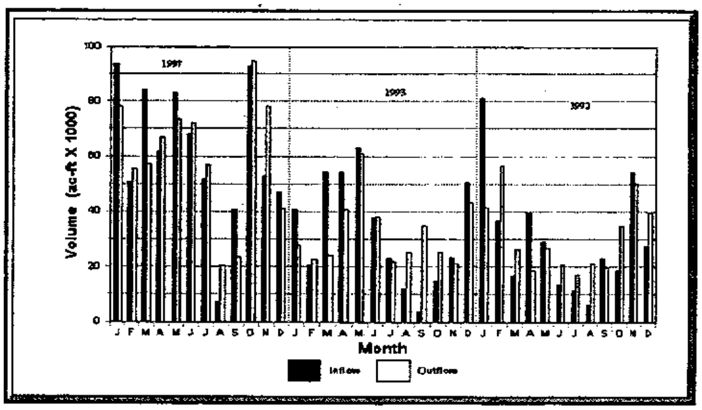

Figure 7. Monthly inflow and outflow (acre-feet) of Spada Lake in 1992, 1993, and 1997.

Table 6. Monthly retention and flushing times for low (1992), mean (1989), and high (1997) water years in Spada Lake, and for selected other years, 1987 through 1997.

Year	Month: Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Mean	Maximum Drawdown (feet)	Cumulative Inflow (ac-ft)	Cumulative Outflow (ac-ft)
Lake–filling (Retention) Time (years)																
1997	0.10	0.19	0.13	0.18	0.14	0.18	0.23	1.47	0.25	0.12	0.19	0.20	0.282	24.7	732,953	717,701
1996	0.14	0.13	0.33	0.19	0.24	0.50	0.89	1.00	0.45	0.16	0.15	0.18	0.363	30.7	538,082	557,382
1995	0.19	0.14	0.26	0.36	0.31	0.45	0.86	0.45	1.04	0.14	0.08	0.19	0.371	21.0	625,731	640,646
1994	0.15	0.36	0.17	0.22	0.33	0.31	0.75	3.31	0.61	0.22	0.20	0.11	0.562	30.5	473,570	434,722
1992														40.2	358,024	373,345
1991	0.16	0.11	0.35	0.19	0.24	0.28	0.50	0.83	1.93	1.22	0.10	0.18	0.508	40.5	512,537	526,519
1990	0.15	0.20	0.20	0.15	0.22	0.19	0.53	1.42	1.91	0.13	0.06	0.22	0.448	27.4	697,374	695,709
1989														28.1	520,739	524,181
1987	0.30	0.26	0.18	0.20	0.23	0.48	0.53	2.08	1.75	2.88	0.30	0.21	0.781	33.2	364,853	374,312
													0.474			
Hydraulic–Residence (Flushing) Time (yrs)																
1997	0.12	0.18	0.19	0.16	0.16	0.17	0.21	0.52	0.44	0.12	0.13	0.22	0.218			
1996	0.13	0.15	0.21	0.33	0.31	0.42	0.51	0.53	0.35	0.18	0.12	0.17	0.283			
1995	0.17	0.16	0.17	0.45	0.47	0.54	0.57	0.55	0.23	0.22	0.08	0.13	0.311			
1994	0.18	0.29	0.23	0.32	0.33	0.40	0.42	0.48	0.43	0.30	0.18	0.15	0.311			
1992																
1991	0.15	0.15	0.21	0.26	0.27	0.41	0.33	0.53	0.25	0.31	0.20	0.14	0.267			
1990	0.14	0.18	0.22	0.20	0.28	0.23	0.40	0.57	0.28	0.19	0.08	0.13	0.241			
1989																
1987	0.27	0.27	0.19	0.32	0.26	0.49	0.34	0.65	0.55	0.46	0.54	0.21	0.380			
													0.287			

Annual Drawdown and Summer Rearing Area

Figure 8 shows monthly mean reservoir surface elevations for two high water years (1997, 1990), two low water years (1992, 1987), and a median inflow year (1993). Since these are mean monthly values, no spill events (elevation ≥ 1450.0 msl) are shown. The Project is managed to spill rarely, if at all. Spill was prevented in six out of the past 11 years, and has averaged 6.1 days/yr (Table 7). Reservoir levels were unusually high in 1997, meeting or exceeding the four other sample years in six of the twelve months (Figure 8). Variance in pool elevation has been greatest in the fall and early winter (October-January).

Maximum annual drawdown is shown in Figure 9. The mean value is 1414 ft msl, or 36 feet below full pool. Drawdown has been less than average in the past four years, ranging from 29 to 36 feet, and was very near the mean in two of these years.

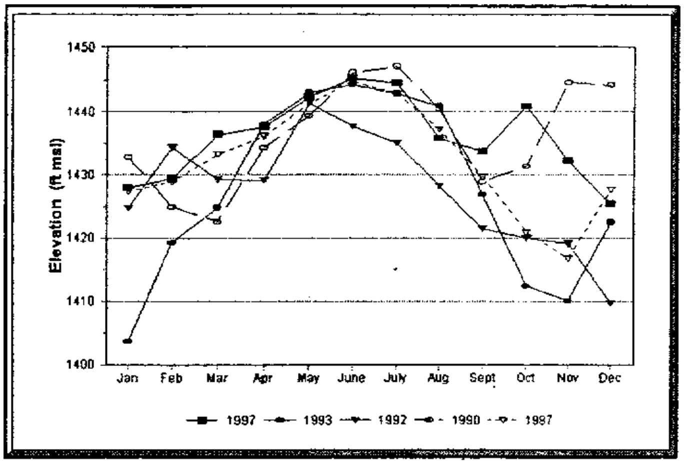

Figure 8. Mean monthly elevation of Spada Lake, 1987, 1990, 1992, 1993, and 1997.

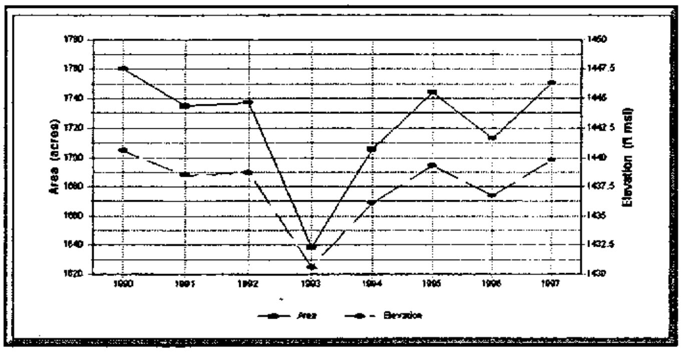

Figure 9. Mean June-September surface area and elevation of Spada Lake, 1990 through 1997.

Table 7. Number of days per month of reservoir spill, and at or above elevation 1445.0 ft (msl), 1987 through 1997. The choice of elevation 1445.0 was arbitrary.

Days/Mo/Yr at Full Pool

Year	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1997	0	0	0	0	0	0	3	0	0	4	0	0
1996	0	3	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	19	6
1994	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	14	7
1989	0	0	0	0	0	0	0	0	0	0	5	6
1988	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0

Table 7. Continued.

Days/Mo/Yr at > El. 1445.0

Year	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1997	0	0	10	0	0	17	10	0	0	12	0	0
1996	7	14	0	0	0	8	0	0	0	0	0	0
1995	0	8	0	0	0	0	0	5	0	14	23	20
1994	0	0	0	0	0	12	3	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	4	0	0	0	18	6	0	0	0	0	0
1990	0	0	0	0	0	20	28	0	0	0	21	19
1989	0	0	0	0	0	0	0	0	0	0	13	11
1988	0	0	0	3	15	8	19	0	0	0	0	0
1987	0	0	0	0	0	13	0	0	0	0	0	0

Since mean monthly drawdown averages roughly five feet in mid–summer (Figure 8), we tallied the number of days per year that the lake was at or above 1445.0 ft msl (Table 7). This occurred an average of 32.8 days/year. With the exception of the unusually severe drawdown in 1993, average summer–long (June-September) elevations have varied from 1436 to 1441, which represent surface areas of 1,711 to 1,760 acres (692 to 712 ha) (Figure 10).

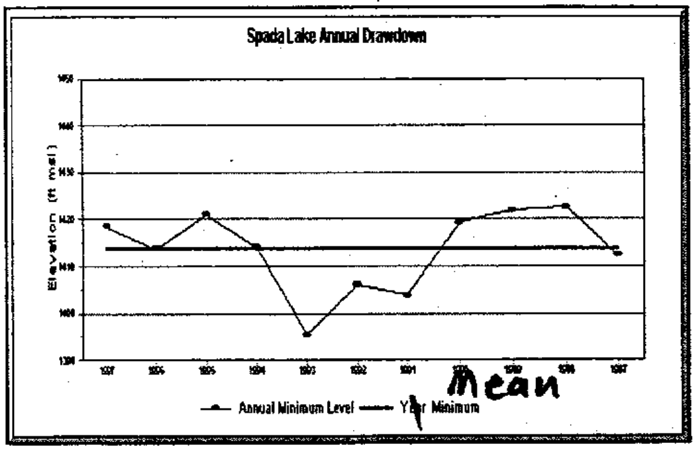

Figure 10. Annual minimum drawdown elevation of Spada Lake, 1987 through 1997.

Fish Species and Brief Life History

Rainbow and Cutthroat

Genealogy

There is no obvious documentation of the origin of the rainbow (*Oncorhynchus mykiss*) and cutthroat (*O. clarki*) found in Spada Lake and its tributaries. Some anecdotal accounts suggest the rainbow may be descendants of steelhead that may have had access to the upper basin.

Dave Mundell, employee of the Everett Water Department between 1952 and 1988, recalled an incident between Carl Oss, Basin patrolman in the early 1950s, and Norm Mattson, retired Washington Department of Game Warden for the Snohomish/Monroe area. According to Mundell (pers. comm. 1998), Oss found 5" to 6" rainbow in abundance in the "late spring" near the confluence of the South Fork and North Fork Sultan Rivers in 1955. Upon inspection of some which were readily collected by hook and line, Mattson allegedly identified them as steelhead smolts.

Mundell also related reports by "a friend of my uncle" of "huge trout being taken up in the Sultan Basin in the late 1930s or early 1940s." When pressed as to where the "Sultan Basin" was, he said "above the canyon." Since there was no lake in the upper basin at that time, "huge" trout may have been anadromous fish of some species, presumably steelhead.

When asked whether any cascades in the upper canyon in the vicinity of Culmback Dam are, or were, fish migratory barriers, Mundell pointed out that the few in that area are designated as passable in Williams *et al.* (1975), notably the one at RM 15.4.

Adding to this is the report prepared by the Washington Department of Fisheries (WDF 1942) which includes a map showing unbroken *potential* salmon use from the lower river diversion dam to a point a short distance above Elk Creek on the Sultan River and more than one mile up Williamson Creek. Apparently those who prepared that map believed salmon could access this area, once access was provided at the diversion dam. However, it's also possible that they were aware of one or more fish passage barriers in the upper canyon, and were assuming they could be laddered or otherwise adjusted, such as Granite Falls on the South Fork Stillaguamish, or Sunset Falls on the South Fork Skykomish (also shown as potential salmon use areas on the same map).

Regarding the Sultan River, the 1946 *Ben Paris Fishing and Hunting Guide to the Northwest* states (pp. 238-239): "**SULTAN RIVER**...The upper reaches, together with **Williamson Creek**, a fair sized tributary, where road ends at ranger station bridge, offer exceptionally good fishing for rainbow and cutthroat trout of average size." None of the lakes or streams of the upper Sultan River had been stocked by the Washington Department of Game at that time. (See Appendix Table 2 for stocking histories of the high lakes draining to Spada Lake.) However, the Washington Department of Game was created in 1933. Other federal agencies (USFS) and county agencies were known to stock trout or char in regional waters prior to 1933 (WDFW file records).

Bob Heirman, long–time Secretary or President of the Snohomish County Sportsmen's Association, advises that the City of Everett's water diversion dam on the lower Sultan River was built in 1915 (Bob Heirman, pers. comm. 1998). Steelhead are known to accumulate below this dam, even to this day (Dave Mundell pers. comm. 1998). Mundell related that the flood gates on that dam were operated in such a way as to minimize the accumulation of large woody debris across the dam crest. At times the flood gate was opened wide to flush debris through, and at these times steelhead could gain passage.

Whether anadromous fish could ascend the Sultan above the level of Culmback Dam (RM 16.5) is a matter of some debate. One or more cascades are known to have existed at that point

(Murray Schuh, pers. comm. 1997), but whether they were a complete barrier is unknown, or at least not well documented. The anecdotal accounts of steelhead use above that point argue that they were not a complete barrier.

Russ Orrell, a retired Washington Department of Fisheries biologist, is a long–time resident and angler of the area. He clearly recalled numerous trips to the Sultan Basin with Grant Bryson, also a long–term area resident, prior to Stage I development. The river and its forks above the canyon were apparently heavily–laden with trout, as "you could catch 20 at any point along the river. Most of the trout were 7 to 9 inches, but some ranged to 12 to 14 inches" (Russ Orrell pers. comm. 1998). These men would hike from the forks confluence "about a mile" downstream into the upper canyon "to the barrier", which consisted of a vertical drop of roughly ten feet over a bedrock shelf. Russ was cautious to point out that this was a shelf, not a steep boulder cascade. Upon further discussion, Russ noted that in his opinion, the chance that the rainbow in the upper basin were of steelhead origin was "pretty unlikely."

Given the history of stocking of all species of trout and Pacific salmon in area lakes and streams, both high and low, by various agencies and groups in the early years of this century (WDFW file records), it seems most likely that the trout are some combination of relict stocks present since the last glaciation, with some additions of unknown stock origin. While a ten foot vertical falls would certainly stop all salmon, summer run steelhead are known to clear such hurdles when flow and plunge pool conditions are ideal.

The genealogy of the cutthroat (*O. clarki*) found in the basin as early as 1946 is problematic, but is also probably a combination of a relict stock, with possible addition/s of one or more "hatchery" stocks.

Distribution

Hook and line sampling, and backpack electrofishing by the principal authors have found rainbow or hybrids near the headwaters of all of the named tributaries of Spada Lake. Cutthroat were found in Williamson Creek and the North Fork Sultan River, but seemed to be nearly absent in Elk Creek and the South Fork Sultan River. Both species have free access to the headwater areas of these same streams.

Timing and Age of Spawning

While more detail is provided in Trout Spawning Period and Age at Maturity, both trout species spawn from mid–winter to early spring, with some probable variability depending on whether the stock involved is strictly resident, or is adfluvial. It is likely that resident forms found high in the tributaries spawn later in the spring than adfluvial fish ascending from the reservoir in December. Most of the trout mature at the end of their third year of life, with low percentages maturing at Age 2 or 4.

Although highly desirable, there have been no quantitative measurements of upstream or downstream migrant numbers of either species.

Tributary Rearing

Adfluvial forms of both species spend one to two, or rarely three, years in the tributaries before entering Spada Lake. See Trout Age, Growth, and Condition for additional detail. Trout were also collected from the tributaries which were one or more year/s old, but which showed no evidence of lake rearing; these are deemed strictly "resident" forms.

Brown Bullhead (Literature Review)

Brown bullhead "catfish" (*Ictalurus nebulosus*) were introduced to the reservoir by uncertain means. The only written opinion on the origin of this species in Spada is that provided by Bradbury and others in Washington Department of Game ((WDG)1982). They state: "Around 1970 someone released brown bullhead catfish in the ponds near the Greider Lakes trailhead. Later, dynamiting of these ponds was erroneously assumed to have eradicated the catfish. At times of high water these ponds overflow and drain into the Sultan River near the truss bridge. In 1979, a brown bullhead was checked in the Spada Lake creel census, and in 1980, several small catfish were captured in Spada Lake near the river's mouth."

This species was apparently not abundant in the reservoir in 1979-80, as Bradbury and others (WDG 1982) made 21 sampling trips in 1979 and 1980, and only collected seven individuals. We collected 210 in a single floating horizontal gillnet set over one night near the mouth of the Sultan River in July, 1997.

We do not have detailed knowledge of the life history of this species in Spada Lake. It is imperative that such be obtained if any brown bullhead control measures are seriously considered. A brief life history synopsis from published literature is provided, below, for reference and planning purposes.

Distribution

We did not endeavor to make a quantitative estimate of the brown bullhead population. Frame nets (Imamura 1975) or baited commercial shrimp pots (Wayne Brunson, pers. comm.) would probably be the most effective gear to collect the species, and make mark–recapture type population estimates. We collected them incidentally in vertical and horizontal gillnets set to collect trout. Catch rates, locations of sets, and such similar data are available from Fall 1995 through Fall 1997 (WDFW databases and file records). We found them in all areas of the reservoir, although they tended to be more abundant in the inlet alluvial fan areas, shallow bays, and other such zones where water temperatures were likely warmer, and/or food resources and cover were more to their liking.

Although brown bullheads are reputed to be bottom and edge–oriented, we were surprised to routinely collect them at intermediate depths in the water column in vertical gillnets set well offshore. (File catch data are available to further study this phenomenon.)

Time, Conditions, and Age of Spawning

From the literature, spawning commences when water temperatures reach about 21 C (Wydoski and Whitney 1979). Imamura (1975) found that they began spawning at this temperature in Lake Washington. Emig (1966) provides an excellent life history overview; in it he notes that brown bullheads "prefer" temperatures "near 21 C for spawning." This temperature does not normally occur until around late July in Spada Lake (Description of the Study Area — Basin Geologic, Vegetative, and Development History), although the inner portions of some of the protected, shallow bays may warm somewhat sooner. Imamura (1975) found that larger, older females were first to spawn, followed by smaller, younger fish in a hierarchical fashion.

Preferred spawning habitat consists of mud or sand nesting areas in dense vegetation, shaded areas, or near objects such as logs or stumps. The nest site is in shallow water, a few inches to several feet deep (Wydoski and Whitney 1979). These conditions are found in great abundance in Spada Lake (unfortunately). Occasionally they nest in burrows, or they may dig holes beneath sunken boards in hatchery ponds (Emig 1966).

Brown bullheads generally mature at Age 3. Spawning may occur "from April through June" (Wydoski and Whitney 1979), and may occur more than once per year (Emig 1966). Females 8 to 13 inches may lay from 2,000 to 13,000 eggs. Time to hatch has been variously reported as 5 to 8 days; 10 to 14 days; 5 days at 25° C; 7 days at 20.6° C; and 6 to 9 days at 20.6° to 23.3° C. Young remain on the nest 5 to 10 days before they begin to swim (Emig 1966).

At hatching, fry are about 6.5 mm total length. The parent protects the school of young for several weeks. Schools are often seen near the shore in shallow water during the summer (Emig 1966).

Other Habitat Requirements

Deep water with a bottom of sand, gravel, or muck is preferred. Adults usually inhabit the deeper portions of the littoral zone in lakes, but feed and spawn in shallow, weedy areas. In very large lakes, they are most abundant in sheltered bays (Emig 1966). These remarks coincide perfectly with our empirical field observations on Spada.

Food Habits

Brown bullheads usually feed near the bottom, foraging most actively in the evening and at night. Fry and young–of–the–year consume chiefly chironomid larvae and zooplankton.

"Young" brown bullheads have been reported to consume chironomids, mayfly nymphs, water mites, and crustacea, as well as some algae and diatoms. Adults are omnivorous; additional dietary items include mollusks, insect larvae, leeches, scuds, earthworms, and terrestrial insects (Emig 1966). These behaviors may place this species in strong competition with the trout for relatively scarce food resources in Spada Lake (Secondary Production and Tertiary Production—Trout Food Habits). This very important management consideration should be addressed through concurrent dietary analysis of both bullheads and trout, using indices or dietary overlap and principal component analysis (Bowen 1996; Cortès 1997).

Movements

Both Imamura (1975) and others authors (cited in Emig 1966) report that brown bullheads may either remain relatively stationary in bays, or move considerable distances (an average of 1.7 miles, and a maximum of 16.2 miles in Folsom Lake, CA).

Age, Growth, and Condition

Wydoski and Whitney (1979) provide a table of average total length at age from various populations and states (reproduced as Appendix Table 3). Based on these values, and assuming somewhat slower growth rates in Spada Lake, 112 mm brown bullheads collected when they were empirically abundant in mid–July, when the reservoir's surface temperature was 18.6 C, were probably Age 2. (It is hard to believe that a relatively cold reservoir such as Spada would grow bullheads faster than the Arboretum area in Lake Washington.) Appendix Figure 1 presents the length frequency of brown bullheads collected from Spada Lake.

We did not observe schools of bullheads in our field work between Fall 1995 and Fall 1997, but we did not seek them out, either. We also did not observe bullheads smaller than 112 mm in any of our gillnet collections (smallest stretched mesh size 13 mm). It is likely that we did not sample in a place or manner that would tend to collect young of the year bullheads.

We provide length-weight data on incidentally–caught brown bullheads in Appendix Table 4 for future reference, and calculate a Fulton–type (K) condition factor since a standard equation for this species has not yet been promulgated from which one may calculate relative weight. From these data, Spada Lake brown bullheads are in relatively good condition based on an assumed isometric growth curve.

Standing Crop

Literature values on standing crop vary greatly; Emig (1966) reports a range of 0.8 to 132 lbs/ac (0.9 to 148 kg/ha), with "most less than 6 lbs/ac" (6.7 kg/ha). Numbers of fish per surface acre range from 5 in Salt Springs Valley Reservoir, CA to 716.5 in Higgins Pond, MA (Emig 1966). Imamura's (1975) population estimates in Union Bay and Mercer Slough of Lake Washington were 21,300 and 11,900, respectively. Assuming approximate respective acreages for suitable bullhead habitat in these two areas of 242 acres and 35 acres yields densities of 88 and 340 bullheads/acre, respectively.

Mortality Rates

Emig (1966) reports a range of annual mortality estimates as 0.04 in Massachusetts waters to 0.25 in Shoe Lake, Indiana. Natural and total annual mortality in Clear and Folsom Lakes, CA, were 0.16 / 0.23 in Clear, and 0.34 / 0.48 in Folsom. Annual angling mortality rates in these same states ranged from 0.06 to 0.25, and averaged 0.116 (Emig 1966).

Eastern Brook Char

Eastern brook "trout" have been stocked into area lakes and streams since the early 1900s (WDFW file records), and many introductions were not documented. Piper and Taft (1925) noted that the "Sultan River" was stocked with 10,000 brookies in 1918, but the location was not specified.

Copper Lake, in the headwaters of Williamson Creek, received two brook char introductions: in 1965 and 1969 (Appendix Table 5). Boulder Lake in the Elk Creek drainage was stocked with brookies in 1981. Close inspection of the outlets of these lakes in 1997 revealed no obvious barriers to fish emigration, particularly during the early summer iceout period. However, the outflow from Copper Lake is subsurface through very coarse rubble once the lake elevation drops to its midsummer level. In addition, any fish which did emigrate, or were washed out of Copper Lake would be dashed down one of the most spectacular, precipitous hard rock chasms in the Cascades before reaching the valley floor.

Evidence for potential fry emigration or washout from Copper Lake was obtained in the fall of 1996 when one 126 mm brook char was collected roughly 2.5 miles up Williamson Creek by electrofishing. Natural reproduction by brook char in Williamson Creek cannot be entirely ruled out. However, the habitat in this stream is not that typically associated with reproducing brook char populations.

Char numbers in Williamson Creek and Spada Lake are apparently extremely low. Only one specimen was collected in Williamson Creek after 14 separate site collections between 1979 and 1996 (Appendix Table 6). None have been sampled in any of the eight full–season creel surveys, in which almost 29,000 trout were inspected (Appendix Table 7). We captured one brookie in a horizontal sinking gillnet in North Bay 2 on April 24, 1997. This is the only one seen after 113 gear sets on the reservoir between 1979 and 1997, from which 1,462 trout were taken (Appendix Table 6). In summary, of 30,433 salmonids collected from the reservoir and tributaries since 1979, only two were brook char.

Other Species

While whitefish (*Prosopium williamsoni*) have been "seen but not collected" in the Sultan River below Culmback Dam (Washington Department of Game 1982), neither whitefish nor sculpins have been seen or collected from Spada Lake or its tributaries.

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