Canadian Technical Report of
Fisheries and Aquatic Sciences No. 1477

July 1986

CASE HISTORIES OF REGULATED STREAM FLOW AND ITS EFFECTS ON SALMONID POPULATIONS

by

D. W. Burt[1] and J. H. Mundie[2]

for

Department of Fisheries and Oceans
Habitat Management Division
1090 West Pender Street
Vancouver, British Columbia V6E 2P1

[1] Present Address:
2245 Ashlee Road
Site D, RR3
Nanaimo, British Columbia V9R 5K3

[2] Fisheries Research Branch
Pacific Biological Station
Nanaimo, British Columbia
V9R 5K6

Cat. No. Fs 97-6/1477E ISSN 0706-6457

Correct Citation for this publication:

Burt, D. W. and J. H. Mundie. 1986. Case histories of regulated stream flo
and its effects on salmonid populations. Can. Tech. Rep. Fish. Aquat.
Sci. 1477: 98 p.

Correspondence should be addressed to J. H. M.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Burt, D. W. and J. H. Mundie. 1986. Case histories of regulated stream flow and its effects on salmonid populations. Can. Tech. Rep. Fish. Aquat. Sci. 1477: 98 p.

(1) An extensive review of 81 case histories of regulated rivers, mainly in the Pacific North West, was undertaken to determine the overall consequences for natural salmonid populations. Sixty-three of the cases gave known outcomes. Fifteen (24%) of these resulted in an increase or in no significant change in numbers of salmonids following flow regulation, whereas 48 (76%) resulted in decreased populations.

An intensive review was made of 8 diverse case histories to obtain a fuller understanding of the ways in which flow regulation can influence salmonid poplulations.

(2) From the extensive review it was found that loss, no change, or gain in salmonid stocks, depended most commonly on the magnitude of the post-project flows. Thus, outcomes of 73% of the case histories in which stocks increased, or remained unchanged, could be attributed either to only slight changes in post-project flows, to increases in mean annual flows, or to increases in flows during the months in which discharge apparently limited salmonid production prior to regulation. Conversely, in 60% of the case histories that resulted in reduced salmonid stocks the reductions were attributable to decreases in such flows. The post-project flows affected salmonid numbers by altering the productive capacity of habitat for fish, but the case histories did not show in detail how this occurred.

Additional factors associated with flow regulation that contributed to a reduction in numbers of salmonids were: blockage of habitat (occurring in 35% of cases with reduced salmonids), sedimentation of habitat (in 29% of cases), fluctuating flows (19%), changes in water temperature (17%), pollution (6%), difficulty of passage for downstream migrants (6%), absence of gravel recruitment (4%), inundation of habitat (4%), and gas supersaturation (2%). The case histories provided examples of solutions to some of these problems.

(3) For most case histories there was insufficient information to say whether pre-project predictions of outcomes proved to be true or false. Two of the intensive cases, however, did provide sufficient information. For these, predictions of improved stocks were not realized, due to unforeseen effects.

(4) It was concluded from one of the sources consulted (Hazel 1976; p. XV) that, as a general guideline for the protection of salmonid stocks, no more that 30% of monthly mean flows should be abstracted; (this guideline cannot be applied in periods of natural minimum flows that may limit fish abundance). The greatest loss of fish is directly related to the removal of greater than 30% of the pre-project flows.

It was concluded from all sources that determination of minimum instream flow needs for salmon and trout in terms of passage, spawning,

incubation and juvenile rearing, while necessary, is not sufficient for protection of fish, in that it does not acknowledge the peak flows of winter (for coastal streams) or of summer (for interior streams) that are required periodically for flushing sediments from the streams and for maintaining the stream's general physical characteristics. Definition of instream flow needs for life phases of fish are of limited use if peak flows are not also defined. In the case histories, forecasts of the magnitude, duration and frequency of dominant flows required to maintain habitat were absent.

(5) It was not within the scope of the review to assess the effectiveness of artificial enhancement of salmonids as compensation for fish losses. Nevertheless, it was noted that the percentage of cases of maintained or increased stocks rose from 23% to 51% if artificially propagated stocks were accepted in the post-project outcome.

(6) Comparisons were made of the effects of flow regulation on salmonids, as seen from the case histories, with the possible effects of the Kemano Completion Proposal of the Aluminum Company of Canada. Of the 81 case histories examined, 32 were regarded as applicable to the Kemano Completion Proposal because they produced habitat changes of the kind that could occur with Kemano Completion. The evidence of 29 case histories indicates that the proposal for the Nechako River has a 10% chance of maintaining the natural stocks, that of 21 cases indicates that the proposal for the Nanika/Bulkley system has a 5% chance of maintaining the natural stocks, and that of 10 cases indicates that the proposal for the Kemano River has a 40% chance of maintaining the natural stocks. The post-project flows were, again, the chief factor determining outcome. The comparisons indicated that ALCAN's proposed protection flows fail to take sufficient cognizance of the scale of ecological interactions associated with changes in flow regime, and especially of the extent to which rivers may change in sedimentary characteristics following reduced discharge. Furthermore, ALCAN's protection flows do not cover the possible effects of fluctuating flows and of increases in coarse fish, and insufficiently cover the effects of pollution, and of total gas pressure. On this evidence it appears that the Kemano Completion Proposal carries a high risk for the affected salmonid populations.

RESUME

Burt, D. W. and J. H. Mundie. 1986. Case histories of regulated stream flow and its effects on salmonid populations. Can. Tech. Rep. Fish. Aquat. Sci. 1477: 98 p.

(1) On a entrepris un examen approfondi des histoires de cas relatifs à 81 rivières régularisées, notamment dans le nord-ouest du Pacifique, pour déterminer l'ensemble des conséquences sur les populations naturelles de salmonidés. Dans 63 cas les résultats étaient connus. Parmi ceux-ci, 15 (soit 24%) ont indiqué une augmentation ou un changement peu marqué du nombre des salmonidés après la régularisation du débit, tandis que 48 (soit 76%) ont indiqué une baisse des populations.

Pour mieux comprendre de quelle façon la régularisation du débit des cours d'eau peut influencer les populations de salmonidés nous avons effectué un examen plus approfondi de 8 cas différents.

(2) Après un examen attentif, on a pu constater que la baisse, le statu quo ou l'augmentation des populations de salmonidés dépendaient généralement de l'ampleur du débit après l'exécution d'un projet. Par conséquent, les résultats dans 73% des cas où les populations avaient augmenté ou étaient demeurées inchangées peuvent être attribués soit seulement à de légers changements dans le débit après l'exécution d'un projet, soit à une augmentation du débit annuel moyen, ou à l'augmentation du courant pendant les mois où le débit limitait selon toute apparence la production de salmonidés avant la régularisation. Inversement, dans 60% des cas où s'est produit une baisse des populations de salmonidés, ces réductions étaient attribuables à la diminution du débit. Le débit après l'exécution d'un projet a affecté le nombre des salmonidés en modifiant la capacité de production des habitats pour les poissons, mais l'historique n'indique pas en détail comment une telle situation a pu se produire.

Il y a d'autres facteurs associés à la régularisation du débit qui ont contribué à une réduction du nombre des salmonidés comme: l'obstruction de l'habitat (se produisant dans 35% des cas avec une réduction du nombre des salmonidés), la sédimentation de l'habitat (dans 29% des cas), les fluctuations du débit (19%), les variations de la température de l'eau (17%), la pollution (6%), la difficulté de passage pour les poissons migrant en aval (6%), des problèmes de gravier (4%), l'inondation de l'habitat (4%) et la sursaturation gazeuse (2%). Les histoires de cas fournissent des exemples de solutions à certains de ces problèmes.

(3) Dans la majorité des cas, l'insuffisance des informations ne permet pas d'affirmer que les prévisions des résultats avant l'exécution du projet se

sont révélées vraies ou fausses. Toutefois, deux des cas plus approfondis ont fourni suffisamment d'informations. En l'occurrence, les prévisions d'amélioration des populations ne se sont pas réalisées en raison d'effets imprévus.

(4) D'après l'une des sources consultées (Hazel 1976, p. XV), nous sommes arrivés à la conclusion qu'en règle générale pas plus de 30% des débits moyens mensuels ne sauraient être soustraits, si l'on veut assurer la protection des populations de salmonidés; (cette règle n'est pas applicable dans les périodes où le débit minimum naturel peut limiter l'abondance du poisson). Les plus lourdes pertes de poisson sont directement liées à la réduction de plus de 30% du débit antérieur à l'exécution d'un projet.

D'après toutes les sources, nous en avons conclu que même s'il fallait déterminer le débit minimum d'un cours d'eau nécessaire au saumon et à la truite pour le passage, la fraie, l'incubation et l'élevage des juvéniles, cette mesure n'était pas suffisante à la protection du poisson parce qu'elle ne tient pas compte des débits de pointe hivernaux (pour les cours d'eau côtiers) ou estivaux (pour les cours d'eau intérieurs), périodiquement indispensables pour chasser les sédiments et maintenir les caractéristiques physiques générales des cours d'eau. La définition du débit des cours d'eau nécessaire aux différentes étapes biologiques du poisson est d'une utilité toute relative, si les débits de pointe ne sont pas eux aussi définis. Dans les études de cas, les prévisions concernant l'ampleur, la durée et la fréquence des débits dominants, nécessaires au maintien de l'habitat faisaient défaut.

(5) Evaluer l'efficacité de la mise en valeur artificielle des salmonidés pour compenser les pertes de cette espèce ne fait pas l'objet de la présente étude. Néanmoins, nous avons constaté que le pourcentage des cas de population maintenue ou accrue passait de 23 à 51%, si les populations propagées artificiellement étaient acceptées dans les résultats postérieurs au projet.

(6) Des comparaisons ont été établies, d'après les études de cas, entre les effects de la régularisation des débits sur les salmonidés et les effets possibles de l'exécution du projet Kemano de l'Alcan. Sur les 81 cas examinés, 32 étaient considérés comme applicables à l'exécution du projet Kemano, étant donné qu'ils ont provoqué des modifications de l'habitat semblables à celles qui pourraient se produire avec le projet Kemano. La preuve de 29 cas montre que le projet de la rivière Nechako offre 10% de chances de maintenir les populations naturelles, celle de 21 cas indique que le projet du réseau Nanika/Bulkley a 5% de chances de maintenir les stocks naturels et la preuve de 10 cas indique que le projet de la rivière Kemano a 40% de chances de conserver les populations naturelles. Ici encore les débits postérieurs au projet ont été le facteur déterminant. Les comparaisons ont montré que les marges de sécurité proposées par l'Alcan ne tiennent pas suffisamment compte de l'échelle des interactions écologiques associées aux changements de régime, et notamment jusqu'à quel point les rivières peuvent modifier leurs caractéristiques sédimentaires à la suite d'une réduction de débit. En outre, la marge de sécurité de l'Alcan ne couvre pas les effets possibles des fluctuations de débit et de l'accroissement des poissons communs, et couvre insuffisamment les effets de la population et de la pression totale des gaz. Devant cette évidence, il semble que l'exécution du projet Kemano présente un risque élevé pour les populations de salmonidés en cause.

1.0 INTRODUCTION

An extensive literature attests to the serious competition and conflicts that exist for uses of freshwater. Because of the economic value of salmonid fishes, of hydropower production, and of water for irrigation, much attention has been directed at trying to determine how the flow of streams can be altered to serve various purposes, without detracting from the fishery resource. Attention has likewise been placed on trying to foresee the outcome on fishery values of abstraction of water, or regulation of stream flows.

Historically, prediction of the effects of flow regulation on fish populations has relied mainly upon field studies and on modelling. A neglected available tool is the examination of existing examples of flow regulation. There are three good reasons for including case histories among the tools of impact assessment. They expose actual outcomes for habitat and fish, they provide insights into the associated causes, and they show what reliance can be placed on earlier predictions. Despite their value "there has been a tendency to ignore what the past can teach us when assessing the impact of a new dam and reservoir" (Effort 1975). This document represents an effort by the Department of Fisheries and Oceans (DFO) to avoid this error with respect to the salmonid resources that might be affected by projects involving water abstraction and regulation. Of particular interest is the proposal of the Aluminum Company of Canada, Ltd. (ALCAN), to complete the Kemano Project.

The objectives of this report, therefore, are to review examples of regulated flow to determine its consequences for salmonid populations, to try to identify the causes of change in salmonid numbers, to review the Kemano Completion Proposal with a view to identifying its most likely effects, and to compare these with the effects of the case histories so that the consequences for salmonids may be predicted.

Two levels of resolution are employed to present the case histories: (1) an extensive overview of many case histories and (2) an intensive detailed study of a few selected ones. The first has the advantage of identifying a wide spectrum of effects and the conditions causing them. Additionally, a large number of case histories yields a frequency distribution of outcomes in terms of fish numbers (i.e., increased, unchanged, or decreased salmonid stocks), and of explanations. The second level of resolution provides a fuller understanding of the complex ecological mechanisms producing the effects. It was found, as the work proceeded, that the majority of the cases for the extensive overview came from the valuable reports of Hazel et al. 1976, and Nelson, Horak, Hale et al. 1976.

The effects of flow regulation, and consequences to fish populations, presented in this paper refer to natural salmonid stocks as opposed to artificial salmonid stocks. The treatment is limited to salmonids because of their economic importance in British Columbia. Discussion is further restricted to natural stocks as they are subject to river conditions through all freshwater life stages and, consequently, reflect the effects of flow regulation. In contrast, artificial stocks are produced in controlled environments (hatcheries, spawning channels, etc.) and do not respond to riverine conditions until release. The definition of natural stocks does, however, include salmonids that are introduced by one-time stocking if they have adapted and maintained their populations by natural reproduction in the river.

2.0 CASE HISTORIES

2.1 EXTENSIVE REVIEW

To provide a broad overview of the effects of flow regulation on natural salmonid populations 81 case histories were examined from British Columbia (3 cases), Yukon Territory (1 case), Washington (7 cases), Oregon (24 cases), Idaho (9 cases), and California (37 cases). Only published case histories were considered; unpublished records were usually not cited. The quality of the data varied greatly. Some cases were based on several years of pre- and post-project population assessments, whereas many were based on judgements made by biologists familiar with the stream. The cases were categorized according to the outcome of flow regulation for natural salmonid stocks (increased, no significant change, or decreased) and by the major causes of the outcome (Table 1; p. 5). For some examples placement into an outcome category was made difficult by the confounding presence of artificial stocks, or by inconclusive or insufficient post-project studies. Such cases were classified if a reasonable judgement was possible. Where a judgement could not be made the outcome was classified as unknown.

In examining explanations for outcomes, it was sometimes necessary to isolate the effects of extraneous factors from effects of flow regulation. The main extraneous factors encountered were fishing pressure, and environmental change resulting from activities such as gravel removal, logging, and road building. Commercial and sport fisheries can have a major influence on populations by determining the escapement of adults to the stream and subsequent recruitment of young. Gravel removal, logging, and road building can alter salmonid habitat with repercussions to fish. Again, a judgement was required to identify the main cause of change in stocks. Cases were excluded where the main causes of change were extraneous factors.

The reader may note a paucity of case histories from British Columbia. The reasons are twofold. Firstly, there is a lack of published post-project studies. The tendency in B.C. has been to invest time and money in pre-project studies (culminating in environmental impact statements) and then to lose interest in the river system once the project is constructed (e.g., Williston, Mica, and Site One dams). Secondly, post-project studies, when undertaken, are usually directed toward determination of minimum flows for fish (based on some form of modelling), rather than on determination of actual impacts and their causes (e.g., Nicola River, Englishman River, Norrish Creek). Some post-project studies do attempt to analyze the outcome of flow regulation, but the incursion of other ecological and managerial factors precludes a judgement of the actual effects (e.g., Fulton River, Pinkut Creek).

Although the explanations in Table 1 are not exhaustive, they should be of value in assessing flow regulation proposals. For example, changes in habitat that are anticipated from a new project (e.g. sedimentation, increased water temperature) may be identified in the table under "explanation". This, in turn, gives reference to case histories where such habitat changes have occurred. Sufficient information is provided for each case history to determine which ones are likely to be significant to the new project.

To determine the performance of past projects in preserving natural salmonid stocks a frequency of outcomes was produced from case histories of known outcome (Table 2; p. 44). Of the 81 case histories examined 63 had discernible outcomes (a list of the 81 cases, with references, is provided in Appendix A; those with discernible outcomes are flagged). Of the 63 cases, 24% (15 cases) showed an increase or no significant change in stocks, while 76% (48 cases) resulted in decreased stocks. On this evidence flow regulation has had about a 25% success rate in maintaining or improving natural salmonid populations.

Given the outcome of flow regulation among case histories, it is of interest to ascertain the causes of the results. To establish this, the explanations from 63 case histories of known outcome were ranked according to their frequency of occurrence (Table 3; p. 45). The importance of the quantity of post-project flows in determining the outcome to salmonids is noteworthy, i.e., unchanged or increased post-project flows explained 73% of cases with increased or unchanged stocks, whereas reduced post-project flows explained 60% of cases with reduced stocks. Both mean annual and mean monthly flows were found to be important. In general, cases that increased or did not significantly alter these, resulted in increased or maintained salmonid populations (examples 1, 2, 3, 4, 9, 10, 11, 12, 13, and 14; Table 1).

As an aside it is worth recording that Hazel (1976), and Nelson, Horak, Lewis, and Colt (1976) include artificial enchancement when judging the status of stocks after flow control. Under their definition of status, flow control projects (including enhancement measures) have had a 51% success rate in maintaining or increasing salmonid populations (Table 4; p. 46). The same case histories, on the basis of natural stocks, give a success rate of 23%. Thus, when artificial stocks are included the success rate of flow control projects is raised from 23% to 51%, an increase of 28%. This value is likely inflated, however, because Nelson, Horak, Lewis, and Colt (1976, p. 48) state that stocking cannot compensate for the very high losses of anadromous fish associated with blocked upstream habitat. Furthermore, the statistic does not, of course, cover the long term effects of artificial propagation on the genetic composition of the salmonid populations.

pg 4 is blank

Table 1. Case histories that demonstrate the outcome of flow regulation on natural salmonid stocks.

Explanation of Table 1

1. References for examples of Table 1 are found in Appendix A.

2. Projects with more than one purpose have the main one listed first. The purpose "pollution abatement" is achieved by reservoir releases, during low flow periods, to dilute pollutants.

3. The occurrence of the phrase "reduced rearing capacity" under the "Comments" column results from its use by Nelson, Horak, Hale et al. (1976). These authors, however, do not identify the factors that caused the reduction (i.e., food, space, cover, etc.).

4. Asterisked (*) case histories are those most applicable to Kemano Completion.

5. Abbreviations of fish species are:

CT	cutthroat trout (*Salmo clarki*)
EB	brook trout (*Salvelinus fontinalis*)
BT	brown trout (*Salmo trutta*)
RB	rainbow trout (*Salmo gairdneri*)
ST	steelhead trout (anadromous stocks of *S. gairdneri*)
TR	trout spp. (general)
DV	Dolly Varden char (*Salvelinus malma*)
WF	whitefish spp. (general)
CH	chinook salmon (*Oncorhynchus tshawytscha*)
CO	coho salmon (*Oncorhynchus kisutch*)
CM	chum salmon (*Oncorhynchus keta*)
PK	pink salmon (*Oncorhynchus gorbuscha*)
SK	sockeye salmon (*Oncorhynchus nerka*)
KO	kokanee salmon (landlocked *O. nerka*)

Table 1

Status	Explanation	Examples	Purpose
Increased natural stocks.	Increased flow.	(1)* Wildhorse Dam, East Fork Owyhee River, Idaho - Nevada.	Irrigation.
		(2)* Montpellier Creek Dam, Montpellier Creek, Idaho.	Irrigation, flood control.
		(3) Antelope Valley Dam, Indian Creek, California.	Recreation and fisheries development.
		(4) Lake Tahoe Dam, Truckee River, California.	Water conservation.
		(5)* Folsom - Nimbus dams, American River, California.	Flood control, hydroelectric power, irrigation.
	Stabilized flow, gravel scarification.	(6)* Big Qualicum River Project, Big Qualicum River, British Columbia.	Enhancement of CM, CO, and CH through: (1) stabilized water flow, (2) increased summer flow, (3) regulated water temperatures.

Comments

Replaced smaller structure. Increased mean annual flow by 66%. RB and EB trout stocks increased because of increased winter flows and decreased duration of no-flow periods. During no-flow periods TR migrate upstream to pool below dam or downstream of first tributary.

Increased mean annual flow by 39%. Monthly flows generally higher, particularly during summer. Increased flow because of leakage through dam and high water yield during brief post-project period (3 years). CT, RB, and BT populations increased.

Spring and summer flow regime increased. TR biomass increased 5 fold. Angling in reservoir introduced golden shiners (bait) which necessitated rotenone treatment.

Native Lahontan CT trout near extinction because of habitat changes below Derby Dam (reduced flows, increased water temperature, reduced water quality, sedimentation and channel erosion) and because of blocked access to Lake Tahoe. RB, EB, and BT were introduced to the system by periodic stocking and appear to be self-sustaining. These species appear to have increased in the river between Reno and Lake Tahoe because of increased flow during May (from near zero to 5.7 cms) and summer. The contribution of stocking programs to this increase is unknown. Also it is important to note that the pre-project period was already regulated. Fish populations (RB, EB, BT) below Reno are very poor because of water abstractions for irrigation at Derby Dam.

Historically annual runs of CH exceeded 100,000. ST runs were probably of similar mangitude. In the pre-project period severe siltation of the streambed due to hydraulic mining and impassible dams seriously depleted CH runs and almost exterminated ST runs. In the post-project period natural spawning of CH downstream of Nimbus Dam has increased to about 30,000. This is primarily due to increased and cooler flows during spawning (see Example 7). There is probably very little natural spawning of ST as these historically spawned upstream of the present Nimbus dam. ST have increased to about 12,000 fish annually and are maintained by a hatchery below Nimbus Dam. The hatchery also produces CH salmon. Populations will probably never reach historic levels because of the 85% of stream habitat blocked by Nimbus Dam.

Egg-to-fry survival and production of CM fry more than doubled with stabilized flows but maintenance of this benefit requires mechanical scarification of gravel to offset sediment accumulation. Freshwater survival of CH and CO did not change after flow and temperature control. The reasons for the absence of benefit to CH and CO are not completely known.

Table 1

Status	Explanation	Examples	Purpose
Increased natural stocks.	Altered water temperature.	(7)* Folsom - Nimbus dams, American River, California.	Flood control, hydroelectric power, irrigation.
	Mitigation practices: (1) rough fish poisoned prior to dam closure, (2) adult CH and ST trucked above dam for natural spawning, (3) altered flow pattern does not hinder adult returns, (4) productive reservoir devoid of rough fish, (5) downstream migrant transport structure having maximum discharge of 7.9 cms (280 cfs).	(8) Fall Creek Dam, Fall Creek, Oregon.	Flood control, pollution abatement, irrigation, navigation, fish passage.
No significant change in natural stocks.	No major change in flows.	(9) Barker Timber Project, Farman Creek, Oregon.	Recreation.
		(10) North Unit Irrigation Dam, Crooked River, Oregon.	Irrigation (used only occasionally).
		(11) Rudio Creek Diversion Dam, Rudio Creek, Oregon.	Irrigation.
		(12) Booher Diversion Dam, Bennet Creek, Oregon.	Irrigation.

Comments

Hypolimnetic releases from Folsom Afterbay (Nimbus Dam) have decreased downstream temperatures. This has contributed to the increase of natural spawning CH during the post-project period.

Upstream and downstream transport problems have been fairly well resolved. Problem of inducing downstream migration in some years, e.g. in 1968 and 1969 reservoir had to be drained to force downstream migration of CH fingerlings.

Main fish use is rearing for CT, RB and some CO. Slight temperature increase but no noticeable effect on rearing spp. or downstream fishery.

Dam and upstream irrigation have caused siltation and temperatures above 21°C for few km downstream, but inflow of clear, cool spring water quickly alleviates both problems. RB use stream reaches below inflow of spring water.

Provides rearing habitat for ST and TR. 1964 flood caused siltation and decline of salmonids but recently stocks have been recovering.

CT and RB may have increased slightly but no studies to verify this. Post-project flows similar to pre-project except that summer minima increased slightly.

Table 1

Status	Explanation	Examples	Purpose
No significant change in natural stocks.	No major change in flows.	(13)* Toketee, Slide Creek and Soda Springs Diversion dams, North Umpqua River, Oregon.	Irrigation, hydroelectric.
	Increased mean annual flow.	(14)* John Hart Dam, Campbell River, British Columbia.	Hydroelectric power.
	Stabilized flow.	(15) French Meadows Reservoir, Middle Fork American River, California.	Water Conservation.
	Unknown.	(16)* Loon Lake Dam, Gerle Creek, California.	Irrigation and domestic uses.
Decreased natural stocks.	Reduced flow.	(17)* Clearwater No. 1 and No. 2 Diversion dams, Clearwater River, Oregon.	Hydroelectric power.

Comments

Flows relatively unchanged except between each diversion dam and its powerhouse where flows are reduced. Fish populations maintained where flows are unchanged and decreased where flow are reduced (CT, RB).

Mean annual flow increased as a result of water imports from the Salmon, Quinsam, and Heber rivers. Main spawning populations are CH and CM. Smaller populations of PK, CO, SK, and ST also occur. Positive effects may have occurred from increased minimum summer flows but no studies were undertaken to verify this. Negative effects were documented to occur from fluctuating flows which impair adult CH spawning success and cause stranding of juvenile salmonids. Quantitative analysis indicated that abrupt flow increases of 50%, or decreases of 30%, significantly disrupted spawning behaviour. Field observations suggested disruption was greater than indicated by quantitative analysis. In general, the degree of disruption was directly proportional to the amplitude of the change in flow. Escapement records of CH returns indicate a decline following flow control (1950s) but an increase since 1960. The resulting average escapement for 25 post-project years (1950-1974) is about 3600 CH which is similar to the pre-project average of about 3000 CH (1935-1949). Flow regulation was therefore judged as resulting in no significant change on natural CH stocks. This condition may not continue as the lack of gravel recruitment is threatening CH spawning habitat. During the same pre- and post-project periods CM escapement declined from an average of 9600 to 2700. The cause of this decline is difficult to assess owing to the effects of land/water uses and fishing pressure.

Project has decreased but stabilized flows. These flows do not maximize TR spawning area but are believed to benefit food production and cover as the river no longer receives heavy annual scouring from peak flows. Exposure of iron ochre in the first 0.8 km below the dam has inhibited fish production in this area.

Diversion of Rubicon River water to Loon Lake has dramatically increased flows in Gerle Creek. Peak flows have increased 10 fold. RB, BT, and EB trout populations have not improved despite increases in flows. An explanation was not available as no post-project studies were initiated.

Mean annual flow reduced 81%. RB and EB populations decreased because of reduced rearing capacity. Deep holes sustain fish during periods of low flow.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Reduced flow.	(18)* Lemolo No. 1 and No. 2 Diversion dams, Clearwater River, Oregon.	Hydroelectric power.
		(19)* Cottage Grove Dam, Coast Fork Willamette River, Oregon.	Flood control, irrigation, navigation.
		(20)* Cougar Dam, South Fork Willamette River, Oregon.	Flood control, hydroelectric power, navigation, pollution abatement, domestic uses.
		(21)* Emigrant Dam, Emigrant Creek, Oregon.	Irrigation, hydroelectric power, flood control.
		(22)* Riverside and Beulah dams, Middle and North Forks Malheur River, Oregon.	Irrigation.
		(23)* Pelton Dam, Deschutes River, Oregon.	Hydroelectric power.
		(24)* Hell's Canyon Dam, Middle Snake River, Idaho.	Hydroelectric power, flood control, navigation.
		(25)* Little Wood Dam, Little Wood River, Idaho.	Irrigation, flood control.

	Comments
ic	Mean annual flow reduced 83%. RB, EB, and BT populations reduced because of decreased rearing capacity. Tributary inflow and deep holes have permitted continued existence of stocks.
l,	Mean annual flow increased 63% but flows sometimes inadequate in fall for CH migration and spawning.
l, ic es.	Mean annual flow reduced 16%; extremes of flow (minima and maxima) drastically reduced. Serious decline in spring CH primarily due to reduced minimum flows during January-June, August, September, November, and December which reduced available spawning, rearing, and overwintering areas and exposed eggs. CT and DV rearing also affected. Instream cover and eggs affected by sedimentation.
ic d	Incidence of minimum monthly flow prescribed by the water licence (0.03 cms) have increased and cause stranding of resident RB and CT trout in oxygen-deficient pools.
	During winter, when reservoirs are storing water, very low flow releases limit TR rearing habitat. TR are forced into pools.
ic	Mean annual flow decreased only slightly, but monthly minima are lower resulting in a reduction in spawning habitat at preferred depths and velocities, and in food supply for RB, ST, and CH.
ic d	Minimum instream flow reserved for fish has not maintained downstream spawning habitat.
l.	EB below dam depleted not by dam but by irrigation diversions 2 miles downstream and by low winter flows.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Reduced flow.	(26) Rock Creek Diversion Dam, North Fork Feather River, California.	Hydroelectric power.
		(27)* Salt Springs Reservoir, North Fork Mokelumne River, California.	Hydroelectric power.
		(28)* Spicer Meadows Reservoir, Highland Creek, California.	Hydroelectric power.
		(29) Lower Lagunitas project, Lagunitas Creek, California.	Municipal and industrial use.
		(30)* Scott Dam, Eel River, California.	Stabilization and storage of flows for Cape Horn Dam.
		(31)* Cape Horn Dam, Eel River, California.	Diversion of flows to Russian River basin for hydroelectric power and irrigation.
		(32)* San Pedro Valley, San Pedro Creek, California.	Diversion for municipal and industrial uses.
		(33)* Nacimiento Dam, Nacimiento River, California.	Water conservation.

Comments

Minimum flows drastically reduced. TR fishery severely depleted as habitat created by project encourages propagation of rough fish spp. which are in direct competition with TR. Eradication of rough fish and restocking with TR were attempted twice but rough fish took over again within 2 years of each attempt.

Maximum monthly flow reduced 38%. Transect study found that minimum flows reserved for fish (TR) were too low to maintain adequate habitat (cover, spawning, and food producing areas). Such flows prevail for as long as 9 months in some years. Fish biomass was noticeably poorer than in an unregulated tributary.

Rapid reduction of flow in autumn from about 50 cfs (1.42 cms) to 2 cfs (0.06 cms) and maintenance of this 2 cfs until mid-winter has resulted in a dramatic decline in the production of RB, BT, and insects.

Limited pre- and post-project studies of CO and ST populations. Flow releases are sometimes too low to satisfy fish requirements, particularly during the dry season.

Water stored for Van Arsdale Reservoir (19 km downstream) which diverts water to another river basin. Access to Van Arsdale reservoir provided by fishway. Scott Dam has severely depleted runs of CH, CO, and ST. Anadromous fish are limited mainly to ST now. Regulation has removed attraction flows for adult migration, created water barriers for adult migration, prevented successful spawning and delayed downstream migrations of juveniles.

Monthly flows reduced 20% to 92%. CH runs virtually eliminated and ST runs seriously depleted. Migrating adult CH are first delayed (insufficient flows for stimulus and passage) at a tributary 50 km below the dam and again at a creek 5.8 km downstream. Short duration spills often induce CH to move further upstream where they are later stranded and their redds exposed.
Spawning habitat below the dam has been reduced by:
-lack of gravel recruitment
-encroachment of riparian vegetation onto flood plain (this physically alters spawning gravel, aids in sedimentation and reduces intergravel flow).

Water abstractions have reduced available habitat for ST and CO have decreased the creek's ability to assimilate pollution.

Flow release pattern ignore ST life stages. Peak winter flows have been reduced, delayed and in dry years totally eliminated.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Reduced flow.	(34) Whale Rock Reservoir, Old Creek, California.	Municipal and industrial uses.
		(35)* Pine Flat Dam, Kings River, California.	Irrigation and flood control.
		(36)* Isabella Dam, Kern River, California.	Irrigation, hydroelectric power, flood control.
		(37)* Friant Dam, San Joaquin River, California.	Irrigation, flood control.
		(38) Crocker Huffman - Exchequer Projects, Merced River, California.	Irrigation, hydroelectric power, flood control.
		(39)* Goodwin, Tullock, Melones dams, Stanislaus River, California.	Irrigation, flood control, hydroelectric power.

Comments
No flows released from the dam. Instream flows reduced to 0 cfs at all times. Annual spawning run of ST made extinct.
Lower portion of river is dewatered because of diversion of flows to irrigation canals. Upper portion of river subjected to reduced flows from October-February because of reservoir storage. Naturally propagated RB limited by these and heavy fishing pressure. Stocking is required annually to maintain the fishery.
Fall and winter flows drastically reduced. This and heavy angling pressure are major causes for decline of natural RB below dam. Periodic flow reductions above the reservoir as a result of diversions for power cause low O_2 levels in the reservoir. Stream flow alterations and other detrimental effects have favoured the propagation of non-game fish which compete with game fish.
Friant Dam catastrophically reduced downstream flows; resultant flows are insufficient for CH and adult ST migrations, spawning, and for juvenile smolt migrations. Water abstractions at Mendota and Sack dams located downstream further reduced or eliminated flows during salmon migrations. Such massive reductions in flow during critical life stages were a major factor causing extinction of major salmon runs between Merced River and Friant Dam. Extinction occurred within 3 years of completion of Friant Dam.
Diversion of flows to district irrigation canals has reduced instream flows rendering fishways at Crocker Huffman Dam and Merced Falls Dam impassable and degraded fish habitat downstream (CH and ST). Reduced flows in spring have decreased survival of emigrating juveniles.
Flow reductions occur throughout the year but are greatest from July to December when mean monthly flows are reduced by 83-98% natural. Results in periodic dewatering of the channel from from Goodwin Dam to Ripon where agricultural returns occur. CH and ST runs have been greatly reduced. Reduced flow has hindered adult migration, reduced available spawning habitat and decreased survival of juveniles (return of adults is highly correlated with flow during juvenile migration 2.3 years earlier).

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Reduced flow.	(40)* New Don Pedro-Le Grange dams, Tuolumne River, California.	Hydroelectric power, irrigation.
		(41)* Lake Henshaw, San Luis Rey River, California.	Irrigation.
		(42) Casitas Dam, Ventura River, California.	Irrigation.
		(43) Lake Sabrina, Middle Fork Bishop Creek, California.	Hydroelectric power, water conservation.
		(44)* Trinity-Lewiston dams, Trinity River, California.	Water conservation for diversion to Keswick Reservoir on the Sacramento River, California.
		(45)* South Alouette River Dam, South Alouette River, British Columbia.	Water storage, hydroelectric power.
	Blockage of habitat.	(46) Dorena Dam, Row River, Oregon.	Flood control, navigation, irrigation, pollution abatement.

Comments

Highest mean monthly flow reduced 66%. Mininum spring and summer flows reduced from greater than 0.4 cms (14 cfs) to near zero. Stream reduced to deep narrow channels which are inadequate to support former salmon spawning populations (CH and ST). Annual run of 75,000-80,000 fish reduced to 5,000 fish 2 years after project completion.

Flows reduced to near zero during Oct.-Dec. There are periods of zero flow releases during dry years. Resultant instream flows are insufficient to maintain a self propagating TR population.

ST runs are near extinction because of reduced flows resulting from Matilija Reservoir (completed 1949). Operation of Casitas Reservoir (completed 1959) further depleted flows in the lower Ventura River with no flows to the ocean except during the wet season. During high water years some ST make it up the Ventura River to spawn.

Insufficient flows for TR. Stocked annually with catchable sized RB.

Reduction of rearing and downstream migration flows have created serious problems for juvenile CH, CO, and ST. (Type of problem was not specified.)

Mean annual flow was reduced by about 89% owing to diversion of water to the Stave River system (percentage based on the years 1916-1925 for natural flows and 1960-1976 for regulated flows). This has reduced the river's spawning and rearing areas (CO, CM, ST, CT). Degradation of the quantity and quality of spawning gravel is thought to be a major factor causing the extinction of PK runs. Some of this degradation was likely caused by gravel removal (terminated in 1956).

Blocked 50% of spawning area for small runs of CH and ST.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Blockage of habitat.	(47) Pelton Dam, Deschutes River, Oregon.	Hydroelectric power.
		(48) Skookumchuk Dam, Skookumchuk River, Washington.	Water storage to augment flows for steam-electric power plant.
		(49) Wynooche Dam/ Aberdeen Diversion, Wynooche River, Washington.	Flood control.
		(50) Dworshak Dam, North Fork Clearwater River, Idaho.	Hydroelectric power, flood control, navigation.
		(51) Hell's Canyon Dam, Middle Snake River, Idaho.	Hydroelectric power, flood control, navigation.
		(52) Blue River Dam, Blue River, Oregon.	Flood control, pollution abatement, irrigation, navigation, domestic use, fish passage in lower Willamette River.
		(53) Cottage Grove Dam, Coast Fork Willamette River, Oregon.	Flood control.

	Comments
c	Blocked about 69 km of scattered spawning area used by ST and some CH.
e ic	Over 50% of river's spawning area blocked. Was principal spawning area for ST, CO, and some CH. Natural CH populations spawning below dam increased because of increased flows, but ST and CO decreased. ST trucked above dam for spawning; CO compensated with hatchery.
l.	Wynooche Dam blocked major spawning area for CO, ST, and CT. These species are trucked upriver for natural spawning; however, high rate of residualism, delayed outmigration, and 13% mortality of juveniles in tailrace have caused decline. Downstream populations of ST and CO were predicted to increase because of increased summer-fall flows but instead populations have decreased.
c	Blocked major ST run and minor CH run. ST compensated with hatchery. Water temperatures were increased in winter and decreased in spring and summer (owing to cold water release structure) and resulted in delayed spawning time, increased productivity and growth of TR. Effects of temperature changes, flow fluctuations, and minimum flows on salmonids are unknown.
c	Blocked major runs of spring and fall CH and ST. No fishway provided. Compensated by artificial propagation.
l,	Lack of passage facility resulted in extinction of annual run of 100 CH. TR population decreased for 2.7 km below dam site in response to reduced flow.
, in	
l.	Blocked only small populations of CH and ST as partial barriers downstream impeded runs. Downstream effects of the dam were much more damaging.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Blockage of habitat.	(54) Dexter Dam, Middle Fork Willamette River, Oregon.	Flood control, power generation, pollution abatement, improvement of water quality, irrigation, navigation, fish passage in lower Willamette River.
		(55) Black Butte Reservoir, Stony Creek, California.	Irrigation, flood control, conservation.
		(56) Scott Dam, Eel River, California.	Hydroelectric power.
		(57) Isabella Dam, Kern River, California.	Irrigation, hydroelectric power, flood control.
		(58) Friant Dam, San Joaquin River, California.	Irrigation, flood control.
		(59) Goodwin, Tullock, Melones dams, Stanislaus River, California.	Irrigation, flood control, hydroelectric power.
		(60) Santa Felicia Dam, Piru Creek, California.	Irrigation, municipal and industrial uses.

Comments

80% of total basin's spawning area blocked. Resulted in loss of one of most productive natural spring CH areas in the Columbia River system.

Gravel diversion dam 22 miles below Black Butte Dam is main cause for decline of CH and ST. Constructed each year and renders stream below dry from about April to November when high flows (500 cfs or greater) wash it out.

80-121 km of stream habitat blocked by dam. Contributed to decline of CH, CO, and ST populations.

TR migrating above the reservoir to spawn are blocked at the headgates of an upstream power diversion.

Friant Dam blocked 36% of the upper San Joaquin's spawning habitat (CH and ST). Sack Dam (constructed of sand bags each year) blocked varying portions of adult CH runs depending on when it was installed. A bypass canal at Sack Dam failed because of insufficient flows and high temperatures in the canal.

Goodwin Dam blocked access to upstream spawning grounds (CH and ST).

Historically, significant runs of ST migrated 97 km up Piru Creek during wet years. Santa Felicia Dam located 2.4 km above the creek's mouth eliminated these runs.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Blockage of habitat.	(61) Trinity-Lewiston dams, Trinity River, California.	Water conservation for diversion to Keswick Reservoir on the Sacramento River.
		(62) South Alouette River Dam, South Alouette River, British Columbia.	Water storage, hydroelectric power.
	Sedimentation, gravel compaction, reduced intergravel O_2.	(63)* Pelton Dam, Deschutes River, Oregon.	Hydroelectric power.
		(64)* Cougar Dam, South Fork McKenzie River, Oregon.	Flood control, hydroelectric power, irrigation, pollution abatement, domestic use.
		(65)* Riverside and Beulah dams, Middle and North Forks Malheur River, Oregon.	Irrigation.
		(66) Foster and Green Peter dams, South and Middle Santiam rivers, Oregon.	Flood control, hydroelectric power, pollution abatement, irrigation, industrial and domestic uses, navigation, fish passage.
		(67)* Scott Dam, Eel River, California.	Stabilization and storage of flows for Cape Horn Dam.

Comments

Trinity Dam blocked 50% of the upper Trinity River spawning grounds (CH, CO, ST). A fish hatchery was unsuccessful in compensating this loss owing to unforseen downstream effects associated with sedimentation.

Dam blocked access for SK, CH, CO, and CM to spawning grounds in Alouette Lake and its tributaries. This was the main cause for the extinction of SK and near extinction of CH. Moderate runs of CM and CO, and small runs of ST and sea-run CT are still present as these species use spawning areas below the dam.

Reduction of discharge resulted in sedimentation, that, in turn, adversely affected the quality of spawning gravel, egg survival and food supply. This contributed to the decline of CH, ST, and RB.

Sedimentation was an important factor causing the decline of CH, CT, DV, and WF. Source of sediments was construction activities and turbid reservoir releases. Deposition of sediments deteriorated spawning, incubation and rearing habitats.

Stream bottom below dam was silted; this prevented natural TR spawning.

Siltation in Green Peter Reservoir reduced the quality of rearing habitat.

Sediments from sources above Scott Dam have degraded fish habitat below the dam; this has contributed to the decline of CH, CO, and ST in this system.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Sedimentation, gravel compaction, reduced intergravel O_2.	(68)* Cape Horn Dam, Eel River, California.	Diversion of flows to Russian River for hydroelectric power and irrigation.
		(69)* Isabella Dam, Kern River, California.	Irrigation, hydroelectric power, flood control.
		(70)* Friant Dam, San Joaquin River, California.	Irrigation, flood control.
		(71)* Goodwin, Tullock, Melones dams, Stanislaus River, California.	Irrigation, flood control, hydroelectric power.
		(72)* New Don Pedro- Le Grange dams, Tuolumne River, California.	Hydroelectric power, irrigation.
		(73) Bridgeport Dam, East Walker River, California.	Irrigation.
		(74)* Lake Henshaw, San Luis Rey River, California.	Irrigation.
		(75)* Trinity-Lewiston dams, Trinity River, California.	Water conservation for diversion to Keswick Reservoir on the Sacramento River.

Comments

Spawning gravel below dam has been degraded by deposition of fines that were periodically sluiced through the dam's outlet pipe prior to 1983.

Sedimentation has occurred in the mainstem below the three diversion canals reducing the quality of TR habitat.

Siltation and vegetation encroachment have taken over spawning gravels below Friant Dam and eliminated the hope of re-establishing CH runs to the San Joaquin River between Merced River and Friant Dam. Gravel mining operations in the stream channel are also gradually decreasing the quantity of spawning gravel.

Siltation, compaction, and vegetation encroachment as a result of reduced flow have decreased the quantity and quality of CH spawning habitat. Significant deterioration occurred over a 12 year period between 2 studies.

Highest monthly flow reduced 66%. Quantity and quality of spawning gravel greatly reduced because of vegetation encroachment (willows) and their entrapment of sediment. Annual run of 75,000-80,000 salmonids (CH and ST) reduced to about 5,000 fish.

Evacuation of the reservoir in 1960 released mud and silt downstream resulting in considerable loss of fish (RB and BT). Planting with catchable sized RB and BT produced from a hatchery was used to restore the fishery.

Highest mean monthly flows reduced by 92%. Loss of flushing action of dominant flows has severely depleted TR habitat through encroachment of vegetation into the stream bed and build up of fine sediments.

Mean annual flow reduced 88% and peak flows drastically reduced. Naturally spawning stocks (CH, CO, ST) below the dam seriously depleted owing to sedimentation and vegetation encroachment on spawning gravel. The worst area of sedimentation is the 13 km below the mouth of Grass Valley Creek. This tributary has a high sediment load due to logging practices.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Sedimentation, gravel compaction, reduced intergravel O_2.	(76)* Tolt Dam, South Fork Tolt River, Washington.	Municipal and industrial uses.
	Fluctuating flows.	(77)* Foster and Green Peter dams, South and Middle Santiam rivers, Oregon.	Flood control, hydroelectric power, pollution abatement, industrial and domestic uses, navigation, fish passage.
		(78)* Merwin Dam, Lewis River, Washington.	Hydroelectric power.
		(79)* Anderson Ranch Dam, South Fork Boise River, Idaho.	Irrigation, hydroelectric power.
		(80)* Lucky Peak Dam, Boise River, Idaho.	Irrigation, flood control, fish and wildlife, recreation.
		(81)* Cabinet Gorge Dam, Clark Fork River, Idaho.	Hydroelectric power.

Comments

Outcome of this case was judged by comparing ST abundance in the South Fork (regulated) with their abundance in the North Fork (unregulated, i.e. control). Redd counts in the South and North Forks indicated fewer spawners in the South Fork. Additionally, smolt abundance in the South Fork was about half that of the North Fork. Substrate analysis indicated that gravel quantity and quality were lower in the South Fork. Sources of fines for both forks included bank failures caused by logging, road building, and natural erosion. Substrate samples taken in Feburary, July, and September suggest fines are flushed from gravels during late winter and spring freshets. It can be postulated that the dampening of freshets in the South Fork has reduced its ability to cleanse spawning gravel of fines. No studies, however, were performed to support this hypothesis. A weakness in judging the outcome for ST based on a comparison of regulated and unregulated forks is the possibility that the South Fork had a lower productivity than the North Fork even before the occurrence of regulation. Pre- and post-dam data were not available to alleviate this weakness. Further, the biological data contradicts computer modelling (IFIM) which predicts that flow regulation should have benefited most ST life stages. The modelling, however, did not incorporate flushing flows.

Daily wide fluctuation have eliminated spawning and rearing habitat (CH, ST, RB, CT) between the dams and reduced food supplies.

Recent decline of CH attributed to stranding of juveniles when peak flows are reduced to the minimum instream flow reservation (MFR). Rate of reduction is more important than the value of the MFR.

Extreme flow fluctuations have exterminated natural stocks (RB, WF) through scouring of spawning habitat and reduction of food supply.

Fluctuating flows have displaced spawning gravels to higher elevations in the river channel and to smaller tributaries. Result has been a decline in native RB trout populations.

Daily fluctuations average 2 m (extreme is 5 m (16 ft)). Low stages inhibit entry of Kamloops trout, DV, CT, and KO into a tributary, disrupt spawning, and expose eggs to desiccation and freezing. Gravel in the streambed has been depleted.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Fluctuating flows.	(82)* Hell's Canyon Dam, Middle Snake River, Idaho.	Hydroelectric power, navigation.
		(83)* Nacimiento Dam, Nacimiento River, California.	Water conservation.
		(84)* Goodwin, Tullock, Melones dams, Stanislaus River, California.	Irrigation, flood control, hydroelectric power.
		(85)* South Alouette River Dam, South Alouette River, British Columbia.	Water storage, hydroelectric power.
	Altered water temperatures.	(86)* Cottage Grove Dam, Coast Fork Willamette River, Oregon.	Flood control, irrigation, navigation.
		(87)* Dexter Dam, Middle Fork Willamette River, Oregon.	Flood control, hydroelectric power, pollution abatement, irrigation.
		(88)* Riverside and Beulah dams, Middle and North Forks Malheur River, Oregon.	Irrigation.
		(89)* Dorena Dam, Row River, Oregon.	Flood control, irrigation, navigation.

Comments
Fluctuating flows have deposited gravel along river banks and sand bars, and adversely affected benthic insects and aquatic vegetation.
Daily flow releases range from 3.96 cms (140 cfs) to 14.30 cms (505 cfs) and inhibit nest construction, spawning and hatching success.
Fluctuating flows due to hydroelectric power generation adversely affected CH spawning habit.
Limited storage capacity of the dam has necessitated spillage into the South Alouette River during CM spawning. This encourages spawning in side channels which later dry up before eggs hatch. Instantaneous flow releases have also occurred in the summer causing scouring of the channel and abrupt changes in temperature.
Warm water releases from the reservoir have produced downstream temperatures in excess of 27°C compared to a maximum of 21°C in upstream locations. Has encouraged propagation of coarse spp. and caused decline of CH, ST, CT, and RB.
Warm water releases from Lookout Point Reservoir (5 km upstream) have increased temperatures below Dexter Dam to 16°C. These do not permit the successful natural reproduction of spring CH below Dexter Dam. Cool water releases from Hills Creek Dam upstream have lowered temperatures somewhat.
High summer temperatures limit TR populations and encourage propagation of coarse fish spp.
Release of warm reservoir water in late summer elevates downstream temperatures to 24°C. This has limited the holding and maturation of spring CH, and has promoted coarse fish which outcompete resident RB and CT trout.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Altered water temperatures.	(90)* Lost Creek Dam, Rogue River, Oregon.	Hydroelectric power, irrigation, reservoir recreation, enhancement of downstream CH and ST populations.
		(91)* Friant Dam, San Joaquin River, California.	Irrigation, flood control.
		(92)* Goodwin, Tullock, Melones dams, Stanislaus River, California.	Irrigation, flood control, hydroelectric power.
		(93)* South Alouette River Dam, South Alouette River, British Columbia.	Water storage, hydroelectric power.
	Passage of outmigrants through reservoirs and over dams.	(94) Foster and Green Peter dams, South and Middle Santiam rivers, Oregon.	Flood control, hydroelectric power, pollution abatement, irrigation, industrial and domestic uses, navigation, fish passage.
		(95) Pelton Dam, Deschutes River, Oregon.	Hydroelectric power.

Comments

Increased winter temperatures have accelerated the timing of emergence, resulting in a 58% decline in juvenile CH. Prespawning mortality of fall run CH increased drastically.

Reduced flows as a result of water obstraction at Friant, Mendota and Sack dams led to high temperatures that were directly lethal or caused migrating salmon to succumb to disease. CH migrating to Sack Dam were observed to be bruised and injured from battling low flows with massive mortalities occurring during hot weather. High water temperatures, induced by low flows contributed to the extinction of salmon runs in the San Joaquin above Merced River.

High water temperatures due to reduced flows have deteriorated CH spawning habitat.

Reduction of flows in summer results in high water temperatures. Data collected in 1982 found maximum monthly water temperatures reached as high as 23.3°C and were consistently over 20°C during the summer. These levels are believed to cause stress and possibly mortality to rearing CO, CT, and ST. The river's rearing capacity is thought to have been reduced as a consequence.

Success of passage of juvenile ST and CH through reservoir is reduced due to competition with coarse fish for food and space, and by predation by coarse fish (squawfish).

Problems with downstream passage of CH and ST resulted in abandonment of fish ladder. Artificial propagation replaced fishway as compensation option.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Passage of outmigrants through reservoirs and over dams.	(96) Whitehorse Rapids Power Development, Yukon River, Yukon Territory.	Hydroelectric power.
	Pollution.	(97)* Prosser Diversion Dam, Yakima River, Washington.	Irrigation, hydroelectric power.
		(98)* Goodwin, Tullock-Melones dams, Stanislaus River, California.	Irrigation, flood control, hydroelectric power.
		(99)* South Alouette River Dam, South Alouette River, British Columbia.	Water conservation, hydroelectric power.
	Inundation of fish habitat by the reservoir.	(100) Foster and Green Peter dams, South and Middle Santiam rivers, Oregon.	Flood control, hydroelectric power, pollution abatement, irrigation, industrial and domestic uses, navigation, fish passage.
		(101) Nicasio Lake, Nicasio Creek, California.	Municipal and industrial uses.
	Lack of gravel recruitment.	(102) Isabella Dam, Kern River, California.	Irrigation, hydroelectric power, flood control.

Comments

Dam was built on migration route of CH. Lake trout, grayling and least cisco also present in the vicinity of the dam. A fishway was built to provide passage but CH populations still declined (other spp. not examined) as a result of smolt mortalities of at least 16% in the turbines (smolts comprise 30% of the downstream CH migrants). The average pre-project escapement of CH (based on the 4 brood years prior to construction) was 1070 fish. The average post-project escapement for the years 1963-1975 was 500 CH.

Irrigation returns introduce nitrates and suspended solids. CH and ST populations had declined before construction (owing to effects of early irrigation practices) but reduced flows aggravated problems and accelerated the attrition of salmonid runs.

Reduced flow plus agricultural and municipal returns have resulted in O2 levels less than 4-5 mg/L which reduce the success of adult CH spawning migration.

Reduced flow has decreased the river's ability to assimilate industrial, residential and agricultural wastes, resulting in reduced dissolved oxygen.

55% of spawning area used by CH and ST were inundated.

3 miles of spawning and nursery habitat (CO and ST) inundated. Fish trapping facility installed to collect adults for trucking to spawning grounds above reservoir. This did not maintain stocks as inundation of spawning and nursery areas severely diminished the stream's carrying capacity. Trapping was abandoned except for wet years when flow releases are sufficient for attraction and passage of adults. Replaced with planting operation (fingerlings and yearlings). Planted juveniles compete with natural juveniles and the adults return early when stream flows are insufficient for fish passage.

Lack of gravel recruitment has decreased TR spawning habitat.

Table 1

Status	Explanation	Examples	Purpose
Decreased natural stocks.	Lack of gravel recruitment.	(103) Trinity-Lewiston dams, Trinity River, California.	Water conservation for diversion to Keswick Reservoir on the Sacramento River.
	Nitrogen super-saturation.	(104)* Hell's Canyon Dam, Middle Snake River, Idaho.	Hydroelectric power, navigation.
Unknown.	Status of natural stocks confounded by artificial stocks.	(105) Prineville Dam, Crooked River, Oregon.	Irrigation, flood control.
		(106)* Big Cliff Dam, North Santiam River, Oregon.	Flood control, hydroelectric power, pollution abatement, irrigation, industrial and domestic uses.
		(107) Fish Creek Diversion Dam, Fish Creek, Oregon.	Hydroelectric power.
		(108) Howard Hanson Dam, Green River, Washington.	Flood control, fish passage.
		(109) Scoggin and Oregon Iron and Steel Co. dams, Scoggin Creek and Tualatin River, Oregon.	Scoggin Dam: irrigation, pollution abatement, municipal and industrial uses. Oregon Iron and Steel Co. Dam: hydroelectic power.

Comments

Lack of gravel recruitment had depleted spawning areas (CH, CO, ST) for 3 km below Lewiston Dam.

Supersaturated water occurs in the vicinity downstream of the dam. This has reduced the numbers of CH and ST migrating to the dam.

ST populations extinct because of blockage by other dams downstream. Status of natural RB unknown owing to planting programs. Habitat, however, has improved owing to increased and cooler summer flows, and decreased deposition of sediments. Mean annual flow was decreased by 20%.

Portion of CH and ST run blocked by dam. Effect of this on natural populations unknown owing to hatchery production. Mean annual flow and monthly flows have increased, and downstream temperatures decreased. This has improved the environment for downstream fish.

Status of natural spawning RB and EB confounded by stocking. Effects of the projects are difficult to assess owing to floods in 1955 and 1964 which decreased fish stocks.

State of natural fish stocks (CH, CO, ST, and sea-run CT) confounded by hatchery production.

Used by CO, ST, and sea-run CT, plus resident RB and CT. Anadromous migrations are impeded by low flows above and below Iron and Steel Co. Dam owing to irrigation withdrawals. State of natural stocks confounded by stocking (CO fry, fingerling, and catchable RB).

Table 1

Status	Explanation	Examples	Purpose
Unknown.	Status of natural stocks confounded by artificial stocks.	(110) Big Bear Lake, Bear Creek, California.	Municipal and industrial.
		(111)* Iron Gate Dam, Klamath River, California.	Reregulation of flows from upstream powerhouses.
		(112)* Shasta-Keswick dams, Sacramento River, California.	Flood control, irrigation, hydroelectric power, recreation, salinity control in the delta, fish and wildlife conservation.
		(113)* Pit #6 and #7 Reservoirs, Pit River, California.	Hydroelectric power.
		(114)* Pleasant Valley Dam, Owens River, California.	Municipal and industrial uses, power production, flow regulation.
		(115) Oroville Dam, Feather River, California.	Hydroelectric power, flood control, water conservation.
		(116)* Coyote Dam, Russian River, California.	Flood control, agricultural and municipal uses.

Comments

Reservoir was chemically treated 3 times eliminating downstream stocks of TR. Treatment was followed by restocking. Resultant TR were self-sustaining. This procedure confounded the effects of the dam on natural stocks.

Status of natural stocks confounded by hatchery production (CH, ST, CO). Phreatophyte encroachment, sediment deposition, and increased water temperature have adversely affected instream salmonid habitat.

Keswick Dam blocked 50% of the Sacramento Basin's spawning habitat (CH and ST). Coleman Hatchery constructed as compensation. Status of natural stocks confounded by hatchery fish. Diversion of water from the Trinity River and hypolimnetic releases have provided increased and cooler summer flows but the lack of gravel recruitment is threatening natural spawning habitat. A spawning channel construction in 1966 may compensate this. Reduction of spring flows that were diluting toxic runoff of copper caused large mortalities in 1957. This was alleviated somewhat by increased discharge from Shasta Reservoir at appropriate times, although smaller fish kills still occur in some years.

Pit River is stocked annually with TR making it difficult to assess the post-project river's ability to naturally propagate fish.

Status of naturally spawning BT and RB is unknown owing to construction of a spawning channel and planting of surplus hatchery brood stock in the channel in 1963. Pleasant Valley Dam blocked and inundated some TR habitat. Power plants in the lower river were adversely affecting egg-to-fry survival through widely fluctuating flows but this has been rectified by modifying the flow release schedule. Water exports in the lower river have increased summer flows and decreased winter flows. Increased summer flows have accelerated the process of oxbow cutting resulting in increased bedload and sedimentation.

Status of natural stocks confounded by hatchery production and later by construction of a spawning channel. Oroville Dam may have improved conditions for natural spawners as it eliminated hourly and daily flow fluctuations (caused by upstream power production) and low late summer flows (caused by irrigation withdrawals) that occurred before the project.

Outplanting of CH and CO in 1956, 1961, and 1969 has confused the post-project status of natural stocks of CH and CO. See also example 126 and 131 for other factors that obscure the status of natural stocks on this river.

Table 1

Status	Explanation	Examples	Purpose
Unknown.	Lack of, or inconclusive post-project studies.	(117)* Middle Fork Project, Clear Branch, Oregon.	Irrigation.
		(118)* Laurance Lake, Clear Branch, Oregon.	Irrigation.
		(119)* Palisades Dam, Snake River, Idaho-Wyoning.	Irrigation, flood control.
		(120)* Gorge Dam, Skagit River, Washington.	Hydroelectric power.
		(121) Howard Hanson Dam, Green River, Washington.	Flood Control, fish passage.
		(122) Themla Adair Keyes Reservoir, Butano Creek, California.	Irrigation.
		(123) Sand Bar Diversion, Middle Fork Stanislaus River, California.	Hydroelectric power.
		(124)* Pit #6 and #7 Reservoirs, Pit River, California.	Hydroelectric power.
		(125)* Coyote Dam, Russian River, California.	Flood control, agricultural and municipal uses.
		(126)* Big Bear Lake, Bear Creek, California.	Municipal and industrial.

Comments
Used by CO, ST, CT, and resident RB. Gravel below the dam has become silted because of inadequate flushing flows. No post-project studies to determine the effect on salmonids.
Siltation has occurred because of inadequate flushing flows. Status of CO, CT, ST unknown as there are no post-project studies.
Mean annual flow increased 22%. Wide flow variations expose banks and islands. Dam blocked spawning runs of CT trout. Food supply was reduced and turbidity decreased. Effects on CT and BR trout unknown as post-project studies were inconclusive.
Mean annual flow decreased 5%. Major concern is flow fluctuations associated with power peaking that cause stranding of CH fry and a reduction in food supply. Some scouring of spawning gravel and streamside vegetation. Although well studied, results do not indicate status of stocks.
Post-project studies involved a different method of population estimates than pre-project studies. As a result it was not possible to compare pre- and post-project population estimates.
Very limited data collected before and after regulation. Creek supports ST and resident RB.
Flows between Sand Bar Dam and Stanislaus Powerhouse (19 km of stream) reduced by half but effects unknown as no pre- or post-project studies were undertaken.
No pre- or post-project studies to determine the status of TR stocks. Known effects included blockage of access to and from Lake Shasta, heavy scouring below Pit #7 due to fluctuating flows, and increased incidence of disease (_Ceratamyxa shasta_) due to releases from the warm top layer of Pit #7.
Lack of pre-project data on stock abundances makes it difficult to assess the status of post-project stocks (ST, CH, and CO).
First dammed in 1884 and upgraded in 1912. Abundance and species of fish unknown prior to regulation.

Table 1

Status	Explanation	Examples	Purpose
Unknown.	Lack of, or inconclusive pre-project studies.	(127) Thelma Adair Keyes Reservoir, Butano Creek, California.	Irrigation.
		(128) Sand Bar Diversion, Middle Fork Stanislaus River, California.	Hydroelectric power.
		(129)* Pit #6 and #7 Reservoirs, Pit River California.	Hydroelectric power.
	Effects of flow regulation confounded by the effects of other land/water uses.	(130) Thelma Adair Keyes Reservoir, Butano Creek, California.	Irrigation.
		(131)* Coyote Dam, Russian River, California.	Flood control, agricultural and municipal uses.
	Short post-project period.	(132) Scoggin and Oregon Iron and Steel Co. dams, Scoggin Creek and Tualatin River, Oregon.	Scoggin Dam: irrigation, pollution abatement, municipal and industrial uses. Oregon Iron and Steel Co. Dam: hydroelectric power.

Comments
Very limited data collected before and after regulation. Creek supports ST and resident RB.
Flows between Sand Bar Dam and Stanislaus Powerhouse (19 km of stream) reduced by half but effects unknown as no pre- or post-project studies were undertaken.
No pre- or post-project studies to determine the status of TR stocks. Known effects included blockage of access to and from Lake Shasta, heavy scouring below Pit #7 due to fluctuating flows, and increased incidence of disease (*Ceratamyxa shasta*) due to releases from the warm top layer of Pit #7.
Effects associated with poor logging practices (sedimentation and log jams) make it difficult to assess the effects of flow regulation. Creek supports ST and resident RB.
Coyote Dam was anticipated to benefit salmonids (ST, CH, and CO) through instream flow releases for fish and increased summer flows. The effects of flow regulation were difficult to assess owing to habitat deterioration caused by extraneous factors such as gravel removal, stream channelization and siltation (associated with logging and road building), downstream water abstractions and summer dams, increased temperature associated with the dams, and pollution from municipal and industrial wastes. Coyote Dam has contributed to the habitat losses through blockage of 53 km of spawning and nursery habitat, and sedimentation of downstream habitat due to turbid releases from the dam (turbid water is the result of the transbasin transfer of flows from the Eel River). Low flows and high water temperatures have eliminated the early run of CH.
Effect of Scoggin Dam on salmonids unknown because of short post-project period at time of report.

Table 2. Outcome for natural salmonid stocks after flow regulation

Location	Projects	Improved	Unchanged	Reduce
B.C.	3	1	1	1
Yukon	1	0	0	1
Idaho	8	2	0	6
Oregon	18	1	5	12
Washington	5	0	0	5
California	28	3	2	23
Total	63	7	8	48
Percent	100	11	13	76
		24		76

Table 3. Principal explanations for the outcomes of natural salmonid stocks exposed to flow regulation.

Explanation	Number of case histories	Percent of case histories
1. Improved or unchanged natural stocks		
Increased flow	6	40
No major change in flow	5	33
Stabilized flow	2	13
Altered water temperature	1	7
Mitigation practices	1	7
Unknown	1	7
2. Reduced natural stocks		
Reduced flows resulting in reduced habitat	29	60
Blockage of habitat	17	35
Sedimentation, deterioration of gravel quality	14	29
Fluctuating flows	9	19
Altered water temperature	8	17
Pollution	3	6
Difficulty in passage of downstream migrants	3	6
Lack of gravel recruitment	2	4
Inundation of fish habitat	2	4
Nitrogen supersaturation	1	2

Notes:

The outcome in a case history may have more than one explanation.

Explanations and their ranking were based on case histories of Table 1.

Table 4. Outcome for salmonid stocks after flow regulation when artificial stocks are included.

Location	Source	Number of projects	Improved	Unchanged	Reduced
Idaho	Nelson, Horak, Lewis, and Colt (1976, p. 33)	11	0	5	6
Oregon	Nelson, Horak, Lewis, and Colt (1976, p. 33)	23	1	12	10
Washington	Nelson, Horak, Lewis, and Colt (1976, p. 33)	7	0	4	3
California	Hazel (1976, p. 42, 43)	40*	8	11	21
Total		81	9	32	40
Percent		100%	11%	40%	49%
			51%		49%

*Case histories without salmonids (nongame species in Hazel's report) were excluded.

2.2 Intensive Review

This section examines eight case histories to provide a more detailed perspective of the effects of flow regulation on salmonids, and to determine whether predicted effects matched actual ones. The number of cases was limited by the availability of pre- and post-project data. The cases presented, however, illustrate a variety of effects. They are grouped as those with positive effects,those with no major effects, and those with negative effects on natural salmonid populations. For each are given references, a note on the case study's significance, the magnitude of the river and associated development, the motive for flow regulation, the effects on salmonids, and a comment on lessons learned.

2.2.1 Regulation with positive effects

Big Qualicum River, B.C., Canada

Lister and Walker (1966), Sandercock and Minaker (1975), Minaker, Sandercock and Balmer (1979), Fraser et al. (1983).

This case study demonstrates the importance of flushing flows to maintain gravel quality. Project development was expressly for enhancing salmonid populations. This objective was achieved for chum salmon. Chinook and coho populations, however, remained unchanged after flow regulation. Benefits to chum salmon required annual gravel maintenance due to unforeseen sedimentation problems. Mechanical scarification of sedimented spawning areas was possible because of the nature of the river channel. This situation may not prevail in other systems.

Physical features of the Big Qualicum River system are: length of river 11.3 km, average width 21 m, drainage area 150 km^2 (including Horne Lake), and mean annual discharge for 13 years of record 8.1 cms (286 cfs). The system supports chum, coho and chinook salmon, steelhead trout, and the occasional pink and sockeye salmon. Regulation, which began in 1963, involves a storage dam at the river source (Horne Lake) and diversion of the single significant tributary - Hunt's Creek. The dam has three outlets which permit some control of temperature.

Flow control was directed at increasing chum, coho, and chinook populations through stabilized winter flows, increased summer flows and regulated water temperatures. Chum salmon were anticipated to benefit most as 95% of their total pre-adult mortality occurs during the freshwater stage. Hunt's Creek was diverted to protect spawning grounds in the Big Qualicum River from excessive discharges. Evaluation of effects was based on five years of observations under natural flows (1959-1963) and nine years under regulated flows (1964-1972).

Mean flows for June to October increased 1.7 fold from 2.7 cms (95 cfs) before regulation to 4.6 cms (162 cfs) after regulation.

For November to May they decreased 0.8 fold from 11.1 cms (392 cfs) before regulation to 8.7 cms (307 cfs) after regulation. Summer minima increased 2.3-3.5 fold from 0.4-1.0 cms (14-35 cfs) before regulation to 0.9-3.5 cms (32-124 cfs) after regulation. Winter maxima decreased 0.3-0.4 fold from 37.9-90.6 cms (1338-3199 cfs) before regulation to 14.3-26.8 cms (504-946 cfs) after regulation.

Extensive temperature control occurred from 1968 onward to provide more optimal temperatures for a hatchery. Resultant mean monthly temperatures at the river mouth during May through September were 0.2-2.6 °C cooler than pre-control. The greatest decreases occurred during June and July when mean temperatures were cooled from 14.8 to 12.2°C (June) and from 15.7 to 13.4°C (July). Mean monthly winter temperatures were also significantly reduced after 1968 (by 1.7°C in December, 2.5°C in January and 2.3°C in February) but this was most likely caused by cooling associated with lower winter flows.

Egg-to-fry survival of chum salmon increased 2.1 fold from an average of 13.7% before flow control to 29.1% afterwards (Table 5). Similarly, total river production of chum fry increased from 9.3 million to 23.4 million. Reduction of peak winter freshets was implicated as the major reason for improved egg survival. This was supported by an inverse relationship between peak winter flows and egg survival (1959-1972).

Despite the increase in mean egg survival of chum salmon after flow control a slight decline was noticed after 1967. Also, annual survival rates after flow control fluctuated widely from 13.7% to 48.1%. These results were attributed to a combination of sedimentation, superimposition on spawning beds and stream improvements. Sediment deposition in the spawning beds resulted from the absence of high winter discharge and its associated powers of transport. The primary source of fines was extensive sand banks. Sedimentation was at least partially responsible for the decrease in egg survival after 1967, and necessitated mechanical scarification annually to maintain gravel quality. Superimposition of spawning was believed to occur at high adult densities. This was supported by a negative correlation (1964-1972) between egg-to-fry survival and female spawner density. Spawner density was, in turn, partially influenced by stream improvements (1965-69) which increased chum spawning area 4 fold by 1969.

Decreased winter temperatures after regulation were not believed to have adversely affected egg survival, as the duration of incubation showed no significant increase (Table 5). Predation on post- emergent chum fry was probably not a major influence on freshwater survival as the large numbers of fry were thought to saturate predator capacities. Potential predators were coho and steelhead smolts, cutthroat trout, prickly sculpins and Aleutian sculpins.

Freshwater survival of coho and chinook salmon was believed to be determined more by success during rearing than during incubation. Increased flows and decreased temperatures during post-project summers, however, did not increase survival of the rearing stages.

Table 5. Changes in the parameters of chum, coho, and chinook salmon of the Big Qualicum River over ten years following flow control; brood years 1959-1972[a].

	Increase (+) or decrease (-) after flow control		
Parameter	Chum	Coho	Chinook
Adult escapement			
Duration (days)	+19**	+26*	--
Completion	ns	ns	ns
Egg retention (%)	-0.4 fold*	ns	ns
Egg incubation			
Duration	ns	ns	ns
Thermal units (°C days)	-161*	ns	ns
Mean temperature (°C)	-1.3*	ns	-1.2**
Migrant fry			
Duration of migration (days)	+22*	--	--
50% completion of migration	+12**	ns	ns
Length (mm)	ns	--	ns
Number produced	+2.5 fold	--	ns
Egg-to-fry survival (%)	+2.1 fold*	--	--
Fry-to-adult survival (%)	ns	--	--
Migrants (fingerlings or smolts)			
Duration of migration (days)		+40**	--
50% completion of migration		ns	+15**
Length		+29%*	ns
Weight		+6.2%*	ns
Condition (mg/mm3)		ns	ns
Number produced		--	ns
Egg-to-fingerling or smolt survival (%)	--	ns	ns
Fingerling or smolt-to-adult (escapement) survival (%)	--	ns	ns

[a] Some brood years were absent from the coho calculations.

-- Information not given or not applicable.

ns $p>0.05$ (no significant change).

* $0.05 > p > 0.01$.

** $0.01 > p > 0.001$.

Furthermore, increased summer flows and decreased summer temperatures showed no correlations with numbers of migrant chinook or coho smolts. These results were difficult to explain. It would appear that increased flow and decreased temperature did not improve the quantity and quality of summer rearing habitat. It is possible that rearing capacity was limited by other factors (e.g., food). For chinook fingerlings, benefits may not have been realized as a substantial portion of their population migrates between March and May when flows were not significantly greater than in the pre-project period.

Length and weight of coho smolts increased after flow control by 6.2% and 29% respectively (Table 5). This was, in part, the result of inclusion of smaller smolts of Hunt's Creek in pre-project samples, but was also related to increased minimum flows and decreased maximum temperatures during summer (smolt biomass was positively correlated with minimum summer flow and negatively correlated with maximum summer temperature). The authors postulated that low flows may have restricted growth by increasing competition for space. High temperatures in the upper river prior to flow control may have exceeded the tolerance of juvenile coho, thereby reducing their growth. Also, higher temperatures before flow control may have increased the food requirements of coho, but not food abundance. Intraspecific competition (e.g., competition for food and space) was indicated by a smaller size of smolts in years of highest production.

Steelhead were insufficiently studied to determine the effects of flow control on freshwater survival and production. Length and weight of smolts, however, increased by 35% and 70% respectively. Correlations of smolt biomass with physical factors were not calculated owing to the difficulty of determining the brood year of migrants.

Marine survival of chum, coho and chinook salmon (based on escapement) did not change significantly after regulation. For chum, marine survival showed no correlation with factors influenced by flow control (fry length, weight, condition coefficient) but was correlated with surface ocean temperatures in the first summer and winter of marine life. For coho and chinook salmon, marine survival was not related to migrant size, timing, ocean salinities or ocean temperatures. Indeed, chinook marine survival tended to decline with high juvenile production, perhaps because of resource limitations in the estuary or at sea. Marine survival of steelhead trout was greater for older smolts.

In summary, flow regulation on the Big Qualicum River in the 10 years following its implementation appears to have benefited the freshwater phase of chum salmon, primarily through stabilization of incubation flows. This benefit, however, can be maintained only by the practice of scarification of chum spawning beds to release accumulations of silt and sand (G. Ladouceur, pers. comm., Big Qualicum Project, RR#3, Qualicum, B.C., V0R 2T0). Even with flow regulation and gravel scarification, variations in egg-to-fry survival occur due to annual differences in spawner density. Coho and chinook salmon populations did not appear to benefit from improved flows and temperatures during rearing. The reasons for this are not completely known. It may be that coho and chinook juveniles in the Big Qualicum are limited by factors other than space and temperature during summer rearing (e.g., food). Also, rearing flows were not significantly different after flow control for early chinook migrants.

The only detailed data subsequent to 1972 are for the years 1973, 1974 and 1975. Chum egg-to-fry survival rates for these years were 26.3, 11.6, and 38.9%, respectively. No freshwater survival rates were available for coho smolts. Chinook egg-to-fingerling survival rates were 5.8% for 1973 and 32.7% for 1984. Such wide annual variations in freshwater survival further indicate the influence of factors other than flow control (e.g., sedimentation and spawner density).

2.2.2 Regulation with no major effects

Barrows Stream, Maine, USA

Havey and Davis (1970), Havey (1974).

This case study illustrates the need for pre-project knowledge of salmonid habitat requirements. Anticipated benefits to rearing Atlantic salmon were not realized for, although the minimum flow was increased it was still below the spatial requirements of the rearing salmon.

Barrows Stream is a small system with river length 2.4 km, mean width 6.8 m, drainage area 20.3 km^2, and normal seasonal flows of 0.007-2.8 cms (0.25-100 cfs). It is used by landlocked Atlantic salmon for spawning and rearing. In fall 1965 a low head dam was constructed on the headwaters (Barrows Lake). It was anticipated that the dam would increase salmon production by providing a minimum flow (0.1 cms) in the dry season 16 times greater than the lowest historic flows, and twice as great as the mean flow from June to September (1963-1965 record). The effects of flow regulation for juvenile populations were evaluated from data six years before and six years after flow regulation(1960-1971).

At the 95% confidence level pre-regulation and post-regulation values for growth, standing crop and survival of juvenile salmon were not significantly different. At the 70% confidence level some differences were significant. For 0+ juveniles mean weight increased 1.3 fold, numerical standing crop doubled and biomass standing crop increased 2.5 fold. For 1+ juveniles biomass standing crop decreased 0.6 fold. The mean annual survival from age 0+ to 1+ was virtually unchanged by flow regulation.

Predicted benefits of flow regulation to landlocked Atlantic salmon, therefore, were not realized by this project on the basis of the data. Although growth and standing crop of 0+ juveniles improved, the improvements were not passed on to 1+ juveniles. This was attributed to the minimum flow which, although higher than normal during the dry season, was barely sufficient to cover the steam bed.

Blacktail Creek, Montana, USA

Kraft (1972)

This case study demonstrates the effect of reduced flow on stream carrying capacity. Experimentally reduced flows lasting three months resulted in emigration of brook trout from test areas and their relocation to pools. Re-distribution was most strongly determined by flow and by pool surface area.

Blacktail Creek has a confined channel with a gradient of 0.76% and flows through a 2.3 km wide grass-covered flood plain in southwestern Montana. From 1965 to 1967 an experimental study was undertaken to determine the effects of flow reductions on the habitat and population of brook trout.

Flows were reduced in three test sections (total length of the three sections was 520 m) while two control sections remained under natural flows (Fig. 1). Flow reductions were calculated from a standard of 1.0 cms (35 cfs), which was an average of the lowest three years of August flows from a six year record prior to 1965. In 1965 and 1966 flows in the three test sections, A, B, and C, were reduced by 77%, 54%, and 31% respectively of the base flow. In 1967 flows in all three test sections were reduced by 90%. Flows were reduced for three months to simulate the irrigation season when flows are abstracted for agricultural crops. Changes in the size of the trout population of a run and a pool within each section were determined, and the changes in physical characteristics (width, depth, current velocity and cover) of the runs and pools were established. Trout movements were monitored by mark-recapture techniques.

Reduced flows in test sections did not significantly increase mortality of brook trout relative to control sections. In 1966, at flow reductions of 77%, 54%, and 31%, no trout emigrated from the test sections and there were no consistent changes in the number of trout, age 1 and older, relative to the control sections. In 1967 at a flow reduction of 90%, however, 30% (100) of the trout emigrated upstream of the test area. In addition, the total number of age 1 and older trout in the test runs was reduced by 62% compared with a 22% reduction in the control areas. In the test pools numbers generally increased compared to a decrease of 32% in control pools. No significant changes occurred in the abundance of under-yearlings at any flow reductions.

The above changes in abundance in test sections are interpreted as the result of movements of trout from runs to pools. This was verified by tagging studies which indicated that trout moved from

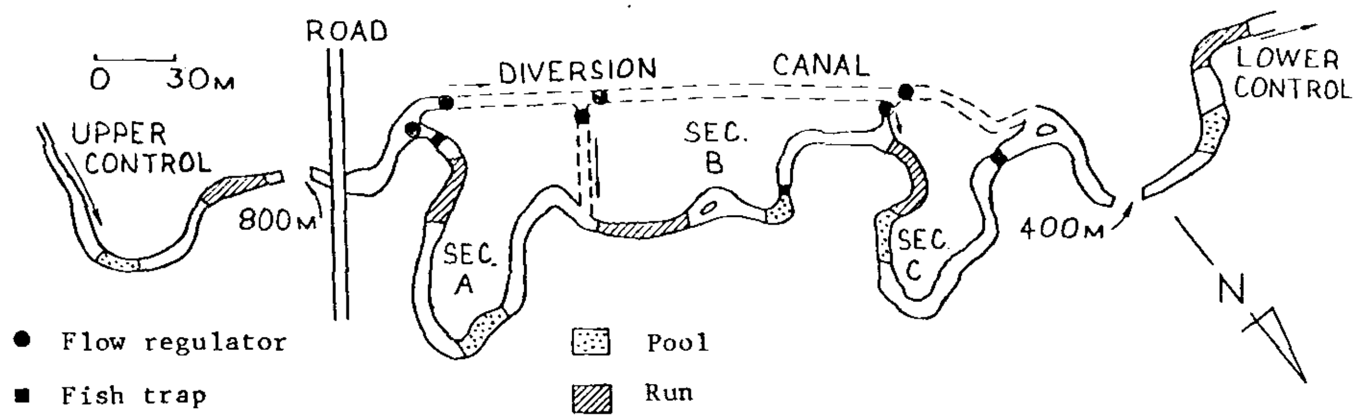

Fig. 1. The study sections (A, B and C) at Blacktail Creek (from Kraft 1972).

one run to another, or into pools, but not from pools to runs. Movement between test sections was very limited. The decreased abundance in control runs and pools presumably reflected migration from control areas; the cause, however, was not explained.

Multiple linear regressions were performed with flow, surface area, average depth, average current velocity, maximum velocity and cover as the independent variables and number of trout per run or pool as the dependent variable. For age 1 and older trout these six variables accounted for 77% and 83% of the variation in numbers in runs and pools, respectively. Surface area was the most important variable in pools, while flow was most important in runs. For underyearling trout these six variables accounted for 92% and 68% of the variation in numbers in runs and pools, respectively. Flow was the most important variable in both runs and pools. At 90% flow reduction the average depth and area of runs and pools decreased by up to 42%, cover decreased by 39-56% and the average velocity decreased by 71-85%. Shallow-fast (<0.5 m deep and >0.30 m/s) and deep-fast (>0.5 m deep and >0.30 m/s) portions were markedly reduced or eliminated in runs and pools. Shallow-slow portions (<0.5 m deep and <0.30 m/s) increased 2.8 fold from 30% at normal flows to 85% at 90% flow reduction.

The response of brook trout to severely reduced flows was, therefore, to concentrate in pools or to leave the area. Desertion of runs was probably a response to reduced quality and quantity of this habitat. Emigrations may have been induced by density-dependent competition. In addition, siltation, which was especially extensive in section A, may have reduced the quality of pool habitat. It is likely that periods of flow reduction longer than three months would have had more serious effects on the trout populations. Additionally, in larger scale projects where much longer stream lengths occur, trout would probably not be able to emigrate from reduced flow areas and would likely be subject to greater mortality.

2.2.3 Regulation with negative effects

Rogue River, Oregon, USA

Everest (1973), Cramer and McPherson (1982), McPherson and Cramer (1982), Smith and McPherson (1982), Satterthwaite (1982), Jacobs et al. (1984).

In this case history flow regulation was anticipated to benefit salmonids, but appears to have actually decreased their numbers because of unforeseen effects associated with changes in water temperature. There is no apparent solution to the problem created.

The Rogue River is 350 km long and drains 13,367 km^2. Spring chinook salmon presently spawn from km 204 to 256, and fall chinook salmon from km 139 to 199. Coho salmon, steelhead trout and cutthroat trout are also present.

Flows are regulated by Lost Creek Dam (km 256) which was completed in 1977 and reached full pool in 1978. Five outlet ports permit temperature regulation to 150 km downstream. The Cole River hatchery (km 255) was constructed to compensate for 30% of spring chinook spawning habitat blocked by the dam.

The dam was intended for hydroelectric power, irrigation, reservoir recreation and to benefit downstream fish populations. Benefits to salmon and steelhead populations were anticipated by way of cooler and greater flows in the summer. Cooler water was expected to reduce adult spring chinook mortalities caused by the bacterial gill disease columnaris. Augmented and cooler summer flows were expected to improve the quantity and quality of salmonid rearing habitat. Studies evaluating the effects of the dam on salmonids were initiated in 1974 and completed for juveniles in 1981, while adult studies will continue until 1986.

Temperatures below Lost Creek Dam (km 247) in the first four years after dam closure (1977-80) were reduced in the summer by averages of 0.9°C in June, 3.2°C in July and 1.7°C in August. Thermal storage by the reservoir, however, increased fall and winter outflow temperatures by averages of 1.6°C in November, 2.0°C in December and 0.9°C in January.

Changes in flow resulting from the dam were determined by comparing the reservoir's outflow with its inflow. On this basis, flow augmentation during the summer increases outflows from mid June to early November with maximum increases during July and August. For example, in 1980 average outflow was 55 cms (1943 cfs) for July and August, while average inflow was 30 cms (1059 cfs) for July and 27 cms (953 cfs) for August. These represent increases in outflow of 1.8 fold and 2 fold for July and August, respectively. The resultant increases in mean monthly flows during the summer in the lower Rogue River (km 48) were not significantly different from the pre-impoundment years of 1966-68, as the natural run-off in 1977-80 was below normal. Reservoir filling during the winter decreased outflows from January to April with the greatest decrease in February. As an example, in 1980 February outflow decreased 0.4 fold based on an average outflow of 22 cms (777 cfs) and an average inflow of 52 cms (1836 cfs).

Changes in turbidity resulting from Lost Creek Dam were determined by comparing inflow and outflow turbidities. On this basis, average turbidities at the outflow were slightly increased but were generally less than 3.5 JTU. Peak turbidities associated with freshets, however, were sharply reduced.

Evaluation of the effects of Lost Creek Dam on juvenile chinook salmon was restricted to wild fish. Initial emergence of juvenile chinook salmon in the first 45 km below the dam occurred 6-8 weeks earlier during 1979-81 compared with 1975-78. This was caused by the unavoidable release of warm reservoir water that elevated incubation temperatures above pre-impoundment levels by averages of 1.1°C in October, 3.3°C in November and 1.8°C in December. As the reservoir becomes homoiothermal, and does not freeze in winter, there was no source of cool water to alleviate this effect.

Steelhead emergence was less affected, as eggs incubate from February to May when release temperatures were closer to normal.

After dam closure the abundance of juvenile chinook salmon declined throughout the Rogue River by an average of 58%. This was possibly caused by blockage of spawning habitat after 1975, and by the earlier emergence of fry. The absence of progeny from spawning grounds above the dam after 1976 probably decreased juvenile abundance somewhat, but cannot account for such a large and ubiquitous decrease. The accelerated fry emergence could have decreased abundance by exposing fry to high flows and low food availability during the winter and early spring. High flows occurred during winter freshets (e.g., January in 1980) and, despite reservoir filling, were significantly higher than flows during normal fry emergence. The literature consulted favours this hypothesis. Further studies, however, are needed for confirmation.

Growth rates of juvenile chinook salmon increased by 56-85% in the upper Rogue River with the greatest increases near the dam. Possible causes were:

1. Improved rearing temperatures. Growth rates of juvenile chinook, coho and steelhead were positively correlated with warmer temperatures in the spring and cooler temperatures in the summer. Dam operation did not significantly alter spring temperatures but summer temperatures were significantly reduced, perhaps to more optimal levels for growth.

2. Reduced intraspecific competition due to decreased juvenile abundance. This was supported by the inverse relationship between growth rate and juvenile abundance.

3. Increased food supply immediately below the dam after impoundment. Studies conducted in 1981 found that Daphnia was discharged from the reservoir during spring and early summer, and was the major food item of juvenile chinook salmon within at least 6 km of the dam.

Correlation analysis established that juvenile chinook salmon grew better with lower spring flows and higher summer flows. Although reservoir filling in the spring reduced flows below normal, it was not determined whether these flows were significantly different from pre-impoundment spring flows. Thus it is difficult to say whether post-impoundment spring flows contributed to the increased growth of juvenile chinook salmon after dam closure. Summer flows, although increased, were not significantly different from pre-impoundment flows and, therefore, probably did not contribute to the increased growth of chinook juveniles.

Unlike the growth rates of juvenile chinook, the rates of age 0 and 1 steelhead trout increased significantly in the middle river, but decreased significantly among age 0 steelhead rearing within 40 km of the dam. Cold water releases may, therefore, have reduced growth in the upper river, but may have increased growth in the middle river.

After dam closure sub-yearling chinook salmon in the upper Rogue River (primarily spring chinook) migrated an average of 30 days later, while those in the lower river (primarily fall chinook) migrated earlier. Scale analysis of adult returns of spring and fall chinook indicated an improved marine survival for later emigrants; thus the effects may be beneficial to spring chinook populations but detrimental to fall chinook populations. The later emigration in the upper river may have been due to improved rearing conditions or to decreased juvenile abundance, both of which may have increased the time required to saturate the river's rearing capacity. Reasons for the earlier emigration in the lower river were not discussed.

The effects of Lost Creek Dam on adult abundance, size and age cannot be fully assessed until salmonids that were juveniles after impoundment return as adults. Correlation analysis showed that chinook adult abundance was positively related to juvenile abundance (brood years 1974-77), that adult size at each age of return was greater for sub-yearlings than for yearlings (brood years 1972-75), and that adult age of return was less for fast growing than for slow growing juveniles (brood years 1972-75).

The timing and rate of adult chinook migrations were unchanged after dam closure. Higher and cooler summer flows from the dam during the drought years of 1978-80 may have prevented a repetition of the 1977 delays.

Pre-spawning mortality of spring chinook decreased after dam closure on account of cooler flows. Pre-spawning mortality of fall chinook, however, increased substantially in 1979 and 1980 but not in 1981. Estimated mortalities of the fall run were 67% in 1979, 76% in 1980, and 4.6% in 1981. The main disease organism was Flexibacter columnaris; however, an unknown pathogen was also discovered. Studies did not identify which pathogen was the primary cause of death. The reservoir and the hatchery have been identified as new sources of F. columnaris.

The foregoing evidence shows that, for salmonids, predictions of the effects of Lost Creek Dam did not match the actual effects, which, in fact, proved to be more negative than positive. Augmented and cooler summer flows did not increase the abundance of juvenile chinook salmon, but rather, warmer winter flows appear to have caused a major decrease in juvenile abundance. Cooler summer flows reduced pre-spawning mortality among spring chinook, but this was offset by the greatly increased pre-spawning mortality among fall chinook salmon. At present, these problems are poorly understood and have no apparent solutions. Other results are difficult to assess as positive or negative, as their explanations are obscure. For example, increased growth and delayed emigration of spring chinook juveniles are positive results if they are a response to improved habitat (i.e., augmented and cooler summer flows), but not if they are due to decreased juvenile abundance. A fuller evaluation of Lost Creek Dam will be possible when the adult studies are completed in 1986.

John Hart Dam, Campbell River, British Columbia

McMynn and Larkin (1953), Hamilton and Buell (1976), Bell and Thompson (1977).

This case history illustrates the negative effects of fluctuating flows for salmonids. These include disruption of spawning, stranding of juveniles, impairment of invertebrate production and scouring of spawning gravels. It also illustrates the negative effect of lack of gravel recruitment to downstream spawning areas. Despite these detrimental effects, escapement records suggest that chinook stocks have remained unchanged after flow regulation. Chum stocks, however, have declined. Present returns of natural chinook salmon may not prevail in the long-term owing to the continued depletion of spawning gravels.

The Campbell River has a drainage area of 1461 km^2 and flows for 90 km from its source in the mountains of eastern Vancouver Island to its mouth in Discovery Passage. Before construction of the John Hart Dam fish migrated 5.6 km upstream to the location of Elk Falls.

After construction of the dam upstream migration was restricted to the generating station at km 5.0 due to low flows between the generating station and the dam. The river below the generating station is shallow, fast flowing, averages 61 m in width, and has a mean annual discharge (1949-1970) of 99 cms (3490 cfs). The largest tributary, the Quinsam River, enters the Campbell River at km 3.2, has a drainage area of 280 km^2, mean annual flow (1956-1973) of 9 cms (326 cfs), and has 25.7 km of river accessible to anadromous fish.

Salmonids native to both rivers are chinook, chum, coho, pink, and sockeye salmon, as well as steelhead and cutthroat trout. Chinook and chum salmon spawn primarily in the Campbell River while coho, pink and steelhead spawners favour the Quinsam River. Sockeye salmon occur sporadically in both rivers. The distribution of cutthroat trout is not well known. The ratio of spawner returns in the Campbell River relative to the Quinsam River is: chinook 170:1, chum 2:1, coho 1:4, pink (even year) 1:1, and pink (odd year) 1:6. Ratios for sockeye salmon and steelhead trout were not provided in the literature.

John Hart Dam was completed in 1947 at river km 5.6 for the purpose of hydroelectric power. Power production was further increased by Ladore Dam (completed 1949) impounding Lower Campbell Lake, Strathcona Dam (completed 1958) impounding Upper Campbell Lake, and by diversions of average flows of 2.8 cms (100 cfs) from the Quinsam River to Lower Campbell Lake, 11.3 cms (400 cfs) from the Salmon River to Lower Campbell Lake and 3.0 cms (105 cfs) from the Heber River to Upper Campbell Lake.

The effect of power development on the hydrology of the Lower Campbell River (i.e. the reach important to anadromous salmonids) has probably been an increase in mean annual flow; however, the magnitude was not determined as gauge sites were changed after regulation. McMynn and Larkin (1953) state that minimum summer flows have increased, while maximum flood flows have decreased, but again, quantitative values are not available. The most significant change in hydrology has been the wide fluctuations in daily and hourly flows that result from the operation of John Hart generating station for power peaking. The operating order for John Hart Dam requires a minimum flow of 13 cms (450 cfs) below the powerhouse, but at the request of the Department of Fisheries this is not reduced below about 28 cms (1000 cfs). The maximum flow is determined by the capacity of the turbines which is 124 cms (4380 cfs). Thus, flows in the lower river generally range between 28 cms and 124 cms. Hamilton and Buell (1976) reported daily and hourly fluctuations ranging from 31.15 cms (110 cfs) to 121.77 cms (4300 cfs). Greater fluctuations occur during spillage at John Hart Dam. The provision for only daily pondage by John Hart Reservoir results in spillage during natural floods, and whenever upstream power production exceeds the production of the John Hart generating station.

Investigations of the effects of flow regulation on Campbell River salmonids (Hamilton and Buell 1976) suggest that flow fluctuations have had four adverse effects: disruption of spawning, stranding of juveniles, diminution of food items, and scouring of spawning gravels. Observations of spawning chinook salmon during flows fluctuating between 33 cms (1171 cfs) and 123 cms (4335 cfs), established that during rising flows females stopped redd digging, both sexes became disorientated and "milled about", and some false-starts in redd digging occurred. When flows returned to the former level females rarely returned to the original nest. During decreasing flows fish moved away from redds causing overcrowing and aggression in peripheral spawning areas. Again, when flows returned to the previous level females did not usually return to their original nest. Quantitative observations indicated that disruption of spawning occurred when discharge was increased by 50% or decreased by 30%. The amount of movement was directly proportional to the magnitude of the flow fluctuation, and decreases were more disruptive than increases. The values obtained were considered conservative, as field observations indicated that disruption was more severe than suggested by the quantitative analysis.

The effects of fluctuating flows on juvenile salmonids were tested in 1974 by a planned reduction of flows from 110 cms (3900 cfs) to 34 cms (1200 cfs). The test had to be terminated prematurely to avoid mortalities of tens of thousands of chinook fry and yearling coho stranded or trapped in pools. Observations indicated that both species were reluctant to abandon their positions during falling water levels.

The effect of increases in flow on the abundance of food organisms was tested by a planned increase in discharge from 31.4 cms (1110 cfs) to 83.5 cms (2950 cfs) (Mundie and Mounce 1976). This resulted in a five fold increase in zooplankton, a six fold increase in benthic organisms and a 12 fold increase in floating terrestrial insects. It was believed that this would result in a temporary increase in food availability, but over the long-term frequent increases of flow would deplete the benthos.

Flow fluctuations were thought to scour gravel from spawning beds, particularly gravel of small and intermediate size. Replacement of spawning gravel has been reduced by the interception of gravel by the John Hart Dam, and by spilling flows insufficient to recruit gravel from the reach between the dam and its powerhouse. The result has been a depletion of available spawning habitat. Chinook salmon are particularly at risk, as their spawning area was limited before regulation. Recently, spawning gravel has been added to the river in an attempt to alleviate this problem. Results have not been documented.

Positive effects resulting from the regulation of Campbell River have not been documented in any detail. McMynn and Larkin (1953) suggested that water required for the turbines during summer would increase available spawning habitat, and that if flows were increased over the spawning beds during the cold months of January to February, anadromous fish would be enhanced. They did not, however, present any biological or hydrological data in support of these hypotheses.

Although the above studies are instructive in documenting some effects of flow regulation, no studies were undertaken to link these effects with actual production of juveniles. For example, no assessments were made of the outcome of spawning disruptions on egg deposition and survival,or of stranding of juveniles on their survival and abundance. The only evidence available by which to judge the outcome of flow regulation for fish numbers is the annual escapement of adults. In the Campbell River the escapement reflects, however, not only flow regulation, but also the commercial and sports fishery, and environmental changes in the watershed, the estuary, and at sea. The estuary may have a major influence on salmon numbers as 89% of it has been claimed by commercial users (Bell and Thompson 1977). Recently this claim has been substantially reduced (Brownlee et al. 1984).

In general, it would appear that chinook populations have remained relatively unchanged by regulation. This is supported by an average escapement of pre-project broods (1935-1949) of 3019 fish, compared with a post-project average (1950-1974) of 3651 fish.

The average escapement of pre-project chum populations (1935-1949) is 9577 fish, compared with a post-project average (1950-1974) of

2678 fish. The timing of this decline suggests that flow regulation may be the primary cause. Regulation was, therefore, judged as resulting in a reduction in chum stocks. Other factors, however, may have contributed to this decline.

In summary, studies indicate that flow regulation on the Campbell River has adversely affected salmonids. Fluctuating flows disrupt spawning, cause stranding of juveniles, diminish food supply and scour spawning gravels. In addition, interception of gravel by the dam, and insufficient spillage, have reduced recruitment of gravels. Despite these negative effects returns of adult chinook have remained relatively unchanged. Chum returns, however, have declined since regulation. The cause of this decline has not been determined, but its timing suggests an association with flow control.

Sacramento - San Joaquin River System, California, USA

Kjelson, Raquel and Fisher (1981, 1982), Stevens and Miller (1983).

This case study demonstrates a positive relationship between flow in a delta (after being altered by many upstream dams) and the success of migrating adult and juvenile chinook salmon. The relationship appears to operate through both density-dependent and density-independent mechanisms.

The Sacramento and San Joaquin rivers flow into a common delta, the Sacramento - San Joaquin Delta. Together they drain about 153,000 km^2. Historically, combined annual flows average 1100 cms (38,800 cfs) but numerous water development projects have reduced this by half. The Sacramento River and its tributaries support over 90% of the chinook salmon spawners, while the San Joaquin River system supports the remainder. Four major runs of chinook salmon occur in the Sacramento system of which the fall run comprises 80%. This amounted to 140,000-300,000 fall run fish annually between 1964 and 1977. Only fall run fish occur in the San Joaquin system. Escapement varied from 10,000 to 78,000 between 1981 and 1985 (M. Kjelson, pers. comm.).

Flows are regulated in both river systems as a result of numerous dams in the upper reaches and two major diversion facilities in the delta. Dammed water is used primarily for hydroelectric power generation and irrigation, while diverted water is exported to the San Joaquin valley and southern California. In 1978, water exports averaged 190 cms (6700 cfs) with 85% originating from the Sacramento River and 10% from the San Joaquin River. Future water development plans include offstream storage reservoirs and channel modifications in the Delta to increase exports.

In this case history the effects of altered flow on chinook populations were not judged by comparing pre- and post-project data, but by correlating annual abundances of migrating smolts, fry and adults with mean flows to the delta for various months. Juvenile abundances were indexed from midwater trawl catches in the estuary, and from collections at pumping station fish screens in the delta.

Annual abundance indices (1967-1978, excluding 1974) for fall run juveniles were positively correlated with river flows during upstream migration, spawning and nursery periods (October to March). Abundance increased approximately 12% for every 100 cms of daily mean December flow, and 7% for each 100 cms of daily mean October-February flow. Possible reasons are:

1. The incidence of redd dewatering is decreased with increased incubation flows. This is probably the most important factor that accounts for the correlation of indices with December flows.

2. Available habitat is increased with higher flows; this reduces intraspecific competition among juveniles. At higher flows adults have been observed to make greater use of tributaries, and consequently their offspring are more widely distributed. Furthermore, net sampling has demonstrated that high flows disperse juveniles throughout the river, delta and San Francisco Bay.

3. Predation on juveniles may be reduced with increased flows due to a decrease in fish density, a greater depth, and greater turbidity of the water.

4. Water quality is improved with increased flows. This increases the success of migrations. In the Sacramento - San Joaquin Delta adult migrations have been halted by oxygen concentrations less than 5 mg/L and by temperatures warmer than 19°C. Survival of smolts migrating through the Delta is inversely related to June temperatures (Kjelson et al. 1982).

5. Flow reversals, detrimental to adult migrations, have less effect when flows are higher. Flow reversals occur in the spring (except in wet years), summer and fall when high export rates at the delta pumping stations draw water up the San Joaquin channel. These disrupt the homing mechanism of migrating salmon and block San Joaquin River spawners from some channels normally used by them.

Annual escapements of female adults to the San Joaquin River were directly correlated with discharge during their nursery and emigration periods (March-June) 2.5 years earlier (1957-1973). Diminished flows during emigration may decrease survival in the following ways:

1. By increasing water temperatures to levels lethal to emigrants. Fish kills due to high water temperatures have been documented in the San Joaquin drainage.

2. By increasing losses at diversion facilities. Reduced flows in the rivers result in an increased proportion of exported water, consequently, more migrants are drawn to the fish screens at the pumping facilities. Salvage collections are made, but many smolts and fry are lost by passage through the screens, by handling during salvage collections, and by predation near the screens.

3. By increasing the disruptive effect of cross-delta diversion flows on migrating juveniles. Mark-recaptures (in 1976) in various delta tributaries indicated higher survival rates for salmon travelling the most direct route to the ocean than for those diverted toward the pumping plants. In addition, mark-recaptures (1969-80) demonstrated increased survival of juvenile fish migrating through the delta with increased May-June flows.

The evidence, therefore, suggests that in the Sacramento - San Joaquin system numbers and survival of juvenile chinook salmon, and subsequent adult returns, increase with increases in flow during upstream migration, spawning, nursery and emigration periods. The effects of high flows during these periods are to increase the quantity and quality of habitat and to increase juvenile dispersal. This results in increased egg deposition and survival, and reduced mortality of juveniles. High flows also diminish the negative effects of water export, again resulting in fewer mortalities.

Saint John River, New Brunswick, Canada

MacDonald and Hyatt (1973), Ruggles and Watt (1975).

This case study illustrates the importance of the relationship between water quality and flow regulation. In this river pollution problems were aggravated by flow regulation, and fish passage facilities and a hatchery were insufficient to prevent the diminution of Atlantic salmon stocks.

The Saint John River is 676 km long with a drainage area of 54,930 km^2 and a mean annual discharge of 765 cms (27,016 cfs). An extensive estuary forms the last 96 km. Atlantic salmon use the river for spawning and rearing.

Seven major hydroelectric projects were constructed on the Saint John River between 1918 and 1968 from its headwaters to almost tidewater. Most have a restricted storage capacity resulting in limited flow control, and consequently, operate as peaking plants that produce rapid short-term fluctuations in downstream flows. Dams that blocked access to spawning grounds were equipped with fish passage facilities with the exception of Tinker Dam on the Aroostook tributary.

Prior to 1969 Atlantic salmon were returning in fairly large numbers (mean annual run for 1949-1968 was 24,000); however, after 1969 runs declined 56% (mean annual run for 1969-1973 was 13,700). This reduction was attributed to a combination of factors:

1. Smolt mortality during passage through turbines and over spillways. The Mactaquac Dam was the main cause of these and a hatchery was constructed 2 km below the dam to compensate for the losses. Its success, however, was not documented in the literature. The Mactaquac dam was constructed in 1969, and from then onwards salmon stocks seriously declined.

2. Biological oxygen demand in the river due to heavy loading of organic effluents. Major effluent sources are pulp and paper mills, and potato processing and starch plants. Impoundments are susceptible to biological oxygen demand (BOD) as effluents settle in them. The worst case, the Grand Falls impoundment, occasionally goes totally anaerobic. In addition, each spring when the flood gates are opened, currents scour the ooze from the bottom and flush it downstream thereby increasing the BOD problem. Insufficient oxygen levels have, on occasion (1969), prohibited the release of adult salmon trucked upriver from the Mactaquac Dam. Reduced oxygen levels are believed to slow upstream migration, and in 1967 and 1968 contributed to delays at the river mouth which resulted in over- exploitation by a fishery.

3. Nitrogen supersaturation below the Mactaquac Dam in 1968 killed about 10% of the upriver run (100 salmon). Supersaturation occurred when air was vented into the turbines to reduce back pressure at low generating levels. Turbine design has since been altered, but an evaluation of the changes does not appear to be documented.

4. Toxicity associated with lignosulphonates has caused fish kills in the Mactaquac hatchery. Lignosulphonate concentrations were not lethal in themselves, but indicated a stage of effluent breakdown to toxic constituents.

The Saint John River illustrates the kind of serious pollution problem that can occur from the interaction of hydroelectric and industrial developments. The effects of the pollution are manifested in Atlantic salmon stocks that have declined dramatically despite fish passage facilities and a hatchery.

Ellerslie Brook, P.E.I., Canada

Smith and Saunders (1958), Saunders (1960).

This case history illustrates the negative effect that impoundments can have on salmonid behaviour. Here, impoundment resulted in an unpredicted inhibition of juvenile and adult Atlantic salmon to migrate.

Ellerslie Brook is springfed, has 2 tributaries, a length of 10km and a drainage area of 26 km^2. Atlantic salmon returns ranged from 0 to 38 (1946-1951) prior to pond formation. Brook trout are abundant in the stream.

In 1952 a 14 m long wooden dam with four spillways was constructed near the stream mouth, producing a maximum drop of 2.5 m. A two ha pond was created behind the dam with depths ranging from 1.2 to 1.5 m. Counting fences were located above and below the pond. Adult salmon captured at the lower fence were placed in the pond to continue their migration.

Pond creation was primarily intended to improve the angling success of brook trout. Atlantic salmon in this stream had little commercial or sport value; impoundment, however, provided an opportunity for studying their biology. Adults were studied for 12 years (1946-1958) and juveniles for nine years (1949-1958).

Spawning success was greatly reduced after pond formation. Adult salmon failed to migrate for five of the seven years of post-impoundment record because of the absence of attraction flows. In the two years when salmon did ascend to the lower fence (with subsequent placement in the pond) most failed to migrate past the pond. Kelts tended to overwinter in the pond itself rather than emigrate, as was common prior to impoundment. This, however, seemed to improve their survival to the estuary.

In the absence of recruitment during the 1951, 52, 55-58 spawning seasons, insufficient juvenile counts were obtained to assess the effect of pond formation on fry and parr survival. Rearing habitat was reduced by 18%. This, however, may have been compensated for by pond rearing (parr and smolts were observed in the pond).

The main effect of impoundment on juveniles was a delayed or inhibited smolt migration. In 1957, 72% of the smolts remained in the pond and subsequently suffered heavy mortalities. Attempts to encourage migration by increased flow releases failed. Losses were attributed to eel attacks and possibly to impaired osmoregulatory capacity.

Although the Ellerslie Brook project is of a small scale, it illustrates behavioural responses that may be applicable to larger projects. These include an impaired motivation, in both adults and juveniles, to migrate. Flow releases could stimulate adults to migrate into the pond but not to go beyond it to their spawning grounds. Finally, flow releases did not alleviate smolt retainment in the pond in 1957. The reasons for the lost drive in smolts and adults were not known.

2.3 DISCUSSION AND CONCLUSIONS

Fisheries managers attempting to assess the impact of flow regulation proposals on salmonid resources are interested in four main questions:

1. What would be the outcome of flow regulation on fish numbers?
2. What are the anticipated effects on habitat and on the life stages of the fish, and what are their causes?
3. How reliable are the predictions?
4. What solutions are there to potential problems?

Much assistance in answering these questions can be gained from a review of case histories of flow regulation.

1. Because of the economic value of salmonids, most regulated flow projects are undertaken with at least some regard for the protection of fish. Nevertheless, the extensive review found that flow regulation has had a poor record of success in preserving natural salmonid stocks: in 63 case histories of discernible outcome 76% resulted in a decrease in salmonids following flow control.

2. The most frequent causes of decline were the removal of large quantities of flow, so that the overall volume available for fish was reduced, and the alteration of the natural seasonal pattern of flow, resulting in reduced volume during periods critical to fish life stages. The converse was true for case histories with improved or maintained stocks, i.e., the main causes were an increase in mean annual flow, an increase in monthly flows during periods that were formerly limiting, or no major change in post-project flows. The importance of flow during critical periods was supported by studies on the Sacramento - San Joaquin system (Section 2.2.3) where the abundance of juvenile chinook was positively correlated with river flow during adult migration, spawning and nursery periods. Frenette et al. (1984) demonstrated the same relationship in a natural stream. They found that the abundance of Atlantic salmon parr in an unregulated river (Matamec River, Quebec) was positively correlated with mean flows during April (hatching and alevin stages) and August (growth period). Hazel (1976, p. xv) concluded from 46 California case histories that

"Project developers and fisheries biologists should strive to maintain the instream flow at 70 percent or more of the pre-project flows for every month". On commonsense grounds, however, this guideline could not be applied to periods of very low flows, in natural streams, that can limit fish production.

The second most frequent cause of decreased stocks was blockage of adult migrations from habitat above dams. In many cases no fishways were provided and no attempts were made to truck fish upstream. Extinction of runs resulted. In others, attempts were made to compensate losses of natural fish by artificial propagation.

The third most frequent cause of reduced salmonid abundance was deterioration of habitat both in quantity and quality through the loss of freshets. Hazel (1976, p. xvi) stated that: "A fundamental short-coming of the California IFR [instream flow reservation] practice is the lack of reservation of peak winter and spring flows powerful enough to maintain and/or renew the basic physical habitat. To maintain native salmonids it is assumed that the physical-chemical nature of the stream must approximate the historic condition. The minimum instream flow needs of salmon and trout in terms of passage, spawning, cover and rearing for minimum flow conditions are generally being satisfied. Technical investigations and negotiations have concentrated on minimum flow requirements... However, if peak winter and spring flows are reduced to the IFRs in effect, the physical habitat will alter and probably be greatly reduced in value for salmonids, because it is these peak flows that annually flush sediments and other debris from the system. Significant reductions in peak flow usually result in greater proportions of fine sediment in spawning gravels, less development of pools and undercut banks and vegetation encroachment all of which will reduce the habitats now measured for minimum IFR purposes." Hazel suggested that projects intending to reduce peak flows by 30% should evaluate the possible effects on the physical habitat. Gislason (1985) stated that elimination of seasonal high flows was not advisable as these are necessary to maintain insect habitat by flushing accumulations of sediment from interstitial spaces between substrate particles. Among case histories of improved or maintained fish stocks, deterioration of habitat was usually not a problem as flushing action was provided by increased or relatively unchanged post-project flows.

It was remarkable that the case histories, in general, did not discuss the time-scale on which rivers change when deprived of dominant flows.

Another frequent cause of decreased stocks among the case histories was rapidly fluctuating flows. These resulted in stranding of juveniles, reduction of insects and scouring of habitat. A fuller description of the effects of fluctuating flows is found in Cushman (1985). Woodin (1984) found that stranding of chinook fry increased during the day relative to the night, and that the rate of stranding during the day was proportional to the rate of the flow reduction. Rate of flow reduction, however, did not appear to be important at night. In contrast, Hamilton and Buell (1976) suggest that the evening and night are the most crucial periods of fry standing. Obviously, more studies are required. Gislason (1985) compared insect abundance on the Skagit River under fluctuating flows (1976) with their abundance under non-fluctuating flows (1977) and found that insect density increased by 1.8-59 times under the non-fluctuating regime. Additionally, insects were most abundant near shore, areas most affected by dewatering. Thus, fluctuating flows can have a devasting effect on the total insect standing crop of a river.

3. It was difficult to assess the reliability of pre-project predictions as the case studies generally did not document the predicted effects, and follow-up studies were not designed to test predictions. Two exceptions are the Big Qualicum and Rogue rivers. Both predicted an improvement in natural salmonid stocks. In the Big Qualicum River chum populations improved; however, chinook and coho populations remained unchanged. In the Rogue River chinook stocks declined.

   The predictive success of instream flow methods for determining minimum protection flows for life stages has not yet been established by follow-up studies of actual outcomes. The case histories suggest that the lack of provision for fresheting flows is a major defect of this approach. For example, the lower gravel quality and steelhead production in the South Fork Tolt River (example 76; Table 1) as compared with the unregulated North Fork suggest that predictions by instream flow methods are not borne out.

   In view of the above evidence future impact assessments should be wary of the dangers of unforeseen or underestimated consequences.

4. The case histories identify some solutions, and some limitations of past solutions, to the problems that arise from flow regulation.

   To avoid direct problems from reduced flow, a guideline is that monthly flows should not be reduced below 30% of the natural regime.

   Blockage of habitat was mitigated with fishways with only moderate success owing to the problems of passage of downstream migrants. In only one case (example 8; Table 1) was this achieved with any success.

   A strategy of artificial propagation has often been adopted to replace stocks blocked by dams. Nelson et al. (1976) concluded, however, from Pacific northwest cases that stocking streams from hatcheries did not compensate for the very high losses of anadromous fish blocked from upstream habitat. It may be noted, in general, that when artificial stocks were included in the outcome of extensive case histories, the percentage of cases with improved or maintained stocks rose from 23% to only 51%. Artificial enhancement, therefore, is not a guarantee of success.

To avoid degradation of river morphology and gravel quality the case histories, and another review (Hazel 1976 p. XVI), suggest that peak flows should not be reduced by more than 30%. Research would be required to determine the magnitude, duration, and frequency of flushing flows. Mechanical scarification may be a solution for accessible, small and shallow rivers.

Possible solutions to reduce stranding of fry caused by flow fluctuations are suggested by studies on the Skagit River (Woodin 1984). If flow fluctuations must occur, the minimum flow should be sufficient to maintain water over preferred fry habitat, and downramping should occur at as slow a rate as possible.

Cold-water release structures were usually successful in alleviating warm summer temperature problems. In cases where the reservoirs did not freeze, however, they were unsuccessful in preventing increased winter temperatures.

Reducing the effects of pollution often involved release of additional flows, e.g., when oxygen levels reached levels critical for fish. The best solution was to combat pollution by treatment of effluents at their source (e.g., St. John River).

3.0 IMPLICATIONS OF THE CASE HISTORIES FOR KEMANO COMPLETION

This section gives a brief account of the Kemano Completion Proposal and then compares the effects found among the extensively and intensively reviewed case histories with the possible effects of Kemano Completion on salmon populations.

3.1 The Kemano Completion Proposal

The following description is taken from Mundie and Bell-Irving (1986).

The Kemano Completion Proposal of the Aluminum Company of Canada, Limited (ALCAN) is the second stage of a hydroelectric development that was begun in 1950. Under an Agreement with the Province of British Columbia Alcan was given permission to divert water of the Nechako River and Nanika River catchment areas to supply the electrical needs of an aluminum smelter at

Kitimat. The first phase of the development was operational by 1955. It consists essentially (Fisheries and Oceans 1984) of the Kenney Dam, on the Nechako River, that impounds an 890 km^2 reservoir. Water is diverted from the west end of this reservoir via a 16 km tunnel through the coastal mountains to the powerplant at Kemano near the coast (Fig. 2). Transmission lines convey power to the smelter at Kitimat. The reservoir has generally been regulated to store water during the spring snow-melt period, with releases of water to the Nechako River during the remainder of the year. There is no discharge of water from the Kenney Dam itself; releases are made from the Skins Lake spillway from which water passes through several lakes to enter the Nechako River at Cheslatta Falls (Fig. 2). The former riverbed of the Nechako between Kenney Dam and Cheslatta Falls is now almost dry. Discharges prior to this development and in the years following the filling of the reservoir are shown in Fig. 3. Releases from Skins Lake spillway have averaged 130 cms (4590 cfs) since 1956, with peak flows occasionally exceeding 425 cms (15002 cfs) (Fisheries and Oceans 1984).

The second, and final, phase of the Kemano development (Fisheries and Oceans 1984) would provide power for two new smelters and would draw upon the unused potential granted under the water licence. A dam would be constructed on the Nanika River (Fig. 2). The reservoir formed (52 km^2) would contain Nanika Lake and Kidprice Lake, and would be connected to the existing Nechako Reservoir (thus linking the waters of the Skeena system and the Fraser system) by a new tunnel - the Nanika tunnel - 6.8 km long. In addition, unused Nechako River capacity would be drawn upon and a further 16 km tunnel would be constructed parallel to the existing tunnel from the Nechako Reservoir to the powerhouse at Kemano. To permit cooling water to be passed down the Nechako River the Kenney Dam would be provided with a deep cold water release structure. Cold water from this source could be mixed with water from Murray Lake, below Cheslatta Lake, to provide cooling flows of up to 170 cms (6000 cfs).

After very extensive studies and environmental assessments ALCAN has proposed regulated flow regimes (Figs. 3, 4; Fisheries and Oceans 1984) for the affected rivers, and would take measures to mitigate predicted negative impacts on salmon stocks resulting from reduced habitat. The proposed mean annual discharge for the regulated Nanika River (Fig. 4) would be 38% of pre-Kemano, i.e. natural, flows, and releases of 75 cm (2648 cfs) for 4 days every 3 years have been suggested as flushing flows to disperse accumulated sediments. The proposed mean annual discharge of the Nechako River would be 16% of the original river (currently it is 31%). Here the cooling flows would serve as flushing flows. The Kemano River, to which the water is directed, would have an approximately twofold increase in discharge.

Prior to the first phase of development the escapements of chinook salmon (_O. tshawytscha_) in the Nechako River were estimated at 3500. Following the development, concerns for the salmon runs (Fisheries and Marine Service and International Pacific Salmon Fisheries Commission 1979) have related to the need for sufficient flows to allow migration of chinook salmon to spawning grounds in the upper Nechako River, and of sockeye salmon (_O. nerka_) to tributary rivers. The sockeye salmon production from tributaries and lakes in the Nechako catchment area currently contributes 18% of the Fraser River sockeye run (International Pacific Salmon Fisheries Commission 1983). There is also concern over high temperatures and the possible loss of

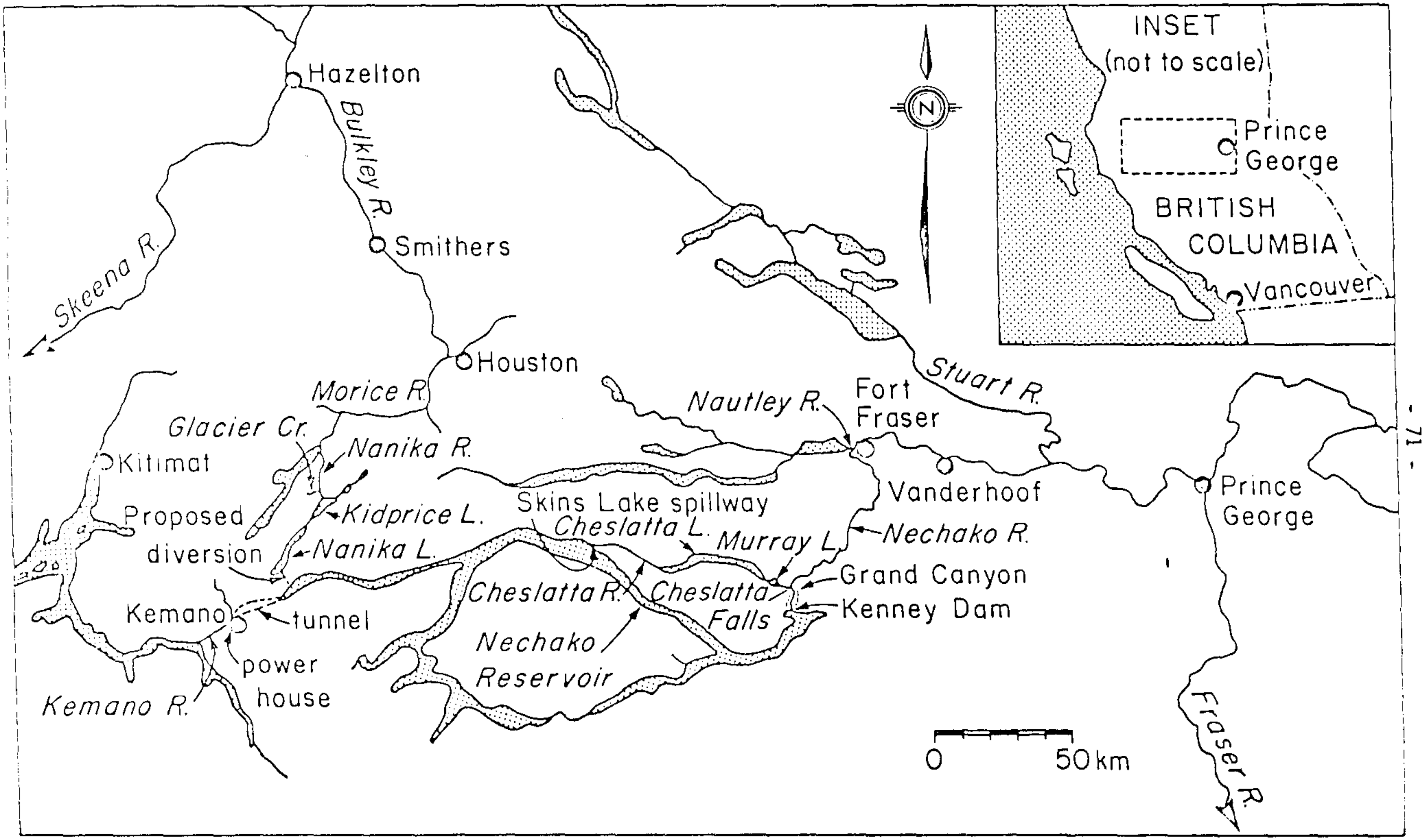

Fig. 2. Sketch map of the Nechako Reservoir and features of the Kemano Completion Proposal.

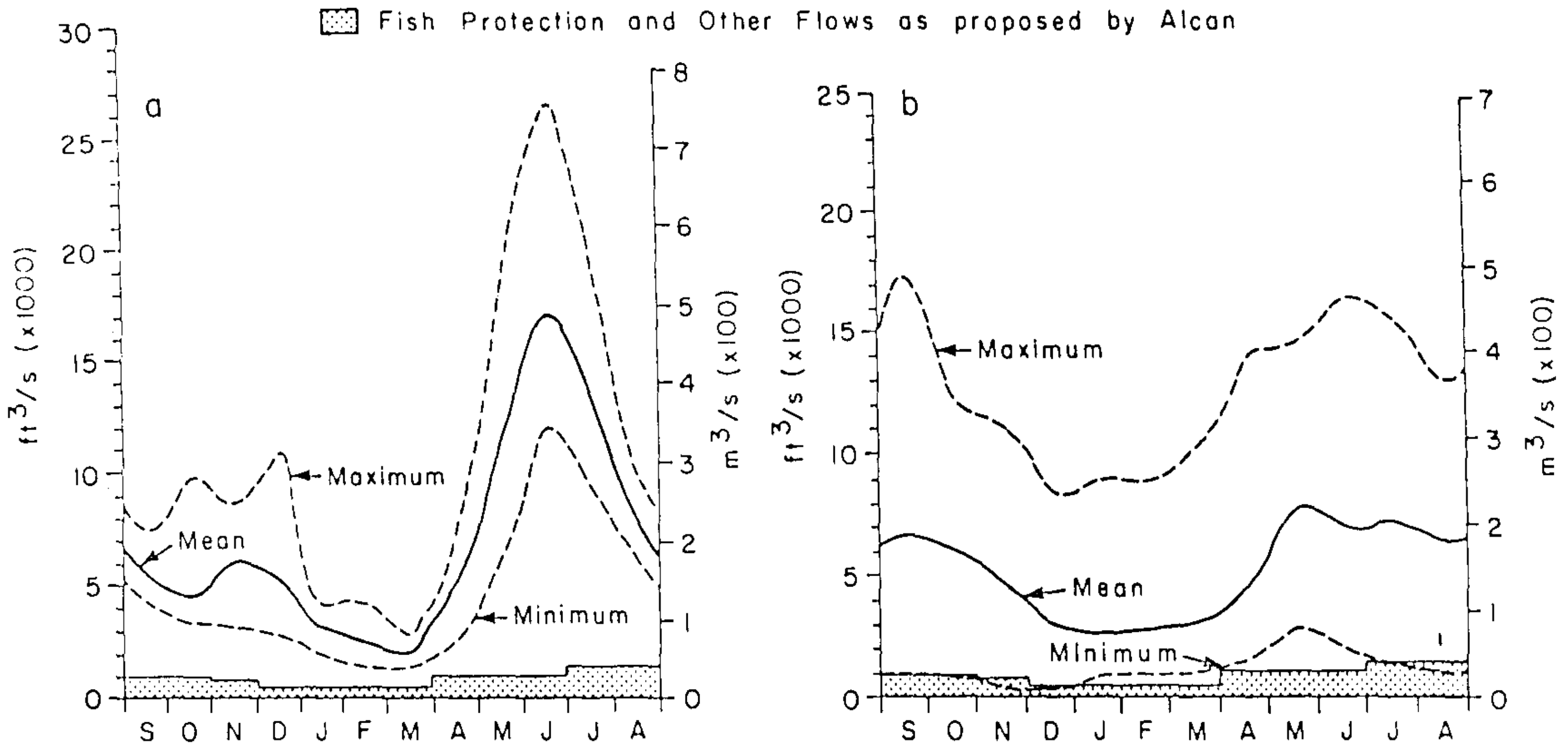

Fig. 3. The Nechako River discharge regime (a) prior to construction of Kenney Dam, and (b) in the years following the formation of the Nechako Reservoir (Fisheries and Oceans 1984). The cooling flows proposed by ALCAN are not shown.

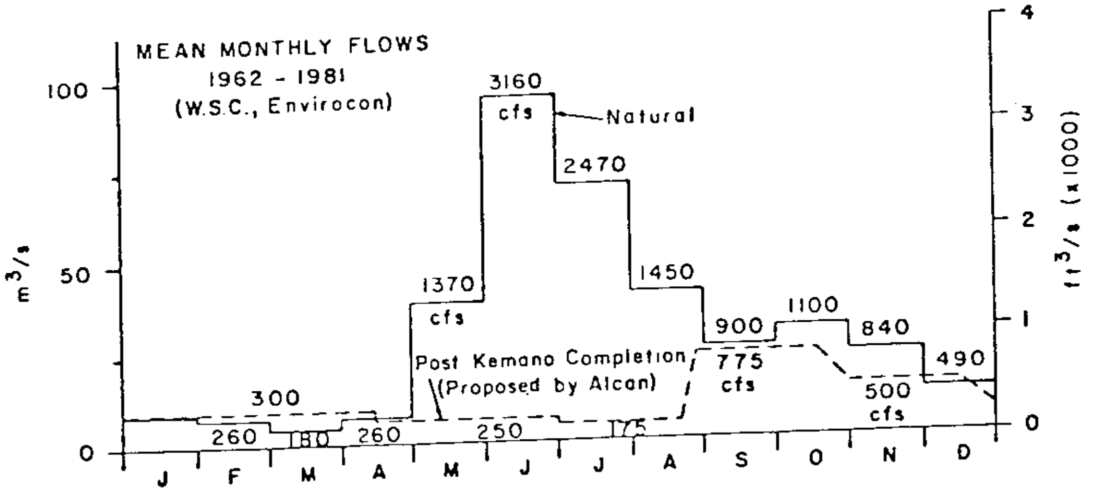

Fig. 4. Natural and proposed discharge regime for the Nanika River (Fisheries and Oceans 1984).

spawning area for chinook salmon in the upper Nechako.

The Nanika River currently supports a significant run of sockeye salmon and smaller populations of chinook salmon and coho salmon (O. kisutch). It flows to the Morice River which has runs of chinook, coho and pink salmon (O. gorbuscha). Here the chinook stock currently amounts to 20% of the total Skeena River chinook escapement. The Kemano River contains these four species and also chum salmon (O. keta).

The cost of Kemano Completion would exceed $2 billion. In October 1984 ALCAN withdrew the proposal owing to a fall in the market value of aluminum, claiming, however, that the proposal would be re-opened when economic conditions improved.

3.2 Effects of flow regulation in the case histories and their possible occurrence under Kemano Completion

Effects for discussion were extracted from the extensively reviewed case histories that were applicable to Kemano Completion (asterisked case histories of Table 1). These are discussed in the order of their frequency among the extensive case histories (Table 6). The conditions (e.g. range of flows, temperatures, etc.) that caused each effect in the case histories are compared with the conditions that might cause the effect under Kemano Completion. Where case histories provide possible solutions to problems these are also presented. Finally, a statement is made on the probability of occurrence of a particular effect on Kemano Completion salmonids from the evidence of the case histories.

Reduced flow resulting in reduced habitat

Reduced discharge can negatively affect salmonids through reductions in available habitat of the various freshwater life stages. After studying 46 case histories from California, Hazel (1976; pp. xiv and 21) concluded that water abstractions greater than 30% of the average monthly flows during seasons critical to fish decreased salmonid stocks. Of concern in the Kemano Completion proposal are (1) reductions in spawning habitat in the Nechako and Nanika rivers, (2) exposure of incubating eggs in the Nechako River, and (3) reductions in rearing habitat in the Nechako, Nanika and Morice rivers. In the following comparisons with case histories flow reductions proposed for Kemano Completion are from Fisheries and Oceans (1984).

Reductions in chinook salmon spawning habitat would occur in the Nechako River under the proposed 84% reduction in September flows to 28.32 cms (1000 cfs). The DFO has calculated that flows of 25.49 to 42.48 cms (900-1500 cfs) are required to maintain maximum spawnable habitat. On the Nanika River proposed flow reductions during spawning are less severe, and would primarily affect the first half of coho spawning when discharge would be reduced by 40% from 23.79 cms (840 cfs) to 14.16 cms (500 cfs).

The amount of spawning habitat lost under ALCAN's proposal can be

Table 6. Principal explanations, from case histories applicable to Kemano Completion, of the outcomes of natural salmonid stocks exposed to flow regulation; also, the possible occurrence of effects in Kemano Completion Rivers.

Outcome and explanation	Nechako River	Nanika River	Kemano River
1. Improved or unchanged natural stocks (7 cases)			
Increased flows (4)			+
No major change in flows (1)	+	+	
Stabilized flow (1)	+	+	
Altered water temperature (1)	+		
2. Reduced natural stocks (33 cases)			
Reduced flows resulting in reduced habitat (23)	+	+	
Sedimentation, deterioration of gravel quality (12)	+	+	
Fluctuating flows (9)	+	+	+
Altered water temperature (8)	+	+	
Increase in pollution (3)	+		
Gas supersaturation (1)	+	+	+
3. Outcome for natural stocks unknown (10 cases)			
Natural stocks confused by artificial propagation (6)			
Lack of, or inconclusive, post-project studies (5)			
Lack of, or inconclusive, pre-project studies (2)			
Effects of flow confounded by extraneous factors (1)			

Notes:

The outcome of a particular case may have more than one explanation.

Numbers in parenthesis are case histories.

Explanations are from asterisked case histories of Table 1.

The applicability of case histories to Kemano Completion was based on their having effects that could possibly occur with Kemano Completion. Some cases showed effects that would not apply with Kemano Completion; see Table 3.

Plus signs indicate possible effects.

predicted by modelling; the case histories, however, reveal some risks and limitations to modelling. For example, modelling is based on physical criteria (e.g., depth, velocity) and does not account for ecological interactions that affect a river's carrying capacity for spawners. In the Big Qualicum River, for example, high spawner density resulted in increased superimposition of redds and, consequently, in reduced egg survival. This type of intraspecific competition could reduce the spawning capacity of the Nechako and Nanika rivers to a greater extent than indicated by modelling. Moreover, and most importantly, modelling assumes that river morphology and spawning gravel quality are unaffected by reduced discharge. In the Tuolumne River (example 40; Table 1) reduction of peak and minimum flows altered stream morphology to deep narrow channels that were inadequate to support former spawning populations. The annual run of salmonids was reduced from about 75,000 fish to 5000 fish. On the South Alouette River (example 45; Table 1) a 98% reduction in mean annual flow has degraded the quantity and quality of spawning habitat, and is thought to have been a major factor in the extinction of pink salmon runs. On the south fork of the Tolt River (example 76) modelling, similar to ALCAN's (IFIM), predicted that flow regulation should have benefited most steelhead life stages, yet, smolt production is lower than in the unregulated north fork. Reduced gravel quality due to sedimentation is a suspected cause of the lower production in the south fork.

Reduced discharge during incubation can expose eggs and alevins to desiccation and freezing. For the Nechako River ALCAN proposes an 82% reduction of the mean natural incubation flows. Moreover, incubation flows would be 50% lower than the proposed spawning flow (fish and "other" flows), resulting in a drop of 18 cm (0.6 feet) in the water level.

The consequences of exposure of eggs and alevins are demonstrated by two case histories. On the Willamette River (example 20; Table 1), exposure of eggs below Cougar Dam was a major factor in the decline of chinook salmon, cutthroat trout, and Dolly Varden char. This outcome was due to the effects of monthly minima rather than monthly mean flows, as the latter were higher or similar to monthly flows during spawning. On the Sacramento - San Joaquin system (Section 2.2.3), the abundance of juvenile chinook decreased with decreased flow during incubation. Exposure of eggs and alevins was implicated as the major cause.

The implication of these two examples to ALCAN's proposal is to highlight a possible outcome of flows lower during incubation than during spawning.

Water abstraction during the rearing and overwintering periods of salmonids can reduce a river's carrying capacity for juveniles. The explanation for this is complex and involves many factors including loss of habitat (i.e., space), changes in quality of substrate, cover, and food supply, and changes in biological interactions (e.g., intraspecific competition, predation and dispersal).

With Kemano Completion, mean monthly flows during rearing (May-August) would be reduced by 81% to 93% in the Nanika River, 23% to 41% in the Morice River and an average of 84% in the Nechako River. Overwintering flows in the Nanika River would be decreased by 40% in November, but increased by 15% to 67% during February to mid April. Overwintering flows on the Morice

River would be decreased by 9% to 16% from October to December, but increased by 5% for March and April. On the Nechako River they would be reduced by 82% during January through March.

ALCAN undertook modelling to assess the effects of changes in rearing and overwintering flows. Estimated losses would be 70% of chinook rearing habitat and 90% of coho rearing habitat on the Nanika River, and 50% of chinook and coho habitat on the Morice River. On the Nechako River ALCAN's modelling predicts no loss of chinook rearing habitat. With respect to overwintering flows ALCAN predicts that increased flows on the Nanika and Morice rivers during the latter portion of the overwintering period would benefit chinook and coho salmon. For the Nechako River ALCAN assumes that overwintering habitat is not limited and therefore the proposed flow reductions would not reduce carrying capacity.

While modelling is helpful for assessing the effects of reduced rearing and overwintering flows, it addresses only the spatial component of carrying capacity. A full analysis should include changes in habitat quality and in biological interactions, both of which influence a river's carrying capacity. For example, reduced quality of rearing habitat contributed to the decline of salmonids in five case histories (examples 20, 21, 23, 27, and 28; Table 1). The explanations were decreases in food supply (examples 23, 27, and 28) and in instream cover (examples 20 and 27) because of sedimentation, and stranding of fish in O_2-deficient pools (example 21). Again, on the Sacramento - San Joaquin system (Section 2.2.3) reduced flows during rearing limited the dispersal of juvenile chinook salmon to suitable available habitat.

Factors determining the carrying capacity of streams are not fully understood. An assessment, however, of the outcome of reduced rearing and overwintering flows for salmonid numbers can be made from the extensive case histories. Among the 23 cases applicable to Kemano Completion, where fish stocks were reduced by decreased flow (Table 6), 11 were reduced primarily, or in part, as a result of decreased rearing or overwintering capacity (examples 17, 18, 20, 21, 22, 25, 28, 35, 41, 44, and 45; Table 1). Three examples (17, 18, and 45) were similar to the Nechako River in the quantity by which the mean annual flow was reduced. In examples 17 and 18, trout populations (no salmon were present) were severely reduced, and their continued existence was dependent on deep holes (examples 17 and 18) and tributary inflows (example 18). In example 45 reduced rearing habitat for coho, steelhead and cutthroat contributed to the decline of these stocks. Six of the examples (20, 22, 25, 28, 35, and 41) are comparable to the Nechako River in that overwintering flows were substantially reduced. Contrary to ALCAN's prediction for overwintering of Nechako River chinook salmon, reduced overwintering flows contributed to the decline of trout and chinook salmon in these cases.

The implications of the case histories for Kemano Completion are, firstly, that assessment of the effects of reduced flow during rearing and overwintering should not be based solely on physical parameters (as is ALCAN's assessment) but should incorporate effects on habitat quality and biological interactions. When these are included the amount of lost habitat may be greater than that calculated by ALCAN. Secondly, the 11 case histories examined here showed that reduced carrying capacity was an important factor contributing to declines in salmonid populations. Thirdly, ALCAN's claim that benefits from increased late winter flows to chinook and coho salmon on the Nanika and Morice rivers would compensate for losses arising from decreased rearing flows is questionable. The benefits predicted are improved egg and overwintering survival. This prediction assumes that increased late winter flows would indeed increase juvenile production and that flow reductions of 23% to 93% during rearing would not affect the rearing capacity of the two rivers. The validity of these assumptions is disputed by the case histories. Egg-to-fry survival may not increase but, in fact, may decrease during the winter if gravel quality is not maintained (see Section 3.2 on Sedimentation), or if emergence timing is altered (Section 3.4). Again, of the case histories involving reduced rearing flow all showed a reduction in rearing capacity. In the light of these examples, it is unlikely that increased late winter flows would offset the negative effects of decreased summer flows.

Sedimentation and reduced gravel quality

One of the most frequently ignored effects of flow regulation is the sedimentation that can result when rivers are robbed of the flushing action provided by freshet flows. Deposition of fines can result in compaction of spawning gravel, smothering of eggs and alevins, filling-in of interstitial spaces between substrate materials that provide cover for rearing fish, establishment of rooted aquatic vegetation, and reduction in food organisms for fishes.

In the event of Kemano Completion sedimentation could be detrimental on the Nanika River as freshet events would be lost. Monthly flows for June, the period of highest flow, would be reduced by 92%. The potential sources of fines include banks and tributaries, particularly Glacier Creek if it were not diverted. ALCAN has proposed flushing flows of 75 cms (2648 cfs) for four days every three years to maintain gravel quality. It is very doubtful that these would be adequate. On the Nechako River sedimentation problems already exist owing to sediment inputs from the Cheslatta River. A greater reduction, therefore, of peak flows and their duration could further reduce the Nechako River's capacity to cleanse its gravels. ALCAN proposes that cooling flows of 170 cms (6000 cfs) would serve as freshet flows.

The reductions in peak flows that can cause sedimentation, and their consequences to fish habitat, are illustrated by 18 case histories (Table 7). Sedimentation occurred with reductions of as little as 10% in highest mean monthly flow (example 63; Table 1). It is difficult to generalize as to the smallest reduction of maximum flow that produced sedimentation, as few values of maximum flow are available in the literature. Hazel (1976) concluded that reductions of 30% or more in peak flows generally resulted in deterioration of substrate quality. Effects demonstrated by the 18 cases included loss of spawning gravel quality, lower egg survival, loss of rearing habitat quality, lower benthic production, and encroachment of riparian and rooted aquatic vegetation.

Variables that influence the amount of sedimentation are the magnitude of peak flows, their duration and frequency, and sources of sediment. Methods of determining whether flow changes will cause sedimentation are at present not reliable. For example, in the case of Pelton

Table 7. Changes in the highest mean monthly and in peak flows after regulation, and the consequences to salmonids; based on case histories that experienced sedimentation.

Case history		Percent change in flow (+ increase - decrease)		Habitat or life stage affected by sedimentation
No.	Name	Highest mean monthly flow	Maximum flow	
6	Big Qualicum River Project	-29%	-70%	Egg survival
63	Pelton Dam	-10%	+3%	Spawning gravel, egg survival, food supply
64	Cougar Dam	No change	-57%	Spawning gravel, egg survival, rearing habitat
65	Riverside and Beulah dams	Unknown	Unknown	Spawning gravel
67	Scott Dam	-16%	Unknown	"Fish habitat"
68	Cape Horn Dam	-32%	Unknown	Spawning gravel
69	Isabella Dam	-32%	Unknown	"Trout habitat"
70	Friant Dam	-68%	Unknown	Spawning gravel
71	Goodwin Dam	-62%	Unknown	Spawning gravel
72	New Don Pedro Dam	-66%	Unknown	Spawning gravel
74	Lake Henshaw	-92%	Unknown	Spawning gravel
75	Trinity-Lewiston dams	-52%	Unknown	Spawning gravel, rearing habitat
76	Tolt Dam	Unknown	Unknown	Spawning gravel
111	Iron Gate Dam	+82%	Unknown	Spawning gravel
117	Middle Fork Project	Unknown	Unknown	Spawning gravel
118	Laurance Lake	Unknown	Unknown	"Siltation has occurred"
131	Coyote Dam	-16%	Unknown	"Downstream habitat"
Sect. 2.2.2	Blacktail Creek	Flow reduced by 90% of the base flow for 3 months		Rearing habitat

Notes:

1. Percent changes in flow were not given for many cases owing to a lack of pre- or post-project studies, or because they were not provided by available literature.

2. Most case studies showed a deterioration of spawning gravel; however, it is likely that egg survival was also reduced.

3. The Iron Gate Dam case had much greater post-project flows, as pre-project flow data included the drought years during the 1930s.

Dam (example 63), the maximum flow actually increased, but the highest mean monthly flow decreased; sedimentation resulted. The opposite was true for the river below Iron Gate Dam (example 111); here the highest mean monthly flow increased after regulation, but a reduction in the frequency and magnitude of maximum flows caused sedimentation.

Solutions for sedimentation problems were documented in only one case history, the Big Qualicum River Project (Section 2.2.1). On this river the substrate is scarified with a "cat". Then follow controlled flow releases of 154% of the base flow for 20 to 24 hours, or 256% of the base flow for 3 to 4 hours. This takes place in July or August and is repeated annually, otherwise chum egg survival begins to decline.

In view of the case histories it must be concluded that ALCAN's proposal for reducing the highest mean monthly flow by 92% on the Nanika River, and by 83% on the Nechako River, has a high probability of creating sedimentation problems. Potential sources of sediment on these rivers include tributaries, banks, release of turbid water, and construction activities. It has been proposed that diversion of the highly turbid Glacier Creek would reduce the amount of sedimentation in the Nanika River. This may not be so if sediments remained in suspension and were released from the reservoir itself. Turbid releases from reservoirs contributed to downstream sedimentation in two case histories; examples 64 and 67 (Table 1). If this occurred the main spawning grounds of the Nanika River would be sedimented to a greater extent than would occur without the diversion, as they lie above the natural Glacier-Nanika confluence.

Alleviation of sedimentation by mechanical scarification is not practicable for the Nanika and Nechako rivers because of their size and depth. Flushing flows appear to be the only practical solution. Volume, duration and frequency are all significant in determining effectiveness. Because of their short duration and infrequency it is doubtful whether the 75 cms proposed for the Nanika River would be sufficient to maintain habitat.

Fluctuating flows

Fluctuating flows (rapid increases and decreased in discharge) can have highly detrimental effects on fish. Such variations of flow may be of concern on the Nechako River in association with the proposed cooling flows, and on the Kemano River in association with power peaking. On the Nechako River ALCAN proposes a new cold water release structure for daily adjustments of temperature during July and August. This would provide release of water up to 130 cms (4500 cfs) around a mean of 40.9 cms (1444 cfs). The possible effects of rapid changes of flow on juvenile chinook have not been addressed. Again, on the Kemano River, no analysis has been directed at the effects of power peaking flows.

Of 33 case histories resulting in reduced stocks, nine could be explained primarily, or in part, by effects of fluctuating discharge (Table 6). Two other cases document adverse effects on life stages, but the outcome was not studied (example 120; Table 1) or was obscure (example 14; Table 1). Typically, fluctuations occurred daily or hourly; quantification, however, was provided for only three cases:

Campbell River (example 14 and Section 2.2.3) - 31 cms to 122 cms
Clark Fork River (example 81) - 1.8 m to 2.1 m (average water level)
Nacimiento River (example 83) - 3.96 cms to 14.30 cms.

Both direct effects on salmonids, and effects on their habitat were demonstrated. Direct effects included:

1. Prevention of spawners from entering tributaries during low flow phases (example 81; Table 1).
2. Disruption of spawning activities (examples 14, 81, and 83; Table 1).
3. Exposure of incubating eggs to desiccation and freezing (examples 81, 83, and 85; Table 1).
4. Stranding of fry (examples 14, 78, and 120; Table 1).

Effects on fish habitat were primarily scouring and displacement of gravel to tributaries and higher instream elevations (e.g., banks and bars). Dams prevented recruitment of gravel to scoured areas. Consequences to fish habitat include:

1. Reduction of quantity and quality of spawning and rearing habitat (examples 77, 79, 80, 81, 82, 84, and 85; Table 1).
2. Reduction of food supply (examples 77, 79, and 82; Table 1).
3. Reduction of aquatic vegetation (example 82; Table 1).

It is difficult to say which of these effects are pertinent to the Nechako and Kemano rivers, as the problem has not been addressed. The severity of the consequences among the case histories warrants its attention. There would seem to be a likelihood of stranding of chinook fry and diminution of food supply on the Nechako River during cooling flow releases. Power peaking flows on the Kemano River could create hazards similar to those previously listed.

Studies on the Skagit River have provided some ways to lessening the stranding of salmonid fry (Woodin 1984), and of reducing the adverse effects on aquatic insects (Gislason 1985). Woodin concluded, firstly, that if flow fluctuations must occur the minimum flow should be sufficient to maintain surface water over preferred fry habitat, and that input of flows from downstream tributaries should be monitored to allow some flexibility in minimum flow releases from the turbines. Secondly, if flow reductions are predicted to result in stranding, they should be timed to take place at night as stranding is less severe at this time. Thirdly, if changes are required during the day the rate of change should be as slow as possible (rate was not important at night). The second conclusion contradicts that of other authors (Becker et al. 1981; Hamilton and Buell 1976) who recommend that changes be made during the day.

A useful review of the effects of fluctuating flows on aquatic systems is provided by Cushman (1985). Many effects and underlying mechanisms are examined. Cushman suggests that re-regulating dams are an additional means of alleviating the negative effects of flow variations while permitting generation of additional power. They are, however, costly.

Altered water temperature

Temperatures of regulated rivers can be strongly influenced by the quantities and temperatures of waters released at dams. Resultant changes in downstream temperatures can affect all life stages of salmonids. For example, growth may be affected, the optimal temperature for growth of chinook fry being 11.2 to 17.8°C (Brett et al. 1982). Again, migration may be affected; for sockeye the optimal temperature for swimming and utilization of energy is 15°C, and temperatures exceeding 20°C are harmful (IPSFC 1983).

Under Kemamo Completion reduced discharge on the Nanika River during the summer would cause temperatures to rise above 19.7°C. These could adversely affect the migration of sockeye and chinook salmon and the rearing of coho, chinook, and trout. For the Morice River maximum summer temperatures would be less than 18.6°C, and would not likely create problems for adult and juvenile salmonids. On the Nechako River, Kemano I has reduced the mean annual flows by 69%. This has resulted in mean daily temperatures during the late summer of 20°C to 25°C in 15 of 27 years following Kemano Completion (IPSFC 1983). These temperatures have impaired the success of sockeye migration. Under Kemano Completion the mean annual flows in the Nechako River would be reduced by 84% from pre-Kemano I. To alleviate the temperature problems that would result from such a large reduction in flow ALCAN has proposed a cold water release structure at Kenney Dam. This would release 10°C water at 40.9 cms (1444 cfs) during July and August, and would maintain a temperature of 17.9°C for sockeye migration. The release of 10°C water at Kenney Dam, however, could create suboptimal temperatures for the growth of juvenile chinook salmon in the upper Nechako River and for the production of their food organisms.

Among the case histories salmonid migration and spawning were adversely affected by temperatures that were much lower than those anticipated in the Nanika, Morice, and Nechako rivers. For example, on the Sacramento - San Joaquin system (Section 2.2.3), temperatures of 18°C in the delta were found to halt chinook salmon migration. In the Middle Fork Willamette River below Dexter Dam (example 85; Table 1) temperatures of 16°C prevented the successful reproduction of chinook salmon. On the Big Qualicum River (Section 2.2.1) high flows in 1962 caused an early migration of adult chinook salmon in the river. The fish entered in spite of high temperatures. During the first three weeks they were exposed to mean daily temperatures between 16°C and 18.3°C on four occasions. As estimated 31% of the females died unspawned as a result.

It is apparent from these examples that the temperatures anticipated on the Nanika, Morice, and Nechako rivers may not be as safe as is predicted for salmonid migration and spawning. The effect of temperature on adults has centered around sockeye migration. In the light of the lower temperatures suggested by the case histories as being critical, the adult phases of chinook and coho should also be considered. In the event of project acceptance, attention should be given to the danger of untimely releases of high flows during construction that could attract adults when temperatures are high.

With respect to the effects of altered temperature on rearing salmonids, it was found that chinook fry of the Rogue River (Section 2.2.3) grew faster at 16°C to 17°C as compared with 18°C to 19°C. Among other cases, survival of juvenile chinook salmon and steelhead, rainbow and cutthroat trout was severely impaired at temperatures of 24°C to 27°C (examples 89 and 86;

Table 1). An additional effect at these high temperatures was the increased propagation of coarse fish that outcompeted juvenile salmonids. The effect of cold water releases was demonstrated on the Rogue River. It was found that greater releases of 12 to 13°C water, as opposed to smaller releases of 10°C water, did not affect the growth of chinook fry near the dam, and provided cooling to a greater distance downstream. Growth of steelhead fry near the dam was slightly depressed, possibly because of the cold water releases.

If juvenile salmonids affected by Kemano Completion respond as did the Rogue River chinook salmon, then summer temperatures of 19°C on the Nanika River, 18.6°C on the Morice River, and 17.9°C on the Nechako River could depress their growth rates. This could have negative consequences for their freshwater and oceanic survival. Additionally, the question of increased coarse fish abundance with elevated temperatures has been unattended in ALCAN's impact assessment. With regard to cold water releases on the Nechako River that would satisfy both sockeye migration and chinook rearing, the Rogue River case history indicates that it would be most effective to release slightly greater flows at slightly higher temperatures (12-13°C) than the flows presently proposed by ALCAN.

There is another life characteristic, that of emergence timing, that warrants attention. This is illustrated by the Rogue River (Section 2.2.3). On this river, heating of impounded water resulted in warmer incubation temperatures that accelerated the timing of chinook emergence. This, in turn, appeared to be the main cause of a 58% decline in juvenile chinook abundance. This demonstrated that altered incubation temperatures can have serious consequences for fish numbers, yet this has received little attention in ALCAN's impact assessment. The problem may be avoided on the Nechako River as, unlike the Rogue River reservoir, the Nechako Reservoir freezes during winter. If Kenney Dam were altered to permit release of this cold surface water then a potential exists to eliminate elevated incubation temperatures. Releases would probably have to be made in conjunction with the proposed hypolimnetic release structure to provide downstream temperatures comparable to those of the natural regime.

Pollution

When flows of rivers are reduced their capacity to assimilate pollutants is diminished. This can result in reduced dissolved oxygen, in increased concentration of toxic compounds, and in algal blooms. These all have adverse effects on fish and invertebrates.

In the event of Kemano Completion pollution could become a problem on the Nechako River in the vicinity of, and downstream of, Fort Fraser, Vanderhoof and Prince George. Existing mean annual flows (i.e., Kemano I flows) would be reduced by 80% at Fort Fraser and 60% at Vanderhoof. These are sites where municipal and industrial effluents are released.

These areas are occupied by migrating sockeye salmon (adults and juveniles) and by all phases of chinook salmon. Limited water quality predictions have been made by ALCAN.

Five case histories demonstrate the interaction of reduced flow and pollution (the Sacramento - San Joaquin system, and the St. John River from Section 2.2.3; and examples 97, 98, and 99; Table 1). In all five, reduced flows concentrated pollutants with adverse consequences to salmonids. Sources of pollution included industrial effluents (particularly pulp mill effluents), municipal wastes and irrigation returns. On the Sacramento - San Joaquin Delta chinook migration is halted in late summer when reduced flows cause oxygen concentrations to drop below 5 mg/L. The success of chinook spawning migrations has been reduced on the Stanislaus River (example 98) by dissolved oxygen levels less than 4-5 mg/L. On the St. John River low oxygen levels delay migrations of Atlantic salmon from the river mouth, and slow their passage upstream. Levels are also sometimes inadequate on the spawning grounds. Additionally, toxic compounds associated with pulp mill effluents (lignosulphonates) cause mortality of juveniles.

The severity of the effects of pollution in terms of fish numbers varied among the case histories. On the Sacramento - San Joaquin system, Yakima River (example 97), Stanislaus River (example 98), and South Alouette River (example 99) pollution was one factor among many that contributed to the decline of salmonids. On the St.John River it was a major cause of reduced stocks. Fish passage facilities and a hatchery proved to be unable to compensate for the losses. In view of these examples the Nechako River appears to have the potential for pollution problems.

Gas Supersaturation

Rivers can become supersaturated with gases (mainly oxygen and nitrogen) when air entrained at the water surface is subjected to hydrostatic pressure at depth. Fish and invertebrates exposed to supersaturated water can develop gas bubbles in their blood and tissues, resulting in blocked circulation, damaged tissue, and ultimately death, either directly, or indirectly through increased susceptibility to predation and disease.

Gas supersaturation could occur in the plunge pool below the proposed Nanika dam, and presently occurs in the Cheslatta plunge pool on the Nechako River. ALCAN's mathematical modelling of total gas pressure (TGP) on the Nechako River for July 15 to August 18, 1981 found that values exceeded 110% for 8.5 days or longer. A TGP of 110% was cited by ALCAN as the upper safe limit (based on Ebel and Raymond 1976) for migrating sockeye and rearing chinook salmon.

Among the case histories gas supersaturation problems were reported on the St. John River (Section 2.2.3) and the middle Snake River (example 104; Table 1). On the St. John River, 10% (200 fish) of migrating Atlantic salmon were killed in 1968. The cause of supersaturation was not spillage of water into a plunge pool but entrainment of air into the turbines to relieve backpressure at low operating levels. Resulting nitrogen levels in the tailrace reached 118-125%. Turbine design has since been modified, but the effectiveness of the alterations is not documented. On the middle Snake River the cause of supersaturation was spillage over Hell's Canyon Dam. TGP levels were not provided. The consequence, however, was a reduction in the number of salmonids migrating to the dam.

While the case histories do not demonstrate a critical level of TGP for salmonids, they do emphasize the potential severity of its consequences. Additionally, a previously unrecorded source (turbines) is illustrated. Future studies of gas supersaturation in relation to ALCAN's proposal should, therefore, be directed at the Cheslatta plunge pool on the Nechako River, the proposed Nanika plunge pool on the Nanika River (e.g., during flushing flow releases) and the reaches below the tailraces on the Kemano River.

3.3 DISCUSSION AND CONCLUSIONS

It may be argued that the validity of comparisons between Kemano Completion and the case histories is in question as the biological objective of Kemano Completion is fish protection, while for the case histories it varied from indifference to fish, to fish protection. Again, it may be argued that ALCAN'S method of predicting effects of Kemano Completion was very sophisticated (IFIM), whereas predictions from the case histories were deductive. Nevertheless, the biological objective of the majority of the case histories was fish maintenance or improvement (see Nelson, Horak, Hale et al. 1976, p. 83). Moreover, the case histories illustrate that predictions based on IFIM are subject to error, as they fail to include the effects of regulation on ecological interactions and on river morphology. For these reasons the foregoing effects demonstrated by the case histories could occur in varying degrees in the event of Kemano Completion.

Other limitations to ALCAN's impact assessment are demonstrated by the case histories. Firstly, ALCAN's claim that increased survival during incubation would compensate for decreased survival during rearing is not borne out by the case histories. Secondly, the effects of fluctuating flows and coarse fish propagation are not considered in ALCAN's impact statement. Thirdly, the effects of sedimentation, pollution and TGP are only superficially addressed by ALCAN. The effects of sedimentation deserve particular attention as these have been highly underestimated by previous regulation projects, yet have had very severe consequences for fish habitat.

Strategies for avoiding some potential effects of Kemano Completion are provided by the case histories. These include cooling flow releases that satisfy both juveniles and migrating adults, and procedures for reducing the harmful effects of fluctuating flows. The case histories indicate that flushing flow releases may be required annually rather than every three years as proposed by ALCAN.

ALCAN's impact assessment predicts that Kemano Completion would result in no net loss of productive capacity. The correctness of this prediction is disputed by case histories applicable to Kemano Completion rivers. When these cases are arranged by outcome (Table 8), it is seen that only 3 of 29 cases applicable to the Nechako River had improved or unchanged salmonid stocks; 1 of 21 cases applicable to the Nanika/Bulkley system had improved stocks; and 4 of 10 cases applicable to the Kemano River had improved or unchanged salmonid stocks. For the cases showing improved or unchanged outcome (6 cases in total) this was generally the result of increased or

Table 8. Outcome for natural salmonid stocks after flow regulation for case histories applicable to Kemano Completion.

	Case histories	Outcome for natural stocks		
		Improved	Unchanged	Reduced
Nechako River	29 100%	2 7%	1 3%	26 90%
Nanika/Bulkley System	21 100%	1 5%	0 0%	20 95%
Kemano River	10 100%	2 20%	2 20%	6 60%
Total	32 100%	4 13%	2 6%	26 81%

Notes:

"Applicability" was based on effects that could occur in the Kemano Completion rivers.

Case histories from which the above table was compiled are listed in Appendix B.

relatively unchanged mean annual and monthly post-project flows. Thus, on the basis of case histories, Kemano Completion carries a high risk of reducing salmonid populations on the Nechako and Nanika/Bulkley river systems, and a lesser risk on the Kemano River system.

4.0 CONCLUDING REMARKS

The purpose of this section is to emphasize some of the salient points that have emerged from the review of case-histories and to present the problem of prediction in a broader perspective than hitherto.

An obvious finding is that several innately different kinds of difficulties stand in the way of relating changes in flow to numbers of salmon. Firstly, there is the difficulty of obtaining estimates of salmon populations with reasonable accuracy. Most counts of escapements are subject to high, and unknown, error. Secondly, there are confounding effects that influence numbers of fish, i.e. the effects of fisheries and the effects, both positive and negative, of environmental changes arising from altered flows. Thirdly, there can be very wide natural variation in population numbers on an annual basis. This makes it necessary to obtain time series of pre- and post-regulation estimates to allow valid comparisons to be made. Fourthly, flow regulation can take many forms. For example, it can be water abstraction spread evenly over a year, or it can be the removal of peak flows, or it can be widely fluctuating discharge with no overall abstraction. While all of these practices qualify as flow regulation the effects of each on salmonid populations would differ widely. Useful generalizations on the effects of regulation are therefore elusive. Finally, before a verdict can be reached on consequences sufficient time must elapse, for initial responses of fish populations may be only temporary and several decades may have to pass before an ecological equilibrium becomes established.

A second finding to emerge from the review of case histories is that flow regulation has most commonly had a negative effect on fish populations. In his comprehensive review of impounded rivers Petts (1984 p. 211) stresses that the effects of impoundments on fish are not always detrimental. The "reduction in suspended loads (a source of great mortality to developing eggs), the regulation of floods and prevention of drought (causes of egg and young fish losses), and thermal regulation (important to many species for reproduction), may prove beneficial." Nevertheless, for the most part environmental changes induced by river impoundments have had negative effects on fish populations, including their demise. Anadromous fishes are particularly vulnerable.

A third finding is that the negative effects that tend to predominate in flow regulation are likely to result from multiple causes. Attempts have been made to define simple "cause and effect relationships, in order to provide predictive models for fisheries management; but most deleterious impacts of reservoirs and dams upon fish species result from the combination of various changes to a number of attributes of the lotic habitats. Relatively subtle changes of a single attribute may appear harmless when viewed in isolation, but when considered as part of the whole system, the addition of many subtle changes may produce conditions which adversely affect particular species. Moreover, many of the changes will occur slowly, so that very gradual habitat-change may produce a slow, but progressive, displacement of indigenous fishes by an exotic, or natural, competitor or predator. Alternatively, the progressive change of some attributes (such as temperature, water quality, substrate composition, etc.) may reach a limiting condition and cause the sudden loss of a particular species." (Petts op. cit p. 235-6).

Mention may be made of the numerous models that have been devised to predict the outcome of flow regulation for benthos and fish (reviewed by Stalnaker and Arnette 1976). These have generally taken no cognizance of flows required to maintain the physical characteristics of the river on which carrying capacity largely depends. Predictions of impacts are not possible, however, if maximum flows, as well as threshold flows for fish stages, are not taken into account. Nor have the models considered the influence of tributary erosion and sediment yield. Because of the complexity of the relationships predictive models relating channel flow and movement of coarse bed materials do not exist. It is therefore not possible to forecast the frequency, extent and depth of scour in biologically-significant gravel beds (Milner et al. 1981). Similarly, knowledge of the effect of flow regime upon benthic invertebrates is fragmentary. For these reasons it is not possible to link flow patterns, sediment dynamics and gravel quality on the one hand to spawning and rearing success of salmonids on the other. Finally, the models do not have time scales in terms of years and decades over which changes must be anticipated.

Some of the shortcomings of in-stream flow models can be attributed to inadequate concepts of the nature of the fluvial system. Fisheries managers, who are among the people most likely to need predictive knowledge of the effects of flow on fish stocks, are not usually limnologists and do not argue from a limnological paradigm or theory about the functioning of aquatic ecosystems (Rigler 1982). Adequate theory, however, is necessary for making predictions.

That an adequate and generally accepted theory of lotic systems is still being sought is manifest from recent reviews of the dynamics of streams (e.g. Fontaine and Bartell 1983, Barnes and Minshall 1983). Nevertheless, it is clear that an essential element of whatever theory finally emerges will be disturbance as a major determinant of biotic diversity, of serial continuity in space and time (Ward and Stanford 1983 a and b) and presumably of levels of productivity associated with the diversity and continuity. Disturbance may be defined as the conspicuous departure of some variable from its typical condition, and the variable may be abiotic (e.g. floods or droughts) or biotic, e.g. predation. Biotic diversity is greatest in communities subjected to moderate levels of disturbance; it is suppressed in stream habitats exposed to severe or frequent disturbances. "Undisturbed" systems, i.e. rivers with their natural range of flows reduced, are in fact disturbed. The natural perturbations of flow are what maintain the system. Again, the natural lotic continuity of a river is profoundly disrupted by a dam that introduces a lentic disruption into the continuum of running water. Given that moderate disturbance is the controlling mechanism in the biology of fluvial ecosystems it is to be expected that flow regulation would produce results that are complex and difficult to predict in precise quantitative terms. In view of this, case histories of the effects of regulation on salmonid populations stand as the most helpful single tool for reaching understanding, and their full and careful documentation is a prerequisite for obtaining predictive knowledge.

ACKNOWLEDGMENTS

Much of the information in this review was collected while the senior author was involved on a FREDY (Fisheries Resource Employment Development for Youth) contract, funded by the Department of Fisheries and Oceans (DFO). Further literature research and completion of this review were undertaken while he held a contract with the DFO. He is indebted to Mr. Gordon Ennis for setting up the second contract that made completion of this report possible. Appreciation is extended to Mr. Gordon Miller, Ms. Pam Olson and Mrs. Martha Hawthornthwaite for use of the library facilities, and for their help in obtaining information. The skills and patience of the typing staff of the Pacific Biological Station are gratefully acknowledged.

The authors thank Mr. Ennis and Dr. Cole Shirvell for critical comments on the manuscript.

REFERENCES

Barnes, J. R. and G. W. Minshall, (eds.). 1983. Stream Ecology: application and testing of general ecological theory. Plenum Press, N.Y. 399 p.

Becker, C. D., D. H. Fickeisen, and J. C. Montgomery. 1981. Assessment of impacts from water level fluctuations on fish in the Hanford Reach, Columbia River. PNL-3813, Pacific Northwest Laboratory, Richland, Washington, USA. (Not consulted in the original.)

Bell, L. M. and J. M. Thompson. 1977. The Campbell River estuary; status of environmental knowledge to 1977. Fisheries and Environment Canada, Special Estuary Series 7: 346 p.

Brett, J. R., W. C. Clarke, and J. E. Shelbourn. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile chinook salmon, *Oncorhynchus tshawytscha*. Can. Tech. Rep. Fish. Aquat. Sci. 1127: 29 p.

Brownlee, M. J., E. R. Mattice, and C. D. Levings. 1984. The Campbell River Estuary: a report on the design, construction and preliminary follow-up study findings of intertidal marsh islands created for purposes of estuarine rehabilitation. Can. MS Rep. Fish. Aquat. Sci. 1789: 54 p.

Cramer, S. P. and B. P. McPherson. 1982. Rogue basin fisheries evaluation program. Annual report. Oregon Dept. Fish Wildl. Contract No. DACW57-77-0027 to U.S. Army Corps of Eng.: 74 p.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North Am. J. Fish. Manage. 5: 330-339.

Dept. of the Environment, Fish. Mar. Serv., Northern Operations Branch. 1976. The Whitehorse Rapids Hydroelectric Development and its relationship to upper Yukon River chinook salmon stocks-an historical review. Prepared for the Yukon Territorial Water Board. 8 p.

Ebel, W. J. and H. L. Raymond. 1976. Effect of atmospheric gas supersaturation on salmon and steelhead trout of the Snake and Columbia rivers. Mar. Fish. Rev. 1191: 14 p.

Effort, I. E. 1975. Foreward to the proceedings of a symposium of the Canadian conference on freshwater fisheries research in Ottawa, 1974. J. Fish. Res. Board Can. 32: 98-100.

Elson, M. S. 1985. A review of the Pitt River watershed. For New Project Unit, Salmonid Enhancement Program, Dept. of Fisheries and Oceans, 1090 West Pender St., Vancouver, B.C. 128 p.

Everest, F. H. 1973. Ecology and management of summer steelhead in the Rogue River. Oregon State Game Commission. Fish. Res. Rep. 7: 48 p.

Fisheries and Oceans. 1984. Toward a fish habitat decision on the Kemano Completion Project; a discussion paper. Dept. Fisheries and Oceans, 1090 West Pender Street, Vancouver, B.C. 79 p.

Fisheries and Oceans. 1985. Inventory of dams in the Fraser River basin. Dept. Fisheries and Oceans, 1090 West Pender Street, Vancouver, B.C. 4 volumes.

Fontaine, T. D. and S. M. Bartell (eds.). 1983. Dynamics of Lotic Ecosystems Ann Arbor Science. 494 p.

Fraser, F. J., E. A. Perry, and D. T. Lightly. 1983. Big Qualicum River salmon development project. Vol. 1: a biological assessment, 1959-1972. Can. Tech. Rep. Fish. Aquat. Sci. 1189: 198 p.

Frenette, M., M. Carson, P, Julien, and R. J. Gibson. 1984. Interaction entre le débit et les populations de tacons (Salmo salar) de la rivière Matamec, Québec. Can. J. Fish. Aquat. Sci. 41: 954-963.

Gislason, J. C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel patterns. North Am. J. Fish. Manage. 5: 39-46.

Gordon, R. N., R. A. Crouter, and J. S. Nelson. 1960. The fish facilities at the Whitehorse Rapids Power Development, Yukon Territory. Can. Fish. Cult. 27: 43-56.

Hamilton, R. and J. W. Buell. 1976. Effects of modified hydrology on Campbell River salmonids. Environment Canada, Fisheries and Marine Service, Technical Report Series PAC/T-76-20: 156 p.

Havey, K. A. 1974. Effects of regulated flows on standing crop of juvenile salmon and other fishes at Barrows Stream, Maine. Trans. Am. Fish. Soc. 103: 1-9.

Havey, K. A. and R. M. Davis. 1970. Factors influencing standing crop and survival of juvenile salmon at Barrows Stream, Maine. Trans. Am. Fish. Soc. 99: 297-311.

Hazel, C. 1976. Assessment of effects of altered stream flow characteristics on fish and wildlife. Part B: California. Final Report. U.S. Fish and Wildl. Serv. Biol. Serv. FWS/OBS-76/33. 48 p. Available from National Technical Information Service, 5285 Royal Road, Springfield, VA 22161, USA.

Hazel, C., S. Herrera, H. Rectenwald, and J. Ives. 1976. Assessment of effects of altered stream flow characteristics on fish and wildlife. Part B: California. Case studies. U.S. Fish and Wildl. Serv. Biol. Serv. FWS/OBS-76/34. 601 p. Available from National Technical Information Service, 5285 Port Royal Road, Springfiled, VA 22161, USA.

International Pacific Salmon Fisheries Commission (IPSFC). 1983. Potential effects of the Kemano Completion Project on Fraser River sockeye and pink salmon. P.O. Box 30, New Westminster, B.C., V3L 4X9. 5 p.

Jacobs, S. E., W. T. Noll, and J. D. Rodgers. 1984. Increase in growth of juvenile spring chinook salmon (*Oncorhychus tshawytscha*) rearing immediately below Lost Creek Dam on the Rogue River. Oregon Dept. Fish and Wildl. Information Report 84-6: 14 p.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1981. Influences of freshwater inflow on chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento - San Joaquin estuary. P. 88-108. *In*: R. D. Cross and D. L. Williams (Eds.) Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Vol. II. U.S. Dept. of the Interior, Washington, D.C., USA.

Kjelson, M. A., P. F. Raquel and F. W. Fisher. 1982. Life history of fall-run juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin Estuary, California. pp. 393-411 *in* V. S. Kennedy (ed.), Estuarine Comparisons. Academic Press, N.Y., USA.

Kraft, M. E. 1972. Effects of controlled flow reduction on a trout stream. J. Fish. Res. Board Can. 29: 1405-1411.

Lister, D. B. and C. E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho and chinook salmon in the Big Qualicum River. Can. Fish. Cult. 37: 3-21.

MacDonald, J. R. and R. A. Hyatt. 1973. Supersaturation of nitrogen in water during passage through hydroelectric turbines at Mactaquac Dam. J. Fish. Res. Board Can. 30: 1392-1394.

McMynn, R. G. and P. A. Larkin. 1953. The effects on fisheries of present and future water utilization in the Campbell River drainage area. British Columbia Game Commission, Management Publication 2: 61 p.

McPherson, B. P. and S. P. Cramer. 1982. Rogue basin fisheries evaluation program. Adult progress report. Oregon Dept. Fish. Wildl., Contract DACW57-77-C-0027 to U.S. Army corps. of Eng. 129 p.

Milner, N. J., J. Scullion, P. A. Carling, and D. T. Crisp. 1981. The effects of discharge on sediment dynamics and consequent effects on invertebrates and salmonids in upland rivers. pp 153-220 in Coaker, T. J. (ed). Advances in Applied Biology, VI. Academic Press, London, N.Y. 332 p.

Minaker, B. A., F. K. Sandercock, and L. I. Balmer. 1979. Big Qualicum River project 1974-1975. Can. MS Fish. Mar. Serv. 1528: 131 p.

Mundie, J. H. and R. Bell-Irving. 1986. Predictability of the consequences of the Kemano Hydroelectric Proposal for natural salmon populations. Canadian Water Resources Journal 11: 14-25.

Mundie, J. H. and D. E. Mounce. 1976. Effects of changes in discharge in the lower Campbell River on the transport of food organisms of juvenile salmon. Appendix A in Hamilton, R. and B. W. Buell op. cit.

Nelson, W., G. Horak, A. Hale, Z. Parkhurst, M. Lewis, D. Wagaman, E. Hoban, and J. Cott. 1976. Assessment of effects of altered stream flow characteristics on fish and wildlife. Part A: Rocky Mountains and Pacific Northwest. Pacific Northwest Region Case Studies. U.S. Fish and Wildl. Serv. Biol. Serv. FWS/OBS-76/81. 399 p. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, USA.

Nelson, W., G. Horak, M. Lewis, and J. Colt. 1976. Assessment of effects of altered stream flow characteristics on fish and wildlife. Part A: Rocky Mountains and Pacific Northwest. Final Report. U.S. Fish and Wildl. Serv. Biol. Serv. FSW/OBS-76/29. 120 p. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, USA.

Petts, G. E. 1984. Impounded Rivers: perspectives for ecological management. J. Wiley and Sons, N.Y., 326 p.

Rigler, F. H. 1982. The relation between fisheries management and limnology. Trans. Am. Fish. Soc. 111, 121-132.

Ruggles, C. P. and W. D. Watt. 1975. Ecological changes due to hydroelectric development on the Saint John River. J. Fish. Res. Board Can. 32: 161-170.

Sandercock, F. K. and B. A. Minaker. 1975. Big Qualicum River project 1973-1974. Can. Fish. Mar. Serv. Tech. Rep. Ser. PAC/T-75-16: 120 p.

Satterthwaite, T. D. 1982. The effects of Lost Creek Dam on juvenile chinook salmon (Oncorhynchus tshawytscha) in the Rogue River, Oregon, p. 122-130. In: T. J. Hassler (Ed.) Proceedings: Propagation, enhancement, and rehabilitation of anadromous salmonid populations and habitat symposium, Humboldt State University, Arcata, California.

Saunders, J. W. 1960. The effect of impoundment on the population and movement of Atlantic salmon in Ellerslie Brook, Prince Edward Island. J. Fish. Res. Board Can. 17: 453-473.

Slaney, F. F. and Company Ltd. 1973. Minimum flow requirements, Alouette River. For Fisheries and Marine Service, Southern Operations Branch, Dept. of the Environment, Vancouver, B.C., 51 p.

Smith, A. K. and B. P. McPherson. 1982. The effects of Lost Creek Dam on downstream temperatures of the Rogue River, Oregon, p. 113-140. In: T. J. Hassler (Ed.) Proceedings: Propagation, enhancement and rehabilitation of anadromous salmonid populations and habitat symposium, Humboldt State University, Arcata, California.

Smith, M. W. and J. W. Saunders. 1958. Movement of brook trout, Salvelinus fontinalis (Mitchell), between and within fresh and salt water. J. Fish. Res. Board Can. 15: 1403-1449.

Stalnaker, C. B. and J. L. Arnette. 1976. Methodologies for determining instream flows for fish and other aquatic life. pp 87-137 in Stalnaker, C. B. and J. L. Arnette (eds.) Methodologies for the determination of stream resource flow requirements: an assessment. U. S. Fish and Wildlife Service, Office of Biological Services, Western Water Allocation, Utah State University, Logan, Utah. 199 p.

Stevens, D. E. and L. W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento - San Joaquin River system. North Am. J. Fish. Manage. 3: 425-437.

Stober, Q. J., C. R. Steward, and F. Winchell. 1983. Tolt River fisheries and instream flow analysis. Final Report for City of Seattle, Dept. of Lighting, Office of the Environmental Affairs and Dept. of Water, Seattle, Washington. FRI-UW-8213. 352 p.

Ward, J. V. and J. A. Stanford. 1983(a). The serial discontinuity concept of lotic ecosystems. pp 29-42 in Fontaine, T. D. and S. M. Bartell (eds.) Dynamics of Lotic Ecosystems. Ann Arbor Science. 494 p.

Ward, J. V. and J. A. Stanford. 1983(b). The intermediate-disturbance hypothesis: an explanation for biotic diversity patterns in lotic ecosystems. pp 347-356 in Fontaine, T. D. and S. M. Bartell (eds.) Dynamics of Lotic Ecosystems. Ann Arbor Science. 494 p.

Woodin, R. M. 1984. Evaluation of salmon fry stranding induced by fluctuating hydroelectric discharge in the Skagit River, 1980-1983. Wash. Dept. Fish. Tech. Rep. 83: 38 p.

APPENDIX A

Case histories examined in the extensive overview[1].

A) Cases from Nelson, Horak, Hale et al. (1976).

**1. Wildhorse Dam (Duck Valley Irrigation Project), Idaho.
**2. Montpellier Creek Dam, Idaho.
**3. Dworshak Dam, Idaho.
**4. Hell's Canyon Dam, Idaho.
**5. Little Wood Dam, Idaho.
**6. Anderson Ranch Dam, Idaho.
**7. Lucky Peak Dam, Idaho.
**8. Cabinet Gorge Dam, Idaho.
9. Palisades Dam, Idaho.
**10. Fall Creek Dam, Oregon.
**11. Barker Timber Project, Oregon.
**12. North Unit Irrigation Dam, Oregon.
**13. Rudio Creek Diversion Dam, Oregon.
**14. Booher Diversion Dam, Oregon.
**15. Tokettee, Slide Creek and Soda Springs dams, Oregon.
**16. Blue River Dam, Oregon.
**17. Cottage Grove Dam, Oregon.
**18. Dexter Dam, Oregon.
**19. Dorena Dam, Oregon.
**20. Pelton Dam, Oregon.
**21. Clearwater No. 1 and No. 2 dams, Oregon.
**22. Lemola No. 1 and No. 2 dams, Oregon.
**23. Emigrant Dam (Rogue River Project), Oregon.
**24. Foster and Green Peter dams, Oregon.
**25. Riverside and Beulah dams, Oregon.
**26. Cougar Dam, Oregon.
27. Prineville Dam, Oregon.
28. Big Cliff Dam, Oregon.
29. Fish Creek Diversion Dam, Oregon.
30. Scoggin and Oregon Iron and Steel Co. dams, Oregon.
31. Middle Fork Project, Oregon.
32. Laurance Lake, Oregon.
**33. Skookumchuck Dam, Washington.
**34. Wynooche Dam/Aberdeen Diversion, Washington.
**35. Merwin Dam, Washington.
**36. Prosser Dam, Washington.
37. Howard Hanson Dam, Washington.
38. Gorge Dam, Washington.

B) Cases from Hazel et al. (1976).

**39. Whale Rock Reservoir, California.
40. Thelma Adair Keyes Reservoir, California.
**41. Friant Dam, California.
**42. Casitas Dam, California.
**43. Black Butte Reservoir, California.
* 44. Salt Springs Reservoir, California.
**45. Spicer Meadows Reservoir, California.
**46. Lower Lagunitas Project, California.
**47. Scott Dam, California.
**48. Goodwin - New Melones Project, California.
**49. New Don Pedro - Le Grange Project, California.
50. Sand Bar Diversion, California.
**51. Santa Felicia Dam, California.
**52. San Pedro Creek, California.
**53. Lake Sabrina, California.
**54. Nacimiento Dam, California.
**55. Lake Henshaw, California.
56. Big Bear Lake, California.
**57. Isabella Project, California.
**58. Rock Creek Diversion Dam, California.
**59. Bridgeport Dam, California.
60. Oroville Dam, California.
**61. French Meadows Reservoir, California.
**62. Pine Flat Dam, California.
**63. Antelope Valley Dam, California.
**64. Loon Lake Dam, and Gerle Creek, California.
**65. Lake Tahoe Dam, California.
66. Coyote Dam, California.
**67. Folsom - Nimbus dams, California.
**68. Cape Horn Dam, California.
**69. Crocker Huffman - Exchequer Projects, California.
**70. Trinity - Lewiston dams, California.
**71. Nicasio Lake, California.
72. Iron Gate Dam, California.
73. Shasta - Keswick dams, California.
74. Pit No. 6 and No. 7 Reservoirs, California.
75. Pleasant Valley Dam, California.

C) Cases from intensive review (see Section 2.2 for references).

**76. Big Qualicum River Project, B.C., Canada
**77. Lost Creek Dam, Oregon.
**78. John Hart Dam, Campbell River, B.C., Canada.

D) Cases from miscellaneous sources.

**79. South Alouette River, B.C., Canada (Elson 1985; Slaney 1973; Fisheries and Oceans 1985).
**80. Whitehorse Rapids Power Development, Yukon Territory, Canada (Department of the Environment 1976; Gordon, Crouter and Nelson 1960).
**81. Tolt Dam, South Fork Tolt River, Washington (Stober, Steward and Wynchell 1983).

Notes:

Some case histories from the source material were excluded as they did not involve salmonids, did not have naturally reproducing salmonids in the pre-project period, or their outcome for salmonids was primarily the result of factors other than flow control.

** Case histories used in Table 2 (i.e., those whose outcome for salmonids was known).

APPENDIX B

Case histories applicable to Kemano Completion.

Case history	Nechako River	Nanika/Bulkley System	Kemano River
Improved natural salmonid stocks			
Wildhorse Dam			x
Montpellier Creek Dam			x
Folsom-Nimbus dams	x		
Big Qualicum Project	x	x	
Unchanged natural salmonid stocks			
*Toketee, Slide Creek and Soda Springs Diversions	x	x	
John Hart Dam	x	x	x
Loon Lake Dam			x
Decreased natural salmonid stocks			
Clearwater No. 1 and No. 2 Diversion dams	x	x	
Lemolo No. 1 and No. 2 Diversion dams	x	x	
Cottage Grove Dam	x	x	
Cougar Dam	x	x	
Emigrant Dam	x	x	
Riverside and Beulah dams	x	x	
Pelton Dam	x	x	
*Hell's Canyon Dam	x	x	
Little Wood Dam	x	x	
*Salt Springs Reservoir	x		
*Spicer Meadows Reservoir	x		
Scott Dam	x	x	
Cape Horn Dam	x	x	
San Pedro Valley	x		
Nacimiento Dam	x		x
Pine Flat Dam	x	x	
Isabella Dam	x	x	
Friant Dam	x	x	
Goodwin, Tullock, Melones dams	x	x	x
New Don Pedro-Le Grange dams	x	x	
Lake Henshaw	x	x	
Trinity-Lewiston dams	x	x	
South Alouette River Dam	x	x	
Tolt Dam	x	x	
*Foster and Green Peter dams	x		x
Merwin Dam	x		x
Anderson Ranch Dam	x		x
Lucky Peak Dam	x		x
Cabinet Gorge Dam	x		x
*Dexter Dam	x	x	

APPENDIX B (cont'd)

Case history	Nechako River	Nanika/Bulkley System	Kemano River
*Dorena Dam	x	x	
Lost Creek Dam	x	x	
*Prosser Diversion Dam	x		
Outcomes for natural stocks unknown			
*Big Cliff Dam			x
*Iron Gate Dam	x	x	
*Shasta-Keswick dams	x		
*Pleasant Valley Dam	x		x
*Middle Fork Project	x	x	
*Laurance Lake	x		x
*Gorge Dam	x		x
*Pit No. 6 and No. 7 Reservoirs	x		x
*Coyote dam	x		

Notes:

Case histories were considered applicable to Kemano Completion if they had effects that could possibly occur in Kemano Completion rivers.

Asterisked (*) case histories were excluded from Table 8 (Section 3.3) because their outcomes were caused by effects not applicable under Kemano Completion (e.g. blockage or inundation of habitat, no major change in post-project flows), or because the outcomes for salmonid stocks were unknown.