

The Effect of Abstraction on Fish and Fisheries



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Contents

	Page
Summary	1
I. Introduction.	2
2. Life Stages Potentially at Risk.	2
2.1 Egg and Emergent Fry or Alevin Stage.	2
2.2 Fry (0+) and Parr(\geq1+).	3
2.2a Predation	3
2.2b Food Supply	4
2.2c Habitat	4
2.2d Temperature	5
2.2e Stranding	5
2.2f Relationship between salmonid abundance and flow	5
2.3 Smolt	6
2.4 Adult	7
2.4a Migration	7
2.4b Fisheries	8
2.4c. Spawning requirements	8
3. Minimum Acceptable Flows (MAF)	9
3.1 Long term studies	9
3.2 Habitat models	10
3.3 Behaviour studies	10
3.4 Catch data	10
4. References	11

Summary

Water is abstracted from rivers for a wide variety of uses including industry, agriculture and potable water supply. Abstraction of water can cause flow reductions, entrainment at water intake screens and for efficient water supply the construction of impoundments, only the potential impact of reduced flows has been considered.

The potential for conflict between abstracters and fisheries and conservation interests is most serious during natural low flow periods when offstream needs, especially those of agriculture, are greatest and instream flows are at their lowest.

For salmonids the effect of flow reduction has the potential to impact at various stages through out their life history. The egg stage is vulnerable to dewatering and in gravel of poor permeability to deoxygenation. At the time of alevin emergence in the spring when initial territories are being established, flow has been found to be important possibly by increasing the amount of suitable habitat and a decreasing the area defended by an individual. During the juvenile freshwater phase a reduction in flow can lead to a reduction in the food supply, cover, predation and a possible increase in exposure to high temperatures, susceptibility to pollutants and to becoming stranded. Certainly studies have reported increases in mortality, and decreases in growth rate and production under conditions of extreme low flows.

The flow at the time of smolt migration has been found to be positively correlated with the number of returning adults. It is postulated that high discharge at the time of smolt migration increases survival by reducing both inter and intra-specific competition, vulnerability to predation and by aiding orientation and thus reducing straying.

For the adults flow is considered to be one of the most important environmental factors inducing salmonids to enter fresh water and ascend rivers. On rivers with highly variable flow regimes salmon have a preference to migrate at the higher flows, while on rivers with more stable flows this was not reported to be the case. Similarly salmon fishing success is strongly influenced by flow condition.

The importance of time series data on fish stocks and angling success together with models which ultimately relate discharge to standing stock are discussed in relation to the setting up of Minimum Acceptable Flows.

The Effect of Abstraction on Fish and Fisheries.

I. Introduction.

Water is required for a wide variety of uses including industry, agriculture and potable water supply. The average daily requirement for England and Wales is 59,200 Ml/d (NRA, 1993a), Public Water Supply accounts for 17,500 Ml/d of this total, while Industry uses 5,500 Ml/d, Agriculture (including spray irrigation) 500 Ml/d, and the Electricity Supply Industry 30,350 Ml/d. This demand for water is met from three main sources; surface water abstractions (32,400 Ml/d), ground water sources (6,900 Ml/d) and from tidal waters (19,900 Ml/d). Over the last decade the overall volume abstracted from surface and ground water sources has remained relatively stable. However since 1981 the amount of water required by the public water supply in England and Wales has increased by 9% from 15,800 Ml/d to nearly 17,200 Ml/d in 1991. About 72% of the water placed into the public water supply is unmetered and of this proportion approximately a third is "not delivered" as a result of leakage from water company distribution mains and customer supply pipes.

The abstraction of water can lead to 1) flow reductions and 2) entrainment at water intake screens, only the potential impact of the former will be considered in this review. The latter has been the subject of an NRA Research and Development project the results of which have been reported by Solomon (1992). In addition, effective water supply can also mean formation of impoundment structures, the impact of such structures on fish and fisheries has been reviewed by Brooker (1981). The potential for conflict between abstracters and fisheries and conservation interests is most serious during natural low flow periods when offstream needs, especially those of agriculture are greatest, and instream flows are at their lowest. The level of impact depends on a number of factors; 1) the amount 2) the rate 3) for how long and 4) when the water is abstracted.

In general a reduction in discharge will result in a reduction in habitat for all species and to an increase in vulnerability to pollution and predation. However as pointed out by Mills (1991) it is usually the salmonid rivers which are selected for abstraction as they originate in areas of high rainfall and are of the required purity as such it is the salmonids which are most vulnerable to any deleterious effects of water abstraction.

2. Life Stages Potentially at Risk.

2.1 Egg and Emergent Fry or Alevin Stage.

Low flow conditions during the winter can result in dewatering of redds (Frost and Brown, 1967; Harris, 1978; Becker and Neitzel,

1985), or to a reduction in the supply of oxygenated water, especially in gravel of poor permeability (Wickett, 1958). A reduction in flow may also result in increased exposure to lower temperatures which may lead to an increase in mortality when temperatures fall below 4°C (Peterson et al. 1977).

For *Salmo salar* Gibson and Myers (1988) reported significant positive relationships between winter discharge (mean February discharge) and survival of 0+ salmon, for five of the six rivers studied. The importance of river discharge and water temperature to egg to fry survival was also observed by Chadwick (1982) who found low survival during cold winters with low water discharge; high egg mortalities resulting from freezing of redds during periods of low flows. A direct relationship was similarly detected by Wickett (1958), for chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*), between discharge during the incubation period (October - November) and the subsequent size of the adult population.

Certain stages may, however, be able to withstand brief periods of dewatering. Becker et al. (1982) found that "eyed" eggs of chinook salmon (*O. tshawytscha*), under laboratory conditions, suffered a 20% mortality after dewatering for 12 days. However, yolk-sac alevins suffered approximately 50% mortality as a result of a four hour daily dewatering over a 20 day period, and nearly all the pre-emergent alevins were killed by one daily dewatering. Sequential daily dewaterings may not reflect the actual situation though they do provide information on the comparative vulnerability of these developmental stages.

Though in general, flow conditions are not considered to be limiting during the winter months, critical conditions for survival of the eggs and alevins may arise where there is considerable winter abstraction or in frost bound catchments.

Reduced flow during the spring, at the time of alevin emergence, has been found to be related to low population densities, for salmonids. Frenette et al. (1984) reported a significant positive correlation for Atlantic salmon (*Salmo salar*), between 2+ and 1+ parr densities and the minimum spring flow two years ($r^2 = 0.72$) and one year ($r^2 = 0.77$) previously.

2.2 Fry (0+) and Parr(>1+).

There are a number of ways in which reduced flow could affect a salmonid population.

2.2a Predation

Salmonids during their first year of life are generally distributed in water less than 25cm in depth (Kennedy and Strange, 1982; Bagliniere and Arribe-Moutounet, 1985). A reduction in water flow or level may result in the loss of these rearing areas and as a consequence, induce behavioural changes in

the O+ fry. Certainly Cambell and Scott (1984) reported for O+ trout (*S.trutta*) that a decline in velocity below 0.3ms^{-1} resulted in a movement off the "riffles" and into the "pools", and the adoption of shoaling behaviour. Similar findings were reported by Kalleberg (1958) for *S.salar*, under experimental conditions. This change in habitat and behaviour may lead to increased vulnerability from predation, both from larger fish already present in the pools (Symonds and Heland, 1978) as well as from terrestrial sources (Ermen and Leidy, 1975; Larimore et al. 1959). Shoals may be subject to greater predation when compared with territorially dispersed individuals in "riffles", especially if the fish are under stress.

2.2b Food Supply

The juvenile stages of both *S.salar* and *S.trutta* feed on invertebrates, a proportion of which are derived from the drift (Frost and Brown, 1967; Maitland, 1965; Wankowski and Thorpe, 1978). As a large portion of the food supply originates on "riffles" its production will be under the control of at least two factors related to flow; namely water velocity and the amount of wetted area (Fraser, 1975). The fact that these stages feed on invertebrates, and if a direct relationship does exist between drift rate and flow (Elliott, 1970) or velocity (Wankowski and Thorpe, 1979), then a decline in flow/velocity will result in a decline in the food supply.

2.2c Habitat

Milner (1982) considered cover, principally as overhead bank cover and instream rubble-boulder areas, as possibly the single most important site attribute determining salmonid abundance. A number of studies have shown the benefits of cover for trout (Boreman, 1974; Boussu, 1954; Hunt, 1969 and 1976; Saunders and Smith, 1962; White, 1975). Swales and O'Hara (1980) mention a number of functions which cover provide, notably concealment, spawning substrate, food source, reduction in temperature and possible territories. The effectiveness of cover in providing these functions will depend on the flow regime.

Under conditions of low flow when there will be a reduction in cover (Kraft, 1972) the population may be subject to an increase in predation and temperature and to a decrease in the food supply. Certainly Lewis (1969) found a direct relationship between the number of adult *S.trutta* in "pools" and the amount of cover available as well as to the current velocity. Cover was the most important variable with velocity significantly increasing the proportion of the total variation in adult *S.trutta* numbers explained by these two variables.

Substrate and flow changes may also effect salmonid abundance through their influence on the number and size of territories, reviewed by Milner et al. (1981). Certainly Solomon and Paterson (1980) postulated that flow was important at the time when

initial territories were being established, in that increased flows resulted in a possible increase in suitable habitat and a decrease in the area defended by an individual. This was supported by Symons and Heland (1978), who reported that the highest densities of 0+ and $\geq 1+$ *S.salar* occurred at velocities between 0.5-0.65ms⁻¹. Slightly wider optima velocities were observed by Scruton and Gibson (1993) of between 0.2-0.6 ms⁻¹.

2.2d Temperature

Elevated water temperatures resulting from reduced flows during the summer months could have a deleterious effect on salmonid populations by reducing survival (Cowx et al., 1984), growth rate (Elliott, 1993; Rimmer, 1985) and possibly also by increasing their susceptibility to pollutants (Alabaster and Lloyd, 1984).

For *S.salar* and *S.trutta* feeding ceases once the temperature has reached 21.6-22.5°C and 19°C, respectively and these species begin to experience thermal stress at 25-28°C and 22-25°C, respectively (Elliott, 1991 and 1981).

In certain areas, low temperatures may also prove lethal with fish freezing to death or dying from oxygen starvation as suggested by Hvidsten (1993).

2.2e Stranding

Rapid changes in water level may result in fish becoming stranded, certainly Hvidsten (1985) observed heavy losses of 0+ *S.salar* in the River Nidelva where levels could fall by 80-90cm in 10 minutes.

2.2f Relationship between salmonid abundance and flow

Though it is evident that these life stages can, theoretically, be vulnerable to a reduction in water flow; a number of authors have demonstrated a relationship between flow and salmonid abundance.

Solomon and Paterson (1980) found that the 0+ population of *S.trutta* in October was directly correlated with the previous April's mean discharge. Similarly for *S.salar* Frenette et al. (1984) reported a significant positive correlation between the 2+ parr density and the mean August discharge two years previous ($r^2 = 0.76$). However, in contrast, the 1+ parr density showed a significant inverse relationship with the mean July discharge one year before ($r^2 = 0.81$), the significance of which is not understood.

The importance of summer (July - August) flow as indicated by rainfall to the survival of *S.salar* from age 0+ to 1+ has been demonstrated by Havey and Davis (1970); a 10cm increase in total July August rainfall increased survival by approximately 17%. However, in the study by Gibson and Myers (1988) summer discharge

(mean July - August discharge) positively enhanced survival of 0+ *S.salar* in only two of the six rivers studied, for the remainder no significant relationship existed.

For *S.salar* smolt production was directly correlated with the level of winter discharge (mean daily discharge, January through March) two and three years prior to emigration ($r^2 = 0.66$), the main age at migration was three and four years (Hvidsten, 1993). Enhanced smolt production at elevated flows may have arisen as a result of a reduction in stranding and in exposure to lethal temperatures.

The importance of flow during the salmon's total residency period in fresh water has been demonstrated by Scarnecchia (1981). Scarnecchia examined the relationship between the catch of coho salmon (*Oncorhynchus kisutch*) by the off-shore troll fishery and stream flow and found a significant relationship between total stream flow for the 19 month period from the time of upstream migration of the adults (November) to the migration of their progeny as smolts (May) and the catch one and two years later ($r^2 = 0.46$ and 0.31 respectively). However no significant relationship existed between low summer stream flow (sum of the mean daily flows for the 60 consecutive days of lowest flows) and catch two years later.

Drought conditions may also provide some information on the possible effects of reduced discharge on fish populations. However, in the long-term studies of Egglisshaw and Shackley (1982) and Elliott (1984) there is no evidence of a decline in *S.salar* and *S.trutta* densities associated with the "droughts" of 1976 and 1983. This may arise because of variation in the quantity of eggs deposited and to the density dependent stock recruitment relationship.

In Elliott (1993) a summary of 25 years (1966-1990) data on the population dynamics of *S.trutta* are presented, during that period there were five years (1969, 1976, 1983, 1984 and 1989) when no rain fell for a 3-4 week period during the months June - August. The effect of the "summer drought" in particular that of 1976, 1983 and 1984 was an increase in loss-rate. A reduction in the growth rate of the 0+ year-class and, as a consequence, a decline in the annual rate of production, in particular for the 1983 and 1984 year-classes. However, only one year-class (1983) showed any long term impact. The number of eggs produced by the surviving progeny were substantially lower than that predicted from the initial egg density and was probably due to the fact that the 1983 year-class was the only one of the 21 to experience two consecutive "summer droughts".

2.3 Smolt

The Salmon Advisory Committee (1993) mention that smolt survival is particularly dependent upon the time they enter the sea and that in certain rivers a delay in smolt migration as a result of

low flow conditions has resulted in reduced returns of adult *S.salar*.

Fraser (1975) cited unpublished data of Fry and Menchen who found a significant positive correlation for *O.tshawytscha*, between the discharge during the period of their downstream seaward migration and the number of returning adults two and three years later. Similar findings were also reported by California Fish and Game Department (1976) (cited by Stevens and Miller, 1983).

Fraser (1975) suggested that high discharge at the time of downstream migration may be favourable to the survival of smolts by providing more living space, thus reducing both inter and intra-specific competition, reducing vulnerability to predation, decreasing losses through entrainment and possibly by aiding orientation and thus reduce straying. This latter point was also highlighted by the Salmon Advisory Committee (1993) for smolts requiring to migrate through impounded areas, their ability to locate the exit being impaired when the current velocity is very low. This may lead to an increase in mortality from a loss of their osmotic capability (Koch et al. 1959) and from predation (Mills, 1991), depending on how long the fish have been delayed.

2.4 Adult

2.4a Migration

Flow has been considered as possibly one of the most important environmental factors inducing salmonids to enter fresh water and ascend rivers, see review by Banks (1969). Certainly the study of Frake and Solomon (1990) indicates that the tendency for adult *S.salar* to remain in the lower reaches of the River Avon is discharge dependent, being more prevalent under low flow conditions. Similar findings have been reported by Smith (1991) and Clarke et al. (1991), in addition the latter also reported a higher level of exploitation under low flow conditions.

Alabaster (1970) showed that the median flows at which *S.salar* and migratory *S.trutta* were trapped on the River Coquet were higher than the median flow available. Similar findings were reported by Cragg-Hine (1984) for salmonids greater than 50cm in length, from the River Lune. In contrast on the River Frome Hellawell et al. (1974) showed that the median flow at which salmonids migrated upstream was lower than the median flow available. This difference is probably attributable to the different flow regimes in the various rivers, the Coquet and Lune having relatively large fluctuations in flow compared with the Frome (Hellawell et al. 1974).

The fact that the flow utilized by salmonids was not constant between years or throughout the same year (Alabaster, 1970; Cragg-Hine, 1984; Hellawell et al. 1974; Smith, 1991) suggests that discharge may act in a secondary capacity modifying the overall pattern of movement. Certainly Alabaster (1970) found

that the median flow utilized, followed the available flow fairly closely. From this it was suggested that, in spate rivers, upstream movement is triggered by natural freshets irrespective of the previous flow rate.

Higher temperatures generally associated with reduced flows may act to retard upstream movement, Brayshaw (1966) concluded that temperature became limiting at approximately 16°C, a similar upstream limit was reported by Gee (1980). In addition reduced flow may cause excessive macrophyte growth, which may have a deleterious effect on salmonid populations. Brooker et al. (1978) found a significant inverse relationship between the biomass of *Ranunculus* spp. and flow during April through June ($r^2 = 0.76$) the natural die-back of which can produce conditions of low dissolved oxygen and result in considerable mortalities of adult *S.salar* (Brooker et al. 1977).

Elevated flows in the autumn/winter flows are important for the full utilization of the head water nursery areas. Such flows result in the eggs being deposited over a wider area and the ensuing smolt production tends towards the upper limit for the system (Hay, 1989).

2.4b Fisheries

For *S.salar* flow has also been suggested as one of the main factors affecting rod catch (Alabaster, 1970; Bunt, 1991; Clarke et al., 1991; Gee, 1980; Jones, 1968; Millichamp & Lambert, 1966; Potts & Malloch, 1991; Stewart, 1968), together with effort (Mills et al. 1986).

Quantification of the effect of abstraction on the catch of *S.salar* has been attempted by Gudjonsson (1965) (cited by Mills, 1991), who estimated an average annual loss of 61.5% of the predicted average catch. This loss was considered attributable to an impairment of living conditions, entrainment of young salmon and the sudden drying-out of the river channel during periods of snow and frost.

2.4c. Spawning requirements

A reduction in water velocity at the time of spawning may result in cessation of the process. Jones and King (1950) observed for *S.salar* that spawning ceased once velocities had fallen to 0.05 - 0.08ms⁻¹, which is lower than that reported by Crisp and Carling (1989) of between 0.15-0.20ms⁻¹ for salmonids in general.

Optima surface velocities for spawning were reported by Jones and King (1950) of between 0.3-0.4ms⁻¹, which is slightly lower than that observed by Beland et al. (1982) of 0.53ms⁻¹.

3. Minimum Acceptable Flows (MAF)

Gustard et al. (1987) concluded from their review of compensation flows below impounding reservoirs that the impact on the downstream aquatic ecology had not generally been considered when such flows were being set, the main determinants being industrial and political considerations. Since the Water Resources Act (1963) and more recently under the 1991 Water Resources Act the opportunity has been available to make recommendations on the setting of MAF. For fish and fisheries there are ~~likely to be~~ a ^{could} suite of different flows; a survival flow, one that safeguards migration and a third which is optimum for the fishery.

Suggestions as to what flow is required to safeguard the resource have been made by Baxter (1961), Collings (1974), Cochnauer (1976), Drake and Sheriff (1987), Fraser (1979), Swank and Phillips (1976), Tennant (1976) and Tessmann (1980) (cited by Stalnaker, 1980) and have certain limitations as they are generally based on theoretical considerations and professional judgement rather than on statistical proof. As such these guidelines should be restricted to the initial planning stages.

However in recent years a more scientific approach has been taken when prescribing minimum acceptable flows to safe guard fisheries interests. On the River Lune, analysis of fish counter data was instrumental in the setting of the present abstraction regime (Cragg-Hine, 1989).

In order for fisheries interests to be evaluated in relation to other water resource demands, it is essential that the requirements of both fish and fisheries are based on defensible scientific principals. Such data can be obtained from a variety of sources.

3.1 Long term studies

There is the in depth, long term study as exemplified by Elliott (1993). Though with additional information on flow it might have been possible to model any relationship between loss rate or growth rate and discharge. If achievable, then the possibility of quantifying the consequences of flow reduction exists. It would then be feasible to calculate the economic value of such a loss, in a similar manner to that presently adopted for fish kills (NRA, 1993b).

and compared with economic benefits of the fishery water.

Such detailed studies are required so that the effect of reduced flow can be clearly identified and separated from the other processes regulating the population. However the results from such studies may be extremely site specific and the findings might not be universally applicable. In addition if such an approach were to be adopted then ideally the studies should take place in those areas where water resources are regarded as exploitable, but this will require considerable foresight.

3.2 Habitat models

In the United States the most widely used approach for determining flow requirements for fish is the Instream Flow Incremental Methodology (IFIM), and is presently being evaluated as a NRA R & D project Johnson *et al.* (1992). It has the advantage that the scientific rationale behind the methodology has been successfully defended against legal challenges in the United States (Johnson *et al.* 1992).

The IFIM concept basically assumes that aquatic species have preferred habitat preferences and these can be described in terms of flow, water depth and substrate or cover. From these measurements and information on a species preference for each of these variables the amount of usable habitat is computed for a range of discharges. It is then possible to predict changes in the amount of usable habitat, which may or may not relate to changes in standing stock, as other factors may be limiting the population. An economic value calculated in a similar manner to that proposed by Kennedy (1985) can be determined and any change in monetary value can be quantified and evaluated against other water users.

IFIM is based on the microhabitat preference of individuals and is generally site specific requiring a high degree of precision and accuracy. However for the initial planning stage, habitat suitability indices based on macrohabitat features may prove satisfactory when evaluating the potential impact of a water resource development scheme (Scruton and Gibson, 1993).

Regression models have also been developed relating salmonid abundance to a number of habitat variables (Binns and Eiserman, 1979; Milner *et al.* 1982). These studies have found significant correlations between salmonid abundance and a combination of site attributes, including water velocity. The habitat model, HABSCORE, presently being developed by NRA/WRC could be used to assess the impact of reduced flows on juvenile salmonid populations, if water velocity or flow could be incorporated into the model.

3.3 Behaviour studies

Guide-lines on flow requirements to safeguard the migration of salmonids through the estuary and up river can be developed from fish counter studies (Cragg-Hine, 1989) and potentially from tracking studies (Frake and Solomon, 1990). A predictive capacity has yet to be developed, but for fish counter data an approach similar to that described for fishery catch data (outlined below) could be employed.

3.4 Catch data

Analysis of the influence of flow on the performance of a fishery is by definition dependent on catch data. In those instances

where daily catch or preferably daily catch per unit effort data are available, it is possible to determine catch per flow day (Millichamp and Lambert, 1966). Ideally such analysis should be carried out on a monthly basis in order to take into account the seasonality of the run and any change in the catch flow relationship. As such data from a number of years will generally be required to provide a large enough data set and adequately cover the range of flows experienced by a fishery. Combining data leads to possibilities of bias in favour of those years when fish were more abundant, such bias can be reduced by standardizing the daily catch data, for on most river systems there are no estimates of the size of the population available for capture.

An ability to model the relationship between daily catch and flow, at least for flows up to the optimum for the fishery (flows in excess of the optimum can be made available to offstream users without any detrimental effect to the fishery) does allow the potential impact of reducing flows on the performance of the fishery to be determined on a daily basis (Aprahamian and Ball, in prep). This can then be translated into monetary terms by assuming a value (Milner, 1993) for a rod caught fish.

In conclusion, it is considered vital that if Fisheries are to compete effectively, with other water users, for the resource, then the value of flow must be presented in monetary terms.

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