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MINIMUM FLOW REQUIREMENT FOR FISH POPULATION AFFECTED BY DAM CONSTRUCTION IN TEMPERATE AREAS

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ABSTRACT

Dam construction on rivers and streams provide desired benefits such as freshwater, hydroelectric power, and fish. Dam-related operation includes flow augmentation procedures such as flow regulation, flood releases or fluctuating flow releases, all of which have a detrimental impact on the downstream aquatic habitat like benthic macroinvertebrate zooplankton, phytoplankton and fish. In order to avoid negative impacts, a minimum flow release downstream of the dam is recommended. Minimum flow is the planned release of small amounts of water for ecological sustenance. During summer, the river to the downstream of the dam becomes dry which is detrimental from the fishery point of view, as the migration of the fishes is disrupted. Fishes are accustomed to live in flowing river conditions, with their life cycle stages requiring the following factors: low silt content, well-oxygenated intra-gravel flows and minimum current, depth, velocity of water, dissolved oxygen. These factors are altered due to dam construction and restricted release of downstream flow. Fishes that feed on the invertebrate organisms like benthos and zooplankton are also affected by dam-manipulated flow. In order to maintain the aquatic habitat downstream of the dam, authorities recommend minimum flow according to the habitat. The significance of minimum flow is that it is needed to keep the streambed wet to an acceptable depth to support fish populations. This paper describes how minimum flow in the river, downstream of a dam, is the main requirement in the life cycle of fish with respect to feeding habit and reproduction. The paper also gives examples of various dam-related recommended flows with respect to the life cycle of the fish.
Keywords: fish, life cycle, minimum flow.

1 INTRODUCTION

Large dam projects will continue to be launched as a central means to realize large-scale irrigated agriculture, industrialization and over all socio-economic development. In spite of these positive impacts, dams also have some negative impacts. They cause fundamental changes in ecosystem function as naturally free-flowing and continuous river courses are transformed into river segments interrupted by impoundments. The effect of impoundments includes a series of changes in the physical condition downstream of the dam. Due to this altered condition, aquatic fauna is seriously affected. An assessment of environmental flow is required to maintain the downstream riverine ecosystem. It is an assessment of the original flow regime of a river that should continue to flow downstream of the dam in order to rehabilitate the river ecosystem.

Limited studies were made for other components of the aquatic ecosystem such as benthic macroinvertebrates. This group of biota consists of various life stages of aquatic insects, worms, and other organisms that live along the bottom of rivers, and includes species such as mayfly and caddisfly larvae. Benthic macroinvertebrates are important food resources for fish. Because they are much more immobile than fish and cannot easily leave an area that is in the process of being dewatered; they are the most likely to be affected among all ecosystem components by periodic decreases in the depth and velocity of water in the rivers [1]. A proper habitat has to be maintained for spawning, recruitment, and maturation of fish stocks. Provisions for passage of fishes during certain phases of their life cycles depend on longitudinal movements along the stream continuum.

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Along the stream continuum, dams and their associated upstream reservoirs have downstream effects on riverine environments and, subsequently, diverse influences on downstream fisheries even beyond the lotic ecosystem. Cumulative effects of dams in catchment basins and tributary streams can significantly block nutrient flow throughout the ecosystem, affecting fisheries production in downstream reservoirs [2], river channels [3], and estuary and marine environments [4]. These downstream impacts and its harmful effects on the fish population are presented in Fig. 1. Ultimately, the significance of minimum flow is that it is needed to keep streambeds wet to an acceptable depth to support fish populations.

2 RIVER REGULATION

Large-scale river regulation was known nearly 5,000 years ago, along the Nile, the Tigris, Euphrates, and the Indus River. The first dam was built at Sadd el Kafara in 2759 BC [5]; yet another marvel of the early 1800s is the Erie Canal [6].

From 1980, in USA, excluding Alaska, only 51 rivers over 100 km in length remain free flowing from headwater to major confluence [7]. Based on the Nationwide Rivers Inventory completed in 1982, only 42 high-quality, free-flowing rivers greater than 200 km in length remain in the 48 neighboring states [8].

In India there are about 1,600 major dams, although they are unevenly distributed in different states [9]. Presently, efforts are on by the Water Quality Assessment Authority to determine the minimum flow requirement of the Indian rivers. This is the resolution which was arrived at in Delhi jointly by the National Institute of Ecology and the International Water Management Institute. Objectives were set in order to achieve the sustainable development of water resources through Water Resources Vision 2045, which was developed by the Department of Water Resources, Government of Rajasthan.

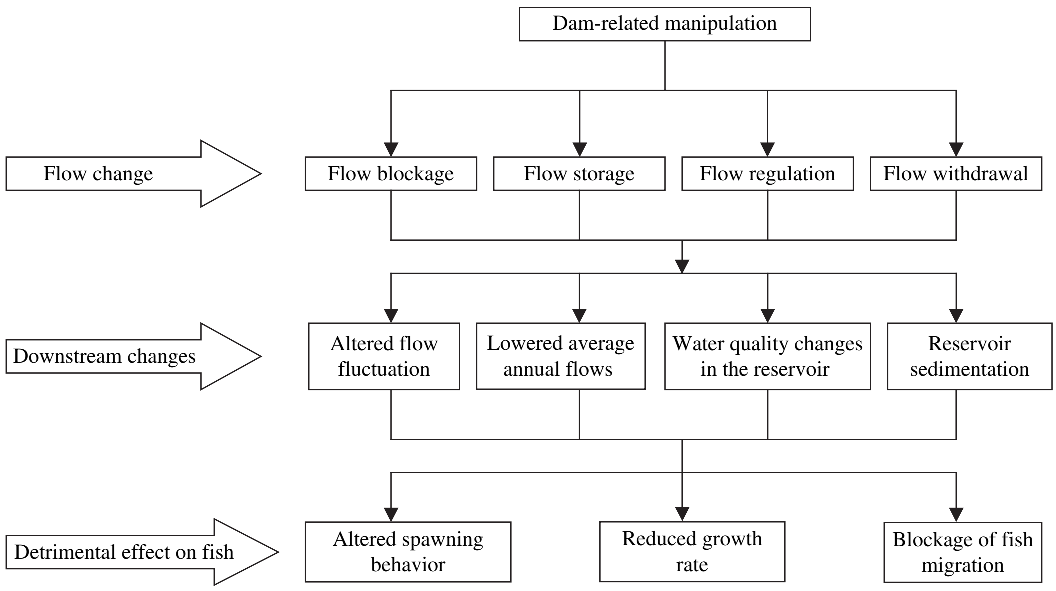

Figure 1: Effect of dam-related manipulation and its downstream impacts, which directly influence the fish population.

Under project planning, preparation and implementation of future projects, an additional concept of minimum flow to the downstream of the storage project was also put forward.

The Allain–Duhangan Hydroelectric Project (ADHEP) in Manali, in District Kulu, Himachal Pradesh, India, has been contemplated as a run-of-the-river scheme to utilize the combined discharge of the Allain and Duhangan streams. A detailed study was carried out to determine the impacts of the project on fish population and appropriate mitigation measures were identified. The study is for the proposed ADHEP which is honeycombed by the perennial Beas River and other streams joining it with considerable water flow. The district was already engaged in pisciculture activities. The total fish production in the district is 177 tons/annum. According to the fish-monitoring plan, the most effective mitigation measure for the impact on aquatic ecology is to ensure minimum ecological flow to the downstream. This ecological flow may be designed based on the habitats of the most valued aquatic species of the river. Based on minimum flows contributed by the other channels' post diversion structures on Allain and Duhangan, water required for ecological sustenance, minimum flows have been recommended downstream of the diversion structures on Allain, which has been found to be 0.226 m^3/s in the month of February during the driest period of 1973–74. It is recommended that a minimum flow of 0.150 m^3/s be maintained downstream of the Allain barrage at all times. Similarly, the minimum flow contributed by the other channels' post diversion structures on Duhangan has been found to be 0.360 m^3/s downstream of the Duhangan weir structure at all times [10].

3 AQUATIC FAUNA AND DAM

Fishes generally feed on invertebrates and benthic macroinvertebrates. It is equally important to include both these groups in flow studies because their abundance is directly proportional to the abundance of the fish.

3.1 Benthic macroinvertebrates

Benthic macroinvertebrates play a central role in riverine trophic structures. They are important processors and consumers of material inputs to the river system and are, in turn, an important source of food for many river fishes. Benthic macroinvertebrates have particular characteristics that make them ideal subjects for flow effects, including their limited mobility. The most important characteristic, however, is that many benthic macroinvertebrates are sensitive to and can be impacted by changes in flow regimes. Reduced flows and dewatering of substrates can result in stranding and desiccation and, in winter, freezing. Additionally, many species that are not exposed to air can be adversely affected by reduced flows and water velocity. Several macroinvertebrate species are of great value as food items for important fish species such as white and yellow perch and channel catfish, which spin webs that allow them to breathe and capture food particles. Reductions in flow decrease the volume of water passing through these 'nets' and thus reduce their efficiency for providing oxygen and sustenance to the organism [1].

3.2 Invertebrates

Invertebrates inhabiting flowing water are adapted morphologically, behaviorally, and physiologically to their environments. The physical–chemical characteristics such as width, depth, gradient roughness, bed type, and hydraulics together with water velocity all influence the invertebrates. The diversity and abundance of invertebrates are greatest in areas of medium water velocity 0.20–0.75 m/s [11]. Invertebrates are also an important part of the food chain for fish.

3.3 Fish

Valid scientific descriptions exist for about 24,600 living species of fishes in 482 families and 51 orders [12]. Freshwater fish diversity is therefore large compared to the other systems. There are approximately 23,000 species of bony fishes. About 10,100 are entirely freshwater and 2,500 move between the sea and freshwater during their life cycle [13]. Some examples of fishes found in freshwater are salmon, steelhead, trout, and shads.

To maintain the fish population, all parameters related to flow are equally important for fishes living in flowing river conditions. The river flow should be of appropriate velocity in relation to the different life stages (e.g. egg, fry, juvenile, and adult) of fish. The life cycle stages require the following factors: low silt content, well-oxygenated intra-gravel flows and minimum current, depth, velocity of water, dissolved oxygen. The natural high and low flows provide important cues for these stages and dam-related manipulation of the natural flow regime can threaten the diversity and abundance of fish populations [14–16]. When the flow regime is regulated, these natural cues are eliminated and the natural reproduction system of native fishes is impaired [17]. Reduction of high flows and flood flows also threatens the quantity of the flood plains of large alluvial rivers, which constitutes important grounds for feeding, spawning, and rearing [18].

Stored water undergoes important changes in temperature, turbidity, and concentrations of dissolved oxygen, silt, and nutrients. As water is released from the reservoir, these physico-chemical changes are transmitted downstream thus altering the living environment of downstream fish populations [19]. Effect on fish populations has been identified in the form of altered spawning behavior and reduced growth rate of individual fishes [20]. The fish stock is also affected by changes in the distribution of aquatic plants and invertebrates that depend on the natural flow regime [21]. Fish species are generally adapted to the natural flow regime, often migratory, and utilize the entire river continuum, including headwaters, flood plains, and estuaries to complete their life cycles [22]. Examples of migratory fish species are carp, salmon, and eel [23]. Moreover, blockage of the river flow isolates upstream spawning areas, impedes ascending fish migration, and kills descending fish individuals that are too big to pass through the turbines. The effects on a particular fish species also depend on its adaptive capacity. Thus some species are exterminated while others recover slowly and still others are able to grow and spawn [24].

4 EFFECT OF DAMS ON WATER QUALITY

The physical, chemical, and biological characteristics of a reservoir are generally intermediate between those of a river and those of a lake [25]. Operation of reservoirs strongly influences their effects on the river downstream and can alter the ecological structure within the reservoir. Releases are perhaps the most ecologically significant aspect of reservoir operation which include [26]:

- quantity and rate of water releases;
- timing of releases;
- depth from which water is released, which in turn affects stratification in the reservoir and water quality downstream and in the reservoir.

The effects of impoundments include a series of changes in the physical and biological conditions downstream of the dam, especially modification of the flow and temperature regimes, and usually greater water clarity.

4.1 Physical effects

Due to the presence of reservoirs and altered flow regimes of the river, the transport of suspended particles and the amount of fine sediments on the streambed are affected. Inflowing sediments settle out of suspension under reduced current velocity within the reservoir, sometimes leading to dramatic loss of water storage capacity. The Cali Dam in Colombia is reported to have lost 80% of its storage capacity within 12 years, despite expensive dredging operations [7].

4.2 Biological effects

Biological changes along downstream of impoundments are substantial and well documented [7, 27–29]. The type of dam and its mode of operation are important determinants of the kind and magnitude of its effect. Dams that release high flow, enough to scour the streambed, lead to the elimination of flora and fauna. Finally, on large rivers with many dams, such as Loire Dam [30], extensive phytoplankton blooms often develop as a result of slow downstream passage of water. The effect of dams on populations of migratory fishes is well known and is of serious concern. Dams block the upstream passage of anadromous fishes such as salmon, shad, and catadromous fishes like eel.

5 MINIMUM FLOW REQUIREMENT

Water management including dams, diversions, and withdrawals collectively result in the reduction of stream flow below the natural level in a certain season or throughout the year, while there must be some minimum flow needed to maintain healthy functioning of the river community. Some of the advantages of minimum flow are:

- increased forage production in the river system would provide more food for trout and other game fish,
- lower summer time water temperature and improved dissolved oxygen content for the river system,
- improved navigation over shoals.

Methods of estimation of minimum flow based on easily obtained measures such as discharge, basins area, or wet perimeters are explained in the following sections.

5.1 Physical Habitat Simulation Model

A major component of the Instream Flow Incremental Methodology (IFIM) is a collection of computer models called the Physical Habitat Simulation Model (PHABSIM). It incorporates hydrology, stream morphology, and microhabitat preferences to generate relationships between river flow and habitat availability [31]. Habitat availability is measured by an index called the weighted usable area (WUA), which is the wet area of a stream weighted by its suitability for use by an organism. PHABSIM allows habitat flow relationships to be developed for any life stage of any species and allows quantitative habitat comparisons at different flows.

5.2 Mean annual discharge

Tennant [32] proposed a 10% mean annual discharge (MAD) as a lower tolerance limit for many aquatic organisms and a 30% MAD for good to optimal water depths and velocities.

5.3 Wet perimeter curves

The relationship between wet perimeter and discharge is sometimes used as an expedient technique for determining the minimum flow allowable for environmental purposes. The critical minimum discharge is supposed to correspond to the point where there is a break in the shape of the curve. Below this discharge, wet perimeter declines rapidly. The technique can be applied to other habitat–discharge relationships, provided the habitat variable increases with discharge [33].

The IFIM approach, which has been developed in western USA, generates a prediction for the amount of the usable habitat for fish as a function of discharge. This is done by coupling two models, where one stimulates the physical habitat preferences of the fishes in the system and the other estimates available variation of habitat space with discharge habitat. Suitability curves are derived from fish abundance and distribution data for each target species over a range of habitat conditions. Depth velocity and substrates are the habitat variables.

In 1995, the Feather River Technical Team of the Anandromous Fish Restoration Program core group listed instream flows as the key limiting factor for Chinook salmon and steel head production in the Feather River. Minimum flows in the Feather River below the fish barrier dam were established by a 1983 agreement between the Department of Water Resources (DWR) and the California Department of Fish and Game. This agreement specifies that DWR should release a minimum of 17 m^3/s below the fish barrier for fishery purposes. This agreement also specifies that the minimum flow requirement in the Feather River downstream will range from 34 to 48 m^3/s during the primary spawning incubation period (October–February) and from 28 to 48 m^3/s during March [34].

6 IMPACT OF MINIMUM FLOW DOWNSTREAM OF THE DAM

The minimum flow requirement in a river is needed to protect and enhance downstream habitat and aquatic resources. Substantial site-specific data, available from studies sponsored by the Maryland Department of Natural Resources Power Plant Research Program and the Philadelphia Electric Company, provided a means of establishing appropriate minimum flow levels. The study examined the effects of different flow regimes on the benthic macroinvertebrates below the dam. Macroinvertebrates consist of aquatic insects and other small organisms that are sensitive to changes in the environmental conditions and are also important food items for many important fish species. Evaluation of the impacts of various flows on macroinvertebrates and resident fish showed that by maintaining continuous minimum flow, the abundance of macroinvertebrates increases 100-fold below the dam [35].

Two specific groups of benthic macroinvertebrates – chironomid midges and hydropsychid caddisflies – were enhanced to the greatest extent, and these two species are particularly important prey items for resident fish populations. Fish-feeding studies conducted at the same time showed that midges and caddisflies were significantly more abundant in the stomachs of three common fish species during years with a minimum flow from the dam than during years with periods of no-flow from the dam. The study documented that the minimum flow of 99.1 m^3/s is beneficial for sustainable development of benthic organisms.

The literature indicates that minimum flow downstream of dam plays a significant role in maintaining fish populations.

6.1 Smith River project

Philpott Reservoir was constructed on the Smith River. The reservoir provides a steady influx that spills through the turbines supplying food for trout. Without the dam, the trout could not have existed in the Smith River, as the water released from the dam is much colder than water that flows freely in the pre-dam area and is termed 'hypolimnetic' because it originates deep in the Philpott Lake. In a stratified or layered reservoir such as Philpott, warmer water accumulates near the surface (the epilimnion), whereas colder, oxygen-depleted water sinks to the bottom (the hypolimnion). This cold water allows the trout to survive and reproduce in the Smith River. Temperatures between 40°F and 70°F are optimal for brown trout to spawn and for best egg survival to occur [36].

6.2 Lewiston Dam

Dam-related fluctuation of stream flow due to hydroelectric facilities may cause increased or decreased downstream cover [37, 38]. Due to decreased stream flow heavy accumulation of coarse sediment fill streambed pools, causing the destruction of spawning riffle gravel nursery and over-wintering habitats for salmon and trout. Proposals to restore and maintain the degraded habitats include controlled one-time remedial peak flows or annual maintenance peak flows designed to flush the spawning gravel. The potential fall earn Chinook natural spawning population of 71,000 has diminished to about 11,250. The main cause of habitat reduction is identified as the loss of flushing flows associated with natural flood events and the high sediment production from extensive land disturbance and erodible sandy soils [39–43]. The new attenuated flow regime does not allow for flood flows that would mobilize gravels and large cobbles, flush gravel embedded sands, and uproot any sprouting vegetation in the streambed. Under the historical Trinity River, flow of a magnitude sufficient to move the bed material were equaled or exceeded 10% to 40% of the time [42] under the present flow conditions.

6.3 Vernita Bar

The Vernita Bar section of the Columbia River immediately below Priest Rapid's Dam in the Hanford Reach is extremely valuable for natural production of Fall Chinook salmon. There has been a significant decline in the production of Fall Chinook salmon since the 1970s. Minimum flow is implemented to increase the production of Fall Chinook salmon. So increasing the flow above the present 1,019.5 m^3/s shows increased spawning habit [44].

6.4 The FERC minimum flow requirement

The first regulatory requirement for minimum flows came from the Federal Energy Regulatory Commission (FERC) requirement. This requirement is the result of the Guadalupe-Blanco River Authority (GBRA) operated hydroelectric plant at the base of Canyon Dam. Article 405 states: "The license shall discharge from the Canyon Dam project a continuous minimum flow of 2.5 m^3/s as measured immediately downstream from the project power house to protect and to enhance fish and wild life resources in the Guadalupe River."

6.5 Selwyn River

The Selwyn River goes dry in summer downstream of Coalgate to below the SH 1 bridge. A continuous flow in this reach during the dry season would provide passage and additional rearing habitat for trout and other fish and improve their fishery. It is estimated that a suitable minimum flow for trout in the Selwyn River would be in the vicinity of 2.5–4.0 m^3/s. This range is believed to be more suitable for juvenile and adult trout. It is also emphasized that a minimum flow of 6–8 m^3/s is needed to encourage trout to become more diurnally active. Because during low flows, trout remain hidden in cover during the daytime and become more active at night [45].

6.6 White River

More than half a century ago, the character of the White River was changed by construction of dams along it. As a result, flooding that had created devastation along the White River ceased, and the dams served to bring electricity to this region of the country. In the process, in Northern Arkansas, the water temperature dropped in the White River, and its branch at the North Fork essentially wiped out the warm water fishery in this region. Bass and other warm-water species native to the river were affected very badly. Minimum flow on the White River was maintained to improve the trout habitat, helping maintain oxygen levels and the temperature of water. The minimum flow would check the fluctuations in water temperature and oxygen level, which is a daily phenomenon that adversely affects the river fish population. Minimum flow basically would provide a steady amount of water downstream and would maintain a constant minimum level of the river even when power generators at the dam are not in use. Anglers and boaters species would also be able to navigate in the river, which was nearly impossible during the low water periods. The US Army Corps of Engineers also indicated that the streambed would not be harmed with minimum flow, which is possible when there is high flow during floods [46].

7 IMPORTANCE OF MINIMUM FLOW ON FISHES

The importance of minimum flow level in a river on some important fish species are discussed below.

7.1 Shads

American shad, hickory shad, and blueback herring belong to the family Clupeidae, which is the largest Atlantic coast member of the family. Shad are sequential or batch spawners with release of groups of eggs as the fish move upriver. Eggs are semi-buoyant and drift in the water column when flows and depths are appropriate. Alosines are highly migratory in nature; these fishes require access to an expansive variety of high-quality freshwater and marine habitats. Eggs of American shad and hickory shad require adequate flows (generally 0.15–0.9 m^3/s) and sufficiently low sediment loads to keep eggs adrift until hatching [47–49]. In river reaches where flows and/or water depths are not sufficient to keep eggs suspended, the semi-buoyant eggs sink to the bottom and roll or bounce on hard substrates but may be suffocated in areas with siltation [49, 50]. American shad requires high but stable flows of high-quality water for spawning and early nursery habitat [51]. Tidal freshwater marshes along the Cooper River (many of which are relic rice impoundments with breached or eroded dikes), which were used extensively for spawning habitat by blueback herring prior to rediversion of flows into the Santee River [52], are less under reduced flows and are partly dewatered or influenced by brackish water. Available fish passage and commercial fishery data indicate that the herring population has declined dramatically since flows were rediverted, presumably because of a reduction in the amount and perhaps quantity of spawning and nursery habitat [53]. Dams, particularly hydropower dams, often produce flow regimens that are not reflective of natural seasonal flows. Pulse flows used for peaking hydropower production can disrupt natural productivity and availability of zooplankton needed for larval and early juvenile forage [51, 54], can displace eggs and/or larva from highly productive habitat, and can disrupt both upstream and downstream migration patterns for adult and juvenile alosines [47, 54–56]. The Santee–Cooper rediversion project improved flow regime and was likely to produce an increase in the quantity and quality of alosines spawning and nursery habitat seaward of St. Stephen Dam and the Rediversion Canal.

7.2 Sturgeons

Atlantic sturgeons and short nose sturgeons belong to the family Acipenseridae. Atlantic sturgeons are the largest living fish with a life span approaching 50 years. Because of the highly migratory nature of sturgeons, particularly the Atlantic sturgeon, these fishes require access to an expansive variety of high-quality freshwater and marine habitats. Within state waters, adult Atlantic sturgeon migrate through near shore Atlantic shelf waters and enter coastal sounds, bays, and inlets to access the river basins in which they spawn. Short-nose sturgeons move primarily from tidal estuarine or brackish channels into freshwater reaches to spawn. Both species spawn in freshwater channel habitats from tidal river reaches to at least as far inland as the fall line in large, unobstructed river basins. Eggs of both species are adhesive, and successful spawning is dependent upon the availability of relatively clean, hard substrates within the river channels for egg adhesion and development. Both spawning and egg survival to hatching are dependent upon habitats with low to moderate flows and limited sedimentation. Atlantic sturgeons generally spawn in waters where the flow rate is 0.2–1.8 m/s (0.7–6.0 ft/s) [57]. Nursery and foraging habitats for both sturgeons (including adults within rivers) include all channel and adjacent out of channel submerged habitats from a few kilometers seaward to estuarine sounds and bays of river basin deltas. Dams and other impediments to migration have eliminated sturgeons from many historical habitats in South Carolina [56], the result being a general reduction in sturgeon populations in even currently accessible river reaches. Atlantic sturgeons prefer moderate water temperatures, 12–24°C (54–75°F); body weight is negatively impacted at higher temperatures [58]. Reduced flows caused by dams can reduce dissolved oxygen to levels unsuitable for sturgeons [59]. For example, dissolved oxygen within the Santee River Rediversion Canal can reach less than 3.0 mg/L and more frequently reaches less than 4.0 mg/L during summer periods with low or no flows from St. Stephen Dam [60]. The Santee–Cooper Rediversion Project completed in 1985 also enhanced year-around flows and average late winter and spring water levels in the Santee River, primarily seaward of the Rediversion Canal. These improved flow regimens have presumably resulted in increases in the quantity and quality of spawning and nursery habitat for both sturgeons seaward of St. Stephen Dam and the Rediversion Canal. Accordingly, both Atlantic and short-nosed sturgeons may have been positively influenced.

7.3 Salmons

Salmon is the common name for several species of fish of the family Salmonidae. Several other fish in the family are called trout. Salmon live in both the Atlantic and the Pacific Oceans, as well as the Great Lakes and other land-locked lakes.

To know the importance of minimum flow level on fishes, the example of Roadford Reservoir has been considered. To maintain and improve natural recruitment of wild trout and salmon population in the River Wolf and other waters located downstream of Roadford Reservoir, an enhanced flow program is followed. To achieve this aim, specific flow discharges must be available throughout the year to enable the successful completion of the life cycle of the fish. Specific flow requirements have been identified for the various life cycle stages of salmon and trout (e.g. salmonids require clean well-oxygenated and high-quality water for survival).

The enhanced flow program has been based on the knowledge of the instream requirements of salmonids as given in Table 1. The interactions between discharge velocity, substrate composition, sediment movement, and physical/chemical habitats and the resulting effect on salmonids both temporarily and specially are complex. Such factors can influence the selection of the sampling site

Table 1: Enhanced monthly flow program with respect to the life cycle of fish.

Month	Events in the life cycle of fish	Water flow (MLD)
November–December	Spawning	45
January–March	Developmental stages of eggs and alevins	25
April–May	Emergence of salmon and fry from gravel to become fish	30
June–September	Maintenance of fish stocks	9

MLD, million liters per day.

and upstream distribution of the adult fish, survival of the eggs and early stages (alevins) in river gravels, emergence, and survival of the older age classes.

Fishes select sites for spawning where the gravel contains low-silt load and well-oxygenated, high intra-gravel flows. Salmons generally deposit eggs in shallow gravel excavations known as redds in the period November–December. A minimum current is a necessary factor, required to initiate motion of the fins. A minimum velocity flow is required to enable the adults to orient to the spawning bed and dig out the redds effectively [61]. Salmon spawning is observed at depths of 0.15–0.60 m, with optimal surface velocities of 0.3–0.4 m/s. The main factor required for spawning of salmonids is the flow with a velocity not less than 0.08 m/s [62]. Salmon spawns at a depth of 0.30–0.80 m and at velocities ranging from 0.44 to 0.97 m/s [63]. At velocities greater than 3.66 m/s spawning is inhibited, as salmon are unable to maintain sustained swimming effort. Trout utilize velocities of 0.22–0.38 m/s and water depths of 0.14–0.28 m. Velocity criteria are directly proportional to the size of the fish. Large fishes are more capable of surviving higher velocities due to their greater overall swimming speed. Salmonids generally avoid spawning in water shallower than their own body depth and at velocities less than 0.2 m/s.

Oxygen consumption by salmonid eggs varies during development between December and April. Total consumption rates of an individual egg and critical concentration increase during embryonic development and then decrease sharply after hatching. Critical dissolved oxygen concentration in water for early eggs is 0.76 mg/L; eyed ova 3.1 mg/L, pre-hatch 5–8 mg/L, and hatching 7–10 mg/L. Siltation and low water velocities will inhibit oxygen supply and removal of metabolic wastes. Sublethal effects of less oxygen supply include morphological changes, reduced size at hatching, premature hatching, and reduced growth rates.

8 CONCLUSION

Dams alter the river ecosystem and subsequently require the development of new relationships between humankind and natural resources associated with these ecosystem. From a fishery perspective, dams and their resulting reservoirs can benefit human societies. Dams, however, usually alter traditional riverine fisheries (i.e. from tail water fisheries), but more commonly negatively. Dams are often the most significant and direct modifiers of natural river flows. They are therefore an important starting point to implement environmental flows. Downstream releases from dams are determined by the design to pass water from the dam. This paper concludes how minimum flow is an important parameter in the life cycle of fishes. Other aquatic organisms, such as benthic macroinvertebrates, also play a key role in the development of fish production. They require 99.1 m^3/s of minimum flow for their abundance. Some examples of dams were also given and the concerned authorities have decided on the minimum flow for the fish species such as sturgeons, shads, and salmon. The operating policies and rules determine the amount and timing of releases for environmental flows [63]. Most previous practices of environmental water allocations were narrowed down to keeping one minimum flow in the river downstream of a major impoundment or abstraction. The minimum flow rate allows a population of phytoplankton to develop, which is further enhanced by an increased supply of nutrients leached from the flooded soil and vegetation, and increased population of zooplankton and so on up the food chain floods this. Hence, the availability of food is also an important criterion for fish production and reproduction. In the entire life cycle of a fish (i.e. from spawning to adult), flow plays an important role. If this flow is not regulated, it may cause a decline in the fish population. In order to maintain fish production, various methods are recommended, namely Tennant's 1976 method [32], wet perimeter curves [11], habitat retention models [64], and PHABSIM [31].

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