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Dammed If You Do

By K.E. Bray

Inscribed on the wall at the Grand Coulee Dam Visitor Centre are the lines:
Roll on, Columbia, roll on.
Your power is turning the darkness to dawn.
So roll on, Columbia, roll on.

And far up the river is Grand Coulee Dam,
The mightiest thing ever built by a man,
To run the great factories and water the land,
It's roll on, Columbia, roll on.

The Columbia River may have been rolling on powering light bulbs, but more than one million salmon trying to return to their natal spawning grounds were stopped dead in their tracks, so to speak. Perhaps not now the mightiest thing built by humans, in the 1930s the Grand Coulee was certainly a show stopper on the Columbia River - the dam that forever blocked anadromous salmon from the upper Columbia and whose effects would be felt to the headwaters hundreds of kilometres away.

From a one metre high beaver dam to the 221 m high Hoover Dam on the Colorado River, where water is impounded fish are usually affected. While beavers and fish have evolved together and beaver dams can often benefit fish, human made dams are a different story. Usually large, immovable, long lasting, and highly controlled, our dams and reservoirs can have extensive effects on species, communities, and ecosystems.

Most large dams (<15 m tall) in the world are built primarily for irrigation, and China leads the way with over 19 000. Major dams (≥ 150 m), such as the Hoover or Grand Coulee, for example, are often built for hydropower, but also serve additional purposes for flood control and river navigation. Canada ranks 3rd in the world for having the most major dams, after the U.S. and the former U.S.S.R.

The impact of dams on fish populations can be complex to describe. Some people spend years (or careers) investigating how dams affect fish populations and devising ways to lessen the damage. Impacts can be separated into two broad categories: those from the physical presence of dams and reservoirs, called footprint impacts, and those arising from the operation of dams, called operational impacts.

Here, very briefly, are some of the major effects of dams on fish in north temperate regions such as western Canada, along with some measures currently used to address the impacts. Keep in mind that, in the connected and complex web of ecology, each individual effect can have continuing and far reaching implications.

Dams bring us many benefits, from power to flood control and water storage for irrigation. They fuel industrial economies and help us maintain our current lifestyle. Part of the cost of having dams though is their impact on fish communities. While there are ways of addressing many of these effects, the ability to do so is often hindered by a lack of information on the pre- and post-dam environment, inadequate or short term funding that precludes essential long term monitoring, and the complex involvement of other threats to fish populations, such as urbanization, forestry, mining, agriculture, industrial development, over harvesting, exotic species, and climate change.

Email: a.w.a@shaw.ca
Website: albertawilderness.ca

The Alberta Wilderness Association,
Box 6398, Station D,
Calgary, AB T2P 2E1
Phone: (403) 283-2025 Fax:(403) 270-2743
Edmonton Phone/Fax: (780) 988-5487

Although we are now aware of the many impacts to fish populations brought about by dam construction and operation, there may still remain unforeseen effects in the future. Our major dams are less than 100 years old, most less than 50, and the long-term impacts of disrupting river ecosystems that naturally operate and evolve in hundreds or thousands of years are yet to come.

Impact or Issue	Means of Mitigation or Compensation
Footprint	
1) The Dam The physical presence of a dam creates a barrier that blocks fish migration, both upstream and downstream, and can restrict or eliminate access to habitat, block anadromous species in some rivers and contribute to nutrient declines (see below), and fragment populations leading to loss of genetic diversity or fitness. Problems related to fragmentation increase in river systems with multiple dams. In some places, dams can protect native fish populations by blocking invasion of exotic species.	At some dams, fish ladders can be installed to allow migration upstream. These do not work for high dams and retrofitting is much more difficult than including them in the initial design and construction. Trucks or barges are used to transport fish upstream and some facilities can use increased flows to encourage downstream migration (see below)
2) **The Reservoir** Creating a reservoir behind the dam can change habitats significantly, e.g. from riverine to lacustrine by flooding a river valley, or less severely but noticeable nonetheless, e.g. impounding an existing lake. The effects are numerous and include: **•Nutrient retention/depletion** The standing water of reservoirs allows nutrients that once flowed through the system to sink and become unusable. After an initial productivity boom following reservoir creation when nutrients (**N**itrogen and **P**hosphorus) are being leached out of the flooded soil, productivity crashes leaving behind an impoverished environment. The situation is exacerbated by multiple dams as productivity declines with each subsequent reservoir in the system receiving fewer and fewer nutrients. The loss of marine derived nutrients because of dams that block anadromous salmon, for example, also compounds the problem of nutrient deficiency. Salmon carcasses are a rich source of N and P readily available to both aquatic and terrestrial organisms (e.g. stream invertebrates, eagles, bears).	•Nutrient addition or fertilisation, such as in B.C. and Sweden, is used to restore historical N and P levels. Fertilisation must be continued in order to maintain productivity levels. Deep water withdrawals from an upstream reservoir to the downstream environment could increase nutrients, as they are more concentrated in the deep, cold waters of the reservoirs. Many dams were not designed for this and the release of very cold water downstream can have harmful effects. Restoration of salmon runs by dam removal is being advocated more frequently and has occurred in some places, e.g. on the Snake River. Removal of major dams is advocated by some, but will likely not occur for a long time. In the meantime, protection of remaining fish stocks

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	and maintaining habitat is considered the least we can do.
•Sediment Sink The reservoir's role as a sediment sink has a far-reaching downstream effect as well. Estuaries are starved of sediment resulting in changes to delta formation, coastal habitats, and ocean/sea productivity. Immediately downstream of the dam, reduced sediment input changes river dynamics by not providing sand and gravel for bars, shoals, islands, etc. Erosion downstream is also increased, as the water no longer carries its normal bedload and therefore 'strips' sediment as it flows. The build up of sediment behind a dam also ultimately limits the life of the facility.	•In Colorado and California, for example, they have been trying out artificial flood flows to replenish sand and gravel bars downstream and have met with some success. The flexibility to operate dams in this manner doesn't always exist.
•Habitat loss Absolute loss of habitat by inundation will occur. Often the areas lost are low gradient sections of streams and fertile valley bottoms. In steep sided mountainous valleys, many tributaries are in hanging valleys so that new reservoir levels often flood usable habitat up to a barrier. There is also the possibility, of course, that existing barriers will disappear under the reservoir, opening up tributary habitat. In the case of an artificial barrier, such a culvert, this is a good thing, but where a natural barrier is removed, the mixing of genetically different above and below barrier populations may be detrimental.	•Habitat protection, rehabilitation, and enhancement of areas remaining or re-creation of specific habitat functions, e.g. by building spawning channels, present a range of options. It not possible, however, to restore or re-create everything, especially large river or wetland habitats. Sometimes off site rehabilitation is considered; i.e., improving habitats or a fisheries elsewhere to compensate for losses due to the dam and reservoir. Some areas stock hatchery fish to replace those lost, although many question the success and use of hatcheries for this type of production.
•The loss of flowing water habitat can create difficulties for fish trying to migrate downstream, such as salmon smolts. The cues and assistance they rely on for getting out to the ocean are removed and they become confused in the still water reservoir environment.	•Increasing flows at certain times of the year helps flush smolts downstream (flushing flows).
•Species Loss Specific and unique genotypes, phenotypes, or populations of fish (or other organisms) may be forever lost, some of which we may never even know about.	•There isn't much anyone can do once they are gone.
•Methylmercury Contamination Flooding terrestrial vegetation leads to the release of methylmercury, a harmful contaminant that bioaccumulates in the food chain and can lead to serious illness or death in humans.	•Consumption advisories or complete closures to fisheries are often implemented, but only time will allow methylmercury concentrations to decline. In some cases, reservoirs are cleared of as much

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•**Greenhouse Gases** Newly created reservoirs contribute to greenhouse gas emissions by releasing CO_2 and methane from decaying vegetation. •**Access and the Human Dimension** Not often considered an impact to fish is the increased access that a reservoir provides to the public, particularly anglers, as new fisheries are developed. Recreational opportunities are touted as a benefit of reservoirs and increased public access can lead to increased pressure on fish populations. Over harvest, illegal harvest, and management actions such as stocking can eliminate populations or alter species composition, particularly if non-native fish are introduced.	standing vegetation as possible prior to flooding which could reduce overall concentrations. Reservoir clearing does not eliminate the problem, however, and comes with its own impacts. Removal of forest cover contributes to lost productivity and lack of habitat in the new reservoir. •Clearing standing vegetation in reservoirs prior to flooding can help reduce CO_2 emissions as well as reduce problems with floating debris and boating hazards in the future. As noted above, however, the same standing vegetation can be very important for aquatic productivity. •Fisheries management activities, such as catch limits, gear restrictions, special licences, bait bans, seasonal limits, enforcement, access restrictions, closures, and sanctuaries.
Operational	
1) **Water Level Fluctuations** Dam operations, especially hydroelectric facilities, result in fluctuating discharges as the demand for water or power changes. Water level fluctuations can have effects both upstream and downstream of the dam. In the reservoir, the drawdown zone eliminates littoral habitat (no plants+no invertebrates=no habitat or food) that could have contributed to reservoir productivity. At times, the denuded drawdown zone is exposed to wind erosion causing dust storms and spreading fine sediment across a large area. Fluctuating water levels also resuspend silt and, potentially, contaminants. Downstream, changing discharges can increase erosion, cause fish stranding, reduce or eliminate riparian vegetation, disrupt groundwater flows, and desiccate invertebrates. Both upstream and downstream, certain water levels can render tributaries inaccessible at	Within limits, water level fluctuations can be reduced by changing both the amplitude and frequency of discharge rates. Reservoir levels can also be somewhat managed to reduce impacts by stabilising water levels at certain times of year. Oftentimes, however, the extent to which changes can be made is quite limited by the necessities of operating the dam for its intended purpose. Shorelines susceptible to erosion are protected, sometimes by armouring with rip rap. Drawdown zones can be planted to reduce wind and water erosion. Fish strandings, if not avoided by reducing the rate of change to water levels, may be helped by salvaging trapped fish, a time sensitive and costly procedure. Tributary mouths can be cleared or access facilitated by constructing step pools/passages, often an ongoing activity.

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critical periods.	
2) **Alteration of the Natural Hydrograph** Daily and seasonal timing of flows is changed by dam operations, which can disrupt migration, spawning, or feeding cues, and make habitats unsuitable or intolerable due to harmful temperature or dissolved oxygen conditions.	As described for the Colorado River above, flows can be managed to a degree to simulate natural discharges. Most dams are not built or cannot be operated with the flexibility needed.
3) Gas Bubble Trauma Operation of the turbines or spilling excess water can force more oxygen into the discharge water causing gas bubble trauma in fish (which is like having the bends). This can weaken or kill fish that are coming through the penstocks or those living in the tailrace.	Changes are usually made to turbine operation that significantly reduce the incidence of gas bubble trauma.
4) Entrainment Drawing water into the penstocks also can draw in fish, some of which make it through the turbines alive, although perhaps somewhat dazed, and some who come through in pieces. This is known as entrainment and represents a loss of biomass to the upstream reservoir, but also can be a rich food source for fish and wildlife downstream of the dam.	Placing of screens or deflectors that discourage fish from coming too close to the intakes, or positioning intakes to avoid depths where fish concentrate can help reduce entrainment.

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