GAS SUPERSATURATION

BY

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1. Gas supersaturation in this document is a condition prevalent in the Snake and Columbia rivers caused by spilling water at dams.
2. The effects of gas supersaturation in fish have been likened to Nitrogen narcosis documented in human divers and others who breath air at above normal atmospheric pressures then return to normal air pressure levels. Divers breathing compressed air in deep water use the Oxygen and accumulate Nitrogen in their blood. If they rise to shallower water and the pressure reduces too fast, the Nitrogen forms bubbles that concentrate in their joints and other areas of the body. The result is extremely painful and often fatal effect. In fish, they absorb air from water through their gills at the level it is dissolved in the water at the depth the fish are swimming. Though they use some of the Oxygen from the air they take in, at supersaturated levels air bubbles circulate with their blood. When the pressure is reduced as when they swim toward the surface, the air bubbles form in thin tissues like the skin, the fins, on the opercula (cheek plates covering the gills), in the roof of their mouth, and behind the eyes. In the 1970s, scientists at Battelle Laboratories placed Doppler devices (tiny microphones) over the aortas of juvenile salmon in shallow troughs in their lab. It was possible to hear the ping of bubbles circulating in the blood. As gas supersaturation increased, the pings increased until fatality caused the pings to go flatline.
3. Battelle scientists also drew minute quantities of gas from bubbles on the fish and analyzed them to be essentially the same consistency of air. Therefore, in fish it is not really the "bends," but total dissolved gas (TDG) that is the problem (Figure 1).
4. Gas supersaturation in the Columbia River began appearing as a problem in in 1965 as spill occurring at the series of dams elevated TDG and the river was supersaturated over long distances. In 1968, John Day Dam (JDA) on the Columbia River closed (ie. the dam gates closed, and the reservoir filled). This happened in May when the spring runoff was underway and juvenile spring and summer chinook and steelhead out migrations were peaking. Only one turbine was in operation, and the rest of the river passed over the spillway. The result was a catastrophic gas saturation problem. Juvenile salmon and steelhead died in droves, and adult salmon perished as well. When I went to work for the Corps of Engineers in 1971, TDG was the first problem to land on my desk.
5. At this point, it is pertinent to describe how gas supersaturation occurs. In nature, where water plunges over a waterfall into a deep pool, air bubbles in the water plunge to depth where pressure on the bubbles force air into solution in the water. The deeper the water plunges the higher the level of saturation becomes. As the water rises toward the surface, it is supersaturated with dissolved air. If there are rapids downstream where bubbles form at

shallow depth, air from the supersaturated water passes back through the walls of the bubbles which burst and let the air back into the atmosphere. In the reservoirs, there is too little turbulence to expel the excess gas. At higher TDG levels, the surface effervesces like Alka-Seltzer in a glass of water. The hiss of gas returning to the atmosphere is clearly audible, but the elevated TDG levels persist dam to dam, and are boosted back up when water is spilled at the next dam downstream. At a demonstration of a TDG monitoring system, high levels of TDG were measured downstream at Vancouver, WA, indicating that TDG remains a problem to the estuary.

6. A typical Corps dam is approximately 100 feet high. The spillways have undershot spillway gates (the water flows under each gate at about 50-feet of depth). The water is instantaneously decompressed from 50-feet of hydraulic head to 0-feet of head as it shoots out from under the gate. As the water sprays out, it is filled with air bubbles. To dissipate the energy of the water, it plunges into a "stilling basin," usually 50- feet deep. The water rolls back on itself dissipating energy to avoid erosion downstream. In some cases, concrete blocks (called dentates) increase turbulence to dissipate energy. Air entrained in the spill is subjected to up to 50-feet of water pressure. Air is forced from the bubbles into solution, thus when the water boils back to the surface, it is supersaturated with air (TDG). At the bottom of the stilling basin, TDG levels up to 150 % have been recorded.
7. With the 1968 spring flood, water was being spilled at Ice Harbor Dam (IHR) on the Snake River, and at McNary (MCN), The Dalles (TDA), and Bonneville (BON) dams. With the spill at JDA, TDG was elevated to levels 130 to 140% from IHR hundreds of miles to the estuary below BON. To make matters worse, Lower Monumental Dam (LMN) was to close in 1969, and Little Goose Dam (LGO) in 1970. The Federal and state fishery agencies declared a catastrophe for the Snake and Columbia River salmon and steelhead. In the regional panic that ensued, the agencies and Corps of Engineers pulled out all stops to save the fish. An interagency Nitrogen Task Group was formed to deal with the problem comprised of the fisheries, Tribal, and environmental agencies as well as the Corps of Engineers, Bonneville Power Administration, and Bureau of Reclamation.
8. One of the measures was to install spillway deflectors (called Fliplips). By adding a ski jump structure (Figure 2) at tailrace water level, the water skates across the surface of the stilling basin causing surface turbulence and preventing plunging to depth. Dentates added to one Fliplip proved detrimental, but smooth Fliplips are effective at minimizing gas supersaturation to about 10,000 cfs flow spill per spill bay. IHR has 10 spill bays, and LMN and LGO each have eight. With three turbines at each dam approximately 130,000 cfs could be passed with safe TDG levels. As flows exceeded that level, TDG still increased up to 130 to 140 % from the upper most dam downstream (Figure 1). Fliplips have been installed at Snake and Columbia River dam spillways.
9. IHR, LMN, and LGO were each constructed with three turbines initially, and three "skeleton bays" or turbine bays with intakes, intake gates and downstream draft tubes that were blocked off. Final concrete work for seating the turbines was not completed. Hydraulic laboratory studies indicated that energy dissipating gates could be installed to allow flow without gas supersaturation through the skeleton bays. The 100-ton gates (slotted bulkheads), a series of funnels that allowed the water to spray out dissipating energy, were tested but after the peak of the juvenile fish outmigration (Figure 2). The fishery agencies said expedite installation at IHR, LMN, and LGO. They were in operation for the 1974 outmigration. In May, Wes Ebel with the National Marine Fisheries Service (NMFS) called me and said it was a disaster. I drove to LGO immediately. There was a windrow of dead juvenile salmon and steelhead a foot wide and 6-

inches deep along the shore. The Corps immediately took the slotted bulkheads out of operation.

10. The next major step was to expedite the installation of the three additional turbines at IHR, LMN, and LGO. Lower Granite Dam (LGR) was to be completed in 1975, so all six turbines were included in the contract. By 1977, all four lower Snake River Dams had full complements of turbines, and the Division Engineer in Portland committed the Corps to spilling as little water as possible to minimize the duration and magnitude of the TDG problem.
11. State environmental agencies and the Environmental Protection agency established TDG standards in the 1970s. At first they wanted to set 105% TDG for the dams. Years of experience at hatcheries with shallow raceways showed that level to be lethal to juvenile salmon (Figure 2). However, water was coming into LGR Reservoir from Hells Canyon at 108% TDG. Therefore, the state and Federal standards for water passing the dams were set at 110% TDG. At that time, NMFS and other agencies said that 110% TDG was safe due to the ability of the fish to swim at depth, exposure for short durations up to 120% TDG were tolerable, but exposure to 125% TDG would result in unacceptable mortality.
12. Juvenile salmon and steelhead transportation was originally developed by the NMFS from 1969 through the 1970s to avoid mortality at the dams, bypass predators in the reservoirs, and make up for the delay in migration caused by the dams and reservoirs. As the TDG problem grew, avoiding gas supersaturation became the fourth purpose of transport over the 400-mile river reach, and trucks and barges were equipped with features to provide normal (approximately 100%) TDG during transport.
13. Another important development that came from the problems of the 1970s was The Nitrogen Taskforce's development of a regionwide TDG monitoring system set up to monitor TDG, water temperature, flow, and other pertinent environmental information at dams and other monitoring stations around the hydropower system. This allowed more control of the TDG problem by regulating power generation and spill at various dams to stay below the TDG standards as much as possible.
14. By the 1990s, the Fish Passage Center, fish agencies and Tribes concluded that juvenile and adult fish could dive deeper and equilibrate gas levels in their blood. These regional experts had concluded that transport was not natural, and spill was a more normal migration tool. The agencies, environmental groups convinced a Federal Judge, the Environmental Protection Agency waived the 110% TDG standard, and the Corps began spilling to 120% TDG.
15. From the 1960s through the 1990s, in collaboration with the fishery agencies, the Corps developed juvenile collection and bypass facilities based on screening juvenile fish out of turbine intakes and routing fish to collection/bypass facilities below the dams. Systems had been refined over the years to provide over 95 to 100% survival of juvenile fish per bypass route. However, the systems only bypassed from 50 to 95% depending on species leaving turbine passage at 87 to 93% survival depend on which dam they passed. Led by the Fish Passage Center, the agencies continued to oppose juvenile fish transportation on the basis that it was not natural. In collaboration with the fishery agencies and Tribes, the Corps experimented with various methods of guiding juvenile salmon from the powerhouse to the spillway. In 1999, the Corps came up with the concept of the removable, raised, or overflow weir concept. Installed in one spill bay at a Snake River dam, up to 10,000 cubic feet per second (cfs) could be passed over the raised weir without entraining air like a normal spill bay, thus not increasing TDG. However,

fishery agencies personnel wanted "training" spill on either side of the raised spillway weir flow to discourage predators. At a Columbia River Dam like MCN, two overflow weirs would provide up to 20,000 cfs of increased TDG flow. Again, the training flow on either side compromised the TDG control by the overflow weirs. Evaluated by NMFS at each dam where they were installed, the raised spillway weirs provide 5 to 7 times the level of passage as normal spill bays.

16. Fast forward to 2000. At a regional meeting about the continuing TDG problem, a Fish Passage Center spokesperson advocated increasing spill at the Corps dams to 125% TDG. Fisheries personnel who had studied the problem firsthand explained that although salmonids can sound and equilibrate TDG in their blood, prolonged exposure to 120% TDG results in sublethal effects. Exposure to 125% TDG and above would result in increasing levels of injuries and mortality.
17. Fast forward to 2020, the Fish Passage Center, agencies, and environmentalists persisted, convincing the judge, Corps, and BPA, and are now running the river at levels up to 125% TDG by using mass spill and minimizing powerhouse operations, bypassing fish, and juvenile fish transportation. This has been accomplished by spilling water from all spillway gates and by minimizing passage through turbines and powerhouse collection/bypass systems. From a high of 90+% of Snake River juvenile salmon and steelhead transported and 10% passing in river, the ratio reversed to 90% passing in river and 10% transported.
18. In a hypothetical case, survival of Snake River juvenile salmon and steelhead decreased as follows:

    90%T X 98%S/T = 88.2% + 10%IR X 50%S/IR = 5% = 93.2% TOTAL Survival

    With spill to 125% TDG survival would be:

    90%IR X 50%S/IR = 45% + 10%T X 98%S/T = 9.8% = 54.8% TOTAL Survival

    Where T = transport, S/T = transport survival, IR = in river passage, and S/IR = in river survival.

19. While the survival of juvenile salmon is being monitored as the 125% TDG spill is being carried out, no real scientific studies comparable to those conducted in the 1970s that concluded that 125% TDG was detrimental are underway. Unless adult returns over the next several years demonstrate marked improvement because of the mass spill program, it will be a very costly mistake.

20. Several things must be considered when rationalizing increasing the use of spill and higher TDG levels to safeguard the fish. Most adult and juvenile salmon migrate in the upper 15-feet of the reservoir. They could migrate deeper to equilibrate the TDG levels in their blood, but do not necessarily do so. In juvenile bypass systems, the fish rise to depths of typically less than 10-feet in depth and pass through flumes less than a foot in depth into raceways that are around 4-feet deep. Unlike the barges that are equipped to reduce TDG to near 100% TDG, collection/bypass systems are not so equipped. Adult salmon and steelhead enter fish collection systems at depths less than 10-feet deep and migrate up fish ladders typically 4 to 6-feet deep. Although some degasification occurs in the turbulence of the ladders, auxiliary water is added from the reservoir above the dam and/or pumped from the tailrace into the ladders and

collection systems. Both adults that fallback through the spillways and juveniles that are being bypassed by spill are subjected to instantaneous pressure decreases of from three atmospheres of pressure to one atmosphere of pressure as they shoot under the spill gates. Literature shows that such decreases are highly deleterious to fish.

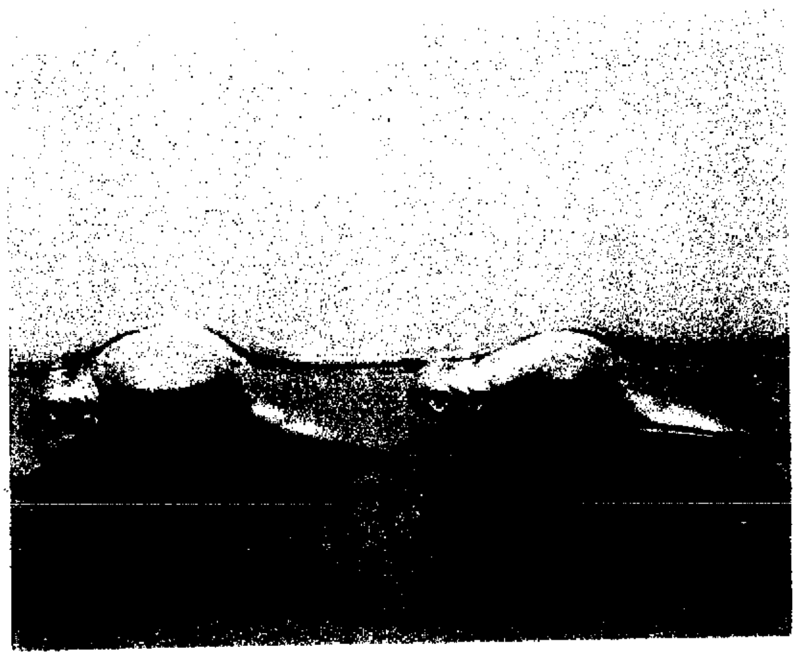


Figure 1: Juvenile salmon in shallow trough with gas bubble disease.

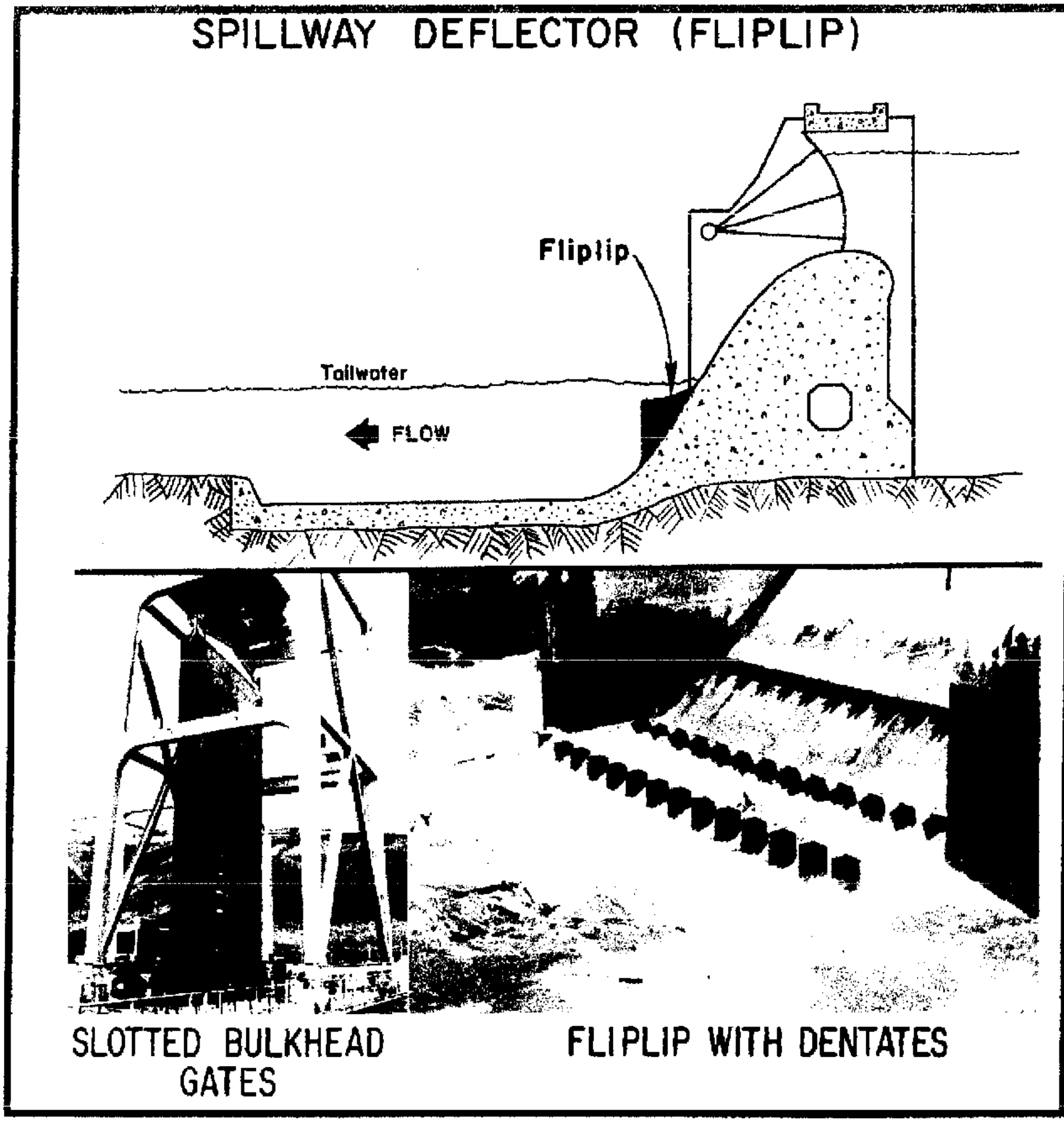
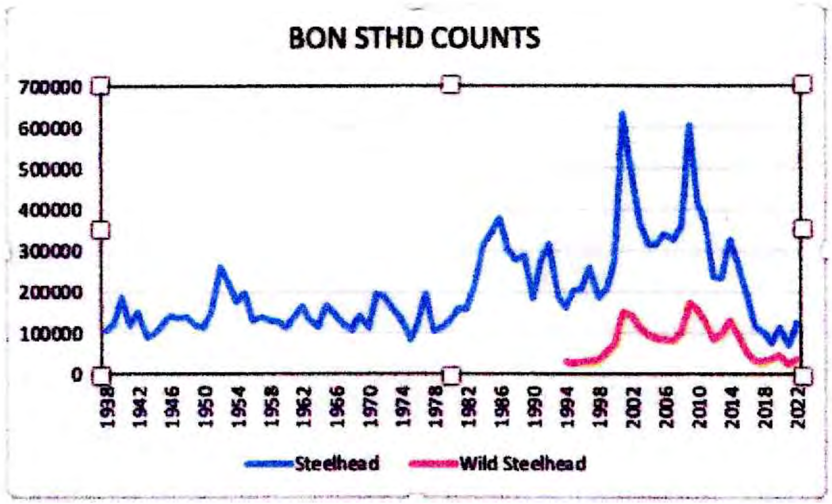


Figure 2. TDG modifications illustrated in NMFS summary report, Ebel, et.al., 1975.

Sources of Information:
https://www.webapps.nwfsc.noaa.gov/apex/nwfsc/r/nwfsc_web_apex/scipubs/search


BON STHD COUNTS
700000
600000
500000
400000
300000
200000
100000
0
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
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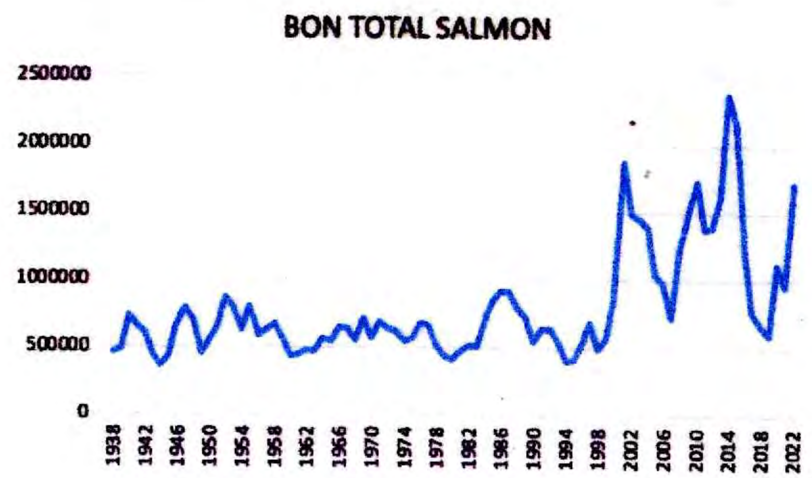
1994
1998
2002
2006
2010
2014
2018
2022
Steelhead
Wild Steelhead


BON TOTAL SALMON
2500000
2000000
1500000
1000000
500000
0
1938
1942
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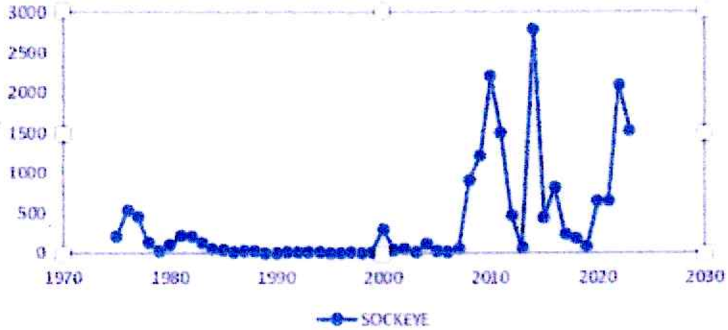
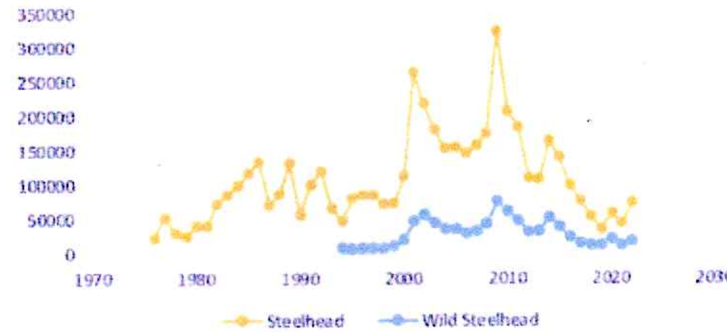
2022

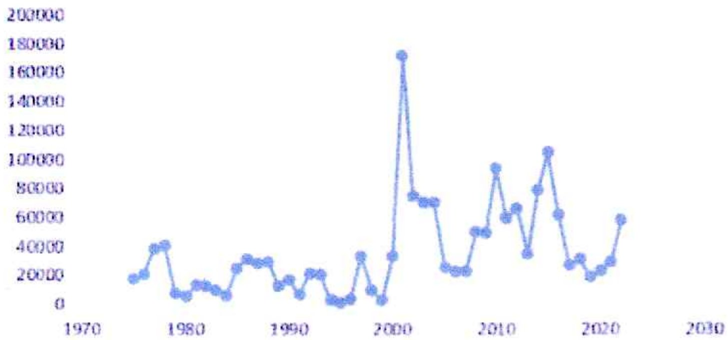
SOCKEYE COUNTS AT LOWER GRANITE DAM 1975 TO 2023



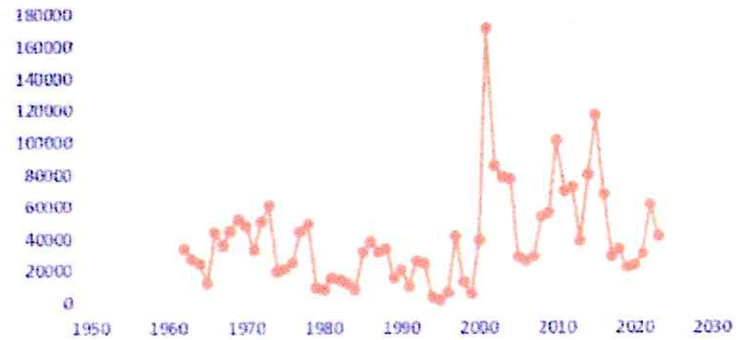
HATCHERY STEELHEAD AT LGR 1975 TO 2022 WILD STEELHEAD AT LGR 1994 TO 2022



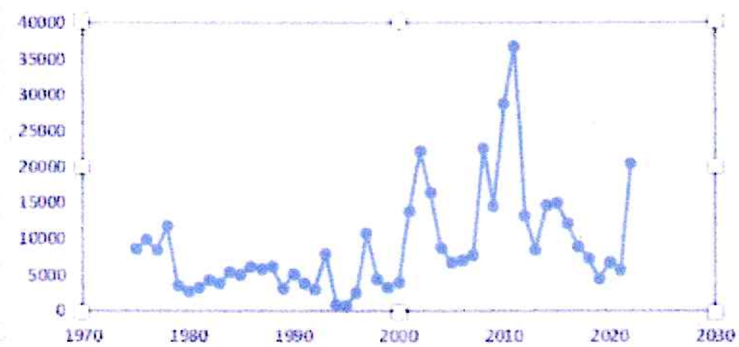
SPRING CHINOOK AT LOWER GRANITE DAM 1975 TO 2022



SPRING CHINOOK ICE HARBOR DAM 1962 TO 2022

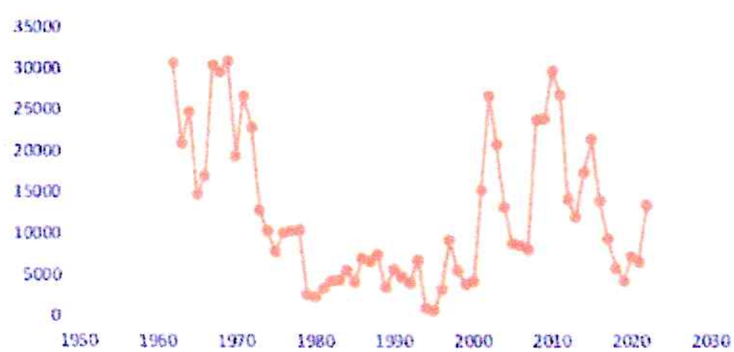


SUMMER CHINOOK AT LOWER GRANITE DAM 1975 TO 2022

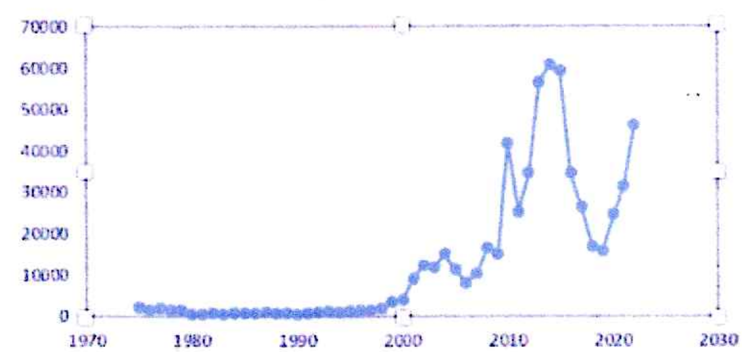


FALL CHINOOK AT ICE HARBOR DAM 1962 TO 2022

SUMMER CHINOOK AT ICE HARBOR DAM 1962 TO 2022

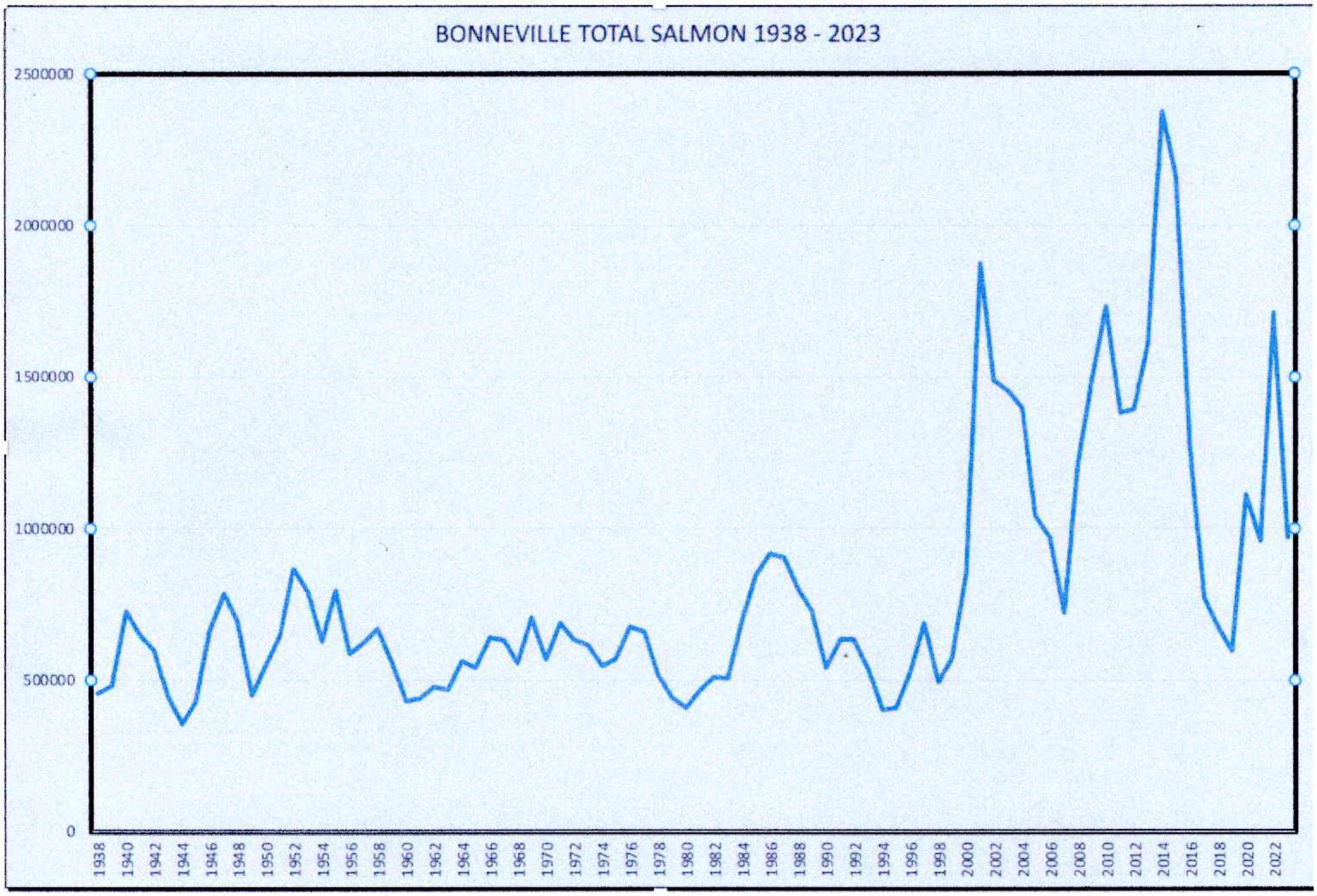


FALL CHINOOK AT LOWER GRANITE DAM 1975 TO 2022



John L. McKern Biography

John McKern is a retired Corps of Engineers Fish and Wildlife Biologist. He came to the Walla Walla District of the Corps in 1971 after attaining a BS Degree in Wildlife Science and an MS Degree in Fisheries Science. His graduate work was on life history biometrics of steelhead trout. His work with the Corps originally concentrated on fish passage at the dams but grew into fish and wildlife measures to mitigate the effects of dams and reservoirs. He administered many research contracts for fishery studies related to the effects of dams, and a pioneering study assessing the wildlife and habitats from the mouth of the Columbia to the Canadian border and the Snake River to Weiser, ID. As a consultant since 2000, he provided expertise to the Idaho Power Planning Council representatives, to the Colville Tribe on Chief Joseph Hatchery, and to the Yakima Irrigators on fish passage at Cle Elum and other Bureau of Reclamation Yakima Basin dams.


BONNEVILLE TOTAL SALMON 1938 - 2023
2500000
2000000
1500000
1000000
500000
0
1938
1940
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1944
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1948
1950
1952
1954
1956
1958
1960
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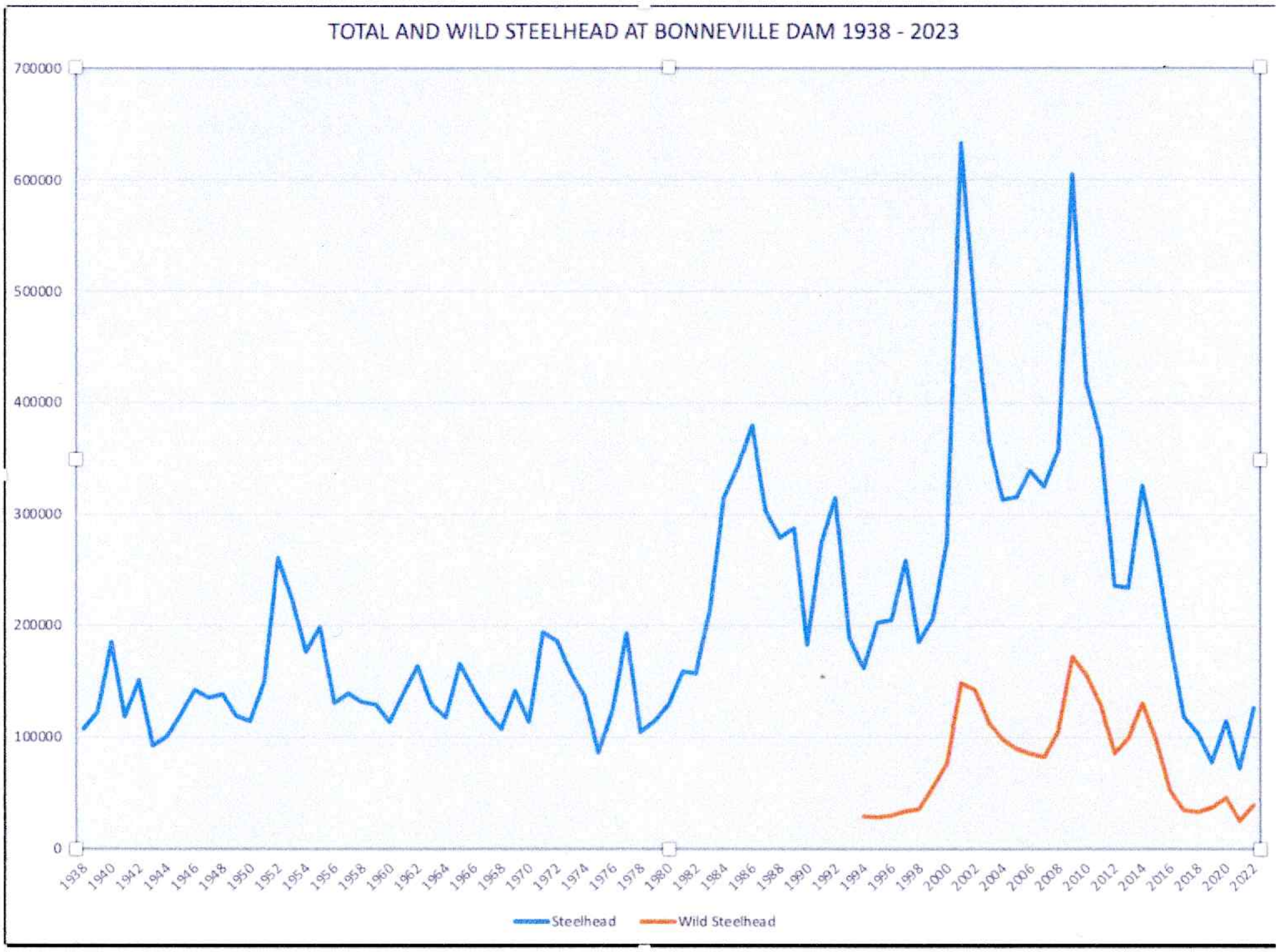

TOTAL AND WILD STEELHEAD AT BONNEVILLE DAM 1938 - 2023
700000
600000
500000
400000
300000
200000
100000
0
1938
1940
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1944
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1956
1958
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2018
2020
2022
Steelhead
Wild Steelhead