Chandalar River **U**nited **M**anagement (CHUM)

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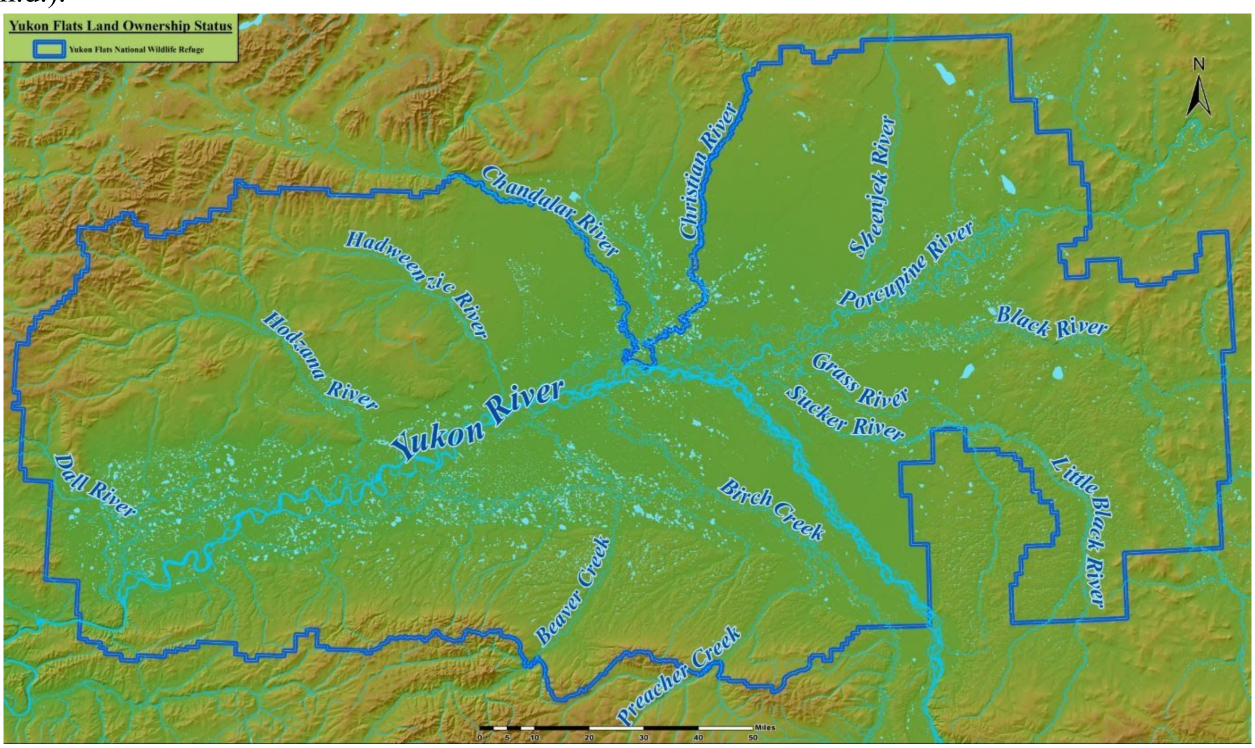
Background

The Chandalar River is a tributary of the Yukon River, with a total drainage area of 15,407 square miles, located within the Yukon-Koyukuk Census Area. It is 567 miles, and joins the Yukon River at the Yukon's 982nd mile (U.S Fish and Wildlife Service, 1990). It is formed by the confluence of the North Fork Chandalar River and Middle Fork Chandalar River, which combine to form the Main Stem, The largest Fork is the East Fork, which joins the Main Stem upstream of Venetie (U.S Fish and Wildlife Service, n.d.). As the East Fork meets the Main Stem, the river flows through the Yukon Flats Wildlife Refuge.

The river is home to several species of fish, much of which are depended upon by the local population, and which also fuel the local sportfishing industry. Arctic Grayling, Northern Pike and several species of whitefish; Humpback, Broad and Round, are abundant. The whitefish have been observed using connected streams to spawn, and additionally utilize connected lakes for both feedings and overwintering. In addition to these species, the river supports Chinook populations, and summer and fall runs of Chum Salmon. Other species that have been documented within the river are Sheefish, Dolly Varden Char, Lake Trout, Burot, Slimy Sculpin, and Longnose Suckers (U.S Fish and Wildlife Service, 1990).

The Chandalar's Stream Flow ranges from 18,400 cubic feet per second to 60,800 cubic feet per second, depending on the year. However, there is no data available beyond 1974 (USGS, n.d.).



History

The Chandalar River received its name from the French term "Gens de Large," which means "nomadic people." This term was used to denote the native populations that lived along the river. Early USGS field notes spelled the term "Chand-da-larg," an Anglicization that created its common name. More recently, the U.S. Board on Geographic Names has pushed to rename some Alaskan sites to their Native names. In 2015, the Chandalar River was renamed the Teedriinjik River, its name given by the Gwich'in native people (Shalev). This name means "Luminous River" or "Shining River."

The major town on the Chandalar River is Venetie, 45 miles northwest of Fort Yukon. It was founded in 1895 by a man named Old Robert because of the location's plentiful fish and game (*Venetie*). In 1899, the USGS recorded about 50 native peoples living on the Chandalar. In 1905, the gold rush brought a large number of miners to a camp upstream from Venetie. However, by 1910, the gold scene at the Chandalar was finished. In 1943, the Venetie Indian Reservation was established with help of other Native towns including the Arctic Village and Christian Village, and they eventually secured 1.8 million acres of land as part of the Alaska Native Claims Settlement Act of 1971. Archaeological evidence shows that the Arctic Village area was populated as early as 4,500 BC (*Arctic Village*).

The population of Venetie consists of descendants of the Neets'ai Gwich'in, Gwichyaa Gwich'in, and Dihaii Gwich'in. They lived a highly nomadic life until the 1950s, using seasonal camps and semi-permanent settlements including Venetie, Arctic Village, and Christian Village. Subsistence activities involving caribou and fish have continued to play a significant role in their daily lives and culture.

Current Groups and Policies

Currently, groups in both countries are working to protect the whole Yukon Watershed, which affects the Chandalar River Subwatershed. For the United States, the main group overseeing the watershed is the Yukon River Inter-Tribal Watershed Council (YRITWC). They are an indigenous, grassroots, non-profit organization consisting of 73 First Nations and Tribes. In 2013, they released the Yukon Watershed Plan, stating their vision of the Yukon River to have "water of such quality that it sustains the health of the people, communities, fish, wildlife, and plants important to the ways of life of the people" (Yukon River Watershed Plan). Their 50 year goal is to be able to drink water directly from the Yukon River. In the report, they detail a myriad of water quality standards to uphold such as temperature, fecal coliform bacteria, and salinity. For example, seven-day mean minimum intergravel dissolved oxygen must be kept at or above 9.0 mg/L in active fish spawning areas and 8.0 mg/L in other areas. At the time of the report, the Alaska Department of Environmental Conservation had only found three water bodies to be impaired, but a stated objective in the report was to have an anti-degradation perspective and policy. Much of the report is focused on increasing monitoring of more sites and more possible pollutants. Because the Yukon Watershed is so large, the YRITWC also encourages the active community members to help in water quality monitoring through the Indigenous Observation Network (Herman-Mercer).

In Canada, the government of Yukon is the main group that assesses the health of the Yukon Watershed. In 2014, they released the Yukon Water Strategy Action Plan, a 5-year plan to tackle water issues in the Yukon Watershed. In this plan, they depicted 6 concrete areas to address: better understanding and managing of groundwater, maintaining access to safe drinking water, planning for present and future water needs, promoting sustainable water usage, improving water management programs, and improving the sharing of water information. They provided annual updates to the public of their progress and held annual water forums for the public to voice concerns. The plan ended in 2019, having achieved various successes such as establishing a permanent groundwater management unit, creating a regular Yukon water forum, and increasing monitoring capabilities with 26 new hydrometric stations. Although this plan finished, it has still set forth future goals including strengthening legislation around well drilling and developing a more refined wetland policy.

Mission Statement

CHUM's mission is to guarantee that the river remains sustainably fishable until the year 2035 and beyond in order to protect the native fish species that occupy the river, which many communities within the river basin are dependent on, and fuel the local sportfishing industry. We also aim to improve overall water quality and mitigate freshwater input.

Problems

CHUM highlights the importance of environmental, economic, and social health in the Chandalar River Basin, a vital sub-basin of the Yukon River Basin. Problems discussed within the following table focus on three interconnected issues that affect various populations of Alaska's unique range of urban, rural, and subsistence living styles.

Problems	**Descriptions**	**Causes**
P1: Water Quality	● Possible sources of released heavy metals such as mercury, arsenic, lead, and zinc ● High sediment loads ● Low nutrients ● Lack of extensive and consistent water measurements ● High freshwater input ● Hard water	● Active gold, gravel, and zinc/lead mines ● Inconsistent and incomplete water testing due to rural area and no water governing committee in Chandalar River Basin ● Increased recreation and sportfishing ● Glacial melting ● Unconsolidated materials line river

P2: Salmon Industry	• Supports chinook, and summer and fall chum salmon • Fish heavily depended upon by Venetie natives • Glacial melting (connected with P3) causes colder temperatures and could prevent salmon spawning	• Glacial melting changes water temperature • Constant and growing fishing needs from subsistence use and sportfishing
P3: Freshwater Input	• Decreases water temperatures (connected to P2) • Estuarine and marine water salinity stress • Marine phytoplankton replaced by brackish and freshwater phytoplankton • Glacial melt flooding • Disrupts natural nutrient cycling	• Glacial melting • Increased development

Table 1. Overview of primary problems, their descriptions, and causes of the Chandalar River Watershed.

Problem 1: Water Quality Degradation

The water quality raw datasets provided by the USGS of Chandalar river were compiled and indicate high freshwater input, high chemical weathering of rocks, low nutrient input, and possible sources of pollution.

Ideal pH for most fish, particularly local chum, is 6.5-8.5, so the Chandalar river samples indicate a sufficient pH of 7.9. High alkalinity acts as an ideal buffer to maintain this pH, although is indicative of water hardness. According to the Water Research Center, the buffering capacity - or alkalinity - should be no less than 20 mg/L. Thus, our value of 105.4 mg/L being over 5x more than this minimum indicates hardness. The total dissolved solids (TDS) average value was found to be 151 mg/L. This suggests hard water with it being slightly on the lower end. Although it is more detrimental to have high levels of TDS, low levels of TDS can cause water to diffuse into cells too fast, swelling the cells of aquatic life and causing fish to float. This alters their ability to move in the water column.

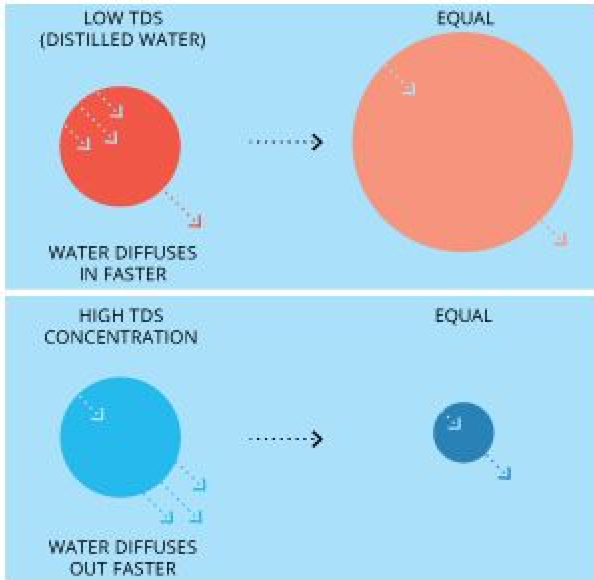


Figure 1. The above figure displays the impacts low TDS vs high TDS would have on cells (Fundamentals of Environmental Measurements, 2014).

Minerals are another factor of essential nutrients to waterways. Silica is a particularly important mineral for plant life. Silica levels are significantly low in the Chandalar river at 2.8 mg/L, although according to APEC Water, rivers usually maintain levels of 5-25 mg/L, low silica levels may be a limiting factor for plants. Manganese, another essential mineral, persisted at 16.5 ug/L. This higher level suggests water hardness, although it is well below the limit of 100 ug/L precaution for industrial use assigned by the EPA according to APEC Water.

These many indicators of water hardness are confirmed with the average measurement of hardness with respect to Ca and Mg measured from $CaCO_3$ to be 120 mg/L. The USGS defines the range of moderately hard water to be 61 to 120 mg/L and the hard water to be in a range of 121 to 180 mg/L. With some samples above 121 mg/L, the Chandalar river is considered to be moderately hard to hard with respect to $CaCO_3$. Hardness and high levels of $CaCO_3$, HCO_3^- ions, and Ca^{+2} ions, are all indicators of heavy chemical weathering of rocks. The alluvial deposition surrounding the Chandalar river with unconsolidated materials, gravel lining the river, and high sediment loads are indicative of this type of chemical weathering via deionization of sediment materials. This area also contains limestone bedrock; thus, this abundance of $CaCO_3$ deionizing in the river water is expected. $CaCO_3$ is also in part responsible for the vibrant blue hue seen in the water, since $CaCO_3$ is known to make water more blue.

Specific conductivity can be an indicator of pollution when values are seen to change since it should maintain consistency in healthy rivers. Chandalar river values from a set of given water sample results from the USGS were found to range from 147 to 308 uS/cm @ 25C. Since this is over a 100 unit range, this is indicative of discharge or pollution input. The average value of 218.94 uS/cm @ 25C is a bit high for typical salmon habitat, as according to the Oregon Watershed Enhancement Board they generally live in rivers with conductance levels of less than 150 uS/cm @ 25C. This could be due to pollution sources such as mines, oil leaks from local storage facilities, or due to high freshwater input from glacial melt.

Water Quality Indicator	**Average Value**	**Applicable Average Ranges**	**Analysis**
Turbidity, JTU	2	1-8 JTU is indicative of moderate plant and animal life (Dulcie, 2015)	Good and suggests moderate aquatic life
Specific Conductance, uS/cm @ 25C	218.94 (Range 147 to 308 uS/cm @ 25C)	Typically ranges <150 uS/cm @ 25C for salmon (Kidd, 2016)	Relatively normal but a bit high for salmon. The large range is an indicator of possible pollution
pH	7.9	pH range for salmon is 6.5-8.5 (Kidd, 2016)	Ideal for salmon and other aquatic life
Alkalinity, mg/L CaCO3	105.4	Alkalinity can act as a successful buffer when it is >20 mg/L (Oram, n.d.)	Ideal for maintaining pH, higher end indicates water hardness
Total dissolved solids, mg/L	151	TDS Range of 150-175 mg/L indicates hard water (Fundamentals of Environmental Measurements, 2014)	Indicates hard water
Nutrients ● Nitrate, mg/L as NO3 ● Orthophosphate, mg/L as PO4 ● Potassium, mg/L	● 0.68 ● 0 ● 0.65	● River Nitrate ranges are typically 0.1-3.0 (LEO, 2011) ● Natural levels of Phosphate in rivers range from 0.01-0.05	All nutrients are relatively low, particularly phosphate which appears to be completely used up. Phosphate is often a limiting factor in aquatic life and is most likely a limiting factor

		mg/L (Kotoski, 1997) ● <132 mg/L for salmon and <1.16 mg/L for daphnia (Kidd, 2011)	in this ecosystem
● Hardness, Ca, Mg, mg/L CaCO3 ● Ca 2+ dissolved, mg/L	● 120 ● 39	● Moderately hard: 60-120 mg/L, hard: 121-180 (USGS) ● >25 high suitability for mollusks	● Since some hardness measurements exceeded 120, this water would be in the range of moderately hard-hard ● High Ca +2 content suggests ideal content for mollusks
Radiation ● Alpha particles, pCi/L ● Radium-226, pCi/L	● 2.95 ● 0.03	● Maximum Contaminant Level (MCL) = 15 pCi/L, MCL goal (MCLG) = 0 pCi/L. MCL = 5, MCLG = 0 (Jacobus et al., n.d.) ● Radium-226 MCL = 5, MCLG = 0 (Patil, et al., 2014)	● Alpha particles are a ionized radiation form of Polonium-210 decay which is carcinogenic at 0.1 pCi/L so Po-210 should be tested ● Radium-226 content possibly sourced from mining efforts
Minerals ● Silica, mg/L ● Manganese, ug/L	● 2.8 ● 16.5	● Silica levels usually 5-25 mg/L (APEC, n.d.) ● Mn levels shouldn't exceed 100	● Silica is significantly low, possibly a limiting factor for biolife since it is a necessary mineral for

		ug/L for industrial use (APEC, n.d.) Most natural levels in rivers range from 11-51 ug/L.	plants ● Average Mn, presence indicates some hardness
Chloride, mg/L	0.6	Average range for rivers is 45-155 mg/L (LEO, 2011)	Extremely low Cl- levels indicate high freshwater content
Fluoride, mg/L	0.1	Safety hazard exceeds 2 mg/L, optimal is 0.7 mg/L (ASTDD, 2016)	Good, below optimal
Sulfate, mg/L	16.5	MCL = 250 mg/L (Oram, n.d.); average for freshwater rivers is 20 mg/L	Well below MCL, ideal
Water Temperature, deg C	6.01	Salmon habitat suitable for adults and juveniles range from 7.2-15.9 deg C (Kidd, 2016)	Annual mean T is too cold for spawning of chum, chum habitat time is limited to summer temperatures

Table 2. Analysis of significant water quality indicators via the raw data provided by the USGS and separately analyzed via Excel to find averages of each quality measurement.

Chandalar River has a history of gold mining, and continues to maintain 9 active mines for gold and gravel next to Chandalar lake at upper Chandalar river. The waters next to the mines have little to no water testing. Since a sizable amount of water testing in this region is volunteer-based, this farther downstream location with little-no residential development lacks the testing required for mining activities. There is also a zinc-lead mine upstream at the flowpoint of Chandalar river, yet the river lacks all records of heavy metal testing that would be prevalent next to a mine of this sort. There is also a bulk fuel field in the middle of Chandalar river at the Venetie village which lacks almost all safety requirements that are required according to the

Alaska Energy Authority. No worker on site maintains training on the handling of bulk fuel according to the most recent available assessment in 2015. Their code violations range from weeping valves, pipes, and tanks, to lack of safety measures such as no fencing, no foundational support, no secondary containers, no locks, and many more (Rhodes ERM, 2015).

Image 1. The above image displays weeping victaulic fittings in their largest bulk fuel site containing 48,900 gallons (Rhodes ERM, 2015).

Problem 1 Solution: Increased Monitoring

The immediate solution that the CHUM plan requires is a consistent and mandatory widespread monitoring system in place complete with heavy metals, radioactive chemicals such as Po-210, and dissolved oxygen - all of which are not readily available through their current volunteer-based testing system. Special consideration would be focused on testing at chum spawning sites, near villages - particularly near Venetie and next to mines.

Due to the hardness of the water, drinking water should be treated with a water softener and should be implemented in the villages throughout the Chandalar River watershed over the next 3 years.

A longer term plan over the span of the next 8 years includes the implementation of a riparian buffer zone in order to filter the high sediment loads and mitigate freshwater input. The untouched forest trees that would line the river would also provide stability for the shorelines, reducing erosion as well as increasing nutrient input into the waters.

An even longer term plan would also entail a conversion from mining, oil, and gas to a more sustainable form of living via renewable energies such as wind and solar power. This would create a plethora of jobs, and should include proper training - something that has not been provided by the oil industry in Venetie. Although, immediate training should also be implemented for those working in the bulk oil fields in Venetie, as well, as this is currently a large source of energy in this region. Proper remediation must also be immediately taken to repair broken and weeping Viculators, valves, pipes, and tanks. Sufficient foundations should also immediately be put in place for the oil tanks, as well as adequate safety measures including fences and locks. This will be a particularly costly remediation but is necessary for the wellbeing of the surrounding environment and safety of the drinking water.

Problem 2: Fall Chum Industry

According to the Alaska Department of Fish and Game (ADF&G), Fall Chum is the most harvested form of salmon in Alaska. Salmon are anadromous fishes, which means they spend most of their lives in saltwater, and move to freshwater to spawn. Shortly after spawning, the adult salmons die. Thus, the importance in production of viable eggs is extremely high. If these eggs do not survive to replace the parents, there will be a net loss of salmon. There are multiple factors that prevent successful growth and survival of these fish. Three main factors deemed as possible deterrents for growth and survival.These factors include water quality, water temperature, and availability of food. Water quality is a large issue in the Chandalar River and was discussed in the previous section. The next factor is water temperature. Alaskan waters are extremely cold, and only home to species that are able to withstand such cold temperatures. Most salmon stay further South, and only few actually make it up to the Chandalar River. Thus, the protection of species that make it up to the Chandalar River is imperative. Studies found the majority of salmon spawn mostly in the main fork of the Chandalar River, below the mouth of the East Fork from mid-September to early October. Around this time, water temperatures can be anywhere from 0 – 2 ℃. Tying in with water temperature, there is a lack of food for salmon. Salmon typically eat benthic invertebrates. With such cold temperatures, it is often difficult to find other species that are able to withstand this type of habitat. Thus, this makes food availability scarce for this important species. There are many fishing villages, especially in the southern portion of the Chandalar River, that rely on Chum Salmon for a winter food source. Another issue for the market is the seasonality of these salmon. Commercially, Chum Salmon is typically canned or dried and sold to locally and internationally. Thus, the continued survival of Chum Salmon is imperative for the economic health of Alaska.

Problem 2 Solution: Fall Chum Hatchery

In the 1970s, once state harvest records plummeted to the lowest numbers ever seen, the salmon fisheries enhancement program began. Since the implementation of the salmon hatchery, salmon harvests have more than doubled. The graph below from the Alaska Department of Fish and Game's Alaska Salmon Fisheries Enhancement Annual Report 2018 shows the increase in production of salmon harvests both naturally and from hatcheries. It shows the hatchery program implemented in 1974. From there, there is a general increasing trend of both wildstock harvest and hatchery harvest. In 2018 there is a decrease in both wild stock harvest and hatchery harvest.

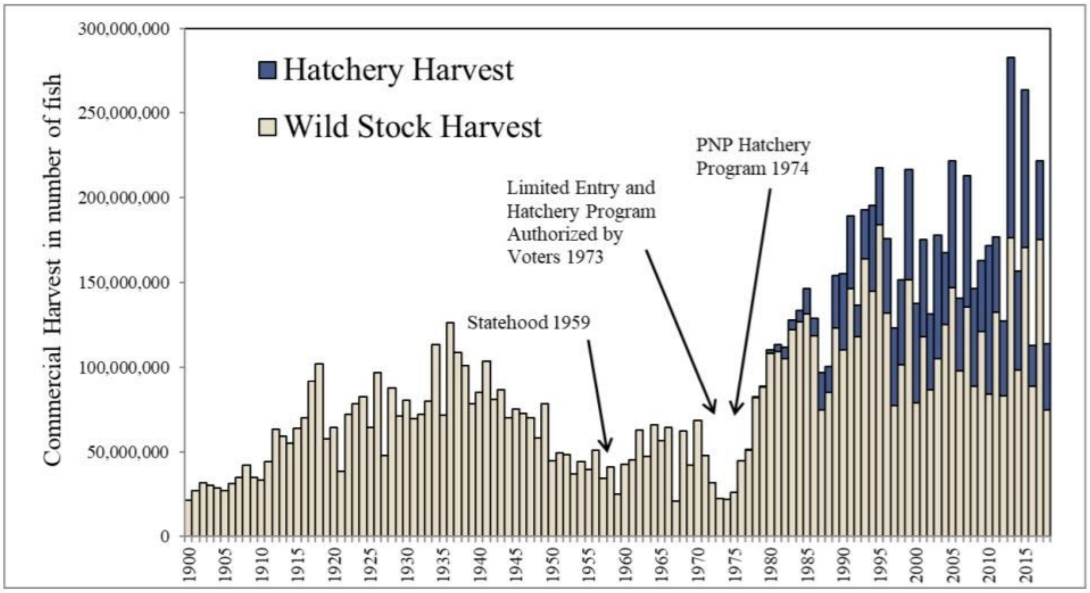


Figure 2. This graph shows the annual salmon harvests of both pink salmon and chum salmon combined. The data ranges from 1990-2018.

Along with this, foreign sales have also increased dramatically. In 2019, Tradex reported an increase in price of Chum Salmon from \$1.48/lb to \$2.40/lb. This indicates a shortage in Chum Salmon across the market. From the graph seen above and the increased price of salmon in 2019, there is another decreasing trend in the availability. This could be due to natural fluctuations in population, but there are steps we can take to make sure these fluctuations do not decrease anymore, but rather increase. Due to the seasonality of the salmon and the shortage of these fish, the implementation of another hatchery would be beneficial to the economy. This salmon hatchery would have a recirculating water system, to preserve the amount of water being used. McClean and Raymond (1983) found that it would only take approximately 10 gallons/minute in a recirculating system for the salmon (for each salmon?--check this). This recirculating system would also allow for the preservation of heat within the system. This would create cost reductions for water use and water heating. This heating system would also allow a more comfortable living situation for the salmon than what they experience in the Chandalar River. The use of salmon on the market from the hatchery as opposed to fishing from the Chandalar River would allow the salmon in the Chandalar River to spawn and survive in a safe and undeterred environment. Switching to the use of hatcheries would allow less anthropogenic impact on the Chandalar River, and would ultimately be beneficial to both the ecological integrity of the river and the biodiversity and abundance of salmon in the river.

Problem 3: Freshwater Input

Freshwater input is a process that occurs 1) during and after glacial melt; and 2) as a result of increased social development in an area. The Chandalar River is located in the state of Alaska, the most northern state in the United States; and sits at approximately 66 degrees North latitude. In the wake of global climate change, polar and other high and low latitude regions around the world are some of the most vulnerable areas in the world to experiencing effects related to melting of the Earth's permafrost and glaciers. The Chandalar River is part of the Yukon River Basin, which ultimately drains into an estuarine environment into the Bering Sea. Estuaries are coastal water bodies composed of brackish water (saltwater and freshwater mixed together) and act as the transitional zone between river and maritime environments. Estuaries are also the home to niche and unique ecosystems and can be altered dramatically by a small amount of change. Global climate change causes estuaries to become extremely vulnerable to the effects associated with melting of the world's permafrost and glaciers, because they desire equilibriums of temperature, nutrients, and salinity in the waters. Freshwater input into the Chandalar River ultimately drives the environment away from these equilibriums that are favored by the deltaic environment further downstream at the mouth of the Yukon River. Aquatic organisms, such as plankton communities are vital to water bodies, as they hold the ability to naturally cycle nutrients and serve as the base of the aquatic food web. Marine phytoplankton can become over-dominated by freshwater and brackish water phytoplankton during episodes of freshwater inputs, disrupting the natural ecosystems and food chains of the Chandalar River and Yukon River Basin.

Increasing development in an area can also result in becoming prone to complications associated with freshwater input. With increased development, comes more roads, buildings, and sidewalks. Pavement and other man-made surfaces that do not let water properly infiltrate the ground are known as impervious surfaces. Impervious surfaces increase the amount and rate of stormwater input into natural drainage systems in an area. These events decrease water quality, decrease water temperature, and decrease downstream salinity. Increased glacial melt flooding from global climate change and increased stormwater input from local development would be highly detrimental to the state of the Chandalar River. Thus, the need to refrain from developing the area is crucial.

In relation to the plan's problems 1 and 2, freshwater input also has the potential to negatively affect the summer and fall Chum Salmon populations of the region. These Chum Salmon rely on water being warmer and excellent in quality for spawning later in their life, after they return from the sea. However, episodes of freshwater input can negatively affect both temperature and quality. During the earlier stages of the life of a Chum Salmon, it relies heavily on the downstream estuary to act as the transitional zone between the time in which they are born and the time in which they convert to become a saltwater fish in order to acquire the majority of its body mass.

Problem 3 Solution: Increased Regulation of Headwaters

Freshwater input can be monitored, regulated, and prevented. Mitigation is needed in order to protect habitats at both the Chandalar River headwaters, and the mouth of the Yukon

River. The first step that is going to be taken is to put field scientists at different sites throughout the Chandalar River with temperature probes and data loggers to monitor water temperatures, and at the mouth of the Yukon River with electrical conductivity data loggers to measure water salinity. Mass balance of glaciers can be determined through the use of remote sensing and digital terrain analysis to account for the aspect of glacial melt and overall climate change in the Chandalar River region. Freshwater input can be prevented by establishing an environmental governance system that inhibits and/or closely monitors the growth of potential areas of industrial contamination and residential imperviousness. The combined efforts of science and policy can cooperatively achieve a solution to the freshwater input where it can be monitored and mitigated at a regional or local level. However, climate change in general that is causing the glaciers to melt is a much larger issue than that of the Chandalar River. If successful, the Chandalar River United Management (CHUM) action plan can be used as a model for efforts on a larger scale.

Evaluation

Each of the proposed solutions have their own benefits and detriments. In order to evaluate the best possible solution for the Chandalar River in terms of sustainability, we will look at each proposed solution through **environmental** impact, **economic** impact, and **equity** impact. These are known as the three E’s of sustainability. The most sustainable solution will meet a majority of these criteria.

The first solution proposed is a multi-faceted plan to combat three major issues with water quality: freshwater input, high sediment input, and pollutant input. This plan would immediately implement a water softener treatment of drinking water across all villages along the Chandalar river. This would be economically costly, but would also improve equity as clean and safe drinking water is a human right. Another immediate solution is to implement consistent and complete water testing across the Chandalar river, with a focus at chum spawning points, villages, and near mining operations. Currently water testing is partially done on a volunteer basis, which leaves much of the testing inconsistent as well as incomplete, lacking heavy metal and total suspended sediment load measurements. This solution would cause positive improvements on the environment in a long term framework. Training and jobs would be provided via the USGS who would mandate these protocol testing. This would in the long term be economically beneficial for the community as well as equitable as it would maintain sustainable jobs for the community. The implementation of riparian buffer zones would be the most beneficial for the environment, as it would replenish nutrients into the river and mitigate sediment and freshwater inputs. However, it would be economically costly. In terms of equity, this would allow for long term safer drinking water and an assurance of long term sustainability on aquatic life. The most extensive and longest implementation in our plan is the implementation of renewable energies in the form of wind and solar power. This would be immediately economically cost effective and negative on the environment during construction, but long term the conversion to a more sustainable and cleaner source of energy would be beneficial to the environment, the economy, as well as the overall equity in the sustainable jobs that would be created and required training that would be provided.

For the second proposed solution, the implementation of a salmon hatchery, there would be a negative impact on the environment. Planning and developing a hatchery would require the use of natural land and there would need to be extra measures to ensure that waste from the hatchery is disposed of properly. In terms of economic impact, the implementation of a hatchery would be extremely beneficial. The hatchery would allow for an increase in job availability in Alaska, and would support the Chum Salmon industry both locally and internationally through the increased availability of the species. However, there will be expenses associated with the construction and maintenance of the hatchery. Although there will be this extra cost, this cost will be offset by the revenue collected from increased local and international trade. Lastly, the implementation of a hatchery meets the equity standard. There is an even distribution of fairness across the board of stakeholders involved in the Chum Salmon industry. The salmon in the Chandalar River are left to recuperate and bring their population numbers back up. There will be an increase in the job market in Alaska, which is a benefit to the community. There will be more salmon produced which will help the industry as well as the utility of the citizens in the area and abroad. Overall, the implementation of a hatchery would have an initial high cost that would later be offset from salmon trade and distribution, as well as high equity across all stakeholders, and the environmental impact can be mitigated to ensure the least amount of detriment to the environment.

The proposed third solution of refraining from development in the area, as well as monitoring Chandalar River headwaters and the Yukon River Basin Estuary environment would be beneficial economically, environmentally, and equitably. Economically, it has the potential to create scientific research positions in the area. Melting of Alaska's glacial areas induce the ability to monitor temperature, salinity, nutrient fluxes, and overall climate change. Scientists and public and private sector companies and organizations can conduct field studies to collect data, process their results, and communicate with the public about their conclusions. Essentially, the only thing that would require money is some inexpensive field equipment and salaries for the scientists. One potential economic factor that could have a negative impact is the plan's objective to refrain from increasing development in the region, however, with over 10% of the Yukon River Basin's human population adopting a subsistence lifestyle, lack of regional development should not negatively affect the area in any dramatic fashion. Environmentally, this solution holds the ability to preserve valuable ecosystems. The previously stated problems of lowering water temperatures, decreasing salinity, and increasing nutrient fluxes are all detrimental to local summer and fall Chum Salmon populations, as well as plankton communities. The estuarine environment at the mouth of the Yukon River relies on a proper balance of warm, brackish water. Episodes of freshwater input at its headwaters, such as the Chandalar River, ultimately lower temperatures and salinity, and increase nutrient loading; all detrimental to estuaries. Refraining from increased development would be environmentally beneficial as well. Less impervious surfaces and industrialized activity translates into less runoff and contamination making it into the river system. Equitably, this solution is favorable to the large percentage of subsistence livelihoods and abundance of unique wildlife and ecosystems that the state of Alaska is home to. As previously stated, freshwater input's effect in this area specifically targets fish and plankton communities; two things that essentially are the base of the regional food chain. Subsistence communities and wildlife populations in Alaska need freshwater input to be monitored, regulated, and prevented in order to preserve the life that they have become accustomed to and value so much throughout their everyday lives.

Conclusion

The most essential solution for the success of the Chandalar River United Management (CHUM) plan is the implementation of a riparian buffer zone. A zone of this nature will ensure that nutrients are restored in the river in order for plankton, algae, plants, and subsequently fish to thrive. A buffer zone will also reduce the sediment loads and freshwater inputs going into the rivers thus reducing water hardness from chemical weathering of rocks.

An immediate implementation of consistent and complete water testing will be required, opening jobs and providing training via the USGS to local citizens. A focus on testing of water temperature, salinity, heavy metals, and Po-210 at chum spawning sites, villages - particularly Venetie, and mines will be taken. Consistent monitors should be set up across the basin by 2022.

Drinking water should begin to be treated with a water softener to mitigate water hardness across villages in the Chandalar river. These treatments should be implemented across the basin by 2024. Remediation of bulk fuel tanks should also be implemented immediately to halt further weeping of valves and tanks. Proper spill plans and spill equipment must be prepared on all sites. Remediations as well as appropriate training at all sites should be complete by the year 2022.

The implementation of a salmon hatchery to improve the harvest of chum and improve the local sustainability on chum should be completely implemented by 2024.

A long term incremental implementation of renewable energies should be implemented by the year 2035. The conversion of oil power to wind, solar, and hydropower - fueled by freshwater input - will create sustainable jobs and provide training for the communities along the Chandalar river and significantly boost the long term economy.

The formation of a distinct Chandalar River Watershed committee will be put in place to fill the current gap of such a committee. A dedicated committee to focus on the Chandalar basin will be beneficial and allow for quicker action for this large and remote watershed. This committee would oversee future watershed management plans, water testing, and future outreach programs.

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