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Jordan River:
A Desolate Coastal River

Introduction

The Jordan River watershed is located along the southwest coast of Vancouver Island, approximately 50 kilometers west of Victoria, British Columbia. Historically, Jordan River supported a large variety of aquatic life including chum, pink and coho salmon, as well as cutthroat, steelhead and resident rainbow trout (Wright & Guimond, 2003). The salmon populations of Jordan River were challenged by industrial development, logging and hydroelectric activities along the river bank (Wright & Guimond, 2003). A dormant copper mine from the early 1900s began it's large-scale operation in 1961along the east bank of Jordan River (Peers, 2012). The copper mine was in high production from 1961 until 1968, and then once again in 1972 until 1974 (Sunro Copper, 2013). In the early 1960s, part of the copper mine collapsed into the Jordan River, allowing the waters to flood the bottom of the mine (Peers, 2012). In 1977, the main access tunnel caved in and the mine has been abandoned ever since (Peers, 2012). Copper leachate and contaminates from the mine have leached into Jordan River over the last century to concentrations where the river can no longer support any aquatic life (Wright & Guimond, 2003). The historic salmon runs no longer flourish in Jordan River at an expense to the mine.

The lands surrounding Jordan River are federally owned and actively operated by Western Forest Products (CRD, 2013). In 2010, the Capital Regional District (CRD, 2013) purchased over 187 hectares of land that borders the east side of Jordan River below the mine site, and east adjacent coastal regions for a provincial park (CRD, 2013). Jordan River currently has three BC Hydro power dams, two reservoirs and a power house located along the river (BC Hydro, 2003). The watershed encompasses traditional territories of three First Nations bands in the area (BC Hydro, 2003). There are multiple stakeholders that would need to be consulted in order to attempt to re-establish salmon populations in the river. This paper will refer to a case study of the Tsolum River in Courtenay, British Columbia, to aid in the intervention of a framework that could be applied to Jordan River that pertains to the re-establishment of salmon populations.

Study Area

The Jordan River watershed is located along the southwest coast of Vancouver Island, approximately 50 kilometers west of Victoria, British Columbia. The watershed drains into the Juan de Fuca Strait, and covers an area of about 165 square kilometers (BC Hydro, 2003). The surrounding area is quite mountainous, in which the topography is steep, and consists of volcanic and intrusive bedrock canyons that are lined with crown land forests that are actively operated by forestry companies (BC Hydro, 2003). The mouth of the river hosts a local log sort, and there are three BC Hydro power dams, two reservoirs, and a powerhouse located along the river (BC Hydro, 2003). The area hosts significant mineral deposits like gold and copper (BC Hydro, 2003; Wright & Guimond, 2003). The mouth of the river also holds a high recreational value in surfing for the local community of Jordan River (BC Hydro, 2003). The hydrology of the area and water sources are mainly precipitation and a limited amount of snow melt that feeds into the river from tributaries throughout the Sooke Hills and the Seymour Mountain Range (BC Hydro, 2003).

Background

Mining in British Columbia has long been one of the world's leading mining industries, and has been a major part of the economy and development of the province and still remains a very active industry today (Martin, 2011). A major challenge with mining is the management of discharge effluent, waste rock, and tailings which are created through mining processes (BC Wild, 2001; Martin, 2011). Tailings are a result of mineralized rock being ground up into fine material for processing with chemicals that aid in the separation process of the final target mineral (BC Wild, 2001) Mismanagement of mining waste, like tailings, can result in heavy metal contamination of waterways, and significant ecological loss (BC Wild, 2001; Martin, 2011). Historically, mine waste materials were unregulated, and deposited wherever convenient without consideration of significant long-term ecological impacts (Martin, 2011). Tailings and discharge effluent from mines were deposited directly into streams or coastal areas, which in turn results in heavy contamination and poor water quality leading to long term detrimental effects (Martin, 2011).

The Jordan River copper mine was discovered in the early 1900s, and did not begin it's large-scale operation until 1961, when Cowichan Copper took over the mine (Peers, 2012). The re-opening of the mine brought mining engineers and their families to Sooke (Peers, 2012). The copper mine was in high production from 1961 until 1968, and then again in 1972 until 1974, the break in the mining periods reflected a drop in copper prices (Peers, 2012; Sunro Copper, 2013). The tailings from the mine were transported in a pipe and ejected into the shallow waters on the coast that was adjacent to the river mouth (Hofer, 2008). The tailings could be seen as a large plume along the coast in aerial photos, and the contamination would seep back into the river due to wave action and collect along the shores (Hofer, 2008). The tailing pipe was poorly engineered and maintained, and was constantly disrupted by slumping of the unstable river banks which caused constant seepage back into the river before reaching the coast (Wright & Guimond, 2003). Abandoned and flooded mine shafts would continually release copper contaminates into the river (Wright & Guimond, 2003). In the early 1960s, part of the copper mine collapsed into the Jordan River, allowing the waters to flood the bottom of the mine (Peers, 2012). In 1977, the main access tunnel caved in and the mine has been abandoned ever since (Peers, 2012).

Hydroelectric development along Jordan River was initiated in 1909 and operated continuously from 1912 to 1969 (Wright & Guimond, 2003). Today, Jordan River has three BC Hydro power dams, two reservoirs and a power house located along the river (Fig. 1)(BC Hydro, 2003). These generating facilities are part of BC Hydro's integrated generation system, and contribute to the only major hydroelectric development on the southwest coast of Vancouver Island (BC Hydro, 2003). The hydroelectric development can generate up to 170 MW of power, and can sustain approximately 35% of Vancouver Island's total electricity demands (BC Hydro, 2003). The Jordan River facility is operated as a "peaking plant" to meet voltage demands during peak seasons (BC Hydro, 2003).

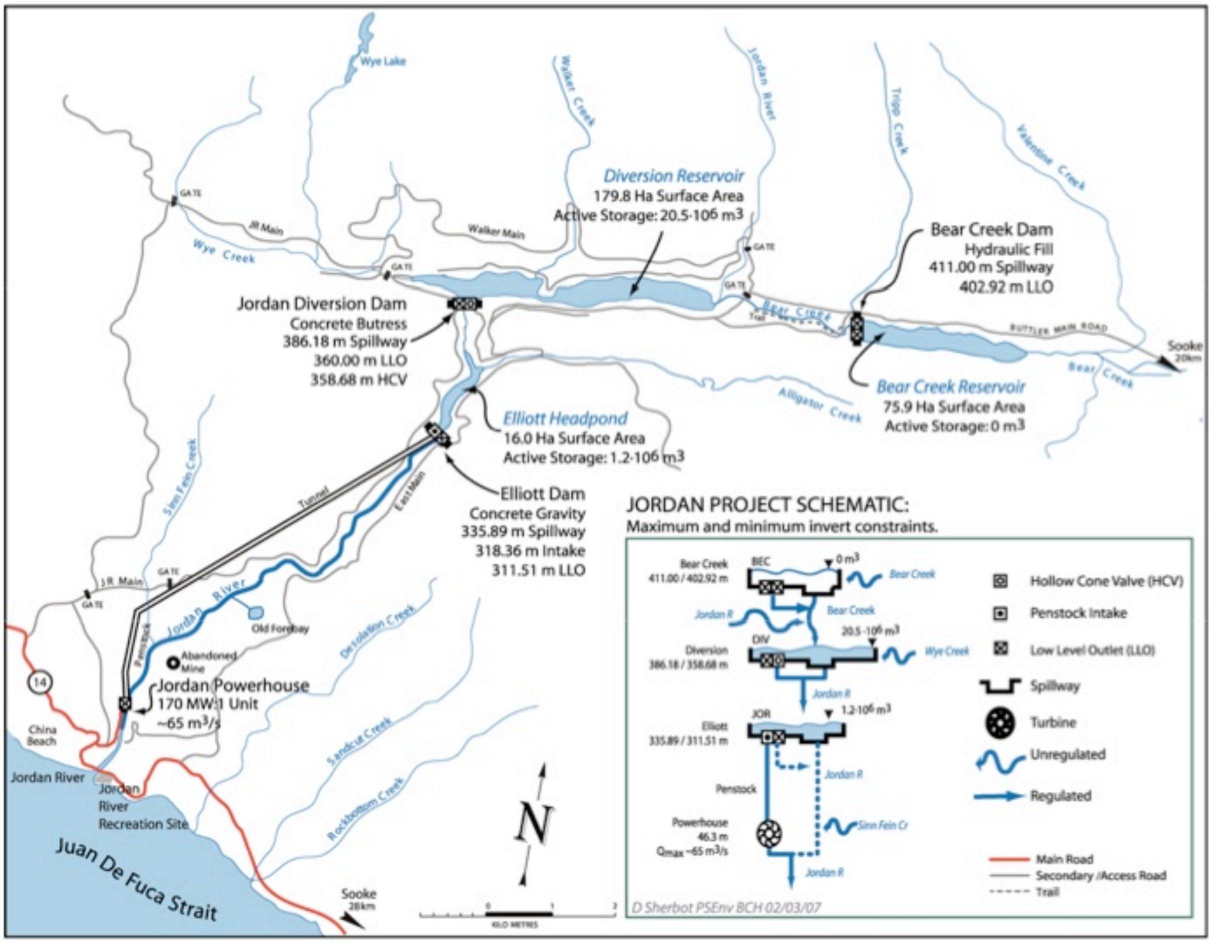

Figure 1. Jordan River watershed schematic of BC Hydro facilities (BC Hydro, 2003).

The Jordan River Water Use Plan was revised by the comptroller of water rights in 2003 to meet the demands of the Jordan River Water Use Consultative Committee in compliance with the *Water Act* (BC Hydro, 2003). The proposed conditions were expected to improve habitat for resident fish populations, and increase the quality of ecological habitat downstream in lower Jordan River (BC Hydro, 2003). The Jordan River Water Use Plan also outlined that BC Hydro would commit to a greater baseflow, that would increase salmonid success in the lower Jordan River by improving water temperature and quality during the summer months (BC Hydro, 2003). The plan also acknowledged the surf swell that was generated at the base of the river, and aimed to reduce turbine discharges at the Jordan River powerhouse during weekend days in March to benefit the local surfing economy of the community (BC Hydro, 2003).

Logging has been active in the Jordan River watershed since the 1880's (Wright & Guimond, 2003). Western Forest Products managed and operated the logging industry since 1934, and conducted booming and tow operations in the lower Jordan River (Wright & Guimond, 2003). A salt marsh was previously located at the present site of the log sort at the mouth of the river but was infilled with materials from a mining slump (Wright & Guimond, 2003).

The Jordan River watershed encompasses the traditional territories of three local First Nation bands including the T'Sou-ke Nation, Pacheedaht First Nation, and Ditidaht First Nation, though no First Nation reserves are established directly within the watershed area (BC Hydro, 2003). The T'Sou-ke Nation have been encouraging a re-establishment of salmon populations in Jordan River, under the incentive of re-initiating their fish and wildlife harvest rights that are outlined in the Douglas Treaty (BC Hydro, 2003).

In the 1950's, pink and chum salmon stocks reached peak numbers between 5,000 and 10,000 adult salmon (Wright & Guimond, 2003). Currently there are no salmon spawning in the Jordan River, or any young salmonids due to copper levels being nearly 40 times greater than the maximum criteria of 2 ug/l for freshwater aquatic life as outlined by the BC Water Quality Guidelines (Wright & Guimond, 2003). Sublethal effects of high copper levels on fish species effect reproduction, behaviour, growth and osmoregulation of young salmonids (Singleton, 1987). Osmoregulation is effected by copper inhibiting the control of water intake or excretion through the gills (Singleton, 1987). Studies also suggested that there is something in the water chemistry that is binding copper, and further research of water chemistry analysis in Jordan River is recommended (Wright & Guimond, 2003).

The CRD recently purchased 187 hectares of land from Western Forest Products to establish a park (Fig. 2) (CRD, 2013). The park would recognize recreational values along the coast adjacent of Jordan River, and will aim to protect surrounding forests and wetlands (CRD, 2013).

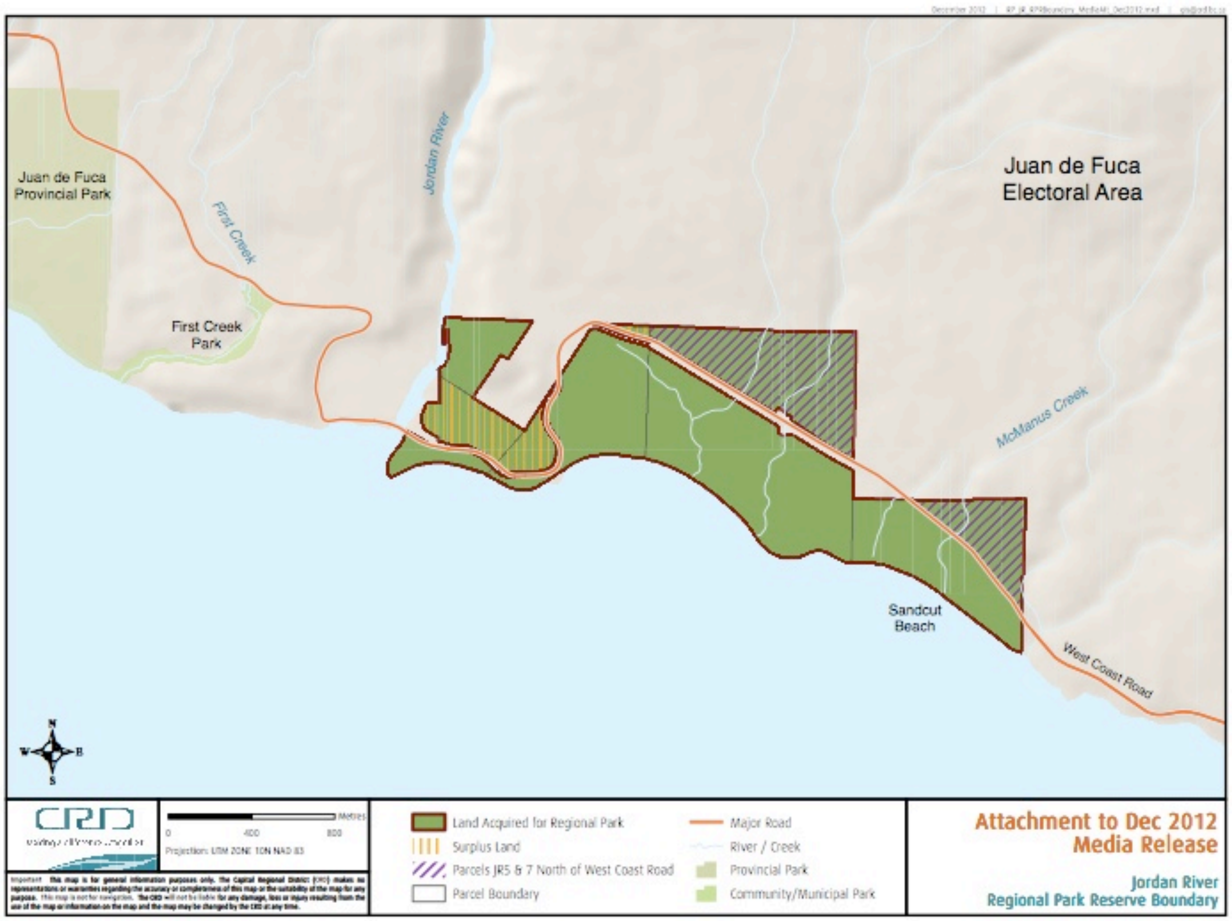

Figure 2. Jordan River Park Boundary as of December 2012 (CRD, 2013).

Case Study

The Mount Washington mine in Courtenay, British Columbia, is referred to as "a short term mine, with long term costs" (BC Wild, 2001). The copper mine was situated on mountainous terrain in the upper portion of the Tsolum River watershed on 13 hectares of land (BC Wild, 2001). The mine was a small, open-pit pit copper mine that was in operation for only a short period from 1964 to 1966 (White & Healy, 2007). Ore was milled from the mine until 1967, when the Mt Washington Copper and Cumberland Mining Company abandoned the mine site after entering receivership (White & Healy, 2007). During its operation, the mine extracted over 360,000 tonnes of ore, and 940,000 tonnes of waste rock (BC Wild, 2001) to produce 17,762 tonnes of copper concentrate (SRK, 2007). After abandonment, exposed open pits of sulphide-bearing pyrite ore and 130, 000 tonnes of waste rock were left to react with air and water which resulted in the formation of sulphuric acid (BC Wild, 2001). The presence of sulphuric acid accelerates the leaching of heavy metals, especially copper (BC Wild, 2001). The acid will continue to leach hard metals from the waste rocks as long as it is exposed to air and water, or as long as the sulphides remain, which can last from hundreds to thousands of years (BC Wild, 2001). This toxic copper leachate entered Pyrrhotite

Creek, then Murex Creek and eventually contaminated the whole Tsolum River watershed (BC Wild, 2001).

The Tsolum River basin once hosted large salmon runs of pink, chum, and coho; along with trout species of steelhead and cutthroat (BC Wild, 2001; SRK, 2007; Sweeten & McLean, 1999; White & Healy, 2007). The river extends from it's headwaters in Mt Washington to the Courtenay estuary (Fig. 3). Records from the late 1940's depict that the Tsolum River supported numbers of over 200,000 pink, 11,000 chum, 15,000 coho, and 3,500 steelhead (SRK, 2007; White & Healy, 2007). These runs were affected by activities that occurred inland, including development and logging along the banks of the Tsolum River, which resulted in increased sedimentation in the river and streams. Post-World War II, river flows of the Tsolum River were disrupted by irrigation for agriculture (White & Healy, 2007). Even more lethal to these agitated salmon runs was the copper leachate caused by acid mine drainage from the Mt Washington mine (BC Wild, 2001). The copper content in the Tsolum River killed young salmonids and deterred adult spawning salmon from returning to the river to spawn in future years (BC Wild, 2001). It was observed that salmon would begin to enter the mouth of the river to spawn, but turn around immediately (Hume, 2011). Following the closure of the mine in 1966, coho stocks dropped from 15,000 to 14 in 1987 (BCMOE, 1995). Coho were a good indicator of the toxicity caused by acid mine drainage and copper leaching in the river since they reside in fresh water for 14 months after hatching (BCMOE, 1995). Local volunteers in partnership with the Department of Fisheries and Oceans (DFO) were optimistic that they could re-stock the river through hatchery fish, and subsequently released over 2.5 million pink salmon into the river in the early 1980's (Hume, 2011; White & Healy, 2007). None of the salmon returned to spawn in following years (Hume, 2011). By 1985, it was determined the the Tsolum River fisheries had been eliminated by acid mine drainage, and it was estimated at an economic $2.7 million loss annually (BCMOE, 2008; BC Wild, 2001; Hume, 2011).

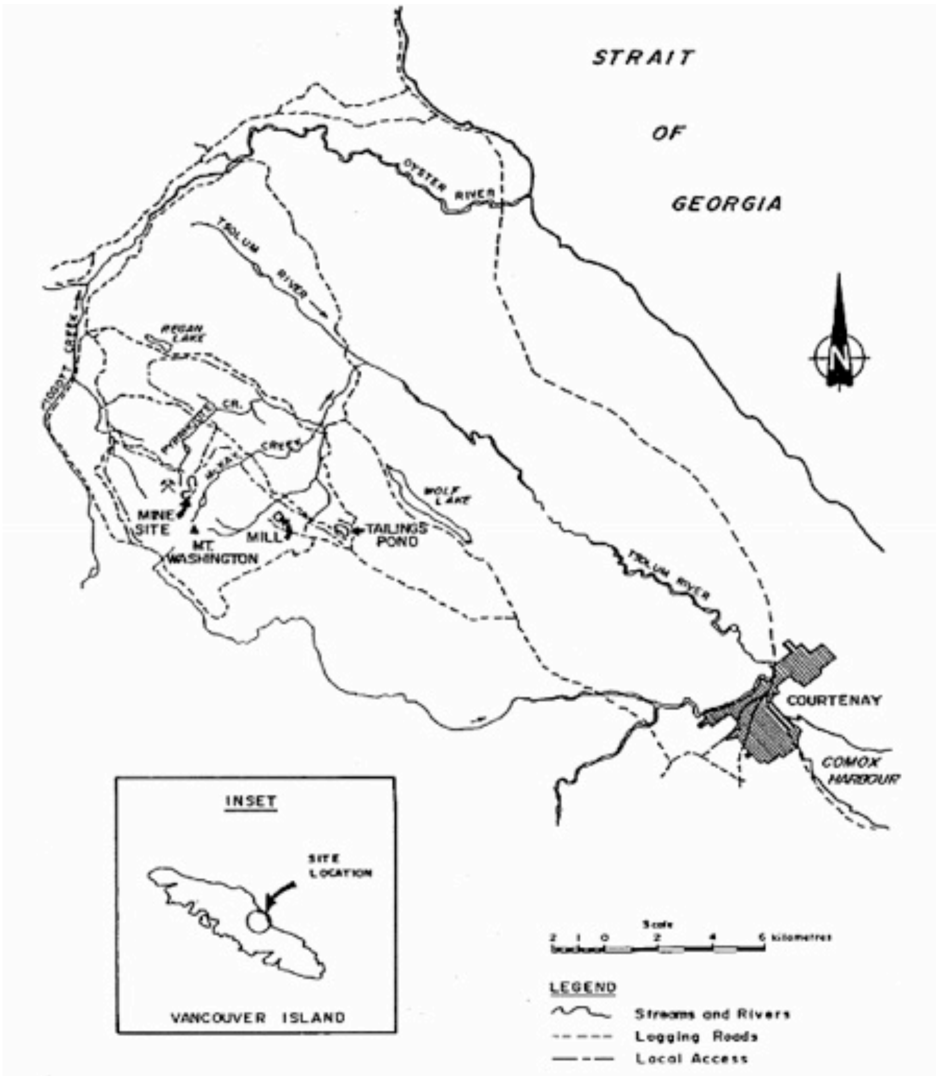

Figure 3. Drainage system downstream from the Mt Washington copper mine (White & Healy, 2007).

The Tsolum River was in desperate need for remediation. The province responded through the Ministry of Energy, Mines and Petroleum Resources by funding a $1.5 million remediation project at the mine site from 1988 through 1992 (BCMOE, 2008; White & Healy, 2007). A till cover was designed to prevent exposure of the waste rock to water and air, and lime was added to the walls and floors of the mine to aid in neutralization of the sulphuric acid (Hume, 2011; White & Healy, 2007). At first there was no effect to the copper concentrate levels in the river during 1993 through 1996, and it was not until 1998 when copper levels reflected a 50% decrease in response to the remediation efforts that were made on site (White & Healy, 2007). The Tsolum River Task Force (TRTF) was created in 1995, that focused on the health of the Tsolum River (White & Healy, 2007). In 1997 a meeting was held in the Comox longhouse that included over 200 residents, to conclude a mission statement that was formed to restore the "Tsolum River watershed to historic levels of health and productivity" (White & Healy, 2007, p. 6). The TRTF reunited all levels of government, First Nations, and community residents to address the Mt Washington mine concerns (White & Healy, 2007). The TRTF was mainly funded by DFO's Habitat Restoration and Salmon Enhancement Program and B.C.'s Urban Salmon Enhancement Program, although mostly this funding was depicted towards their end goals, and neglected to address actual mining reclamation measures. The Tsolum River Restoration Society (TRRS) was formed in 1998 to continue restoration work along the Tsolum River when funding ran out for the TRTF (White & Healy, 2007). The TRRS worked with the Ministry of Environment (MOE) and Environment Canada to monitor water quality, but funding remained an ongoing concern (White & Healy, 2007).

The Tsolum River Partnership was formed in 2001 between Timber West, MOE, TRRS, the Pacific Salmon Restoration Society, Environment Canada, and DFO (BCMOE, 2008; White & Healy, 2007). Environment Canada issued a direction under Section 38(6) of the *Fisheries Act* in June 2001, to the owners of record of the surface and mineral rights (White & Healy, 2007). Esquimalt and Nanaimo Railway had owned the lands since their original land grant in 1884, and had sold the surface rights to a forest company (White & Healy, 2007). Both companies were required to prevent the deposit of harmful substances at the confluence of Pyrrhotite Creek and Murex Creek, that would aid in the destruction of fish habitat (White & Healy, 2007). In 2003 the partnership created the Spectacle Lake Wetland at the triple confluence of McKay, Pyrrhotite and Murex Creeks that drain in the upper portion of the Tsolum watershed to improve water quality (BCMOE, 2008; Hume, 2011; White & Healy, 2007). The wetland has already deemed itself quite successful, reducing copper levels in the Tsolum to about 40% - levels that allowed fish stocks to return (BCMOE, 2008; White & Healy, 2007). Although the wetland only presented a life expectancy of 5 to 10 years (BCMOE, 2008).

In March 2006, Minister Penner presented a $50,000 grant to the Pacific Salmon Foundation (BCMOE, 2008; Hume, 2011). The focus of the grant was "to be used towards the evaluation and design of an engineered remediation plan for the abandoned mine site" (BCMOE, 2008). Additional funding was also presented through community organizations, and the provincial and federal governments contributed $4.5 million for remediation of the mine in 2008 (White & Healy, 2007). SRK Consulting were hired as leading experts in mine remediation and their goal was to determine the best remediation design for the mine, and associated costs (BCMOE, 2008). SRK worked very closely with the Tsolum River Partnership, and was overlooked by the Mining Association of BC (BCMOE, 2008; White & Healy, 2007). There was much discussion around what type of remediation practices should be employed to reduce the acid mine drainage in context with overall costs and ongoing maintenance (BCMOE, 2008; Hume, 2011; SRK, 2007; White & Healy, 2007). These included flooding the mine to seal the ore underwater; capping with concrete or other impervious materials; excavating trenches to redirect water away from the site; or collecting run off and allowing it to flow through a treatment plant (Hume, 2011). Most of the options were deemed only partial solutions or impractical (Hume, 2011; White & Healy 2007).

The final decision was to cap the Mt Washington site with a waterproof seal that consisted of polyester and bitumen (Hume, 2011). The seal is highly durable and is less expensive than soil cover, and costed about $1.44 million to install (White & Healy, 2007). The seal is rolled over the material like a giant carpet, and prevents any water or oxygen from infiltrating (Hume, 2011). The seal was implemented in 2009 through 2010, and proved very successful (Hume, 2011). Copper levels are below target, and there has been substantial change in the water quality of the Tsolum River to the point that it is deemed no longer an issue (Hume, 2011).

The Tsolum River was toxic to aquatic life for over 40 years due to acid mine drainage, and could not support local salmon runs (BC Wild, 2001; Hume, 2011; SRK, 2007; White & Healy, 2007). Now, the Tsolum River supports various species of aquatic life, and over 1000 adult coho have returned to spawn - a record stock return that had not been observed since 1959 (Hume, 2011). Steelhead have also returned to the river, although the pink and chum salmon runs have not recovered yet, there is still much work and effort being done to restore the Tsolum River to historical numbers (Hume, 2011). The cost of the loss of fisheries and combined clean-up of the mine's acid rock drainage has been estimated in tax payers dollars to cost over a total of $60 million (BC Wild, 2001).

Discussion

The remediation efforts outlined in the case study of the Tsolum River could be used as a framework for Jordan River. A public engagement strategy could be used to relay knowledge about the mine to neighboring communities, and engage the public. This can include a centralized meeting in Jordan River that discusses the public values of the Jordan River watershed, and focuses on the topic of the contaminated mine site and water quality objectives of the river. A key aspect of the Tsolum case study that made it successful was the amount of public awareness it relayed through societies and individuals in the community. These public meetings would uncover valuable information that could be presented to government agencies, as well as broadcast current knowledge about the state of the mine and aquatic life in the river. The public awareness can extend beyond the Jordan River community, and reach out to educational institutions on Vancouver Island and the media. The more attention Jordan River receives, the more likely there will be a response from government agencies and societies to fund a restoration and remediation project.

The Tsolum River's restoration success was mainly dependent on the engagement of regional governments including First Nations, in the area. TRTF and TRRS were originally small collections of individuals in the community, like residents, local politicians, volunteers and First Nations. These societies had agreed upon a common goal, that concluded restoring the health of the river and salmon populations. Similar societies could be established in Jordan River within the community, and funding could be addressed through grant applications, the media, and briefing notes. The main sources of funding for salmon restoration in the Tsolum River included the Ministry of Environment, DFO and local salmon enhancement programs. The Ministry of Energy, Mines and Petroleum Resources initially funded $1.5 million for remediation of the mine site in Mt Washington (White & Healy, 2007).

The case of the Tsolum River would be recognized by government officials, and foreshadows what could be done to Jordan River. The Tsolum River provides a successful example, where salmon populations were restored, and the mine was remediated to prevent future contamination. Initially the government granted funding for the restoration of salmon, but after a series of failed attempts further research revealed that the source of the problem was coming from contaminants in the mine and no salmon populations would be supported until the water quality was improved. In the case of Jordan River, funding can be initially directed to water quality research and remediation of contaminant sources of the mine, and focus later on salmon restoration measures once the water quality has been restored back to natural quality. The Tsolum River overall cost was estimated at about $60 million to restore fish populations and remediate the mine site (BC Wild, 2001). Jordan River may cost significantly less since there is already supporting evidence that the water quality is poor and the mine is the source of contamination (BC Hydro, 2003; White and Healy, 2007); therefore mistakes that were addressed in the Tsolum River can be avoided and save cost.

A major part that lead to the success of the Tsolum River case study is the partnerships that were formed between stakeholders, societies and different levels of government. The Tsolum River Partnership included Timber West, MOE, TRRS, the Pacific Salmon Restoration Society, Environment Canada, and DFO (SRK, 2007; White & Healy, 2007). Partnerships are key for consulting measures in determining major decisions, and engage a variety of different stakeholders. Currently, BC Hydro has expressed that they will mediate their average baseline flows of the dams to consider salmon habitat (BC Hydro, 2003), and the CRD has acknowledged the copper mine in their public consultation report (CRD, 2012). A partnership needs to be formed between all the stakeholders, to conclude a common agreement. A partnership can be formed in Jordan River between provincial and federal governments (Environment Canada, DFO, and MOE), BC Hydro, the CRD, Western Forest Products, a community association of Jordan River, and local salmon hatcheries. This partnership would engage concise communication, and influence important decisions that involve activities in the Jordan River watershed. Such a partnership would be consulted if a major mine remediation was to be conducted in Jordan River, and the partnership would overlook and aid as a resource in determining the best options for the community.

Restoration of the river could be a community effort through the engagement of universities and secondary schools in the region. A wetland could be established at the mouth of the Jordan River to filter toxic copper leachate and return quality water to the environment. The wetland would improve water quality and enhance fish habitat. Habitat degradation is one of the primary factors in the decline of salmon populations (DFO, 2005; Feist *et al.*, 2003, Haberstock *et al.,* 2000; Jackson *et al.*, 2000; Pinkerton, 1994; Wilcove *et al.*, 1998). A major challenge with salmon is that their habitats are defined as the entire watershed from the headwaters to the open ocean (Jackson *et al.*, 2000). Water diversion, dam construction, mining, industrial pollution, and logging practices are responsible for salmon habitat degradation in watersheds (Pinkerton, 1994). Salmon habitat relies heavily on water quality, and stream temperature, flow, chemistry, sediment amount, and surrounding vegetation are all major variables that determine a healthy salmon habitat (Haberstock *et al.,* 2000; *Habitat Studies,* n.d.). There are an infinite number of ecosystems that depend on the nutrients that spawning salmon bring into the forest. Salmon are culturally valuable to coastal First Nation's communities, and are of great economic importance to commercial fisheries in British Columbia. Salmon are enjoyed recreationally, and by locals and tourists alike. Salmon stocks are also significant to the economies of local communities (White & Healy, 2007).

The salmon population in the Tsolum River held an annual economic value of $2.7 million (White & Healy, 2007). If salmon stocks were restored in Jordan River, they would contribute to the local economy. The spawning salmon would ignite sports fishing and other recreational activities in the river, and satisfy local First Nations tribes. Spawning salmon would bring more tourists to Jordan River and support the local economy.

Further research is recommended on the Jordan River watershed, specifically regarding water quality analysis, mine remediation, and restoration practices that would benefit the return of local salmon runs.

Conclusion

The Tsolum River case study can be used as a framework for the Jordan River watershed, and provides a successful example where salmon populations were restored, and a mine was remediated to prevent future contamination. A public engagement strategy could be used to increase awareness on the mine contamination, and engage the public. The more attention Jordan River receives, the more likely there will be a response from government agencies and societies to fund a restoration and remediation project. Currently, BC Hydro has expressed that they will regulate their average baseline flows of the dams to consider salmon habitat (BC Hydro, 2003), and the CRD has acknowledged the copper mine in their public consultation report (CRD, 2012). A partnership needs to be formed between all the stakeholders of Jordan River to conclude a common agreement. This partnership would engage concise communication, and influence important decisions that involve activities in the Jordan River watershed. Such a partnership would be consulted if a major mine remediation project was to be conducted in Jordan River, and the partnership would overlook and aid as a resource in determining the best options for the community. Restoration of the river would be a community effort, and a wetland could be established at the mouth of the Jordan River to filter toxic copper leachate and improve water quality to enhance fish habitat. If restoration and mine remediation efforts were successful, spawning salmon would fuel sports fishing and other recreational activities in the river, and satisfy local First Nations bands. Spawning salmon would bring more tourists to Jordan River and support the local economy. Further research is recommended in regards to water quality analysis, mine remediation, and restoration practices that would benefit the return of local salmon runs in Jordan River.

Sources

BC Hydro. (2003). *Jordan River Water Use Plan: revised for Acceptance by the Comptroller of water rights*. Burnaby, British Columbia: BC Hydro Water Use Planning.

BC Ministry of Environment Lands and Parks (BCMOE). (1995). *BC Environment Water Quality Branch, Water Quality Assessment and Objectives for Tsolum River Basin,* pp 11-12.

BC Ministry of Environment and Ministry of Environment, Mines, and Petroleum Resources. (2008). *Backgrounder: History of Tsolum River restoration*. Accessed on March 27, 2013 by: www.gov.bc.ca

BC Wild and Environmental Mining Council of BC. (2001). *Acid Mine Drainage. Mining and Water Pollution Issues*. Environmental Mining Council of BC.

Capital Regional District (CRD). (2013). *Jordan River Regional Park.* Retrieved March 26, 2013 from: http://www.crd.bc.ca/parks/

Capital Regional District (CRD). (2012). *Jordan River Regional Park Boundary: Public Consultation.* Comment Report. Retrieved March 26, 2013 from: http://www.crd.bc.ca/parks/

Department of Fisheries and Oceans (DFO). (June 2005). *Canada's policy for conservation of wild pacific salmon*. Vancouver, Canada: Department of Fisheries and Oceans.

Feist, B. E., Steel, E. A., Pess, G. R. and Bilby, R. E. (2003). The influence of scale on salmon habitat restoration priorities. *Animal Conservation*, *6*, 271–282. doi: 10.1017/S1367943003003330

Haberstock, A. E., Nichols, H. G., DesMeules, M. P., Wright, J., Christensen, J. M. and Hudnut, D. H. (2000). Method to identify effective riparian buffer widths for Atlantic salmon habitat protection. *Journal of the American Water Resources Association, 36*,1271–1286.

Habitat Studies (n.d.). Retrieved from the Department of Fisheries and Oceans website on February 5, 2013 from: http://www.dfo-mpo.gc.ca

Hofer, T.N. (ed.) (2008). *Marine Pollution: New Research.* Nova Publishers: Hauppauge, NY.

Hume, M. (2011). Life has trickled back to a 'lonely, dead river.' *The Globe and Mail*.

Jackson, S., Marx, J., & Wescott, H. (2000). Organics play role in salmon recovery in pacific northwest. *Biocycle*, *41*(4), 73.

Martin, T.E. (2011). Mine waste management in wet, mountainous terrain: Some British Columbia perspecitves. *Proceedings Tailings and Mine Waste 2011.*

Peers, E. (2012). The mine that flooded. *The Sooke News Mirror.*

Pinkerton, E.W. (1994). Local fisheries co-management: a review of international experiences and their implications for salmon management in British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, *51*(10), 2363-2378.

Singleton, H.J. (1987). Water Quality Criteria for Copper – Technical Appendix. Ministry of Environment and Parks, Water Management Branch, Province of British Columbia.

SRK Consulting Engineers and Scientists. (2007). Mt Washington Mine Remediation Detailed Design. Tsolum River Partnership.

Sunro Copper. (2013). Mine History. Available at: http://www.sunrocopper.ca/history.htm

Sweeten, T. and McLean, W. E. (1999). The toxicity of copper to pink salmon fry migrating down the Tsolum River. Unpublished Data, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C.

White, W. and Healy, P. (2007). Mount Washington mine remediation project. *British Columbia Mine Reclamation Symposium 2007,* pp 1-12.

Wilcove, D., Rothstein, D., Dubow, J., Phillips, A., and Losos, E. (1998). Quantifying threats to imperiled species in the United States. *Bioscience*, *48*, 607–615.

Wright, M.C. and Guimond, E. (2003). Jordan River Pink Salmon Incubation Study. *BC Hydro Coastal Fish and Wildlife Restoration Program*. Available at: www.bchydro.com