MERCURY EVOLUTION AND IMPACTS OF TWO HYDROLOGICAL DAM – THREE GORGES DAM AND LA GRANDE DAM

by

Yuting Du

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FACULTY OF NATURE RESOURCES MANAGEMENT
LAKEHEAD UNIVERSITY
THUNDER BAY, ONTARIO

April 2017

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resource Management

Lakehead University

April 2017

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ABSTRACT

Du. Y. T. 2017. MERCURY EVOLUTION AND IMPACTS OF TWO HYDROLOGICAL DAM – THREE GORGES DAM AND LA GRANDE DAM. 32pp.

Keywords: Chinese Sturgeon, Mercury Level, Migratory Fishes, Three Gorges Hydroelectric Dam, La Grande Hydroelectric Complex, Negative Impacts, Zebrafish,

Hydrological dam are widely used to generate electricity. At present, hydrological power is deemed be clean energy, because it does not have greenhouse gas emission. However, many reports and researches show that hydrological dam has negative impacts on water and creatures. This paper discusses the negative impacts of Three Gorges Dam and La Grande Complex for changes of mercury level. The Three Gorges Hydrological Dam is the largest hydrological dam in the world that located at Yangzi River in China, but after building the dam, the mercury level is increasing rapidly; the number of fishes that live in the Yangtze River is decreasing and the water quality is also decreasing. Similarly, in Canada, the La Grande Hydroelectric Complex also has the same negative impacts as the Three Gorges Hydrological Dam.

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ACKNOWLEDGEMTS

I wish to express my sincere gratitude to Dr. Jian Wang, who is my supervisor, for providing many bits of help to me to complete this thesis.

I also would like to express my special thanks of gratitude to Dr. Brian McLaren who give me lots of suggestions when I did the research.

I am really thankful to them

Secondly, I would also like to thank my parents and friends who helped me a lot in finishing this project within the limited time.

I am making this project not only for marks but also increasing my knowledge.

Thanks again to all who helped me.

INTRODUCTION

Mercury is naturally distributed element, which occupies one over thirty billion of the Earth rock total weight (Shang 1982). Although mercury exists in water, atmosphere, rock and soil, the content of it is minimal.

Water is the most important part of life. At present, the water does not only maintain lives but also provide the power for the human. Hydrological dam is the representative of the use of water. Hydroelectric power is the mostly used renewable energy, which can provide the clean, pollution-free and abundant energy (Encyclopedia of Science 2016). Dam construction plays vital roles in controlling flood, retaining water, irrigation and power supply (Li et al. 2013). This paper will discuss on the two typical hydrological dam in China (Three Gorges Dam) and in Canada (La Grande Dam) to study the mercury evolution and impacts before and after completion of the dams.

History of Building The Three Gorges Dam

The Three Gorges Dam in China is the largest hydrological dam in the world, and it is located on the Yangtze River, which is the longest and important river in

China (Zhang et al. 2007). Depending on the report from the government of China in 1994, the objectives of building the Three Gorges Dam are storing water, controlling flood and generating electricity.

In 1958, Chinese Academy of Sciences investigated and analyzed the aquatic organism in planned Three Gorges Dam area and put forward the suggestions on the fisheries using (Jiang and Zhu 1992). After multi-investigation, the establishment of the Three Gorges Hydrological Dam started in 1994 officially and in 2003, the Three Gorges Hydrological Dam started to be filled and the water level increased to 175 m above sea level (ASL) in 2009 (Gao et.al. 2016). Depending on the report of the China Three Gorges Corporation in 2014, the reservoir flood control capacity of Three Gorges dam is 221.5 hundred million m^3, which can decrease the flood probability during Jingjiang River reach 10% per year to 1% per year. Especially in 2012, the flood peak was 71200 m^3/s, but there did not occur any flood due to the protection of the Three Gorges Dam. Moreover, the Three Gorges Dam provide about 882 hundred million kWh every year and reduce the cost of shipping. Hydroelectric power is the clean energy, which the Three Gorges Dam can reduce one hundred million ton CO_2 emission load, two million ton SO_2 emission load, ten thousand ton CO and 3.7 million tonnes oxynitride emission load (The Three Gorges Corporation 2013); therefore, the Three Gorges Dam is benefit for the environment to some extent.

History of Building La Grande River

The La Grande River hydroelectric project, known as the La Grande Complex, is located in the James Bay, Quebec. Quebec has an abundant water system, providing beneficial geographical conditions for the hydroelectric project. The original plan for the La Grande Complex is to construct five hydrological power stations on the La Grande River (La Grande 1, La Grande2, La Grande 2-A, La Grande3 and La Grande 4). In addition, in the plan, there is a powerhouse called Laforge 1 along the Laforge River, which is located on the influent of the La Grande River upstream of La Grande 4 reservoir.

The Three Gorges Dam and the La Grande Complex provide a lot of benefits for people, but it also damages to the creatures that live in and surrounding the Yangtze River and La Grande River differently (LI et al. 2013; Verdon et al. 1991)

Especially, there is some evidence that after completing dam, the content of heavy metal, particularly the content of mercury, is increased. The increasing mercury level harms to the fish and the soil around the Yangtze River and La Grande River. There are many ways that can result in rising mercury level in lakes, but this paper only concentrates on the situation that mercury enters into the reservoir by releasing from soil and plants after impounding.

In addition, in Yangtze River, there are some migration fishes, but the Three Gorges Dam impedes this migration fishes back to the upstream to spawning, which lead to the reduction of anadromous fishes（Yi and Wang 2009）. Meanwhile, the same situations also occur in La Grande River in Quebec, Canada. The development of river result in the fishes cannot live in a peaceful lake and river; furthermore, the hydroelectric projects make the habitat of fishes fragmentation; therefore, the fishes cannot multiply. In general, although the hydrological projects give lots of benefits to communities, it reduces the biodiversity around the projects and provides more chances for mercury residue due to the restoring water.

Literature Review

Mercury is naturally distributed element, which occupied one over thirty billion of the Earth rock total weight (Shang 1982). Although mercury exists in water, atmosphere, rock and soil, the content of it is minimal. In the rock and soil, the concentration of mercury is 0.05 to 30 ppm; additionally, in the natural water body, the concentration of the mercury is only one of billions. Although the concentration of natural mercury is mineral, by the development of industries, human's activities accelerate the mercury cycle and change the distribution of mercury (Shang 1982). The most influential activities are deforestation and cultivation. Forest canopies can capture the Hg in the atmosphere and absorb particular mercury (Melendez-Perez 2014). However, deforestation breaks the forest canopies, which mercury can move easily. Moreover, topsoil under the old growth forestry contains more mercury than other (Gamby et al. 2015). Based on research in Ohio in 2015, the content of mercury in old – growth forest is about 90 μ g/g dry wt; in new – growth forest the content of soil Hg is about 60 μ g/g dry wt; the mercury content in soil under fallow grassland and agriculture fields are similar, which is about 30 μ g/g dry wt (Gamby et al. 2015). Compare the concentration between soil under the old- growth forest and under agricultural fields, about half of mercury in the topsoil has already volatilized because of deforestation and cultivation.

Furthermore, natural disturbances also expedite the mercury cycle and change the distribution (Maynard et al. 2014). Forest is thought as a pool of mercury in the mercury cycle (Zhou et al. 2014). Mercury accumulates on the tree's foliage, bark, and branches. Interception and fallen litters transfer the mercury to soil. Wildfire has the ability to mobilize mercury from organic litter and soil (O-horizon soil) and shallow mineral soil (A-horizon soil), but fire cannot move the mercury from deep mineral soil (C-horizon soil) (Engle et al. 2006). Generally, wildfire releases Hg as HgO, meanwhile, the moisture in the atmosphere can enhance the discharge of particular mercury (Friedli et al. 2003). Mercury bind by soil matrix begin to release from soil at 150 °C; therefore, during the forest fire, Hg can be reemitted from soil matrix when soil has been heated enough (Woodruff and Cannon 2010). Wildfire also can release Hg directly (Friedli et al. 2009). Fire burns the biomass and vaporizes the Hg that stored in the biomass. In vegetation, the mercury concentration follows the order by foliage > root > bark > branch > bole (Zhou et al. 2014).

Additionally, flooding is another important factor that transfers the mercury. Riparian soils are important in transporting the mercury. The liberating of mercury in riparian soil has dynamics between different depth and time during flooding (Poulin et al. 2016). According to the research of Brett A. Poulin in 2016, the mercury transformation and release dynamics have obvious differences between soil horizons, especially about 20 cm in soil. The O horizon, containing massive organic soil and litter has a mercury pool that transforms easily during flooding with organic matter by HgS. In A horizon, which is mineral soil, the Mercury present as HgS but mobilized as HgO in gas. The HgO. Compared to HgO, HgS is easier to dissolve in water. Meanwhile, the existing of HgO also indicates that the HgS is instability. Therefore, the Mercury in O horizon is easy to volatilize with flooding.

Mercury cycle explains the factors that induced the mobilization of mercury and can link the natural disturbance with artifact pollution. (Figure 1). Industries release Hg^{2+} to the atmosphere. Through interception, Hg^{2+} enters into water and soil and accumulates in the body of plant and animals. Deforestation, cultivation, flooding, wildfire and other human activities and natural disturbance release the mercury from soil and biomass.

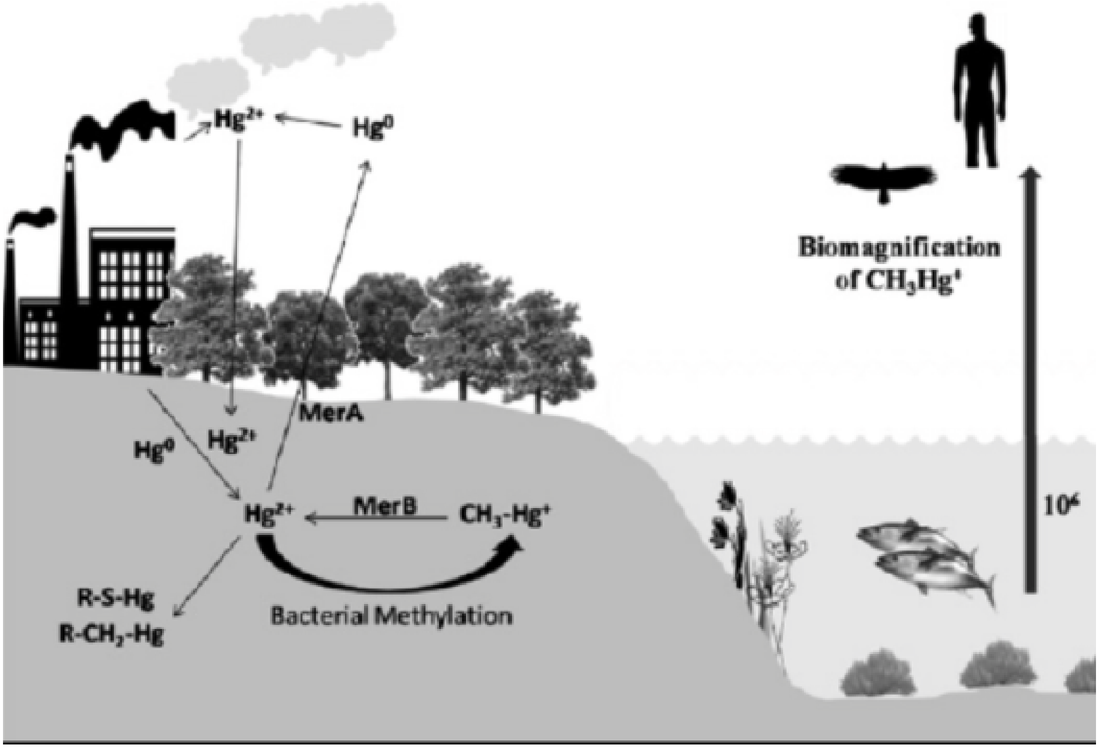

Figure 1 Mercury Cycle (Dash and Das 2012)

In addition, hydrological dam also can result in mobilization of mercury and transfer mercury into water. In summer in 2015, British Columbia researchers undertook an investigation on fish for mercury contamination of the waterways that connected to a massive hydro dam reservoir to respond for the First Nations, who think that their fish has already been destroyed by building the hydrological dam (Justine Hunter 2015). The Williston reservoir is the seventh-largest reservoir in the world. Because the Bennett Dam was built, much vegetation and soils were drowned.

The plants and other organic matters decayed and released the mercury into the Williston reservoir. The other evidence is the Wabigoon River, which located in Ontario, Canada. Wabigoon River was affected by dam since 1898 (Jackson 2016). Wabigoon river formed Clay lake. In the year 1941, the total concentration of mercury is about 0.083 $\mu g\ g^{-1}$. The content of mercury in Clay lake tended to increase from the year 1941 to year1997 and in the year 1968, the content of mercury reach its peak. In the year 1968, the concentration of mercury in Clay Lake was about 4.865 $\mu g\ g^{-1}$, which means that the influence of hydrological dam is persistent and as the time pass by, the concentration of mercury is reinforced (Jackson 2016).

Methods

The Three Gorges Hydroelectric dam and the La Grande Hydroelectric Complex are the two-mega projects in China and Canada. This paper will compare the variation of mercury levels and the impacts on the fish.

All the data from the Three Gorges Hydroelectric dam are found from journal articles like Science, report of university researchers, and the Three Gorges Hydroelectric Cooperation. For the statistics of the La Grande Hydroelectric

Complex, I found data on research papers by other persons and books that introduce the La Grande Hydroelectric Complex. For the comparison between these two projects, I only use the data for 10 years after establishments of the Three Gorges Hydroelectric dam and the La Grande Hydroelectric Complex. Therefore, for the Three Gorges Hydroelectric dam, I only choose the data from the year 2006 to 2016. For the La Grande Hydroelectric Complex, it contains four different power stations and the time of accomplishment was different; therefore, it is hard to decide that what time range of the data I can use. To be fair, I choose the data after the decade of establishment for each station.

For comparison, I used the graph and table to compare the variation of mercury levels between these two hydroelectric projects; moreover, figure and table display the variations of the mercury contents, before and after the establishment of the dam.

RESULT

The Three Gorges Dam in China

Changes of Mercury

The Three Gorges Hydrological Dam is the largest project in China, which located at the Yangtze River. The large-scale project has impacts on the environment certainty (Pan et al. 2012).

The Three Gorges Hydrological Dam has some negative impacts on the environment. In the water-level-fluctuation zone of the Three Gorges Reservoir Area, the mercury release from the soil and plant into the water. As the time of water flooding increased, the total Hg is decreased in soil and the concentration of total Hg increased distinctly, meanwhile, the content of the MMHg are also increased in both water and soil. After twenty-one days, the concentration of total Hg in the water is 2.52 times than in the soil (Li et. al. 2014). The Hg that released from the soil and plant to the water also has the influence on the fish. Through the investigation of the content Hg in the zebrafish in the Three Gorges reservoirs area, the content of total Hg in the head, viscera and muscle rise about 32.77%, 40.56%, and 42.21% differently after the flood.

Another investigation also supports that the Three Gorges Dam will bring the Hg pollution and the major reason is the soil erosion. In the location of the Three Gorges Dam, the surface condition is very complicated and the landform is extremely undulates terribly, which lead to the grievous soil erosion. Furthermore, the establishment of the Three Gorges Dam resulted in the manmade soil erosion; therefore, the Three Gorges Dam accelerates the Hg pollution in the river (Yang and Ding 2007).

Base on the analysis of heavy metal in Three Gorges Reservoir, the concentration of mercury was increased and reached the peak in 2005, after 2005, the mercury content started to decrease (Wang et al. 2007) (Figure 2). In 1999, the concentration of mercury was 0.42 mg*kg^{-1}. However, in 2005, the concentration of mercury increased to 0.59 mg*kg^{-1}, and the value of the mercury decreases rapidly. Especially in 2007, the first investigation showed that the concentration of mercury is 0.46 mg*kg^{-1}, but in the second research, the value decreased to 0.109 mg*kg^{-1}.

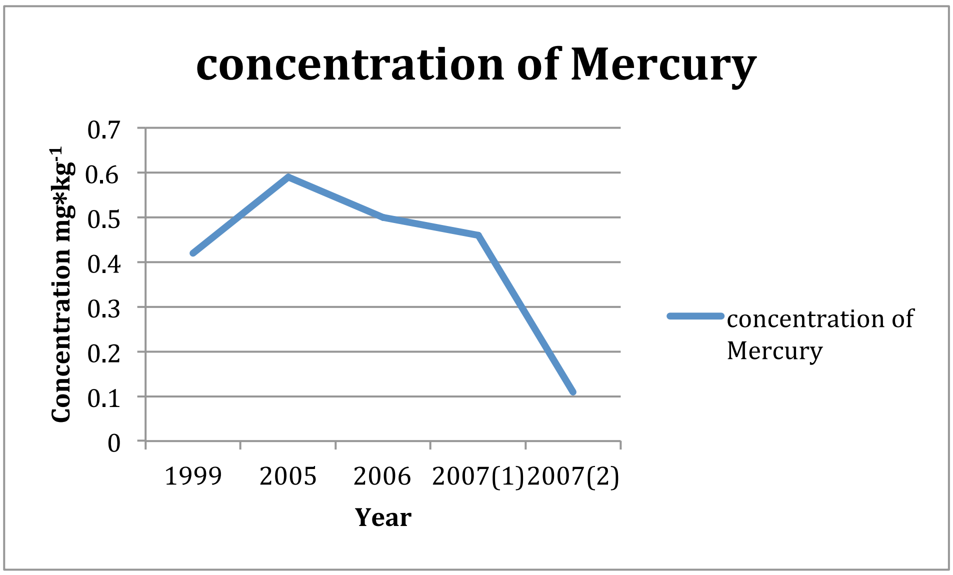

Figure 2 Concentration of Mercury (Wang et al. 2007)

Table 1 Value of Mercury

Element	Max Value $mg*kg^{-1}$	Min Value $mg*kg^{-1}$	Average $mg*kg^{-1}$	Relative Standard Deviation	Background Value in Yangtze River $mg*kg^{-1}$
Mercury	0.158	0.047	0.109	36.767	0.08

Additionally, comparing to the background of mercury content in the Yangtze River, the concentration of mercury at present is greater (Want et al. 2007). From the table 1, we can see that in the past, the value of mercury in Yangtze Rive is 0.08 mg*kg^{-1}. However, the max value of mercury content is 0.158 mg*kg^{-1}, which is three times than the base value (Wang et al. 2007).

Impacts on Fishes

The dam itself also has the influence on the fish, especially on the migratory fish (Jiang and Zhu 1992). Before construction of the Three Gorges Dam, the Three Gorges reservoir region has one hundred and twenty-seven kinds of the fish base on the investigation. While from 2005 to 2006, only 108 kinds of fish were found in the Yangtze River. The main reason is that the original habitat is fragmented because of the construction of the Three Gorges Dam (Yang et al. 2012).

Another situation is that the number of migration fish is decreasing. For the River-Lake migratory fish, some spawning sites were submerged by reservoir water after the establishment of the Three Gorges Dam and the temperature of the reservoir water is low, which is harmful to the spawning site when the low-temperature water flows into the sites. Therefore, the decrease of the spawning sites' quantity and quality can lead to the decline of the number of River-Lake migratory fish. For the River-Sea migratory fish, the dam caused the reduction of the flood crest, which results in the decline of the fecundity of anadromous fish (Jiang and Zhu 1992). The Chinese Sturgeon (*Acipenser Sinensis)* is the representative migration fish in Yangtze River, which is also one of the native sturgeons in the Yangtze River. Chinese Sturgeon grows in the Yellow Sea, the East China Sea, and the South China Sea and migrates upstream of Yangtze River for reproduction. However, in the last decades, the numbers of Chinese Sturgeon become less and less due to the construction of the Gezhou Dam (GD) in 1981. The GD was built on the spawning migration route of the Chinese Sturgeon, which blocked the route and reduced the population size of the Chinese Sturgeon fishes. In 2010, the Chinese Sturgeon was classified as a critically endangered species by the International Union for Conservation of Nature Red List. After construction of the Three Gorges Dam (TGD), the migration route was blocked further, Moreover, before the Three Gorges Reservoir (TGR) impounding in 2003, the population of the adult Chinese Sturgeons before spawning activities was 298 to 524 individuals, but after TGR impounding, the number changed to 106 to 316, which decreased 64.4% (Figure 3) (Gao et. al. 2016).

The times of the spawning were decreased because of the TGR impoundment. Depending on the report in 2016 (Gao et. al. 2016), before 2003, the Chinese sturgeon in the spawning site has two spawning activities each year, but from the year 2003 to 2013, there was only one spawning activity per year. In addition, the days of the first spawning activities were also postponed.

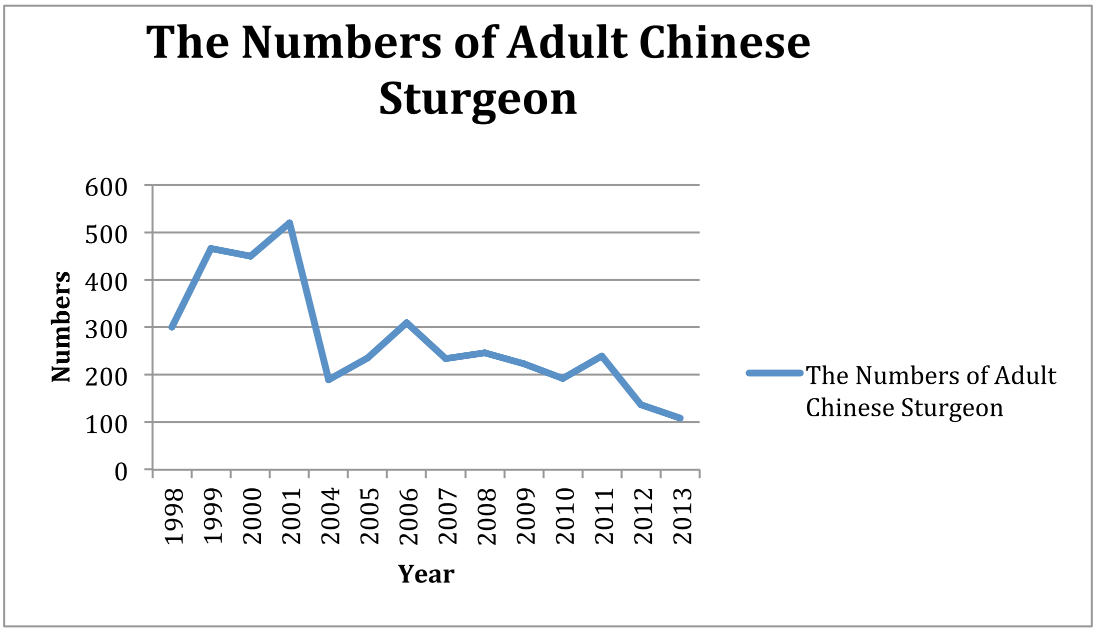

Figure 3 The numbers of Adult Chinese Sturgeon (Gao et. al. 2016)

From 1997 to 2002, the first spawning activities were around October 21, and the second spawning activities were from end of the October to middle of November. But after 2002, the first spawning activities were put off to around November, especially in 2008, the first spawning activity was around November 30. In 2013, the second spawning activity was in the middle of the December.

Furthermore, the quantity of the Chinese sturgeon eggs also decreased after the TGR impoundment. Between 1997 to 2002, the number of the eggs is around 15 million, however, from 2003 to 2013, after the TGR impounding, the numbers decrease about 70.6% (Figure 4), which is around 4.4 million (Gao et. al. 2016).

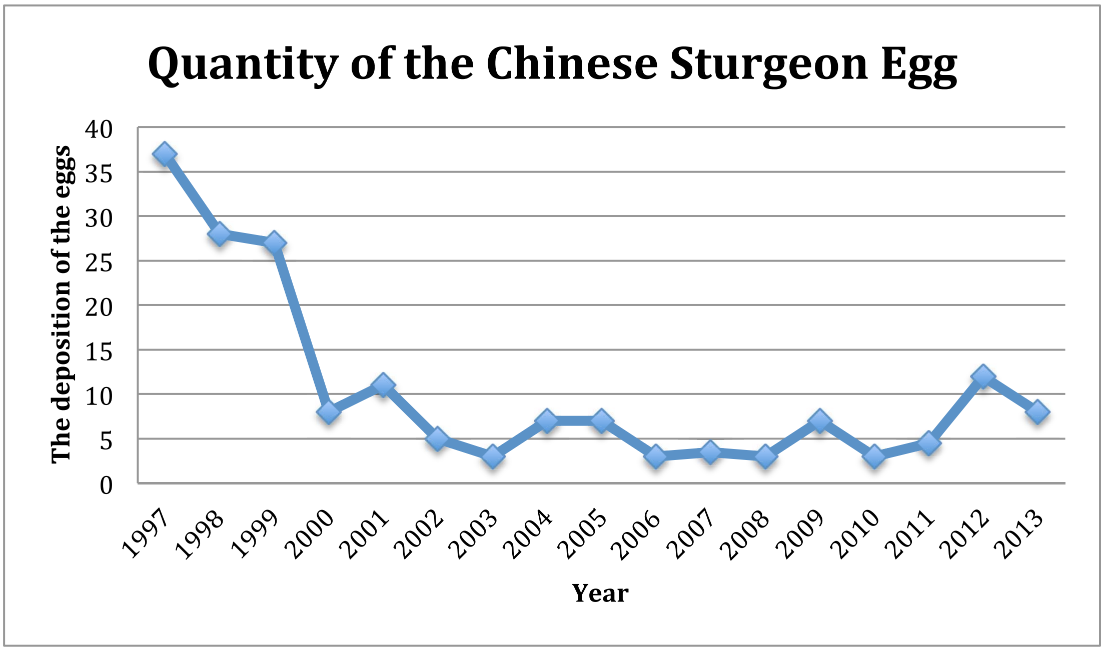

Figure 4 Quantity of the Chinese Sturgeon Egg

The La Grande Hydroelectric Complex in Canada

Changes in Mercury Level

The La Grande Hydroelectric Complex is named after the La Grande River. 176,000-km^2 areas are covered by the La Grande hydroelectric complex and 9,900 km^2 among the covered area has been flooded to develop reservoirs (Societies of energy from James Bay 1988:183).

After the impoundment of reservoirs, depending on the massive researches, the mercury levels in the fish are increased (Roger 2000). The concentrations of Hg in the La Grande Hydroelectric Complex reservoir fish are 6 times higher than in other natural lakes fish (Bodaly et al. 1997). And also, the reservoir releases the water that containing mercury to the downstream, which has the negative influence on the environment of downstream (Schetagne and Verdon 1999). According to a study of Caniapicau reservoir (Roger 2000), about 78.4% of total Hg delivered to the downstream transferring into dissolved Hg and 5% unfiltered total Hg was associated with suspended particulate matter (SPM) (Figure 5). Moreover, 64.3% unfiltered MeHg was transferred to the dissolved MeHg, while 33.2% was delivered to the SPM (Figure 6).

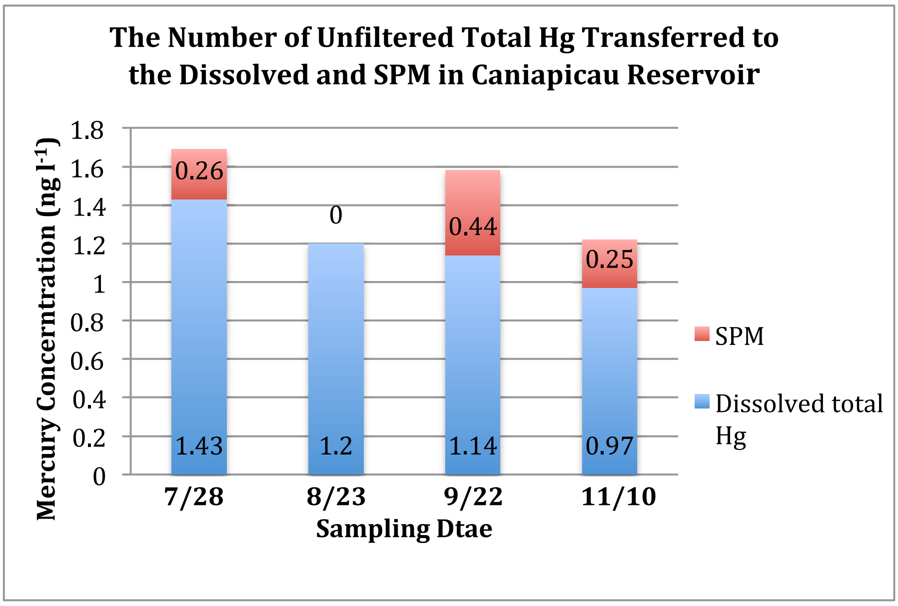

Figure 5 The Number of Unfiltered Total Hg Transferred to the Dissolved and SPM (Roger 2000)

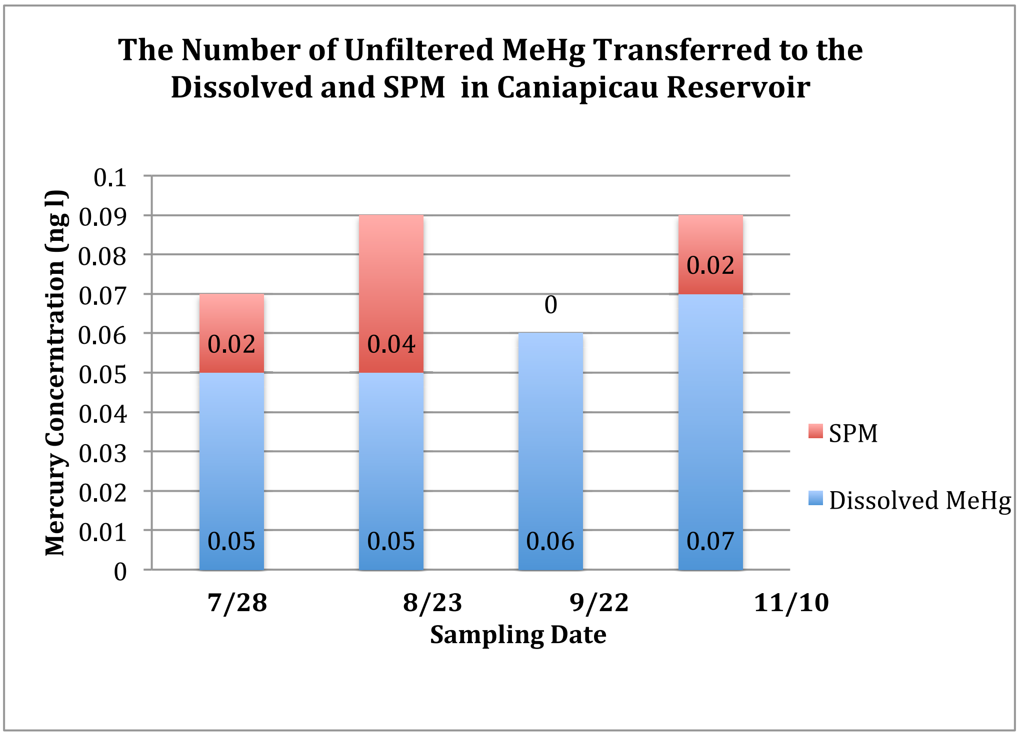

Figure 6 The Number of Unfiltered MeHg Transferred to the Dissolved and SPM (Roger 2000)

Another investigation shows that after the impoundment about eleven years, the mercury level for six to seven-year-old fish are 3 times higher than the same kind of fish in the natural lake at same ages, which also support that the La Grande Complex has negative impacts on the fish (Jean 1998).

From 1978 to 1996, the total Hg concentrations were measured in reservoirs area by fish (Roger and Richard 1999). After impoundment, the Hg concentration increased quickly, and the concentration reached the peak after impoundment for five to nine years in non-piscivorous fish and after impoundment for ten to thirteen years, the concentration grew to the point in piscivorous fish. Then the mercury level started to decrease and after 20 years, the mercury returned to the natural level (Roger and Richard 1999). From 1978 to 1988, the monitoring also shows five years after filling the reservoir, the Hg concentrations went up because the four areas were rapidly filled and slowly restored. In the La Grande 2 reservoir, the Hg level of the lake whitefish (*Coregonus clupeaformis*) decreased from 0.16 mg kg^{-1} to 0.57 mg kg^{-1} at five years after impoundment (Verdon 1991).

As a hydrological dam, the La Grande Complex has the same influence on the fish populations as the Three Gorges Dam. Between 1977 and 1992, the catches per unit of effort (CPUE) were monitored with experimental gill nets, recruitment, growth, and condition (Deslandes 1995). The purpose was to assess the impacts of the impoundment on the six main fish species. The results show that at many stations, the CPUE increased distinctly after filling the reservoir; while at the end of the series, the CPUE has a tendency of reduction. Furthermore, at the two bay stations of the La Grande 2 and Opinaca reservoirs, the CPUE was increase obviously. Nevertheless, the CPUE for some species, such as walleye (*Sander vitreus*), white sucker (*Catostomus commersonii*), and longnose sucker (*Catostomus catostomus*), decreased in some area (Deslandes 1995).

DISCUSSION

The Three Gorges Hydrologic Dam and the La Grande Complex are both large projects in the world. However, the TGD only has one hydro-dam and one reservoir, but the La Grande Complex has five hydro-dams and five reservoirs (Table 2).

Table 2 Information of The Three Gorges Hydrologic Dam and The La Grande Complex

	Three Gorges Hydrologic Dam	The La Grande Complex
Location	Hubei Province	Quebec
River Name	Yangtze River	La Grande River
Opening date	2003	1994 (La Grande 1) 1981 (La Grande 2) 1992 (La Grande 2A) 1984(La Grande 3) 1984 (La Grande 4)

Three Gorges Dam located in Yichang City, Hubei province. Hubei province is located in the central of China and in the south of the line of Qinling Mountain – Huai River (Wikipedia 2017). In Hubei province, 56% area is mountain; hill takes up 24%; plain accounting for 20%. Hubei surrounded by mountains on three sides and the middle of the area is flat. The La Grande complex is located in the Quebec, which in the eastern part of Canada. More than 95% of Quebec's land lies within the Canada shield. This land is a very flat area with some mountains. The shield is formed by glaciers in the successive ice ages; therefore, Quebec has a system of abundant rivers, which is a powerful support for the hydrological dam.

Both the Three Gorges Dam and La Grande Hydrological Complex result in the increasing of Mercury in river and reservoir. Depending on the investigation of the concentration of mercury in the fish body, the fishes in La Grande River have stronger impacts obviously. The concentration of mercury in fishes after building La Grande Complex is six times than before, but the concentration of mercury in fishes after building Three Gorges Dam is about 1.5 times than before.

Base on the investigation of water quality, in both of these dams after four to five years after impounding, the concentration of mercury is increasing continually and reaching the peak. After 20 years, the mercury level tends to decrease to the normal level. The reason is that the increasing of mercury after building dams originates in soil. The soil is a mercury pool. The reservoir area will cover a part of land with soil and vegetation. After four or five years, the mercury in the soil and plants are released totally into the water and as time goes by, as the water evaporation, the mercury returns to atmosphere again.

The mercury in fish does not result in the death of the fish. Mercury can store in the fish body for a long time (Food and Drug Administration 1995). Fish absorb the methylmercury from water and other aquatic organisms, especially for the large predators, they can assimilate more methylmercury from their prey and cooking cannot reduce the level of methyl mercury because the methylmercury binds with fish tissue tightly, therefore, the mercury that existed in the fish bodies has negative impacts on human (Food and Drug Administration 1995).

The reason of the death of fish after building the hydrological dam is that the dam blocked the river, which results in the habitat fragmentation. Especially for the migratory fishes, the evidence of Chinese sturgeon shows that the large dam on the river can bring destructive damages to the migratory fishes.

CONCLUSION

Hydropower is a clean energy, which reduces the emission of pollutants (Canadian Hydropower Association 2017). However, the “clean” energy still results in pollution. Mercury pollution is one of the most severe problems that Hydrological dam brings. Through many investigations, the concentration of mercury is increase after impounding of the reservoir. In China, because of building Three Gorges Dam, the mercury level in the river and reservoir increase two or three times than before and mercury has already accumulated in the body of fishes. By the research, the mercury content in the fish body is increase around 40%. Similarly, in Canada, Hydropower also bring some question. Base on the research of La Grande Complex, the mercury transferred from soil to the water. The concentration of mercury in fish that live in dam reservoir is almost six times than the fish in the natural lake. However, the mercury that caused by building a hydrological dam is a gradual decline.

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APPENDICES

APPENDIX1

Table 1 Value of Mercury (Wang et al. 2007)

Element	Max Value mg*kg^{-1}	Min Value mg*kg^{-1}	Average mg*kg^{-1}	Relative Standard Deviation	Background Value in Yangtze River mg*kg^{-1}
Mercury	0.158	0.047	0.109	36.767	0.08

Table 2 Information of The Three Gorges Hydrologic Dam and The La Grande Complex

	Three Gorges Hydrologic Dam	The La Grande Complex
Location	Hubei Province	Quebec
River Name	Yangtze River	La Grande River
Opening date	2003	1994 (La Grande 1) 1981 (La Grande 2) 1992 (La Grande 2A) 1984(La Grande 3) 1984 (La Grande 4)