The effect of dams in the decomposition of organic sediments in the Amazon River

The Center for Advanced Studies Research

Word Count (without citations): 4003

Abstract

Dams create hydroelectric power by converting kinetic energy from water flow to electrical energy. This is generally thought to be an environmentally friendly means of energy production. However, dams have potential serious detrimental effect on river ecology that must be considered as well. Currently the number of proposed large-scale dams outnumber existing large-scale dams by a factor of three to one. Dams stop essential nutrient-rich organic sediment from traveling downstream and interfere with the equilibrium of the river. The goal of this study is to increase the understanding of the complex interaction of large dams on river ecology by studying relevant peer reviewed scientific articles. Specifically, articles evaluating the concentration of organic sediment, methane and carbonic acid relative to water depth and relative to the distance upstream and downstream of the dam were critically reviewed, analyzed, and graphically displayed.

This review demonstrated that organic sediment and methane concentrations were lowest the farthest upstream of the dam and increased in a parallel fashion as samples were taken closer to the dam. For any distance from the dam, Methane and organic sediment concentrations were also higher at greater water depths where the organic substances are decomposed by anaerobic bacteria which are more concentrated on the river floor. By decomposing organic substances, the anaerobic bacteria also produced carbon dioxide which combined with water to form acidifying carbonic acid. This acidification was facilitated by the higher higher water pressure that is present at greater water depth.

Introduction

The Amazon River is home to more than 2,500 identified fish species (Lessa, 2015). Dams block the distribution of essential organic sediments that play an important role in maintaining a stable river pH. Organisms are only capable of adapting to minimal changes in pH. There are more than 50 large dams currently in use in the Amazon River and there are plans for the construction of approximately 150 more dams. (Vaidyanathan, 2012). These dams create “clean” energy for the Latin American countries by providing an alternative to the burning of fossil fuels in the production of electricity. Latin American countries are attempting to utilize hydropower as an efficient way to boost their economy. By using renewable energy, these countries can rely less on mining or buying fossil fuels (Nazareno & Lovejoy, 2011).

Figure 1 shows the current efforts to implement new dams in the Amazon (Fraser, 2015).

Hydropower is described as the usage of water as a power source and has been used since the ancient Greeks. The Greeks were the first to utilize hydropower by using water to turn a wheel that was used to ground wheat. Since then, hydropower has evolved and is now predominantly used in hydroelectric dams for a controlled release of water to convert the water’s kinetic energy to turn turbines and create electricity (National Geographic, 2009). Hydroelectric power is one of the most common clean energy sources in the United States and is one of the primary ways the United States is trying to combat global warming. The higher volume of water flow and the greater drop in elevation causes the water to gain more force and velocity which turns the turbines faster thereby creating more electricity (Fearnside, 2006; Fraser, 2015; U.S. Energy Information Administration, 2017, Figure 2). With the invention of electricity, humans have begun to rely more and more on electrical energy. This has caused many countries to develop cleaner sources of energy like hydroelectric power in order to reduce pollution and the production of greenhouse gases that contributes to global warming from the burning of fossil fuels (Mathews & Tan, 2015).

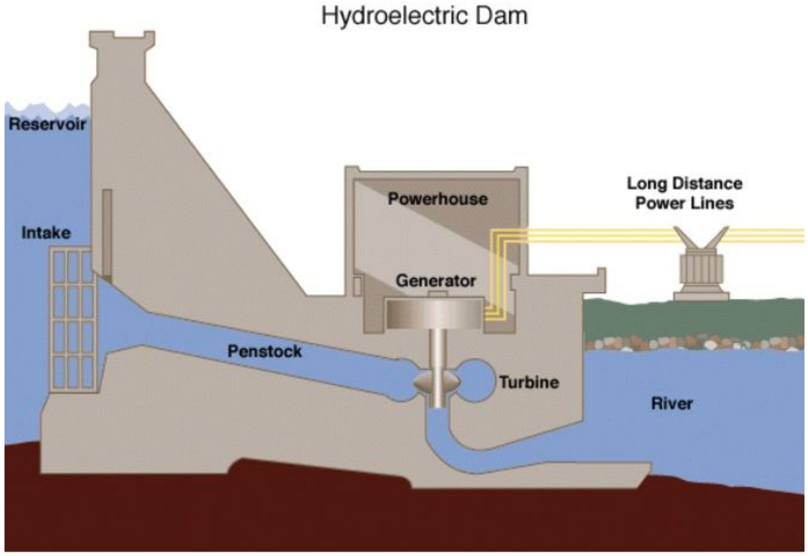

Figure 2. The typical layout of a hydroelectric dam, complete with long distance power lines that allow for potential energy to be transported long distances and a turbine spun by the water (U.S. Energy Information Administration, 2017).

Hydroelectric power is popular because, in most locations, hydroelectricity is the largest and cheapest source of “clean” energy (Fraser, 2015). In fact, in 2008, hydroelectric power generated about ten times the energy of solar, wind, and geothermal energy combined (Schiermeier et al., 2008). However, the production of hydroelectric power is geographically restricted to areas that have rivers with appropriate flow rates and elevation changes. In areas such as Brazil, where fast flowing rivers are common due to the Amazon Rainforest, hydroelectric power is extremely efficient. Brazil has increased their interest in renewable energy, specifically in hydroelectric power, and now produces 47 percent of their energy from renewable sources (Duailibe, 2010).

While receiving 47 percent of energy from renewable resources is a step in the right direction, hundreds of dams are used as a way to control the release of water and produce electricity (Latrubesse et al., 2017). Dams can have a number of deleterious side effects such as forced relocation of people, destruction of local habitat, interrupted migration of fish, sediment build up above the dam and reduced soil fertility below the dam, and deforestation which occurs during the construction of the dam (Macmillan Publisher, 2011). On the positive side, Hydroelectric power also helps the local economy by providing construction jobs and selling clean energy. Some countries, such as Greenland, profit off of electricity by selling it to other countries (Rosen 2016). All these factors must be considered is evaluating the value and economic viability of the construction of a hydroelectric dam.

With respect to the deleterious effect on the organic sediment concentration caused by a hydroelectric dam, Latrubesse tested the sediment concentration before and after a dam was built, from 2001-2015 (Figure 3). He reported a decrease in the mean annual surface suspended sediment concentration of 20 percent in the Amazon River (Latrubesse et al., 2017).

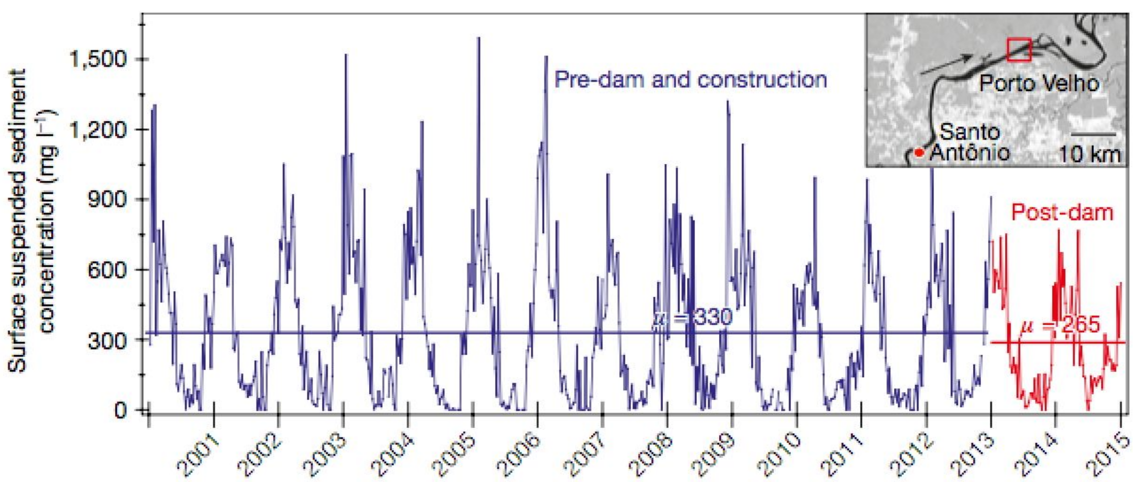

Figure 3. This figure shows the sediment levels for the years before and after the construction Porto Velho damn. The extreme drop represents a lack of sediments in the rivers which in turn affects micro bacteria, fish, and other neighboring organelles (Latrubesse et al., 2017).

It is important to evaluate the effect of a dam on sediment buildup to assess its overall environmental impact. Organic sediments can be any size and act to enrich the soil with nutrients. Areas where sediments are deposited are often very fertile and rich in biodiversity (Rutledge et al., 2012). A major problem of dams is they stop or slow the passage of organic sediment and topsoil into lower levels of the river (Figure 3)(Winemiller et al., 2016). By testing the sediment concentration over a long period of time, including before and after the dam was created, Latrubesse proved that dams block the travel of sediments downstream and starve the downstream of river of nutrients. Latrubesse conducted his study over a period of 15 years to show a consistent trend before the dam was placed that couldn't be thrown off by one anomalous year. His study supports documents a fairly consistent sediment concentration before the construction of the dam. After the dam was constructed, sediment concentration dropped downstream of the dam. This occurred because the the dam disrupted the transport of sediment by slowing the river's natural water flow thereby causing sediment to slowly sink and become deposited at the bottom of the river upstream of the dam. Dams starve the lower parts of the river of nutrients that allow biodiversity to flourish. Dam's restriction of sediments not only deprives the lower river of nutrients, but also shortens the lifespans of dams. When the sediments settle on the bottom, they eventually interfere with the passage of water through the turbines of the dam which then becomes less efficient (Perlman, 2016).

Another major problem that occurs when dams block sediments is the release of the very same greenhouse gases that were supposed to be mitigated from the reduction in the burning of fossil fuels. When dams block organic sediments, the sediments may decompose into carbon dioxide, methane, and nitrous oxide (Deemer et al., 2016). Dams usually release less greenhouse gases, but in some cases they can release an amount similar to that of burning fossil fuels (Tollefson, 2014). Accordingly, it is important to investigate and carefully evaluate the consequences of constructing more dams. Although decomposition of organic sediment is a natural cycle, the decomposition of sediment above a dam produces methane and carbon dioxide and is much more deleterious and different from its decomposition when it flows downstream and fertilizes fields and is incorporated in new plant growth. Unfortunately, the dam creates the perfect place for anaerobic bacteria to thrive. If the creation of dams could be improved by reducing its blockage of sediments, it would improve the efficiency and lifespan of the dam and there would be less deleterious decomposition of organic sediment, less carbonic acid production, and less methane release.

The carbon dioxide gas emitted from the decomposing organic substances acidifies the water (Perlman, 2016). The carbon dioxide and water react to form carbonic acid, which lowers the pH of the water (Penn State, 2017). Normally the organic sediments would be more dispersed and their decomposition would regulate the river's pH. However, dams cause sediments to decompose together and significantly lower the pH in that region by releasing carbon dioxide gas that reacts with the water to for carbonic acid (Castello & Macedo). As a result, the river is left extremely acidic in some areas, while other river areas become basic

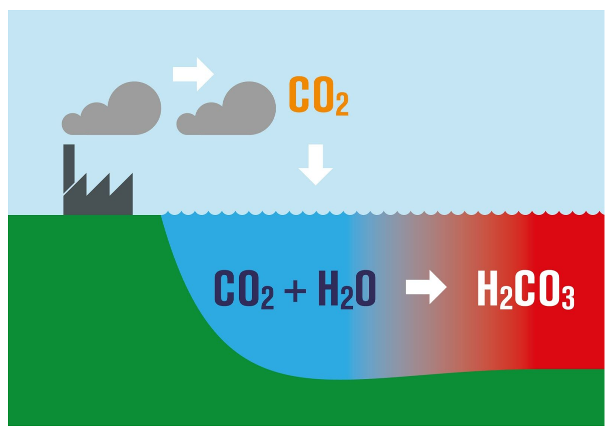

Figure 4 shows the chemical reaction with carbon dioxide and water react together to form carbonic acid, like what happens when dams release carbon dioxide. As a result, an acid is formed and the water becomes acidic (Penn State, 2017).

due to the lack of carbonic acid. In ocean acidification, carbon dioxide comes from the air. However, with hydroelectric dams, the additional carbon dioxide comes from the decomposing organic sediments (Figure 4). Both ocean acidification and river acidification result from carbon dioxide in water in the form of a gas, but the extra carbon dioxide comes from different sources. The pH of the water lowers as it becomes more acidic. As the pH decreases, the solubility of toxins such as mercury, lead and other toxic metals increases. The higher solubility means that the toxins are more mobile and move faster throughout the rivers, endangering more people and organisms alike (Fondriest Environmental, 2013). With proper investigation and modification, dams that produce greenhouse gases similar to that of burning fossil fuels can be avoided.

Currently, there are no methods to reverse the effects of dams on the water quality and the biodiversity (Figueres et al., 2017). There are still ways to minimize the impacts of a dam, but once the dam is in place the river will never be the same again. However, this does not mean that the whole river will die. The river loses a large part of its microorganisms due to its lack of sediments, which creates a ripple effect because now there is now less food for every level, leaving the animals competing for food. Many animals starve or are eaten, but in the end, those species best able to adapt survive. This also results in a lack in biodiversity. Unfortunately, like putting a broken plate back together, you can never get everything in the same place it used to be, the river ecosystem will not ever be the same as it once was.

The academic conversation pertaining to hydropower would be benefited by researching the the role the Belo Monte Dam on the organic sediment concentration. The academic conversation would gain a new detailed perspective about the role anaerobic bacteria and water pressure play in the decomposition of organic sediments. This project is relevant because there are over 150 dams that are being planned on being implemented in upcoming decades (figure 1) (Fraser, 2015). If dams harm rivers, then it is important that construction of new dams is modified. The current number of planned dams would dramatically alter more than 150 ecosystems. It is important to know the difference between a worthwhile hydroelectric facility and a harmful one. The academic conversation about whether hydroelectric facilities are worthwhile would be more completely measured by including the impact of the change in the concentration and type of sediments in the river ecology. One possibility is to avoid building dams in rivers with high concentrations of organic sediments. Additionally, modifying dams to avoid trapping organic sediment and topsoil will be most important. The academic conversation on hydroelectric power could help determine a dam will be cost effective and where they will be most beneficial for the longest period of time.

Purpose

The purpose of this study is to investigate the effects of the Belo hydrodam, on rivers in the Amazon. These findings could help prevent the creation of new destructive dams in the Amazon River as well as, many other important rivers around the world. Preventing the creation of harmful dams is essential in halting the destruction of river ecosystems. The effect of dams are often neglected with people not understanding the widespread repercussions. This article gives specific examples of how dams directly interfere with sediments and their essential role in the survival of a river ecosystem. The purpose of this study is to show that hydropower has serious consequences and there should be increased regulations on the allowed locations for dams. This would minimize the destruction dams can play in the Amazon River.

Overarching Research Question

How does the presence of dams influence the decomposition of organic sediments in the Amazon River?

Research Questions

Do dams influence the decomposition of organic sediments in rivers?

Alternate Hypothesis:

Dams increase the decomposition of organic sediments at the location of the dam.

Null Hypothesis:

Dams have no effect on the decomposition of organic sediment in rivers.

Dams decrease the decomposition of organic sediments at the location of the dam..

Methods

Research was obtained through systematic literature review, through public publishing of peer-reviewed journals and articles. Research Engines such as Google Scholar, Ebscohost, Nature, U.S. Energy Information Administration, and mentors with a Phd were used to collect papers published primarily between 2007 and 2018. Keywords and phrases, such as sediment depletion, organic sediments, anaerobic bacteria, sediment decomposition, methane concentration, and concentration of organic compounds, were used to help identify papers and useful information. Papers were analysed to show a correlation between dams and decreased sediment levels. Then references of articles with multiple figures were additionally used. Then all papers including methane, carbon dioxide, and organic compound sediments at differing depths and distances from the dam were recorded and combined to create data tables.

Studies were included in a systematic literature review based on the following standards

1. The range of studies taken were from 1995 to 2018
2. The studies focused on the the environmental impact of hydroelectric dams in order to narrow the topic.
3. Articles relating to organic sediments, sediment blockage, methane release, and organic sediment distribution were all accepted, but articles not including the specific distances from the dam and depths were omitted from being part of the data tables. Then all concentrations were converted into microMolars to show correlation between different studies.

Results

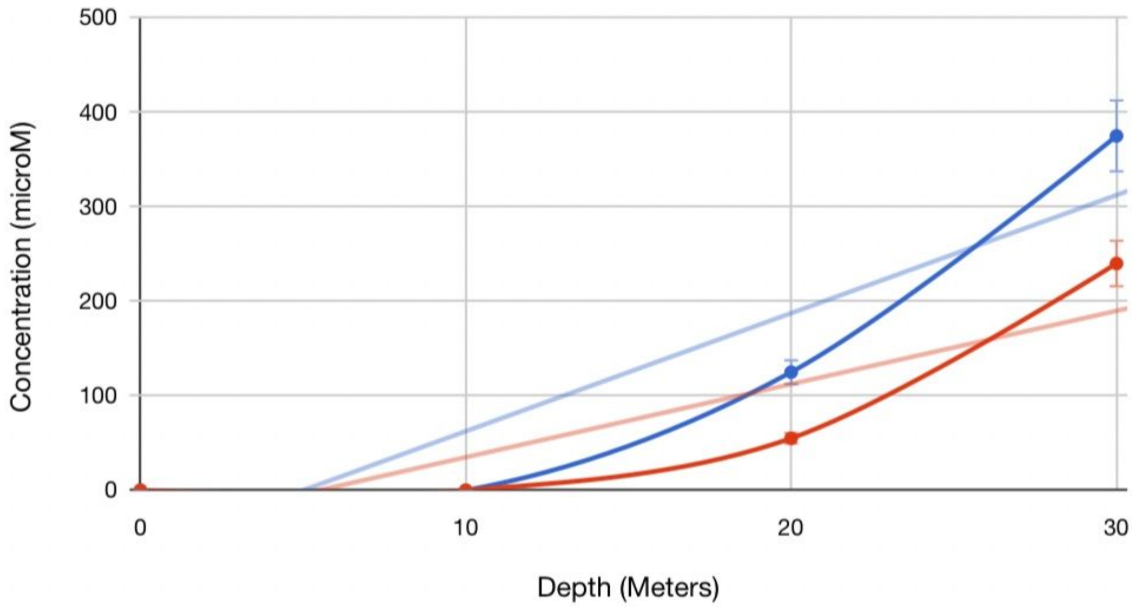

Figure 5 shows the increase of methane concentration as depth increases just before the dam (Kemenes, 2017; Fearnside, 2012)

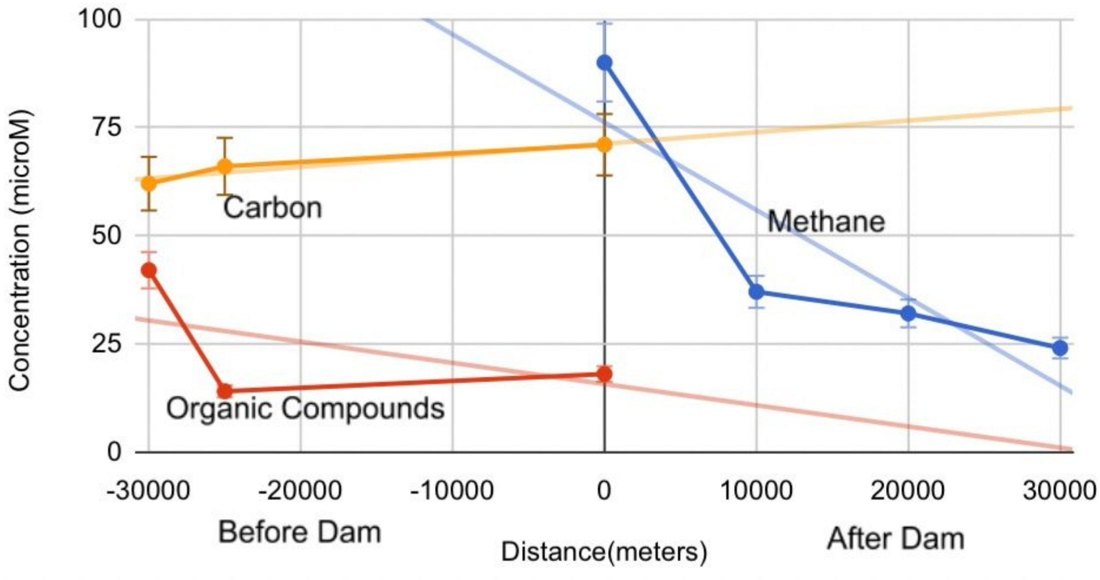

Figure 6 shows the increase in carbon and organic matter closer to the dam and the decrease in methane as one gets farther from the dam (Kemenes, 2017; Torrente-Vilara, 2011; Fearnside, 2012; Cardoso, 2013)

The methane gas levels were increased as depth was increased and were measured using the dissolved concentration of methane, water quality, and bubble occurrence from a multiparameter probe. Methane gas levels just before the site of a dam were near zero when close to the surface but increased to a micro Molarity of 375 and 240 when at a depth of 30 meters in two different rivers (Figure 5). Inversely, as depth decreases so does the methane concentration and as you get further from the bottom of the dam, the methane concentration drop. The methane concentration at 20 meters down and at the site of the dam was calculated to have a micro molarity of 90, which then at the same depth but 10000 meters downstream there was decreased to a micro molarity of 37. Methane levels decrease as they get farther from the site of a dam and as the depth of the sample is decreased (Figure 6).

As organic compounds, or almost all carbon containing compounds with the exception of carbonates, approach the dam, their concentration increases. The organic compound micro molar concentration 25000 meters before the dam was 14 while at the dam it increased to 18 once it reached the site of the dam. The carbon compound concentration increased by a micro molarity of 4 when staying at a depth of 20 meters. The decrease in organic compound concentration and increase in carbon compound concentration, which are the same thing as organic compound but from a different study, from 30000 meter before the dam to 25000 meters before the dam or from a micro molar concentration of 42 to 14 represents the area considered to be the reservoir. The reservoir is considered to start on average 25000 meters before the dam, at which point the sediment levels nearing the dam begin to accumulate as their concentrations increase (Figure 6). As compounds neared the dam and were submerged at deeper levels, their concentrations increased.

Discussion

Dams lead to a buildup of organic sediments which then decompose, releasing the methane and carbon dioxide gas (Figure 6). The organic and carbon compounds, both of which technically are organic compounds, received a change in sediment concentration as they approached 25000 meters upstream of the dam, or around the beginning of the dams' reservoir. Both slopes then at the beginning of the reservoir stabilized and stayed on a constant increasing concentration as the organic compound approached the dam. This increasing organic sediment concentration supports the fact that sediments become blocked at the dam and begin to chemically decompose, releasing methane and carbon dioxide gas.

Once the sediments have either passed through the dam or gotten stuck at the dam, they often times will begin to decompose. The highest concentration of methane gas released closest to the dam represents the most organic sediment decomposed was at the dam too (Figure 6). Methane levels decrease as you get further from the dam, supporting the fact that as you get further from the dam the downstream river sediment concentration decreases and also it proves that dams block a majority of the sediments, leaving but a fraction of what there used to be to be distributed evenly along the same sized river.

As the depth of the methane increased so did the concentration, meaning that more methane was being produced at lower depths from the decomposition of another probably organic, substance (Figure 5). However, decomposition in areas of high pressure favor the reactants, meaning usually they don't decompose very much. So this means that something else aided in the break down into methane and carbon dioxide. The biggest hint is that while increased depth increased methane concentration, but not because there was a strong pressure, but because the anaerobic bacteria like in oxygen free dark places and just happen to also be in strong pressure. The anaerobic bacteria decomposed the organic material and produced methane gas and carbon dioxide gas. The methane levels near the surface were close to zero because the anaerobic bacteria prefers dark and non-oxygenated waters rather than the surface.

The carbon dioxide gas then reacts with the water to create carbonic acid and the waters that have high concentrations of decomposing organic sediments are more acidic. This increased acidification is dangerous for animals near the dam. In addition, the area below the dam is deficient in organic sediments, meaning it has too high of a pH. While pH changes in very small increments, it is still best to avoid any changes, no matter how small. Even the slightest change in pH can have a drastic effect on nature's equilibrium. The river's pH is extremely sensitive and even the slightest change can be catastrophic. The pH can change overtime giving animals time to adapt, but dams and other human caused changes present an immediate change, with little to no time for rivers to adapt.

The change can be compared to that of ocean acidification, where the exoskeletons of minute organisms are weakened or destroyed, allowing only a small fraction of them to be survive. In addition, changes in pH also increase the solubility of elements in water, specifically toxins. This increases the mobility of toxins in the river, causing them to be absorbed by fish and humans. Even the smallest changes can affect plant growth and microorganisms levels. The correlation between river sediment levels and their effects from dams is apparent, with dams destroying the ecosystem where they are implemented.

Limitations

The limitations of this work include the inability to perform physical tests measuring the change in pH because there was a large deficit of articles that included a well documented calculation of pH and organic sediment concentration before the dam was created, after the dam was created, and at different distances from the dam site. While there are plenty of results recording the pH of different dams at the dam sites, these cannot be combined because the dams are located too far from one another and there is an absence of long term results due to the length of time required for such a study. As a result, I was unable to determine how acidic the dam would make the water because I could not make exact calculations because I didn't know how many organic sediments were decomposing and I since I did not take any personal tests and very few articles included toxin levels in the water, which would become soluble in an acidic solution. If you're near the dam where its acidic, there also are higher toxicity levels with varying danger levels depending on how many toxins are in the water.

Another limitation was how different articles measured sediment concentrations at different depths, making it far harder to combine the research from various articles. The largest limitation is however time. Like for the pH, time is essential for measuring the organic sediment concentration change before and after the dam is created. In addition there will need to be multiple spots where the samples are taken from. In order to have legitimate data there must be at least five years or more before the dam to show there isn't a bad year to throw off the values and another one year for the finish of the dam, and then five more years years to ensure all your answers are correct and not based off a bad year.

Conclusion

The data presented in the figures rejects the null hypothesis and proves dams do increase the decomposition of organic sediments at the site of a dam by creating the perfect living place for anaerobic bacteria to thrive because there is a continuous organic sediment income, minimal light, and minimal oxygen levels. The increased pressure causes the reaction between carbon dioxide and water to shift towards the products, because it has the lesser number of moles, resulting in more carbonic acid. The harmful effects of dams through blocking the release of river sediments was proven through various peer reviewed studies. Sediments were shown to increase methane concentration at the site of a dam, increase acidification at and above the dam, and decrease nutrient rich sediment levels downstream. The creation of new hydroelectric power dams, specifically in the Amazon Rainforest, should be prevented in order to protect the natural environment. The creation of dams creates a flood plain above the site of the dam which often holds many organic compounds such as plants. These plants are swept away by the now larger river, bringing them downstream until the organic compounds are blocked by the dam. The dam blocks all organic compounds that previously would have flowed freely and picks up more organic substances that would not have been moved had the dam not been created. This now increased sediment concentration decomposes, abruptly releasing large levels of carbon dioxide and methane gas, both of which are dangerous greenhouse gases. The carbon dioxide gas also reacts with the water, causing increased acidification in areas with high carbon dioxide gas, increased solubility of toxins, and decreased acidification in areas deficient in organic substance decomposition. Through changing the acidification levels, stopping nutrient rich sediments from enriching downstream rivers, and the release of dangerous greenhouse gases, dams negatively impact the environments they are created in. While the complete prevention of new dams is more of a dream than a reality, dams should still stopped being placed in rivers with high sediment concentrations. Rivers with high sediment concentrations not only will release more methane than rivers with lower concentrations, but they will also will block up the dam, shortening the amount of time it can function.

Further Work

One of the major reasons hydroelectric dams are so devastating is because organisms have a small amount of time to adjust to their new environment. One possible solution to at least minimize the results of dams, would be to calculate the estimated change in the river's pH and organic sediments, and calculate how long the river would take to adjust to the changes with a minimal environmental effect. The river sediments could then be slowed before the creation of a dam giving the river an adjustment period. By allowing the river to adjust over just a small period of time the organisms would at least be given the chance to adapt and adjust to their new environment.

However, the best option would be to educate people about the destruction of dams, causing them to invest in solar power, tidal power, wind power, or other cleaner sources of energy. In coastal areas with strong currents, hydropower can be used similar to a dam, but without blocking off rivers. The ocean current turns turbines, creating kinetic energy, which then is transferred into electrical energy. Turbines in the ocean would not block the spread of sediments, eliminating one of the main environmental impacts of dams. Also unlike dams, it wouldn't create massive flood plains above the hydropower station.

It would be beneficial to perform a long term term study on the change in pH, above and far below the dam to see how the pH raises as the samples get further from the dam. Due to the decreased decomposition of organic sediments downstream and increased neutralization of the carbonic acid the acidity would slowly decline, This would cause the water quality to become less and less regulated. In addition to taking samples, the concentration of fish and thickness of fish egg shells would be measured to better see the negative effects of small changes in pH in their environment.

Finally it is essential that people learn how to conserve energy and that current technology is improved to use less energy. People can limit their energy usage by investing in solar panels as a way to take increased responsibility in saving their planet.

Acknowledgements

I thank the following experts for their advice and feedback throughout this project: This paper has been with the aid of Dr. Malhotra, Dr. Rothschild, Bronte Brazier, Emily Htway, Michelle Magnusson, and Mr. Lott. I also would like to thank Chloe Mayhue, Emily Crivier, Alyssa Stovall, Bret Ketola, Amanda Dawley, and Sawyer Sipes.

References.

ARAÚJO, J. C., GÜNTNER, A., & BRONSTERT, A. (2010, January 19). Loss of reservoir volume by sediment deposition and its ... Retrieved March 12, 2018, from http://www.bing.com/cr?IG=FBFC20F0BDC148C7BD127C9BF4B367A9&CID=24EBF70EEFD861663213FCBEEE77607A&rd=1&h=1hhT78kZKgo0NncUOUdYnGlEVIwTj

iyG-lZw1pYFgmI&v=1&r=http%3a%2f%2fwww.tandfonline.com%2fdoi%2fpdf%2f10.1623%2fhysj.51.1.157&p=DevEx,5066.1

Ash, K. (2010, October 24). Methane Emissions from Tropical Dams. Retrieved from http://large.stanford.edu/courses/2010/ph240/ashe1/

Atkins, E. (2016, December 11). Dammed and diversionary: The multi-dimensional framing of ... Retrieved March 22, 2018, from http://www.bing.com/cr?IG=59F86EE61609483EADF1C3A1C899564F&CID=165A74D8036865910BBF7F6302C76407&rd=1&h=ftoWph46eApMp1VmOVsybR7OjF_tGDETkKN6Id1Smvk&v=1&r=http://onlinelibrary.wiley.com/doi/10.1111/sjtg.12206/full&p=DevEx,5064.1

Berchin, I., Garcia, J., Heerdt, M., Moreira, A., Silveira, A., & Guerra, J. (2016). Energy production and sustainability: A study of Belo ... Retrieved March 22, 2018, from http://www.bing.com/cr?IG=EDDFEC82A2794341ADB22B4915406B0F&CID=081ACE8653C96BF91F57C53D52666A28&rd=1&h=SY9967jVRkAq05gv_4yov4KJsWBd1T6DO8R7cs_ZLEc&v=1&r=http://onlinelibrary.wiley.com/doi/10.1111/1477-8947.12085/abstract&p=DevEx,5066.1

Bolch, T. (2017). Hydrology: Asian glaciers are a reliable water source. *Nature,545*(7653), 161-162. doi:10.1038/545161a

Carbon Dioxide and Carbonic Acid. (2006, December 21). Retrieved March 01, 2018, from http://ion.chem.usu.edu/~sbialkow/Classes/3650/Carbonate/Carbonic%20Acid.html

Cardoso, S. J., Vidal, L. O., Mendonça, R. F., Tranvik, L. J., Sobek, S., & Roland, F. (2013, April 09). Spatial variation of sediment mineralization supports differential CO2 emissions from a tropical hydroelectric reservoir. Retrieved March 15, 2018, from https://www.frontiersin.org/articles/10.3389/fmicb.2013.00101/full

Castello, L., & Macedo, M. (2015, November 9). Large-scale degradation of Amazonian freshwater ecosystems ... Retrieved March 22, 2018, from http://www.bing.com/cr?IG=87EC0B134CEB4F4486E473C7A19226A6&CID=0440508A117F6CB81BD15B3110D06D41&rd=1&h=s86pJjmqlc1203zsdF2VlGS9AWW3QSdQAkUy-0eOfus&v=1&r=http://onlinelibrary.wiley.com/doi/10.1111/gcb.13173/full&p=DevEx,5068.1

Castello, L., & Macedo, M. (2015, November 9). Large-scale degradation of Amazonian freshwater ecosystems ... Retrieved March 22, 2018, from http://www.bing.com/cr?IG=87EC0B134CEB4F4486E473C7A19226A6&CID=0440508A117F6CB81BD15B3110D06D41&rd=1&h=s86pJjmqlc1203zsdF2VlGS9AWW3QSdQAkUy-0eOfus&v=1&r=http://onlinelibrary.wiley.com/doi/10.1111/gcb.13173/full&p=DevEx,5068.1

Cuyahoga River Water Quality Monitoring Program, & Cleveland State University. (n.d.). Water Quality. Retrieved March 01, 2018, from https://www.grc.nasa.gov/www/k-12/fenlewis/Waterquality.html

Deemer, B. R., Harrison, J. A., Li, S., Beaulieu, J. J., DelSontro, T., Barros, N., . . . Vonk, J. A. (2016, October 05). Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis | BioScience | Oxford Academic. Retrieved February 27, 2018, from https://academic.oup.com/bioscience/article/66/11/949/2754271

Duailibe, A. K. (2010). Brazils renewable energy success. Nature, 468(7327), 1041-1041. doi:10.1038/4681041b

Fantin-Cruz, I., Pedrollo, O., Girard, P., Zeilhofer, P., & Hamilton, S. K. (2015, October 23). Changes in river water quality caused by a diversion hydropower dam bordering the Pantanal floodplain. Retrieved February 27, 2018, from https://link.springer.com/article/10.1007/s10750-015-2550-4

Fearnside, P. M. (2006, May 07). Dams in the Amazon: Belo Monte and Brazil's Hydroelectric Development of the Xingu River Basin. Retrieved March 01, 2018, from https://link.springer.com/article/10.1007/s00267-005-0113-6

Fearnside, P. M. (2005, February 03). Brazil's Samuel Dam: Lessons for Hydroelectric Development Policy and the Environment in Amazonia. Retrieved March 23, 2018, from https://link.springer.com/article/10.1007/s00267-004-0100-3

Fearnside, F. M. (2013, December 19). Impacts of Brazil's Madeira River Dams: Unlearned lessons for hydroelectric development in Amazonia. Retrieved March 12, 2018, from https://www.sciencedirect.com/science/article/pii/S1462901113002724

Fearnside, P. M., & Pueyo, S. (2012, June). Reservoir Emissions. Retrieved March 12, 2018, from https://www.internationalrivers.org/campaigns/reservoir-emissions

Figueres, C., Schellnhuber, H. J., Whiteman, G., Rockström, J., Hobley, A., & Rahmstorf, S. (2017). Three years to safeguard our climate. *Nature,546*(7660), 593-595. doi:10.1038/546593a

Fondriest Environmental, Inc. (2013, November 19). PH of Water. Retrieved March 01, 2018, from http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

Fraser, B., & National Geographic. (2015, April 19). Amazon Dams Keep the Lights On But Could Hurt Fish, Forests. Retrieved February 28, 2018, from https://news.nationalgeographic.com/2015/04/150419-amazon-dams-hydroelectric-deforestation-rivers-brazil-peru/

Friedl, G., & Wüest, A. (2001, October 5). Disrupting biogeochemical cycles – Consequences of damming. Retrieved March 12, 2018, from https://www.bing.com/cr?IG=14D4A6D663234735AADFA4C6B37B5A75&CID=2ECAF68B207D62CF3FCBFD3B21D2630A&rd=1&h=m7NRkq7DweUV_yebRYpKHhyXl8rYBg3U08ubaUAqMDM&v=1&r=https%3a%2f%2flink.springer.com%2fcontent%2fpdf%2f10.1007%252Fs00027-002-8054-0.pdf&p=DevEx,5062.1

Hydropower. (2009, October 09). Retrieved February 27, 2018, from https://www.nationalgeographic.com/environment/global-warming/hydropower/

Kapnick, S., Delworth, T., Ashfaq, M., Malyshev, S., & Milly, P. (2014, October 22). Karakoram glacier anomaly resolved, a cold case of climate science. Retrieved from https://www.sciencedaily.com/releases/2014/10/141022123537.htm

Kemenes, A., Forsberg, B. R., & Melack, J. M. (2007, June 23). Methane release below a tropical hydroelectric dam. Retrieved March 14, 2018, from http://onlinelibrary.wiley.com/doi/10.1029/2007GL029479/full

Kristensen, E., Ahmed, S. I., & Devol, A. H. (1995). Aerobic and anaerobic decomposition of organic matter in marine sediment: Which is fastest? *Limnology and Oceanography,40*(8), 1430-1437. doi:10.4319/lo.1995.40.8.1430

Kummu, M., & Varus, O. (2006, October 12). Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River. Retrieved March 12, 2018, from https://www.sciencedirect.com/science/article/pii/S0169555X06003229

Latrubesse, E. M., Arima, E. Y., Dunne, T., Park, E., Baker, V. R., D'Horta, F. M., . . . Stevaux, J. C. (2017). Damming the rivers of the Amazon basin. *Nature,546*(7658), 363-369. doi:10.1038/nature22333

Ledec, G., & Quintero, J. (2003, November). Good and Bad Dams NEW5 - World Bank. Retrieved March 12, 2018, from http://www.bing.com/cr?IG=3C1A6BCF0E2C41C8968758BC83009098&CID=3ABFEFA11E6F6CF60200E4111FC06D2D&rd=1&h=5ckPvrXgH7SWfAzTrynhxPIhefDBxmpdgxvhhmQvVsk&v=1&r=http%3a%2f%2fsiteresources.worldbank.org%2fLACEXT%2fResources%2f258553-1123250606139%2fGood_and_Bad_Dams_WP16.pdf&p=DevEx,5064.1

Lessa, A., Santos, M., Maddock, J., & Bezerra, C. (2015, August 04). Emissions of greenhouse gases in terrestrial areas pre-existing to hydroelectric plant reservoirs in the Amazon: The case of Belo Monte hydroelectric plant. Retrieved March 22, 2018, from https://www.sciencedirect.com/science/article/pii/S1364032115007145

Macmillan Publisher. (2011). Dammed if They Do.

Macmillan Publisher. (2016). Renewable Boom.

Maeck, A., DelSontro, T., McGinnis, D. F., Fischer, H., Flury, S., Schmidt, M., . . . Lorke, A. (2013, June 25). Sediment Trapping by Dams Creates Methane Emission Hot Spots. Retrieved March 12, 2018, from http://pubs.acs.org/doi/abs/10.1021/es4003907

Mathews, J. A., & Tan, H. (2014). China leads the way on renewables. *Nature,508*(7496), 319-319. doi:10.1038/508319a

Nazareno, A. G., & Lovejoy, T. E. (2011). Giant dam threatens Brazilian rainforest. *Nature,478*(7367), 37-37. doi:10.1038/478037b

Penn State. (2017, March 23). OCEAN ACIDIFICATION. Retrieved March 01, 2018, from https://sites.psu.edu/blanchardcivicissues/2017/03/23/ocean-acidification/

Perlman, H. (n.d.). PH -- Water properties. Retrieved February 27, 2018, from https://water.usgs.gov/edu/ph.html

Perlman, H. (n.d.). Sediment and Suspended Sediment. Retrieved February 27, 2018, from https://water.usgs.gov/edu/sediment.html

Pritchard, H. D. (2017). Asia's glaciers are a regionally important buffer against drought. *Nature,545*(7653), 169-174. doi:10.1038/nature22062

Quiroga, A., Lancelotti, J., Riva-Rossi, C., Tagliaferro, M., Asorey, M., & Pascual, M. (2015). Dams versus habitat: predicting the effects of dams on habitat supply and juvenile rainbow trout along the Santa Cruz River, Patagonia. Hydrobiologia, 755(1), 57. doi:10.1007/s10750-015-2217-1

Rosen, J. (2017). Arctic 2.0: What happens after all the ice goes? Nature, 542(7640), 152-154. doi:10.1038/542152a

Rutledge, K., McDaniel, M., Boudreau, D., Ramroop, T., Teng, S., Sprout, E., . . . Hunt, J. (2012, October 09). Sediment (K. West & J. Evers, Eds.). Retrieved February 27, 2018, from https://www.nationalgeographic.org/encyclopedia/sediment/

Schiermeier, Q., Tollefson, J., Scully, T., Witze, A., & Morton, O. (2008, August 13). Energy alternatives: Electricity without carbon. Retrieved from http://www.nature.com/news/2008/080813/full/454816a.html?message=remove

Sperling, E., & The TerraGreen Society. (2012). Hydropower in Brazil: Overview of positive and negative ... Retrieved March 22, 2018, from https://www.bing.com/cr?IG=2F4D378CD4CB46668518D231F9D56488&CID=2B47B3ED49EB65F61D0CB8564844646F&rd=1&h=a1u_ZGFKG7Z58mRCv_xa_ui88jBGOu-aisLJ9yoJuv8&v=1&r=https://www.researchgate.net/publication/257711885_Hydropower_in_Brazil_Overview_of_Positive_and_Negative_Environmental_Aspects/fulltext/0267a5960cf2946d9a2235c8/257711885_Hydropower_in_Brazil_Overview_of_Positive_and_Negative_Environmental_Aspects.pdf&p=DevEx,5066.1

Tollefson, J. (2014). Power from the oceans: Blue energy. *Nature,508*(7496), 302-304. doi:10.1038/508302a

Torrente-Vilara, G., Zuanon, J., Leprieur, F., Oberdorff, T., & Tedesco, P. A. (2011, April 20). Effects of natural rapids and waterfalls on fish assemblage ... Retrieved March 14, 2018, from http://www.bing.com/cr?IG=21EF04E175C746BE8BC31EDFEF12ED06&CID=0611FB25BEEC604D35F8F097BF436155&rd=1&h=qSehmErZyvSNJvFAwRLnKRaGObSNL

e9ixfp3TwIlD6k&v=1&r=http%3a%2f%2ftedesco1.free.fr%2fTorrente-Vilara%2520et%2520al.%25202011.pdf&p=DevEx,5091.1

Tousif, S. M., & Taslim, S. M. (2011). Producing electricity from geothermal energy. *2011 10th International Conference on Environment and Electrical Engineering,2*(5). doi:10.1109/eeeic.2011.5874669

Tundisi, J. D., Goldemberg, J., Matsumura-Tundisi, T., & Saraiva, A. (2014, August 18). How many more dams in the Amazon? Retrieved March 14, 2018, from https://ideas.repec.org/a/eee/enepol/v74y2014icp703-708.html

U.S. Energy Information Administration. (2017, June 13). Energy From Moving Water. Retrieved February 28, 2018, from https://www.eia.gov/energyexplained/index.cfm?page=hydropower_home

Vaidyanathan, G. (2012). Hydropower threatens Andes–Amazon link. Nature. doi:10.1038/nature.2012.10488

Wang, X., Peng, L., Su, C., & Cheng, G. (2017, May 15). Impact of Hydropower Dam Development on River Ecosystems ... Retrieved March 14, 2018, from https://www.bing.com/cr?IG=2A45DBF475134F58A259D0658C30EF61&CID=2BB2399C3F936D6E3718322E3E3C6CFD&rd=1&h=c9AFOCa0ha9prnHMKBtLOHtWVHYo_p1Of8Jv0MYg8Do&v=1&r=https%3a%2f%2fwww.researchgate.net%2fpublication%2f320289165_Impact_of_Hydropower_Dam_Development_on_River_Ecosystems_Ecopath_Model_Application_on_the_Red_River_in_China_as_an_Example&p=DevEx,5075.1

Winemiller, K. O., McIntyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., . . . Sáenz, L. (2016, January 08). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. Retrieved March 01, 2018, from http://science.sciencemag.org/content/351/6269/128