Universiteit Utrecht

The impacts of river diversion on agriculture and biodiversity

Name: Frederik Leemkuil
Student nr: 5672155
Supervisor: Kees Klein Goldewijk
Second reader: Marjanekke Vijge
Submission date: 24-12-2019
Word count: 5592

Bachelor thesis for the degree of Bachelor of Science (BSc) In Global Sustainability Science

Table of contents

1. Abstract

In this research a closer look will be taken to the consequences of river diversion and dams on agriculture, biodiversity and their socio-economic impacts. The knowledge of these consequences is important, since the diversion of a river can cause significant problems for the welfare of existing ecosystems, and sometimes even for humans. At the hand of case studies the impacts will be mentioned, and explained. It is found that there are very diverse consequences linked to river diversion and dam construction. Ranging from salinization issues to habitat loss and fragmentation. Although more research into and education of the consequences is required, it is important to oversee the range of impacts river diversion can have on biodiversity and agriculture.

2. Introduction

Humans have been diverting rivers for a long time, with an early river diversion dating to 2600 BC, in Ancient Egyptian Wadi Al-Garawi (Bazza 2006). There are multiple reasons to detour a river. Using the water for irrigation, flood prevention and creation of a water basin are multiple examples. Although river diversion can bring very significant benefits to communities, it also has risks.

The diversion of a river can have a very significant impact on local or regional ecosystems. For example, ecosystems can be very dependent on bacteria and algae in the water because they might provide nutrition for plants and bacteria/algae consuming life forms. This is one way of disrupting an entire ecosystem from the ground up, caused by a disruption of the flow of water (Kingsford 2000). Also, disrupting a river that is connected to a cave system can have disastrous results as well. Cave systems are often connected to a single water supply, severing this connection might cause extinction for the organisms living in the cave. (McAllister 2001).

The diversion of a river might also cause huge problems for agriculture, even though a large amount of areas, especially dry and/or poor areas, highly depend in river diversion for irrigation. For example, the diversion of the Ganges river at Farakka, India has caused increased levels of salinity downriver, which disrupts the agriculture in Bangladesh (Mirza 1998 & 2006). Furthermore, it is very likely that there are socio-economic consequences of river diversion. Though I expect that these are linked to the consequences on agriculture.

It is important to have knowledge of the effects and consequences of river diversion on biodiversity for sustainable and socio-economic purposes. The drainage of a downriver basin might destroy entire ecosystems, which in turn could be very important for local residents. Establishing conclusions on what might be the most common impacts of river diversion is very important. This study compares the results of an extensive literature review, of researches that all have a relation towards river diversion and its effects and consequences on biodiversity and agriculture. The following question will be answered in this research: What are the consequences of river diversion? The following sub-questions will also be answered: What are the impacts on biodiversity? What are the impacts on agriculture? What are the socio-economic impacts?

Additionally, it is also a possibility that there are cases of river diversion where there are no negative impacts, but rather positive effects. This means that if found, these cases will also be presented to provide a broader, and clearer view of the consequences of river diversion.

For this study it is necessary to have a clear definition of river diversion. I think that when a river is diverted to a different direction, rather than around an area or obstacle, it is possible to compare the effects to the effects of a dam or similar obstruction. In the case of a dam the downriver area is withheld of receiving a sufficient, or any amount of water. A river diversion that changes the direction of a river will have a similar effect. For the case of this study these two kinds of diversion will be mentioned. A change of direction will still be called a River Diversion, and a diversion that makes the river move around an area or obstacle will be called a River Detour. Definitions are mentioned in the theory section.

3. Theory

3.1 Definitions

- River Diversion: *"A river diversion is an artificial channel that is used to divert all or part of the river flow. Some river diversion are temporary in order to permit construction work to be carried out and others are permanent."* (Fisher & Ramsbottom 2001). In the case of this study, river diversions mentioned will be permanent diversions. Additionally, I think the effects of a river diversion can be cautiously compared to the effects of a dam or similar river obstruction.
- River detour: "*Water diversions consist of a system of structures and measures that intercept clear surface water runoff upstream of a project site, transport it around the work area, and discharge it downstream with minimal water quality degradation for either the project construction operations or the construction of the diversion."* (Department of Public Works 2008). These forms of diversion are mostly used for short term projects, like dam construction, after which the river diversion is reverted.
- Biodiversity: *"Biodiversity is the variety of life on Earth, it includes all organisms, species and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems."* (Benn 2010)
- Agriculture: *"The science, art, or practice of cultivating the soil, producing crops, and raising livestock and varying degrees of preparation and marketing of the resulting product."* (Merriam-Webster 2020)
- Downriver (basin): *The (former) basin or part of a river that comes after the section of the river mentioned.*

3.2 Context

Agriculture

Although river diversion can lead to high risks for agriculture, one of the main reasons to divert a river is for the benefit of agriculture; irrigation. Irrigation is a form of river diversion. Altering or splitting up the flow of a river to use the water or agriculture is irrigation. The growth of irrigated area has dropped significantly from 2% per year to 1.3% per year between the years 1970 and 1982 (Postel 1998). This is mostly caused by reduced investments in irrigation systems by international donor institutions due to rising construction costs and a declining amount of viable location for dams or river diversions (Postel 1998). This is only logical, since most areas that require the need of irrigation would already have acquired it by now, or because installing irrigation in those area might prove to be too difficult (Valipour 2013). Although there might be a big shortage of water or crop production, it is a very unwise to solve this problem with increased amounts of large dams and river diversions. These options have proven to be one of the primary causes of the destruction of habitats and extinction of species worldwide (Postel 1998).

Salinization

Accumulation of salts (salinization) in irrigated soils happens when evaporation exceeds precipitation, which means that the water that contains soluble salts evaporates and leaves the salts behind. When these salts are not leached out by other water sources they will accumulate. The extend of salinization also depends on which water is used. For example, brackish water and wastewater with a high level of soluble salts will drastically increase the rate of salinization. Salinization leads to toxicity in crops, reduction in soil fertility, reduction of availability of water to plants by reducing the osmotic potential of the soil solution, and a significant change in the hydraulic properties of soil (Vengosh 2003).

Biodiversity

There are multiple ways in which river diversion can hurt biodiversity. Firstly, water diverted from rivers for municipal use, i.e. flushing toilets, showering cooking, may be discharged into the ocean

and/or rivers directly from the sewage system. Although most places make use of a wastewater treatment plant, most large cities do not, especially in poor regions. This wastewater can kill animals or plants directly, or indirectly by affecting the surrounding ecosystem (Clemmens & Allen 2005).

Secondly, diverting a river can cause it to be disconnected, or difficult to reach, for aquatic species. This has a direct impact on these species since it will interfere with their habitats and mobility. Some species might find the need to travel to, through or from certain areas to feed, reproduce or simply migrate which can be made impossible by the diversion of a river (Fu et al 2003). Additionally, water diversions might cause temperature changes in the water, which can cause a habitat to become uninhabitable by certain species since most fish are very sensitive to water temperature changes (Meier et al 2003).

Thirdly, salinity threats in water quality can lead to negative effects on aquatic biota and ecosystem. Water salinity in rivers can also lead to or stem from dry land salinity, thus will also have a negative effect on dry land biodiversity (Goss 2003).

And lastly, river diversion might have big impacts on the floodplain of a river. Altering a floodplain can cause ecosystems in a very large area to see significant changes. A reduction in size of a floodplain, or an alteration in the frequency of flooding might cause problems for a large amount of species or plants inhabiting the area (Pearlstine 1985).

4. Methods

This research uses the descriptive and comparative method. First a very thorough literature review has been conducted according to the rules of Pautasso (2013), from which information necessary for the conclusion will be gathered. All literature has been gathered through Google Scholar or Researchgate. Literature sources will be provided. This method seem very reliable, and valid. This is because it has to be assumed that scientific research papers that have been peer reviewed are reliable and valid. The results of the literature research will be compared and explained with and/or against each other in the discussion. Results mentioned in the study might be found contradictory or not directly related to the research, reasoning for their inclusion will be mentioned in the discussion. At the end of the results a clear table will be provided to shortly summarize all the different consequences of river diversion on agriculture and biodiversity.

In the result section of this study the direct and indirect effects of river diversion will be mentioned. In the discussion the reason for the inclusion of indirect results will be mentioned, if and why they are significant enough for the study to be included. This will be done to avoid confusion and to put everything together into its entirety. Also, most, if not all, existing literature on the effects of river diversion are case studies, which means that these case studies will be used as examples of consequences. The results of these studies will be used to explain the results. Furthermore, solutions proposed by different scientists will be provided in the discussion section of the study.

5. Results

5.1 Agriculture

Effects of river diversion on agriculture

Salinization

One of the most problematic consequences for agriculture due to river diversion is the salinization of the soil. This problem is the most common in arid or semi-arid areas. Examples are the Nile Delta, the Murray-Darling Basin in Australia, the Aral Sea Basin in Central Asia and the San Joaquin Valley in the United States. It is estimated to cost 27.3 Billion US Dollars annually around the world to fight the loss of crops (EU Commission 2019).

Salinization of irrigated soils is a problem that affects about 20-24% of all irrigated lands around the world. In about 10% of these irrigated lands the salinization might be severe enough to actually reduce the crop yields substantially (Postel 1998 and Vengosh 2003). This is a result of the mismanagement of irrigation. Inhabitants of these areas are often poor and undereducated, meaning that they do not have the means to counter or prevent soil salinization. Additionally, some areas use wastewater as the water for irrigation, though in these areas the wastewater is not clean enough for domestic use, let alone agriculture. Although, concerns for the environment and human health often retain wastewater from being used for irrigation (Ferrer Polo 2008).

Discharge change and more

Diverting a river can prove to yield significant positive effects, but when done without thought to the consequences it can prove to be problematic for other people. For example, in Farakka (India), the government commissioned a diversion of the Ganges River because the river was proving to be difficult to navigate through (Mirza 1998 & 2006). Although, this river did not end in India. The diversion happened about 18 kilometers from the border of Bangladesh. The diversion of the Ganges at Farakka has caused some very significant changes in the hydrology and ecology of Bangladesh. Namely, the discharges of Ganges branch rivers in Bangladesh have changed; increased discharge during monsoon season, and decreased discharge during dry season. Aggradation in the Gorai River due to sedimentation. And the Southwest region of Bangladesh suffers from increase salinity, which has caused significant problems for forestry, industry, drinking water and especially agriculture sectors. And especially since agriculture is the main economic activity (contributing to about 35% of the GDP as of 1995) of the Ganges basin and about 410 million people live here (Mirza 1998).

Positive effects on agriculture

Irrigation is one of the main reasons for river diversion. Irrigation is done for the main purpose of increasing agricultural production, which contributes to about 70% of the total world water consumption. Of all the arable land in the world, about 18% is irrigated, and 40% of the food produced comes from irrigated lands (Šoštarić 2012). Irrigation a worldwide necessity to increase food production, considering that almost all countries worldwide can experience dry seasons, even the tropic regions (Myneni 2007).

5.2 Biodiversity

"Large dams and river diversions have proven to be primary destroyers of aquatic habitat, contributing substantially to the destruction of fisheries, the extinction of species, and the overall loss of the ecosystem services on which the human economy depends. Their social and economic costs have also risen markedly over the past two decades" (Postel 1998)

Effects of river diversion on biodiversity

Flood Control

Diversion of a river might cause a downriver floodplain to receive insufficient water. Seed germination might be affected by river diversion. In the Santee River Floodplain (South Carolina) most seeds are unable to germinate during a flood, of course there are exceptions to this, like black willow and eastern cottonwood. In the study of Pearlstine (1985) they used the model developed by Shugart & West (1977) to determine species survivability. Afterwards, if a seed was allowed to germinate, whether the seedling will survive is dependent on annual flood duration, this is one of its environmental conditions (Pearlstine 1985).

Flood control diversion along the Mississippi river, along with artificial dikes and the closure of distributaries have significantly increased the salinity levels of the estuaries connected to the river (Das et al 2012). The levels of salinity in water bodies play a very important role in the survival of organism, i.e. which organism can survive? Especially in estuarine systems (Das et al 2012). Ecosystems can be changes by even the smallest change in salinity level. This is because the salinity level reduces biodiversity and abundance directly or indirectly. Directly because the presence of salts has a direct impact on the osmoregulation of certain organisms. Indirectly because it interferes with inter-specific competition, predation and algal community structure (Schallenberg et al 2003). The salinity level of water also directly influences the distribution and composition of fish species in estuaries. Changes in salinity affect the metabolic cost of osmoregulation is fishes and the efficiency of food conversion. For example, salinity levels affect the filtration and respiration rates of oysters (Das et al 2012).

Additionally, the flood control diversion of the Mississippi River (namely by the Old River Control Structure) has caused significant losses to coastal wetlands by obstructing land formation. Land formation is caused for the most part by sediment delivered by the river. Flood overtopping and overbank sedimentation cause these sediments to accumulate. The water from the flooding of the river also reduced the salinity of the marsh and provided nutrients. The absence of these floods has caused the marshlands to starve, breakup and disperse. These diversions were implemented to prevent the flooding of the area, though ironically the flooding is what kept these marshes alive (Wheeler 2000). In addition to river diversion can also cause a disruption in nutrient delivery. This can cause a disruption in the growth of species, and eventually even extinction if the disruption is large enough. The delivery silicates to offshore marine areas is very important, and a disruption can cause significant problems for the biochemistry and algal ecology of these coastal areas (Rosenberg 2000).

Water temperature changes

Water diversion has an impact on river temperature. Note that river diversion does not increase or decrease the temperature of a river, but rather changes its temperature regime; the seasonal differences become more extreme (Žganec 2011). River diversion causes the diverted river and/or the resuming river to have a lower flow rate. This lower flow rate causes a river to have "more efficient net heat exchange with the atmosphere and the sediment due to larger surface/volume ratios and longer residence time" (Meier 2003). Natural forms of water heating like solar radiation, heat exchange with the sediment, long wave radiation, dissipation of kinetic energy, convection and evaporation, are enhanced or inhibited by river or stream diversion. Although these effects (aside from dissipation) do not play a role in the diversion of steep stream or rivers. Only river sections consisting of a gradual slope are affected by river diversion (Meier 2003). According to Gu et al (1998) water temperature is "one of the most significant and widely measured physical properties of water as most of the physical properties of water are functions of temperature". High water temperature in warm regions for a prolonged amount of time can be lethal to aquatic life. Some species of fish cannot survive water temperatures above 25^{o}C for longer than a week (Gu et al 1998).

Habitat loss and fragmentation

Dams and river diversion can, and in most cases will, disrupt the seasonal flow patterns of to which species in the region have adapted. Altering the natural flow regime of a river can cause a cascade of reactions resulting in lower native species richness and distribution; the simplification of a system (Habit 2007). River diversion can also disrupt the seasonal migration paths and cause habitat loss/fragmentation (Rosenberg 2000). Habitat fragmentation poses a worldwide problem for biodiversity. Although it is known that habitat fragmentation causes a problem, the process is so complex and variable that it is not known exactly how. There are two research methods of finding the impacts of habitat loss/fragmentation; Species-oriented and pattern-oriented research. The formed is based on existing ecological causalities, which improved the quality of research, but it is also impossible to study all the individual species. Pattern-oriented research provides general insights that are broadly applicable, but the results might be oversimplified and ignorant towards subtle differences between species (Fischer & Lindenmayer 2007). Additionally, species that are native to the region affected by loss/fragmentation of habitat suffer the most, as these species have evolved and adapted to a certain (micro)climate and vegetation (Rogan & LacherJr 2018). If a river is diverted through an area that had no river beforehand it will cause biodiversity problems.

Additionally, structures build in the river for the purpose of reservoir formation of river diversion can damage aquatic organisms as they move through them, or hinder them from moving through, causing habitat fragmentation (Tahmiscioğlu 2007).

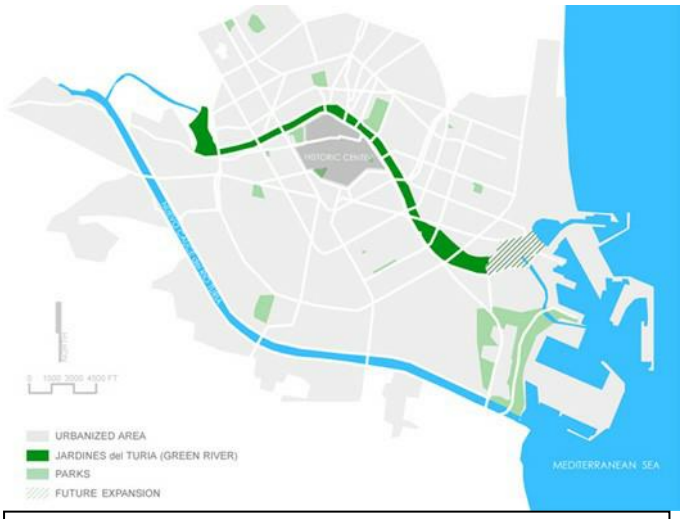

Figure 1: Turia Fluvial Park (Green area in the middle)

Positive effects of river diversion on biodiversity

In Valencia something special happened. The Turia river, which originally flowed through the center of the city, has been diverted (river detour). After the flood of 1957, *The Great Flood of Valencia,* a plan was devised to divert the river around the city in two parts. The diversion project finished in 1969 (Montañana & Esteve 2002).

After the diversion a 4.736 hectares park was laid out in the former river bed of the Turia; The Turia Fluvial Park. This park is a positive impact on biodiversity, as the park can be considered an ecological corridor. Ecological corridors connect patches of habitat that would normally be disconnect from each other. This results in an increase of mobility and migratory action of species. Especially in Valencia since the park is located in areas of high density urban development. Additionally the construction of this ecological corridor also promoted the presence of fresh water in its vicinity. The variety of birds, fish and insects have increased significantly due to the diversity of the habitat and the sudden presence of fresh water. (Viñals 2012).

River diversion can also be implemented in some cases without causing (relatively) much negative effects. The Mississippi River, for example, has a lot of active distributaries, though some of those distributaries have closed. These closures, together with the construction of flood control dikes and flood control diversions along the river have caused estuaries to stop receiving freshwater from the river. There are some scientists and managers that concur that controlling river diversions along the river to lead water back into the coastal wetlands can reverse coastal land loss. They are also positive that river diversions can be effective in reducing high salinity through the provision of sediments and nutrients (Das et al 2012). Although these are scientific solutions to a problem that has existed for a long time, there are also some concerns. In the Mississippi river, high nutrient

concentrations have caused uncontrolled algae growth which led to eutrophication in the coastal waters on the northern parts of the Gulf of Mexico. This is not the only concern however. An increase in nutrient provision could also cause faster soil decomposition, lower accumulation of biomass belowground and lower soil strength, which severely impacts marsh plants (Das et al 2012).

5.3 Socio-economic

Since one of the most prominent reasons for river diversion is irrigation, it is safe to assume that agriculture plays a big part in the worlds social environment and economy. Especially in poor countries it contributes most to the national economy. And in these countries irrigation is especially essential since their environments are often dry or unwelcome to agriculture (Döll & Siebert 2002). Combined with the fact that these countries also often lack the means to efficiently use irrigation, makes for a rather significant impact. Excessive water usage is not the main worry of the farmers in these areas. Crop yield, i.e. economic value, is the main worry in these parts of the world (Altaweel 2013). This means that rivers might be diverted for the purpose of irrigation without looking at the further consequences of this diversion. This has caused concerns for water scarcity.

Excessive water usage has caused a worldwide water scarcity, as 70% of the worldwide water consumption is for agriculture. According to Mekonnen & Hoekstra (2016) "Freshwater scarcity is increasingly perceived as a global systemic risk. We find that two-thirds of the global poppulation (4.0 billion people) live under conditions of severe water scarcity at least 1 month of the year". This means that improper use of irrigation is already causing worldwide problems concerning the water stock.

Dams or river diversions may cause increases in water sourced illnesses like typhus, typhoid fever, malaria and cholera. The spread and grow of water borne diseases are enhanced by slow moving or stagnant water. Especially malaria and Filariasis, which are both spread by mosquitoes, which thrive in slow moving or stagnant waters (Loch & Howard 1994).

In some cases towns will be forced to move to make room for a river diversion. Residents living among the Red River in Minnesota, North America, fear that their towns will be sacrificed in order to save two larger cities from chronic flooding (Kolpack 2009). It has happened in the past at the Three Gorges Dam in 2008 in China, when a million people were forced to move. And happened again in 2014 when 345.000 villagers from the Hubei and Henan provinces were forced to move because of the construction of a water transfer system (Kuo 2014).

Positive impacts

Because irrigation causes an increase in crop yields in general, it can be safe to assume that the economic benefits of irrigation are present as well. Especially in poor areas like Bangladesh, where agriculture contributes to 17% of the national GDP and provides employment for 45% of the population as of 2017 (Rahman 2017). This means that providing irrigation, or flood prevention can have significant impacts on the agriculture in this area.

The Valencia Fluvial Park project has sparked the interest in and importance of the conservation of biodiversity. And because of the communication to society, the transparency of the project, it was ultimately possible to estimate the economic value of the local ecosystem, which is necessary to achieve sustainable growth. The spark in interest in the public has also caused an increase in public support towards green corridors and sustainability in general. (Estruch-Guitart & Valls-Civera 2019).

↓Subquestion	Negative impacts of river diversion	Positive impacts of river diversion
Agriculture	-Salinization -Reduced water flow	-Possibility of irrigation -Increased crop yield
Biodiversity	-Floodplain destruction -Increased salinity levels in soils and water -Obstruction of land formation -Habitat loss and fragmentation	-Can reduce salinity through nutrient and sediment provision -Special case: Turia Fluvial Park. Construction of an ecological corridor, which increases biodiversity.
Socio-economic	-Water scarcity -Increase in water sourced illnesses -Forced relocation of villagers	-Increased crop yield -Special case: Turia Fluvial Park project has made economic value estimation and public support possible.

Table 1: Summary of all the impacts in result the results

6. Discussion

6.1 Problems and difficulties

The first problem with the research it the subject might be too broad. In order to stick to the subject I found it unfeasible to go too much into depth. This resulted into the research being more or less a summation of the impacts of river diversion. Some of the impacts could have received some more attention, but I decided to focus on the most prominent impacts more; habitat loss/fragmentation and salinization. Nevertheless, a broad research into the effects of river diversion is also worthwhile, since it shows the bigger picture of the impacts the big river diversion operations can have on the environment and its inhabitants. Additionally, most case studies were based around the negative impacts of river diversion. This is because most of the articles were based around these impacts. Which is logical considering that the existence of river diversion and dam construction proves that there are positive impacts. And that these, if the stakeholders know about the negative impacts, outweigh the negative impacts.

Additionally, the research was not conducted on a time scale. Although I think that some impacts might happen more quickly than others, temperature changes in water quicker than salinization for example, the time it takes for the impacts of river diversion to kick in were not taken into account. Additionally I also did not take into account the time of publication of the reference articles, although I think this does not make much of a difference, since the only variable between old and new publications would be prior knowledge.

The case studies and existing articles were only selected when they applied to any of the sub questions. This was done to keep the direction of the research in mind. For this research a broad perspective was chosen, and adding more conditions to research and case study selection would cause and require more in depths research into all the different impacts. Although, this can perhaps be a good idea for further research, to focus on one of the impacts and provide an in-depth analysis of these.

It is difficult to compare the effect of river diversion to each other. Imagine two ecosystems with the same climate and environmental conditions on different places on the world, and a dam or river diversion was placed in both areas. Even if both the diversions are identical in the reason for construction, the effect of the diversion might be completely different. The river might play a much bigger role in the ecology of one area than the other. If flora and fauna have adapted differently to the river than the consequences of the diversion might prove to be different as well. One area might encounter a trophic cascade, while the other might not feel any consequences at all. Additionally, in some cases, like the Ganges diversion in India, natural causes might also play a part on the impacts. Which, if they do, can significantly alter the results of case studies into the effects of river diversion. This means that it is not always easy to obtain concrete evidence of the effects of river diversion on the biodiversity and agriculture in the region. For example, the salinity in the Ganges region is also influenced by interannual variations (Mirza 1998).

Lastly, defining a difference between river diversion and river detour might have been redundant in the case of the results, since no comparisons have been made between the two definitions. Although, for the purpose of a comparison between river diversion and dam construction it has been very useful. In most cases dams or river diversions are a combination of the two definitions anyway. This is because diverted rivers often do not change direction entirely, but are rather branched off into a different direction, and dams will often still let water through, despite being an obstacle (CTCN n.d.)

6.2 Connections

It important to explain the connection between agriculture and biodiversity. Agriculture in itself causes a disruption in biodiversity. Large areas of land are converted for the purpose of the cultivation of one or a couple of crops. This disrupts habitats of animals previously living in the areas, but might also disrupt the flow of nutrients or groundwater around the area.

Socio-economic impacts were also included, because biodiversity and especially agriculture also link to this. For example, excessive and inefficient agriculture can lead to salinization, which can lead to harvest problems, which can lead to food shortage and land degradation, both which have effect on the inhabitants of the land. Or water borne diseases which can strive in stagnant or slow moving water as the result of river diversion or dam construction.

It is important to remember that these are not all the impacts of river diversion, just the most prominent ones. Frankly it is impossible within the word limit and timespan to conduct a research into all the impacts river diversion can have on agriculture and biodiversity and their socio-economic factors.

In this study the effects of irrigation were the primary topic of the effects on agriculture. Although it could be argued that these are no direct effect due to river diversion. Irrigation in itself is not the cause of salinization or ground degradation in areas that are prone to it. It is the fact that water flow is not enough to rinse the salt out of the soil or provide enough new nutrients to the soil. Nevertheless, I thought the consequences of irrigation on agriculture, through soil salinization were an effect of river diversion, and should thus be included. The same counts for the socio-economic impacts. These were also indirect consequences of river diversion, but nevertheless provide good insights into further effects it might have and possible solutions for the impacts. The positive impact of the Turia Fluvial Park can be considered an effect of a river diversion as well. Since the park is built on the former river bed of the Turia River. Although it is an indirect effect I think it should be included as well, since it was a great idea and opportunity to create an ecological corridor and important landmark in Valencia.

6.3 Possible solutions

Although it is impossible to simply quit using irrigation simply because it harms the environment, it is possible to decrease the negative effects it brings. For example, India and Bangladesh signed a 30-year treaty on sharing the dry season flow of the Ganges River. Although the current dry season flow is not enough to meet the requirements of both countries. Research on the optimization of the dry season flow is necessary (Mirza, M. M. Q. 1998).

Mismanaging of irrigation is one of the leading causes of soil salinization, but it is argued that in most cases salinization as an effect of irrigation could have been prevented with simple engineered strategies; artificial leaching for example. Although most areas prone to salinization are dry and poor areas, this should not be a problem. The problem in these cases is the economic mindset of these areas. The cultivation of a high amount of crops is the number one priority of the inhabitants, meaning that there is no time left for the fields to fallow, or to allow the effect of natural leaching to take their turn (Altaweel 2013). Leaving these areas to rest for a while, or installing low water use devices meant to leach the soil of their accumulated salts is a must. Solutions for this problem would be to introduce a government program that allows agricultural producers to install artificial leaching devices, or something similar, for a significantly lower cost (i.e., subsidization). Additionally, education of agricultural producers can also promote the reduction of salinization significantly. Education might not prove to be a solution for small scale agricultural producers, since they might need the funds of production in the short term. Although, large scale agricultural producers might benefit from this, since it will profit them in the long term. Additionally, increased efficiency of irrigation can be acquired through the use of pressurized irrigation. This method of irrigation uses a much smaller amount of water. But, the installation of such a system is very expensive and thus might not be economical for some regions that suffer from poverty (Valipour 2013).

In general, as said before, the scope of this research of very broad. River diversion could use more research into its impacts, especially research into differentiating the effects of river diversion from natural causes and the causes for habitat loss and fragmentation. This is necessary because the natural causes are often much more subtle than anthropological impacts. And the causes for habitat loss and fragmentation are very complex and variable.

7. Conclusion

What are the impacts on agriculture? The most prominent impact of river diversion on agriculture is salinization. Salinization affects about 20-24% of all irrigated lands, especially in arid and poor regions. Considering that 70% of worldwide water consumption comes from agriculture, makes this a very significant number. Not only salinization causes a problem, but also reductions to water flow, which will decrease the amount of water available for agriculture, whilst also increasing salinity levels in water and soil. The single most important positive effect of river diversion on agriculture is the possibility of irrigation. Irrigation significantly increases crop yields in regions where this would otherwise be low, or where it would even be impossible to cultivate land.

The impacts on biodiversity are more diverse. With habitat loss and fragmentation being the leading cause of biodiversity loss in the world. Changing water flow patterns, and changes to migration paths are the biggest causes for habitat loss and fragmentation due to river diversion. Although, it is known that river diversion causes problems for habitats, it is not exactly known how, so more research into this is required. Floodplain destruction, increased salinity levels and the obstruction of land formation are also problems, but these are mainly caused by flood prevention measures. Positive impacts on biodiversity from river diversion or not well known, or scarce. The special case of the Turia Fluvial Park shows a great consequence of river diversion for biodiversity, and much can be learned from this case.

The socio-economic impacts of river diversion have more impact on humans, obviously. Concerns for water scarcity, increases in water borne illnesses and forced relocation of villagers are the prime socio-economic problems caused by river diversion. Positive impacts include the possibility of irrigation, which can significantly increase crop yields and thus economic welfare of regions that highly depend on agriculture. And projects that promote biodiversity, like the Turia Fluvial Park project, can increase public interest and appreciation of ecosystems, whilst also making an estimation of the economic value of ecosystems possible.

All in all, the consequences of river diversion are very diverse, and some even so complex and variable that now much is known about them right now. Some impacts might even have natural causes. It is necessary to educate people more about the consequences of river diversion, so that they may handle appropriately to prevent, or at least mitigate them as best they can. More in depth research into the consequences of river diversion is necessary to find out how they happen, and to provide knowledge of the natural causes that might also have effect.

8. References

Agriculture. In *The Merriam-Webster.com Dictionary*. Retrieved January 20, 2020, from https://www.merriam-webster.com/dictionary/agriculture

Altaweel, M. (2013). Simulating the effects of salinization on irrigation agriculture in southern Mesopotamia. Archaeopress.

Bazza, M. (2006). Overview of the hystory of water resources and irrigation management in the near east region. *Food and Agriculture Organization of the United Nations.*

Benn, J. (2010) *What is biodiversity?* United Nations Environment Programme, World Conservation Monitoring Centre

Clemmens, A. J., & Allen, R. G. (2005). Impact of agricultural water conservation on water availability. In *Impacts of Global Climate Change* (pp. 1-14).

CTCN (Climate Technology Centre & Network) (n.d.). Flow through dam for flood control. *Adaptation Technology Database*

Das, A., Justic, D., Inoue, M., Hoda, A., Huang, H., & Park, D. (2012). Impacts of Mississippi River diversions on salinity gradients in a deltaic Louisiana estuary: Ecological and management implications. *Estuarine, Coastal and Shelf Science*, *111*, 17-26.

Department of Public Works (2008). Storm Water Services Devision *Water diversions.*

Döll, P., & Siebert, S. (2002). Global modeling of irrigation water requirements. *Water resources research*, *38*(4), 8-1.

Ferrer Polo, F. J., Pérez-Martín, M. Á., Pérez, F., & Artés, J. B. (2008). Specific combined actions in Turia River during 2005-2007 drought. *Options Mediterraneennes. Serie A: Seminaires Mediterraneens*, (80), 227-234.

Fischer, J., & Lindenmayer, D. B. (2007). Landscape modification and habitat fragmentation: a synthesis. *Global ecology and biogeography*, *16*(3), 265-280.

Fisher, K. & Ramsbottom, D. (2001) *River diversions, A design guide.* page 5.

Fu, C., Wu, J., Chen, J., Wu, Q., & Lei, G. (2003). Freshwater fish biodiversity in the Yangtze River basin of China: patterns, threats and conservation. *Biodiversity & Conservation*, *12*(8), 1649-1685.

Goss, K. F. (2003). Environmental flows, river salinity and biodiversity conservation: managing trade-offs in the Murray–Darling basin. *Australian Journal of Botany*, *51*(6), 619-625.

Gu, R., Montgomery, S., & Austin, T. A. (1998). Quantifying the effects of stream discharge on summer river temperature. *Hydrological Sciences Journal*, *43*(6), 885-904.

Habit, E., Belk, M. C., & Parra, O. (2007). Response of the riverine fish community to the construction and operation of a diversion hydropower plant in central Chile. *Aquatic conservation: Marine and Freshwater ecosystems*, *17*(1), 37-49.

Kingsford, R. T. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology*, *25*(2), 109-127.

Kolpack, D. (2009). Downstream towns worried about Red River diversion. *The Associated Press, MPR News.*

Kuo, L. (2014). China's desperate need for water is forcing the relocation of hundreds of thousands of people. *Quartz.*

Pautasso, M. (2013). Ten simple rules for writing a literature review.

Loch, K. & Howard, G. (1994). Water-related vector-borne disease. *Us National Library of Medicine, National institutes of health.*

McAllister, D. E., Craig, J. F., Davidson, N., Delany, S., & Seddon, M. (2001). Biodiversity impacts of large dams. *Background paper*, *1*.

Meier, W., Bonjour, C., Wüest, A., & Reichert, P. (2003). Modeling the effect of water diversion on the temperature of mountain streams. *Journal of Environmental Engineering*, *129*(8), 755-764.

Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. *Science advances*, *2*(2), e1500323.

Miguel Montañana Palacios y Santiago Tormo Esteve (2002). Grupo Español del IIC (ed.). LOS AZUDES DEL TURIA EN LA VEGA DE VALENCIA. ASPECTOS FUNCIONALES, CONSTRUCTIVOS Y MORFOLÓGICOS DEL SISTEMA DE MESTALLA Y SU CONSERVACIÓN COMPATIBLE CON LOS USOS ACT

Mirza, M. M. Q. (1998). Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. *Environmental management*, *22*(5), 711-722.

Mirza, M. M. Q. (Ed.). (2006). *The Ganges water diversion: environmental effects and implications* (Vol. 49). Springer Science & Business Media.

M.J. Viñals; M. Morant; P. Alonso-Monasterio (2012): Connecting urban and rural areas through a green corridor. Case study of the Parc Fluvial del Turia (Valencia, Spain). In Research Studies on Tourism and Environment(ISBN 978-1-61209-946-0). Ed. Nova Science Publishers (New York), pp.313-324.

Myneni, R.B., et al. (2007) Large seasonal swings in leaf area of Amazon rainforests. Proceedings of the National Academy of Sciences (PNAS). March 20, 2007.

Pearlstine, L., McKELLAR, H. E. N. R. Y., & Kitchens, W. (1985). Modelling the impacts of a river diversion on bottomland forest communities in the Santee River floodplain, South Carolina. *Ecological Modelling*, *29*(1-4), 283-302.

Postel, S. L. (1998). Water for food production: will there be enough in 2025?. *BioScience*, *48*(8), 629-637.

Rahman, T., (2017). Role of Agriculture in Bangladesh Economy: Uncovering the Problems and Challenges. *International Journal of Business and Management Invention.*

Rogan, J. E., LacherJr,T. E. (2018). *Reference Module in Earth Systems and Environmental Sciences*

Rosenberg, D. M., McCully, P., & Pringle, C. M. (2000). Global-scale environmental effects of hydrological alterations: introduction. *BioScience*, *50*(9), 746-751.

Schallenberg, M., Hall, C. J., & Burns, C. W. (2003). Consequences of climate-induced salinity increases on zooplankton abundance and diversity in coastal lakes. *Marine ecology progress series*, *251*, 181-189.

Shugart Jr, H. H., & West, D. C. (1977). Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. *Journal of environmental Management*.

Šoštarić, J., Marković, M., Šimunić, I., & Josipović, M. (2012, January). Irrigation-wish or necessity. In *INTERNATIONAL CONFERENCE TEAM 2012*.

Tahmiscioğlu, M. S., Anul, N., Ekmekçi, F., & Durmuş, N. (2007, March). Positive and negative impacts of dams on the environment. In *International Congress on River Basin Management* (pp. 22-24).

Valipour, M. (2013). Necessity of irrigated and rainfed agriculture in the world. *Irrig. Drain. Syst. Eng. S*, *9*, e001.

Vengosh, A. (2003). Soil Salinization. *Treatise on Geochemistry, 2003*. Chapter 9.09.7.

Wheeler, C.D., (2000). Louisiana Coastal Land Loss. *The Louisiana Environment.*

Žganec, Krešimir. (2011). *The effects of water diversion and climate change on hydrological alteration and temperature regime of karst rivers in central Croatia. Environmental Monitoring and Assessment. 184. 10.1007/s10661-011-2375-1.*