Potential Policy Projects for Decreasing Fluoride Concentrations in the Groundwater of Aguascalientes, Mexico

– A Cost-Benefit Analysis

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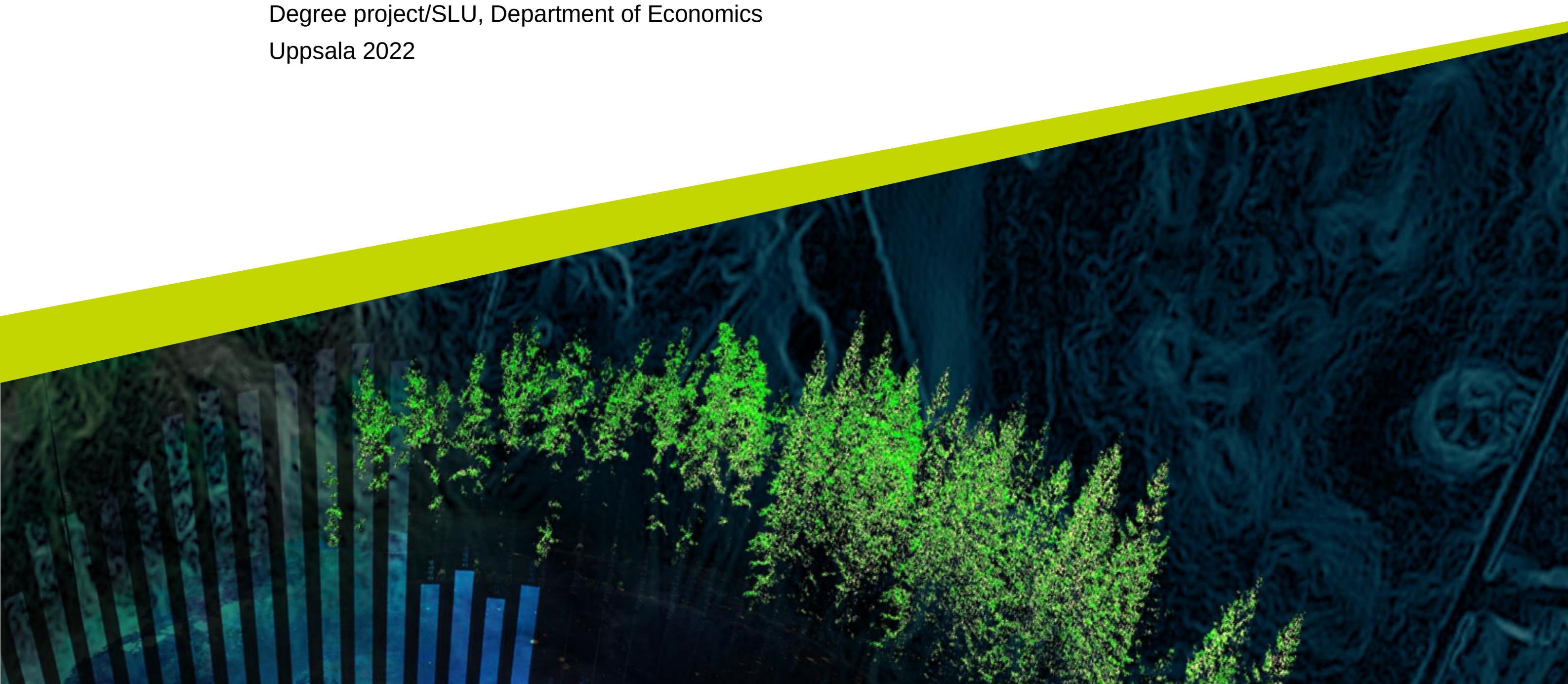

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Abstract

Reductions in groundwater quality due to aquifer depletion is a growing issue globally and will become more prominent with continued climate change and population growth. Dry regions are particularly vulnerable to this issue due to their reliance on groundwater for water supply. Therefore, urgent attention to improving groundwater management in such areas is essential in regional budgets and policy agendas. This thesis aims to provide insight and initial estimates on the potential net social benefits associated with two policy projects intended to increase the groundwater quality in the semi-arid state of Aguascalientes, Mexico. The focus lies on the aquifer of Valle de Aguascalientes, where fluoride contamination due to aquifer overdraft is becoming increasingly problematic. The projects evaluated are the installation of fluoride removal units using electrocoagulation (Project A), and the implementation of centre pivot irrigation systems (Project B). Policy evaluation is performed using cost-benefit analysis. The results show that Project A is associated with a net present value (NPV) of 159 262 033.17 USD and Project B with an NPV of -123 864 575.35 USD. However, due to the uncertainty associated with these estimates, the resulting recommendation is to not accept either project until the certainty of the policy evaluation is increased. Nevertheless, the information provided in this thesis may be helpful in planning for future studies.

Keywords: Aguascalientes, Cost-benefit analysis, Fluoride removal, Centre pivot irrigation, Sustainable development, Environmental policy

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Abbreviations

CBA	Cost-Benefit Analysis
CAGR	Compound Annual Growth Rate
CONAGUA	The National Water Commission of Mexico
CPI	Centre Pivot Irrigation
CVM	Contingent Valuation Method
DCE	Discrete Choice Experiment
GHG	Greenhouse gas
gpm	Gallons per minute
GWP	Global Warming Potential
ha	Hectares
INAGUA	The State Water Institute of Aguascalientes
NPV	Net Present Value
PV	Present Value
PPP	Purchasing Power Parity
SCC	Social Cost of Carbon
SDR	Social Discount Rate
SLU	Swedish University of Agricultural Sciences
WTP	Willingness-To-Pay

1. Introduction

This chapter, in particular section 1.1, outlines the issues related to groundwater depletion in dry regions, primarily focusing on Aguascalientes[1], Mexico. In section 1.1.1, the current groundwater governance structure in Mexico is described. In section 1.1.2, a narrower focus is taken to provide a detailed description of the study area. Lastly, this study's aims and objectives are presented in section 1.2.

1.1. Problem Description

Groundwater quality reduction due to aquifer depletion is a growing issue globally. Freshwater availability is negatively affected by temperature increases due to climate change, and population growth and land use/land cover change reinforce this trend (Ojeda Olivares et al. 2019). The problem is of particular concern in drier regions where water resources are scarce, and surface water can only satisfy a small portion of the water demand (Morris & Gallardo Cabrera 2018). The high reliance on groundwater in such regions – especially in countries with expanding urban areas and increasingly active agricultural and industrial sectors – often lead to aquifer overdraft and groundwater deficit (Konikow & Kendy 2005). This fact threatens both ecosystems and the livelihoods of current and future generations.

In this sense, groundwater deficit alone is arguably problematic, although it also gives rise to numerous other problems. Castellazzi et al. (2016) mention examples such as land subsidence, irreversible damages to the aquifer's ability to store water and increased water contamination risks. In Aguascalientes, Mexico, the state water institute (INAGUA) (2021) notice the latter as the most urgent problem. They state that the groundwater contamination arises due to poor water governance and difficulties with financing water infrastructure. They further note that the present contamination is an issue of growing public health concern which is likely to continue given the current water extraction patterns.

The growing concern for the contaminated groundwater's effects on the public health in Aguascalientes is evident in the state water plan for 2021-2050

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[1] This report considers the state of Aguascalientes, if not else is specified. The state is composed by the city of Aguascalientes (the state capital) and the ten municipalities Asientos, Calvillo, Cosío, Jesús María, Pabellón de Arteaga, Rincón de Romos, San José de Gracia, Tepezalá, El Llano, and San Francisco de los Romo (INEGI 2020).

(INAGUA 2021). In the plan, INAGUA expresses that of highest priority is to increase the quality of life for the state inhabitants, and the main strategies they have formulated to achieve this goal target the overexploitation of the groundwater resources and their diminishing quality. Therefore, the effects of groundwater deficit and the associated contamination on the public health in Aguascalientes is the main focus of this thesis.

As in many other semi-arid regions worldwide, the groundwater contaminant of most significant concern in Aguascalientes is fluoride. Fluorides occur naturally in groundwater due to fluoride-bearing minerals in the rocks, soil, and sediments surrounding the aquifer (Jha et al. 2013). However, in aquifers where continuous overdraft occurs, diminishing groundwater levels forces extraction from greater depths, resulting in fluoride contamination (Morris & Gallardo Cabrera 2018). This thesis focuses on the aquifer of Valle de Aguascalientes, from which the state extracts most of its groundwater (Sainz-Santamaria & Martinez-Cruz 2019a) and where fluoride contamination is prominent.

The National Research Council (2006) states that when occurring at moderate levels (0.4-0.7 mg/L), fluoride can positively affect human health – it reduces the risk of caries and strengthens bones. However, they explain that long-term exposure to excess fluoride levels can have adverse effects. They report that in areas where the groundwater concentration of fluoride exceeds 1.5 mg/L, consumers are at higher risk of being diagnosed with dental fluorosis. Dental fluorosis, they describe, is a condition that in mild cases causes decolourisation of the teeth surface (often in the form of yellow or brown spots), and in severe cases, makes the teeth mottle and become deformed.

Furthermore, the National Research Council (2006) explains that dental fluorosis primarily develops during the first eight years of life – during the enamel's transitional or early maturation stage. The Council further states that whether the condition is developed or not is a consequence of the cumulative intake during this period. Dental fluorosis development in adult teeth only occurs as a result of concomitant enamel dissolution, i.e., caries development (Fejerskov et al. 1994). These two aspects exemplify that the timing and duration of exposure to high-fluoride drinking water is a critical factor impacting the severity of the condition, the National Research Council (2006) states.

The National Research Council (2006) further report that in areas where the fluoride levels exceeded 2 mg/L, the cases of severe dental fluorosis rise sharply and long-term water consumers are also at risk of developing skeletal fluorosis. As described by the European Commission (2010), this disease induces alterations of the bone structure that weaken the bone strength. In turn, they explain, these altered conditions increase the risk of fractures, immobility, pain, and in the direst cases, severe crippling. The negative effects associated with the two previously mentioned values lay the basis for the WHO's guidelines for drinking water quality regarding fluoride. The guidelines state that fluoride concentrations in drinking water should be < 1.5 mg/L. However, they stress that national guidelines also should consider the general fluoride intake from other sources, such as food or air. In Mexico, the WHO guideline is applied (Secretaría de Salud 2000).

Fluoride has been recognised as one of the chemicals that are of most significant concern to human health when concentrations exceed the recommended limits in natural waters (Bhatnagar et al. 2011). Thus, it is essential to tackle the issue of fluoride contamination in the aquifer of Valle de Aguascalientes. In doing so, consideration should be taken both to policies aiming to decrease the fluoride concentrations through water treatment and to policies that target the underlying problem – the aquifer overdraft. As previously mentioned, INAGUA (2021) recognise the need for strengthened water governance and infrastructure to achieve the latter. More specifically, they mention the need to target the irrigation systems used in agriculture.

The agricultural sector consumes the majority of the permitted groundwater extraction in Aguascalientes (CONAGUA 2018a). There are various factors in the present groundwater management policies and governance structure that induces the high extraction in this sector. For example, Muñoz-Piña et al. (2006) mention the national subsidy programs promoting agricultural activities. Specifically, they mention the electricity tariff 09, which has as its principal purpose to reduce costs for the energy needed to extract groundwater for irrigation of agricultural lands. The authors also argue that the subsidy creates other distortions, such as false profitability of certain 'thirsty' crops and disincentives for farmers to implement more efficient irrigation technologies.

As Sainz-Santamaria and Martinez-Cruz (2019a) point out, the majority of the currently used irrigation methods in Aguascalientes are, in fact, highly inefficient. They explain that the majority of the land is irrigated using gravity-based systems which are characterised by low water application efficiency and therefore give rise to large water losses. To strengthen the productivity and efficient use of irrigation water, INAGUA (2021) recognises the need for a comprehensive strategy and highlights the current lack of commitment from all sectors regarding these aspects. They claim that technical and financial fortification must be given to irrigating farmers to overcome these issues, and that increased regulations need to be imposed.

According to the UN (n.d.), 14.4 percent of the world's population live in semi-arid regions. They project that by 2030, near half of the world's population will live in areas with high water stress, which may displace between 24 million and 700 million people in arid and semi-arid regions. They state that there is a relationship between population density and aridity, and claim that in no other ecological zone has the population growth rate been as high as in drylands[2]. These statements suggest that the health problems affecting todays' residents in semi-arid regions will become even more prominent in the coming years, characterised by continued population growth and climate change. While these issues have been documented for numerous semi-arid regions worldwide (for example Bhatnagar et al. 2011; Sainz-Santamaria & Martinez-Cruz 2019a; Haldar & Gupta 2020), the potential of policy interventions are often overlooked in the policy and research agendas.

However, due to the growth potential of these regions in the near future, both regarding population and agricultural activities, it is essential to study the effects of groundwater contamination on human health and how the current water extraction patterns affect the water quality and quantity for the local communities.

[2] According to the UN (n.d.), 'drylands' include arid, semi-arid and dry sub-humid areas. They state that in the context of sustainable development, the term typically excludes deserts.

Aguascalientes is a good example of such a community, and the state is therefore an adequate objective to study for initial estimates of these effects. The problems related to groundwater depletion in the state are unlikely to be solved unless policies that aim to ensure water quality and prohibit continuous overdraft are implemented. This thesis, therefore, focuses on evaluating one policy project that directly treats the excess concentration of fluoride in the drinking water in the semi-arid region of Aguascalientes, and another policy project targeting one of the leading causes for the underlying problem of groundwater depletion in the state – the irrigation of cropland.

1.1.1. Groundwater Governance in Mexico

Hayes (2021) explain that groundwater is a common pool resource – it is non-excludable and rivalrous. He describes that these properties give consumers incentive to maximise the value they can derive from the resource as fast as possible, i.e., before other consumers deplete it. In other words, Hayes states, these characteristics make aquifers susceptible to the tragedy of the commons. Therefore, Hayes claims that in order to avoid complete depletion, government regulations must be imposed or voluntary collective action working for sustainable management of the resource must be organised.

In Mexico, all surface and groundwater resources are properties of the state (OECD 2015), and Wilder et al. (2020) explain that water has been recognised as a human right since 2012. They claim that this fact has given standing to the citizens in the debate on water access and sanitation imbalances and increased the democratisation of water governance. Nevertheless, water consumption cannot be free of charge as infrastructure and human capital are needed to extract and supply the water (Chenoweth 2018). Sainz-Santamaria and Martinez-Cruz (2019a) explain that all users pay for water consumption, although the price varies across sectors. For example, agricultural users pay nothing unless they exceed their allowance, they state.

Moreover, Sainz-Santamaria and Martinez-Cruz (2019a) criticise the Mexican groundwater management policies and claim that investments in water infrastructure projects are often negatively influenced by the one-term limitation for state administrations of six years. They argue that this limitation affects planning horizons for infrastructure projects, as undertaking great investments helps government officials gain credibility in the short-term. Such investments, the authors explain, are induced further by the fact that the cost is shared by the federal government, where officials face the same one-term limit. However, according to the authors, these significant investments are rarely cost-effective in the long run as they often contribute to overdraft of the water resources.

Sainz-Santamaria and Martinez-Cruz (2019a) further report that previous policy measures have failed to ensure future groundwater supply from the aquifer of Valle de Aguascalientes. They argue that accurate policymaking on groundwater management is inhibited by the fact that data on the aquifer are scarce, scattered, and expensive; despite it being one of the most studied in the country. However, considering the previously mentioned significant yet cost-inefficient investments already happening related to water infrastructure, the argument can be made that there is space in policymaking to form more efficient groundwater management policies. Such policies should promote agricultural decisions that impose less pressure on the aquifer of Valle de Aguascalientes, such that the quality of the consumed water can improve.

1.1.2. Area of Study

The state of Aguascalientes is located in north-central Mexico. Ruiz-Alvarez et al. (2019) explain that it has a cold semi-arid climate (BSk) according to the Köppen climate classification system, which is reflected, for example, in the average annual total precipitation (516.8 mm). They report that the lowest average values are measured in March (3.4 mm) and the highest in July (130.4 mm). The semi-arid climate is also reflected in the variation in average temperature. Ruiz-Alvarez et al. state that January is the coolest month on average, where the average annual minimum temperature of 8.6°C is normally reached. They further report May to be the hottest month on average, during which the average annual maximum temperature of 25.9°C is typically measured.

Additionally, Ruiz-Alvarez et al. (2019) state that the average annual evaporation from the earth surface to the atmosphere is 1958.5 mm. The monthly values follow the average temperature patterns closely; December shows the lowest values (113.7 mm) on average and May the highest (235.5 mm). Finally, they report that the estimated ratio of precipitation and potential evapotranspiration[3] (P/PET) is 0.35. This ratio is a common measurement of aridity, and a region is classified as semi-arid if $0.2 < P/PET < 0.5$ (Estrela et al. 1997). With continued climate change, there is a risk of these measurements increasing, causing alterations of other components of the water cycle as well (Zhan et al. 2019).

Aguascalientes has approximately 1 425 600 inhabitants (INEGI 2020). According to Data México (2021) 57.8 percent of the population is considered economically active, which is close to the average in Mexico. They further state that the agricultural sector employs just over one percent of the workforce. Despite the small percentage of people working in the sector, agricultural activities play a significant role throughout the state. For example, the state capital devotes 39.3 percent of the metropolitan land area to crops and 26.2 percent to pastures, and among its main economic activities are crop cultivation and livestock farming (SENER 2015). This extensive spread of agricultural activities is a leading cause for the high water consumption in the area.

The most cultivated crops in Aguascalientes are alfalfa, corn, wheat, chillies, peaches, and wine grapes (Nations Encyclopedia n.d.), which all require large quantities of water (Mekonnen and Hoekstra 2011). Due to the low precipitation in the area, irrigation is necessary to satisfy the water demand of these crops. Foster et al. (2004) mention that switching to less water demanding crops that are

[3] Potential evapotranspiration is defined as the evaporation from a grass covered area that does not lack water in the root zone and where no heat storage occurs in the ground (SMHI 2021)

better suited for the area’s climatic conditions has been discussed as a potential measure to decrease the water consumption in the area. However, they claim that because the actual effects of doing so on groundwater savings are uncertain, no further measures have been taken to induce such changes.

Another factor impacting the high water consumption in Aguascalientes is the low efficiency of the currently utilised irrigation systems, Sainz-Santamaria and Martinez-Cruz (2019b) explain. They estimate that 46-90 percent of the cultivated area in the state is irrigated using flood irrigation – an ancient method where farmers distribute water using furrows in the fields or spread it evenly across the surface, mimicking a flooding (see

Figure 1). They also estimate that the remainder of the irrigated land utilises pressurised sprinkler systems, most commonly centre pivot irrigation (CPI) systems (see

). Sainz-Santamaria and Martinez-Cruz (2019a) further claim that Mexico – as many other developing countries – is currently transitioning to more efficient irrigation technologies and that a continued expansion of CPI systems thus may be seen henceforth.

Figure 1: Example of Flood Irrigation
Source: Vanuga, J. (USDA) (2002)

Figure 2: Example of CPI System
Source: Tanja Folnović (n.d.)

The National Water Commission (CONAGUA) (2018a) reports that Aguascalientes's concessioned water volume in 2017 amounted to 623 hm^3. Out of the water consumed, they denote that 445 hm^3 (71 percent) originated from groundwater. Furthermore, CONAGUA explains that 479 hm^3 (77 percent) of the concessioned water volume in the state was consumed by agriculture. Out of this volume 303 hm^3 (63 percent) came from groundwater, they state. The majority of the agricultural land in the state is found within Irrigation District 01, located in the municipality of Pabellón de Arteaga (Sainz-Santamaria & Martinez-Cruz 2019a). The district uses 30.8 hm^3 of groundwater to irrigate 3 794 hectares of land (CONAGUA 2018b). Because it is within Irrigation District 01 that the majority of the groundwater extracted for irrigation is consumed, this thesis will primarily focus on this area.

In comparing the water consumption to the total renewable water[4] resources in the state, CONAGUA (2018a) notice a high level of water stress. They report that the total renewable water resources per capita in 2017 was 394 m^3 – the third lowest in the country. CONAGUA (2018b) also concludes that all five aquifers that cross the state borders, as shown in
, are overexploited and in a condition of deficit. Of these aquifers, Sainz-Santamaria and Martinez-Cruz (2019a) explain that the aquifer of Valle de Aguascalientes, which is the focus of this thesis, is the largest one.

[4] Renewable water refers to the amount of water in a region that can be used in a sustainable manner; that is, the water replenished naturally by rainfall or inflows (CONAGUA 2018a).

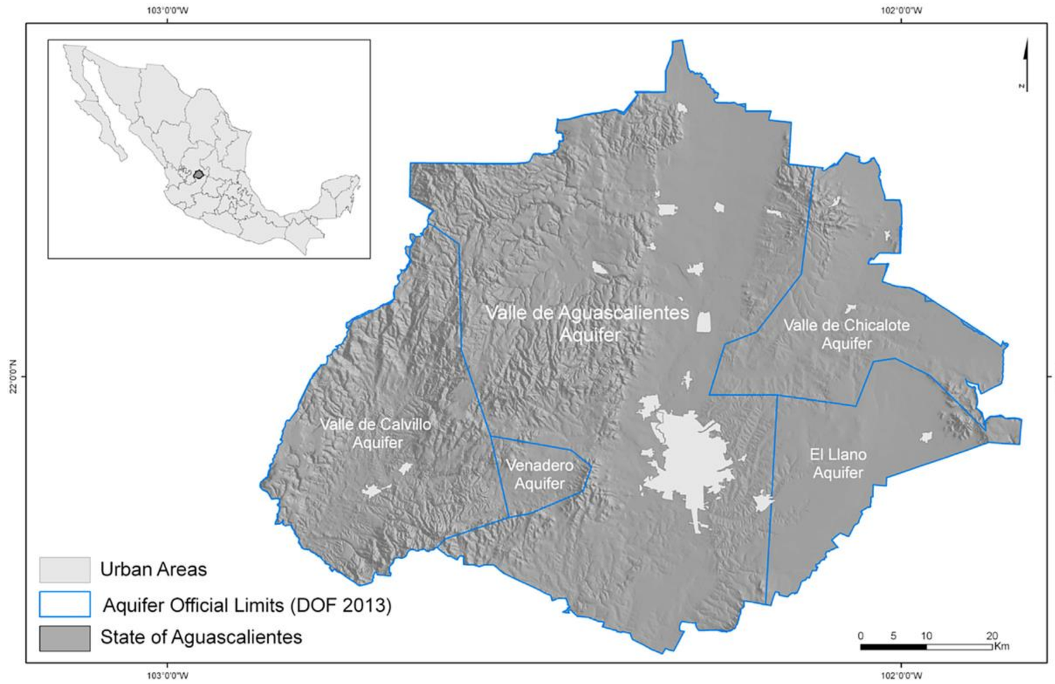

Figure 3: Location of the aquifer of Valle de Aguascalientes
Source: Sainz-Santamaria and Martinez-Cruz (2019a, p. 45)

As previously mentioned, the aquifer of Valle de Aguascalientes is the primary source from which the groundwater consumed in Aguascalientes is extracted and one of the most studied aquifers nationwide. It is part of the inter-state aquifer of Ojocaliente-Aguascalientes-Encarnación (Sainz-Santamaria & Martinez-Cruz 2019a), and according to CONAGUA (2020), the annual extraction from Valle de Aguascalientes amounts to 348 hm^3. However, they also report that the annual recharge of the aquifer, that is, its volume of renewable water, is 250 hm^3, making the extraction volume almost 40 percent higher than sustainable levels. Out of the 1 468 active waterworks (i.e. wells and norias) connected to the aquifer, CONAGUA states that 854 units (58.17 percent) are destined for agricultural use, 31 units (2.11 percent) are destined for livestock and 26 units (1.77 percent) for domestic use.

When extracting groundwater, electricity is needed to pump the water from the aquifer to above-ground levels. Because 75.22 percent of the electricity produced in Mexico comes from fossil sources (Ritchie & Roser 2020a), the current groundwater extraction gives rise to high amounts of emissions. The General Law on Climate Change acknowledges Mexico's dependency on fossil energy sources and states that 35 percent of the electricity shall be generated from renewable sources in 2024 (Cámara de Disputados del H. Congreso de la Unión 2020). The law also states that 50 percent of the country's greenhouse gas (GHG) emissions should be reduced by 2050 compared to 2000. Today, 21.04 percent of Mexico's electricity is generated by renewable sources (Ritchie & Roser 2020a), and the GHG emissions were 4.41 percent lower in 2020 compared to 2000 (Ritchie & Roser 2020b).

Moreover, CONAGUA (2020) concludes that the water in Valle de Aguascalientes, based on the latest update of the water availability in the aquifer, is of relatively good quality. According to their report, only two chemical concentrations exceed the maximum permitted limits: fluorides and nitrates. As previously mentioned, fluoride contamination of groundwater has been recognised as a significant human health issue in the state. Therefore, this thesis focuses on the negative impacts of excess fluoride concentrations in the groundwater of the Valle de Aguascalientes aquifer.

As shown in

Table 1, data gathered by CONAGUA (2021) on the water quality in the aquifer of Valle de Aguascalientes show an upward-sloping trend in the average fluoride levels[5] since the first measurements were published in 2012. In all years except 2012, the average fluoride concentration exceeds the WHO recommendation of < 1.5 mg/L. In 2013 and 2018, the concentrations even exceeded 2 mg/L. Over all the measured years, the average fluoride concentration amounts to 1.85 mg/L. This level is lower than the concentration causing concern for skeletal fluorosis (2 mg/L) but above the concentration where daily intake increases the risk of dental fluorosis (1.5 mg/L).

[5] The average concerns the average over all sites measured in a specific year.

Table 1: Average fluoride concentration in the aquifer of Valle de Aguascalientes 2012-2020.

Year	**Average fluoride concentration**[a]	**Above WHO/Mexican standard of < 1,5 mg/L**
2012	1,03	No
2013	2,04	Yes
2014	1,82	Yes
2015	1,74	Yes
2016	1,81	Yes
2017	1,75	Yes
2018	2,02	Yes
2019	1,89	Yes
2020	1,92	Yes
All years	**1,85**	**Yes**

[a] The average concerns the average over all sites measured in a specific year.

(Data source: CONAGUA (2021b))

The average concentration is reflected in the high prevalence of dental fluorosis among 7-8-year-old children in Aguascalientes, according to González Dávila (2021). In total, the author found that approximately 43.25 percent suffer from the disease; approximately 32.89 percent showing mild symptoms, 8.37 percent moderate, and 2 percent severe. Because dental fluorosis is generally not developed in adult teeth (Fejerskov et al. 1994), it can be assumed that the prevalence and distribution are the same for the entire population of Aguascalientes if even those individuals who have gone through treatment are included.

INAGUA (2021) recognise the state's groundwater resources problems and stresses the necessity of adopting strategies to stabilise its principal aquifer. Such strategies, they state, should include efforts to improve the efficiency in water usage, increase the available volume and sanitise the water. As an example of a previous such effort, Sainz-Santamaria and Martinez-Cruz (2019a) mention the artificial recharge of the aquifer executed by the state administration of 2010-2016. They state that the cost of this project amounted to a total of approximately 25.1 million USD. Of the total, approximately 16.2 million USD was taken from the federal budget and approximately 6.7 million USD was taken from the state government's budget. Additionally, operational costs of approximately 2.2 million USD annually were required[6]. Despite the size of this project, the authors claim that no evidence of the recharge project's effects have been provided.

In 2021, the State Government of Aguascalientes (2021) budgeted approximately 1.2 USD for rehabilitation, modernisation and technification efforts of water-related projects. Out of this amount, approximately 0.6 million USD came from the federal budget and approximately 0.3 million USD from the

[6] USD values are expressed in 2019 USD values and have been adjusted after conversion from MXN to USD using the PPP for Mexico in 2017 of 8.914 (OECD 2021).

producers[7]. The 2021 budget is similar to the initial budget for such efforts in 2020. However, the 2020 budget was subsequently updated from 1.2 million USD to 2.3 million USD[8] in order to finance the installation of a 1 530 m long piping system for irrigation of 131 ha of arable land (CONAGUA 2021a).

Based on the aforementioned issues, Sainz-Santamaria and Martinez-Cruz (2019a) claim that Aguascalientes faces a challenge in the coming years. The challenge, they claim, consists of meeting the water demand of their growing population and industrial sector while securing drinking water quality and maintaining irrigation water supply to the agricultural sector. This thesis focuses on the drinking water quality and irrigation water supply by considering the potential of two alternative policy interventions to ensure that the aquifer of Valle de Aguascalientes is not to be depleted entirely in the future.

1.2. Aim and Objectives

The overarching aim of this thesis is to provide insight and initial estimates on the potential net social benefits to humans associated with two different policy projects aimed at ensuring the water quality in Aguascalientes with respect to fluoride. The projects considered are:

- **Project A: Installation of fluoride removal units utilising electrocoagulation on all wells destined for drinking water.**
  This project is an 'end-of-pipe solution', that is, it aims to remediate the fluoride contamination at the last stage before consumption.
- **Project B: Implementation of centre pivot irrigation (CPI) systems on all land currently irrigated using flood irrigation in Irrigation District 01.**
  In contrast to Project A, Project B targets one of the most prominent underlying problems giving rise to the fluoride contamination in the state – the continuous aquifer overdraft.

These projects are chosen as they target different points of the problem spectra and contrasting their impact therefore can provide valuable insights on where an intervention is most effective. Both projects are described in greater detail in chapter 2. The projects and their estimated effects are subsequently discussed in relation to the baseline scenario in chapter 5 to reach the aim of this thesis. The study focuses on groundwater extracted from the aquifer of Valle de Aguascalientes for drinking and irrigation purposes and how that extraction affects the water quality and quantity from the same aquifer. The time frame considered is 30 years, as recommended for water supply/sanitation projects by the European Commission (2015). To learn about the net social benefits of the projects, the specific objectives of this study are as follows:

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[7] USD values are expressed in 2019 USD values and have been adjusted after conversion from MXN to USD using the PPP for Mexico in 2020 of 9.522 (OECD 2021).

[8] USD values are expressed in 2019 USD values and have been adjusted after conversion from MXN to USD using the PPP for Mexico in 2020 of 9.522 (OECD 2021).

- To estimate the social costs and benefits of the two projects using existing data and literature, as well as insights gathered via conversations with researchers and other experts.
- To analyse the collected data using economic cost-benefit analysis (CBA) in order to determine the net social benefit of the respective project.
- To evaluate the potential of the projects to ensure good-quality drinking water and change the current extraction patterns from the aquifer of Valle de Aguascalientes.
- To discuss the probability of successful implementation.

Due to the growth potential and increasing vulnerability to climate change in semi-arid regions, it is essential to deepen the knowledge of the groundwater resources' state in these regions. Also, the potential of policy interventions to ensure drinking water quality and sustainable groundwater extraction in the long run must be evaluated in order to be included in the policy and research agendas to a greater extent. To the author's knowledge, a CBA has never been carried out regarding a fluoride removal project, nor concerning a switch from flood irrigation to CPI systems in Aguascalientes. Thus, this thesis contributes to the literature relevant to studies carrying out CBAs for drinking water quality and irrigation water quantity interventions in the state, and potentially also in other semi-arid regions.

2. The Projects

This chapter outlines the two projects evaluated in the CBAs. These projects are evaluated as they can potentially reduce the high fluoride concentrations in the groundwater that currently affect Aguascalientes' inhabitants. Project A involves the installation of fluoride removal units utilising electrocoagulation throughout the state and is described in section 2.1. Project B considers the implementation of centre pivot irrigation (CPI) systems on land previously irrigated with less efficient systems in Irrigation District 01. Project B is presented in detail in section 2.2.

2.1. Project A: Installation of Fluoride Removal Units Using Electrocoagulation

As described in section 1.1.2, the fluoride concentration in the groundwater extracted from the aquifer of Valle de Aguascalientes exceeds the levels recommended by the WHO. González Dávila (2021) claim that the high fluoride concentration in the groundwater is the main reason for the high prevalence of dental fluorosis in the area. Dental fluorosis can also be caused by excessive fluoride intake from other sources, such as ingestion of food grown using high-fluoride irrigation water or swallowed fluoridated toothpaste (National Research Council 2006). However, due to González Dávila's (2021) claim, the share of such cases is assumed to be negligible in Aguascalientes and is, therefore, not considered in this thesis.

Furthermore, González Dávila (2021) claim that the high prevalence of dental fluorosis will persist as a public health problem unless technologies to remove fluoride from drinking water are adopted. Castañeda et al. (2021) state that numerous fluoride removal technologies exist today, although most are costly. However, they state that one of the lower-cost removal alternatives operate using electrocoagulation. With this technology, they explain, water passes through an electrocoagulation cell in which a series of electrochemical reactions occur. These reactions initiate coagulation of the fluoride ions in the water, where flocs are formed that can be removed from the water and reduce the fluoride concentration.

Haldar and Gupta (2020) carried out an experiment in which a fluoride removal unit using electrocoagulation was tested. In their experiment, the electrocoagulation cell utilises aluminium electrodes and DC power connection to initiate coagulation of the fluoride ions and thus the formation of flocs. The flocs are subsequently removed through a sand filter, which is regularly backwashed to avoid clogging, they explain. The backwash water is cleaned through a sand bed to secure safe disposal. They further describe that the electrocoagulation cell is combined with a downstream column of activated alumina to ensure the unit's success. They explain that through this addition, the treatment unit can guarantee that the treated water is safe for drinking, even if the fluoride levels in the water from upstream are effluent or if the electrocoagulation cell is malfunctioning.

Haldar and Gupta's (2020) electrocoagulation unit was installed in the Nalagola village, located in West Bengal, India. The village residents suffer from high fluoride exposure due to the high concentrations of the chemical in the groundwater. Haldar[9] also mentions that four other units, which operate using the same technology, have been implemented in the area. He mentions that the unit running for the longest time has been operating for around ten years, and the demand and funding for its service are still strong.

Haldar and Gupta (2020) explain that at maximum capacity, the unit in the Nalagola village treats 600 L of water per hour, amounting to 5 259.49 m^3 per year. They also state that the fluoride levels in the groundwater of the Nalagola village are reduced from 2.1 mg/L to < 1 mg/L post-treatment. In other words, the electrocoagulation unit operates at a 50-60 percent efficiency, according to the authors. Haldar[10] further claims that the technology could be scaled to 5-6 times this capacity without compromising the fluoride removal efficiency, and that ongoing experiments are currently running to prove this claim.

In this thesis, the installation of multiple units using the same technology as in Haldar and Guptas' (2020) experiment will be analysed. The units will be installed as an addition to the existing groundwater distribution network. Due to the installed units' long-term operation in India, as described above, the assumption is also made that once a unit is installed, it will operate until the end of the 30-year period considered in this thesis. Thus, it is assumed that the technology remains fixed over the period in terms of capacity and fluoride removal efficiency. The same assumption is made regarding the number of pumps destined for drinking water.

With operations at full capacity, there would be an initial need for 181 electrocoagulation units throughout Aguascalientes to cover the state's drinking water demand in year 0. Thereby, it is necessary to install seven units at each of the 26 wells destined for drinking water, assuming that each well extracts the same amount of water annually. Additional units will be installed each year, as demand for drinking water is forecasted to increase (Amarasinghe & Smakhtin 2014). With the rate of fluoride removal presented in Haldar and Gupta (2020), the fluoride levels in the groundwater in Aguascalientes would with certainty be reduced to < 1.5 mg/L after treatment, given current levels.

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[9] Arindam Haldar, PhD, Indian Institute of Engineering Science and Technology, Interview 2021-11-16.
[10] Ibid.

2.2. Project B: Implementation of Centre Pivot Irrigation Systems

As described in section 1.1.2, the majority of the allocated water in Aguascalientes is consumed by agriculture. In Irrigation District 01, most of the water in this sector is allocated to irrigation. Rogers et al. (1997) claim that the application efficiency of flood irrigation, which is the most common irrigation method used (Sainz-Santamaria & Martinez-Cruz 2019b), ranges between 50-90 percent. Rogers et al. (1997) further claim that for CPI systems – the most commonly used pressurised irrigation system in Aguascalientes (Sainz-Santamaria & Martinez-Cruz 2019b) – the same range is 70-90 percent. If the lower bound values of the application efficiencies of the respective systems are compared, CPI systems are 40 percent more efficient than flood irrigation systems. The calculations following in this thesis are based on this difference in application efficiency.

Based on the assumption of higher application efficiency of CPI systems, Sainz-Santamaria and Martinez-Cruz (2019a) studied the expected net average water extraction from the aquifer of Valle de Aguascalientes under four different irrigation policy scenarios. All scenarios have previously been discussed in policymaking and involve the following:

- Scenario 1: 100 percent of the agricultural land in Irrigation District 01 are irrigated using pressurised sprinklers.
- Scenario 2: 50 percent of the agricultural land in Irrigation District 01 are irrigated using pressurised sprinklers, whereas the other 50 percent are irrigated using a less efficient technology.
- Scenario 3: 100 percent of the agricultural land in Irrigation District 01 are irrigated using improved tillage, drip irrigation and canal optimisation in flood irrigation systems.
- Scenario 4: 50 percent of the agricultural land in Irrigation District 01 are irrigated using improved tillage, drip irrigation and canal optimisation in flood irrigation systems. The other 50 percent are irrigated using a less efficient technology.

Sainz-Santamaria and Martinez-Cruz's (2019a) results showed that only when Scenario 1 was considered was the average water extraction expected to decrease substantially compared to a no policy scenario. They also mention that although drip irrigation may be a more efficient method, the feasibility of implementation in Aguascalientes is low. Martinez-Cruz[11] explains that drip irrigation is not much discussed in policymaking for two reasons; (i) the resistance from farmers of crops that benefit from receiving water through the leaves and (ii) the high capital costs. Sainz-Santamaria and Martinez-Cruz's (2019a) find that the installation of CPI systems is more feasible, although, they do not include any monetary estimates of the costs and benefits of such a project. Thus, further analysis is necessary to determine its potential success.

[11] Adan L. Martinez-Cruz, PhD, Swedish University of Agricultura Sciences, Personal communication 2021-08-31 – 2021-12-23.

In this thesis, the implementation of the CPI systems is assumed to happen in year 0 on all cultivated land currently irrigated using flood irrigation in Irrigation District 01. For the purpose of calculation, the share of the land concerned is assumed to be the average percentage of those presented by Sainz-Santamaria and Martinez-Cruz (2019b), i.e. 67.89 percent. Furthermore, the CPI systems are assumed to have a lifespan of 15 years (RMCG 2018; Montero et al. 2013), and thus, reinstallation will occur every 15 years. The irrigation and pumping technology, as well as the number of pumps, are assumed to be fixed over the studied period. However, the arable land demand – and thereby irrigation water demand – is expected to grow over the period. Thus, annual costs will include installation and reinstallation costs for successively added units.

3. Methodology

In this chapter, the CBA methodology is introduced more elaborately. Section 3.1 presents the essence of the theoretical framework from which the CBA methodology is developed. The methodology itself is described in section 3.2. The outline of the method is presented in more detail in section 3.2.1, with the specific steps to take and various options available. Section 3.2.2 subsequently provides an overview of the main limitations and criticism towards the CBA methodology. The last section of this chapter – section 3.3 – states the key assumptions that have been adopted in this thesis due to time and financial constraints.

3.1. Theoretical Framework

Boardman et al. (2014) claim that CBA can be thought of as a microeconomic tool to measure efficiency. The methodology, they explain, relies on the Kaldor-Hicks compensation criterion, which is closely related to Pareto efficiency. If an allocation of goods is Pareto efficient, no alternative allocation exists that makes at least one person better off, without making anybody else worse off, Boardman et al. state. In other words, a Pareto efficient allocation is an optimal allocation. However, a Pareto efficient allocation is often challenging to achieve in policymaking and is thus considered an ideal rather than a decision rule.

Generally, a weaker – but more feasible – decision rule is sufficient in policymaking. Boardman et al. explain that with this decision rule, a project that achieves a potential Pareto improvement is accepted. A potential Pareto improvement is achieved if those who gain from a project (i.e., the winners) can, in principle, compensate those who are made worse off by the project (i.e., the losers) without becoming worse off themselves. The Pareto improvement is achieved when the compensation is paid (Kolstad 2011).

The Kaldor-Hicks compensation criterion is less stringent than the concept of Pareto improvements, as compensation must only be possible in theory (i.e., as in a potential Pareto improvement situation) (Kolstad 2011). In CBA, the Kaldor-Hicks compensation criterion is illustrated by the net social benefits created from the project. The net social benefits are generated by subtracting the costs imposed on all losers from the benefits given to all winners. If a project produces positive net social benefits, it is, in theory, possible for the winners to compensate the losers and thereby achieve a Pareto improvement. Thus, the project should be accepted according to the Kaldor-Hicks compensation criterion.

In order to estimate the net social benefits of a project, costs and benefits are valued and expressed in monetary terms. Boardman et al. (2014) explain that for regular goods, the valuation can be done through estimating the respective market demand curves. However, there is normally no market to observe regarding environmental goods, services, and impacts. Therefore, non-market valuation methods must be utilised. According to the OECD (2018), the most commonly used valuation methods are Contingent Valuation Methods (CVM) and Discrete Choice Experiments (DCE). However, they state, such studies are in general expensive and time-consuming. Therefore, they claim that when original studies cannot be carried out, the analysis must rely on results from previous studies of a similar project. This alternative relies on the concept of value transferring, which is described in greater detail in section 3.2.1.

3.2. Cost-Benefit Analysis

CBA is a commonly used tool in policy evaluation to determine the usefulness of a project or policy intervention. The European Commission (2015) describes an economic CBA as a microeconomic tool for assessing a project's impact on social welfare. Welfare changes, they explain, are measured through attributing monetary values to the positive and negative outcomes of the project – discounted over a set period of time – and summing them. This inclusion of non-financial economic values is the main difference between a financial CBA and an economic CBA (OECD 2018).

Summing the discounted monetary values over time generates the project's net social benefits or the net present value (NPV) (European Commission 2015). If multiple projects are included in the CBA, their performance is most commonly compared through contrasting their respective NPVs. Additionally, the project(s) should be compared to a baseline scenario, which the Commission defines as the case in which no intervention is implemented during the period. They state that the baseline scenario is characterised by maintaining the current operational management and assuming that the same policies in place today will be in place throughout the period studied.

3.2.1. Method Outline

Boardman et al. (2014) present that an economic CBA is traditionally performed in nine steps:

1. Specify the set of alternative projects.
2. Decide whose benefits and costs count (standing).
3. Identify the impact categories, catalogue them, and select measurement indicators.
4. Predict the impacts quantitatively over the life of the project.
5. Monetize (attach dollar values to) all impacts.
6. Discount benefits and costs to obtain present values.

7. Compute the net present value of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation.

(Boardman et al. 2014, p. 6)

In step one, the setting of the study is outlined. Boardman et al. explain that this involves specifying the location, scale, and duration of the projects that the CBA will consider as precisely as possible. Concerning the scale, the European Commission (2015) emphasises the importance of the project being a self-sufficient unit of analysis, meaning that all necessary aspects for successful implementation should be included. As an example of what this entails, they mention that a project considering establishing a new landfill must also include the connecting roads for waste delivery to it. Otherwise, they claim, the project’s scale is underestimated, and it should not be considered a self-sufficient unit of analysis.

The European Commission (2015) further mentions the importance of considering the relevant socio-economic conditions, existing policy and institutional aspects, and existing infrastructure and services in the specification of the study. They also note that additional relevant aspects, such as environmental or cultural conditions, can be included. This first step is of great importance to determine the suitability and potential success of the project, as the implementation and future management of it is dependent on the current context.

The second step involves defining all the relevant stakeholders of the project, i.e. identifying who has standing. Boardman et al. (2014) point out that different ideas exist in the literature regarding determining who should have standing. They explain that some claim that a global perspective is in order, where everyone for whom a project’s benefits and costs will occur should have standing. Others, they state, argue for a more local perspective, where who has standing is typically limited to stakeholders within a particular nation and a specific time frame. In this thesis, a local perspective will be taken in the CBA. However, a global perspective will also be incorporated in discussing the implications of the suggested policies in the long run.

Based on the stakeholders identified as having standing, which impacts to include in the CBA are determined in step three. Boardman et al. (2014) explains that the impacts should explicitly state whether a benefit or a cost – monetary or otherwise – is imposed on a certain stakeholder due to a particular element of the project. Also, an appropriate measurement indicator based on the available data should be specified for each impact category.

Furthermore, Boardman et al. (2014) describe that step four involves making projections about the sum of effects resulting from the project. To perform this task successfully, the European Commission (2015) mentions the importance of choosing an appropriate time frame, or reference period, for the project. The choice, they argue, should be determined by the project’s implementation period, as well as its “economically useful life and its likely long-term impacts” (pp. 41). For water supply/sanitation projects, the Commission recommends using a reference period of 30 years.

The fifth step involves valuing the individual impacts in monetary terms. In general, Boardman et al. (2014) state, the monetary values of the benefits in the

CBA are determined by studying stakeholders' Willingness-To-Pay (WTP). In well-functioning markets, the WTP can be decided by studying the relevant market demand curves, they explain. However, they continue, the concept of WTP can be challenging to apply when no market exists, which is often the case when considering environmental impacts. The use of WTP may even be inaccurate, as in distorted markets, where the market prices (if observable or existent at all) may not accurately reflect the social value of an impact.

Nevertheless, the economic analysis in step five is necessary to estimate the social value of the costs and benefits and ultimately determine the project's contribution to welfare. Therefore, alternative methods utilising non-market valuation should be applied in situations where WTP cannot be used. The most common method, Boardman et al. (2014) explain is using shadow pricing. They explain that shadow pricing involves either adjusting observed prices which are decidedly incorrect or assigning values when values do not exist. They describe that the idea is to make the price come as close as possible to measuring the true social value of a change and thereby make it usable in the CBA.

Another alternative when the WTP cannot be estimated is to utilise value transferring. The OECD (2018) explain that value transferring entails using a previous estimate of a non-market good from an original study to value the costs and benefits of a new project. They explain that value transfers can be done in three different manners; (i) unadjusted value transfer, (ii) adjusted value transfer and (iii) value function transfer. In this thesis, unadjusted value transfer is applied, which entails "borrowing" a value directly from an original study (OECD 2018).

The OECD (2018) denote that when utilising value transferring – especially the unadjusted approach – a trade-off is made between the simplicity and accuracy of the analysis. Therefore, they state that the validity of the methodological approach should be tested. However, they also mention that such tests may require as costly and time-consuming investigations as an original study, in which case the purpose of utilising the method is lost. As a guide for the analyst making this trade-off, Brookshire (1992, see OECD 2018) suggest that in studies where the aim is to, e.g., provide an initial estimate of the potential benefits of a policy option, a relatively low level of accuracy may be acceptable. Nevertheless, the OECD states that the analyst must specify the criteria used to determine the original study's quality and the feasibility of utilising the value transfer approach.

After the impacts have been estimated in monetary terms, the costs and benefits occurring over time must be discounted to obtain their present values (PV) in step six. In an economic CBA, the social discount rate (SDR) is used for discounting. Boardman et al. (2014) explain that discounting is done partly to reflect the general preference for obtaining benefits today rather than in the future, and partly to account for the opportunity costs associated with investing in a project. The formulas used to calculate the PV of all benefits (B) and costs (C) are:

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} \tag{1}$$

$$PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \tag{2}$$

In equations 1 and 2, *t* denotes the year in which the benefit or cost occurs, *n* denotes the entire period during which the project is in place, and *r* denotes the SDR. Choosing an appropriate SDR is complex, especially when considering environmental issues. The chosen SDR will reflect how trade-offs are made between the present and the future, and thus, how the project's impacts are valued over generations. If not otherwise stated, the SDR applied in this paper is 3 percent, as recommended by the European Commission (2015).

Based on the PVs calculated in step six, the NPVs of the individual projects are calculated in step seven. The formula is given by subtracting the PV of the costs from the PV of the benefits, i.e.:

$$NPV = PV(B) - PV(C) \tag{3}$$

Boardman et al. (2014) explain that the simple decision rule when multiple mutually exclusive projects are evaluated in a CBA is to accept the project with the largest, non-negative NPV. Both Boardman et al. and The European Commission (2015) mention the possibility of using the internal rate of return and the benefit-cost ratio as alternative decision rules. However, they conclude that the NPV decision rule is the most reliable, and therefore, this rule will be applied in this thesis.

Because of the uncertainty related to, for example, predicting the monetary values of impacts and the SDR, step eight includes performing a sensitivity analysis, Boardman et al. (2014) state. The European Commission (2015) explains that the analysis should consider one variable at a time and determine the effects of varying it on the NPV. They also state that the analysis should focus on the most critical assumptions and variables not to become overly detailed. Furthermore, they note the importance of using isolated independent variables to avoid distorted results and double counting. Ultimately, Boardman et al. (2014) conclude, the CBA will result in a policy recommendation of whether to invest in a project or not in step nine.

3.2.2. Limitations and Criticism

As with all models applied for the analysis of complex systems, there are various limitations of the CBA methodology. First, the decision rule based on the greatest NPV does not guarantee that the project in question is the best available project. The design of the CBA only allows for a limited number of projects to be treated, and it is only between those specific projects that the rule prioritises. The rule does not consider that there may be other, more beneficial projects available. In other words, the recommended project may contribute to a more efficient allocation of resources, although it may not be the most efficient allocation.

Furthermore, Boardman et al. (2014) note the various disagreements among analysts concerning certain aspects of analysis. What effects may occur over the analysed period, how these effects should be valued and which discount rate to use are all examples of aspects subjected to varying opinions. A general problem with CBA is that it is impossible to include all aspects of change due to time and financial constraints. Therefore, some critical impacts will most likely be omitted from the analysis. Thus, the outcome of the CBA may differ depending on the analyst's ideas of what impacts are the most important to include. Decision making based on a CBA may thereby be subject to analyst bias.

Moreover, Boardman et al. (2014) mention various idealistic and ethical arguments under which the CBA methodology often falls subject. For example, they point out that not all political and philosophical schools of thought agree with the utilitarian idea that one person's utility loss can be traded off by another person's utility gain. Such opinions become particularly evident in economic CBAs, as impacts occurring to individuals from a particularly vulnerable socio-economic group may be weighted higher than impacts occurring to individuals from other socio-economic groups. This logic goes against certain fundamental values of various schools of thought, such as individualism or equality, and have therefore caused disagreements among critics and supporters of the methodology.

The aforementioned critique further relates to the issues of deciding who (and what) has standing and what particular effects that will occur over time. Such issues become especially evident when studying environmental impacts, as their ramifications are generally difficult to delimit throughout the Earth ecosystem. According to Boardman et al. (2014), critics therefore argue that analysis must happen from a global perspective and that special care must be taken to tipping points and effects occurring in the distant future. However, there are currently no generally accepted guidelines stating one correct way to decide who and what should have standing, and which perspective should be used for analysis.

Closely related to the previously mentioned criticism is the debate of whether environmental goods and ecosystem services should be valued in monetary terms or not. Matthews et al. (2000) mention that some critics argue that monetising such goods and services is unethical, as those goods and services may then lose some of their intrinsic values (e.g., recreational, spiritual, or cultural values). Additionally, Costanza et al. (1997) argue that it is the responsibility of current generations to preserve the world's natural resources for future generations regardless of whether their value can be monetised or not. Also, they claim that because it is impossible to know how future generations will value these resources, it would be to restrict their freedom of opinion if current generations were to value them.

Lastly, because not all costs and benefits can be valued in monetary terms, it is necessary to complement the quantitative analysis of a CBA with a discussion to provide a more complete picture for decision making. Boardman et al. (2014) argue that the general accuracy of the CBA methodology will improve over time, although that it currently must be evaluated for each project. Ideally, they state, various ex-ante CBAs should be performed at different points in time and be followed up by ex-post CBAs. Thus, one comparison study alone is rarely sufficient to provide basis for decision making, which is another shortcoming of the CBA methodology, they claim.

3.2.3. Motivation

Despite the above-mentioned limitations and criticism of the CBA methodology, it offers advantages to this study. There are three main reasons behind the choice of methodology for this thesis. Firstly, CBA is well suited for desktop studies, which was a necessary requirement for this thesis due to the travelling restrictions imposed by the Covid-19 pandemic. Secondly, the results of the CBA are presented in an apprehensible manner and offer a clear overview of what benefits and costs have been included in the decision-making process. Because the aim of this thesis is to provide insight and initial estimates, easily interpreted results are of importance if this thesis is to be useful for future studies. In addition, little to no previous knowledge of economic theory is required to interpret the results, which is the third reason for why the CBA methodology was chosen for this thesis. These facts enable researchers from any field to utilise the results in further studies on the subject. Also, the presentation of the results offers an increase in transparency of the policy evaluation process and thereby allows for inclusive discussions among stakeholders.

3.3. Key Assumptions

In this section, the key assumptions made regarding projections in the development of certain variables are presented briefly. A complete presentation of the assumptions that have been made in this thesis can be found in Appendix 1. Throughout this thesis, costs and benefits are expressed in 2019 USD values. This year has been chosen for reference as it is a sufficient amount of time after the financial crisis in 2008 for the US dollar value to be considered stabile. Furthermore, it is the most recent year in which prices were not affected by the Covid-19 pandemic. Monetary conversions from other currencies are made using Purchasing Power Parity (PPP) exchange rates to account for differences in price levels between countries.

Because aquifer data are difficult and expensive to obtain and existing data on the aquifer of Valle de Aguascalientes are scarce (Sainz-Santamaria & Martinez-Cruz 2019a), assumptions have been made regarding the effects of a change in water extraction. Based on the data reported by CONAGUA (2020) on water extraction and active waterworks, it is assumed that 0.3 percent of the total amount of water extracted from the aquifer annually is used for drinking purposes. Furthermore, it is assumed that the drinking water demand will increase over the 30 years considered in this thesis. However, most water demand projections found were published around the turn of the century. Because the drinking water demand depends mainly on population growth, economic development, and water efficiency (Amarasinghe & Smakhtin 2014), the accuracy of those projections today is subject to debate.

According to Cosgrove and Rijsberman (2000), the domestic water demand was projected to increase by 47 percent between 2000 and 2025. However, Amarasinghe and Smakhtin (2014) report that already in 2005, the actual domestic water withdrawal had increased by 48 percent. They also suggest that the rapid historical growth presented by Cosgrove and Rijsberman is unlikely to be seen in the future. For the purpose of calculation, a drinking water demand increase of 30 percent until the end of the period is assumed in this thesis. This rate is arbitrarily chosen – although with guidance from the previously mentioned numbers and ideas – and has been included to illustrate the likely increases in future water demand.

On an annual basis, the increase in drinking water demand is computed using the Compound Annual Growth Rate (CAGR), presented in equation 4.

$$CAGR = \left(\frac{EV}{BV}\right)^{\frac{1}{n}} \quad (4)$$

The CAGR is based on the ending value (EV), the beginning value (BV) and the number of years considered (n) (Fernando 2021). The CAGR is to be seen as a representational figure showing the annual growth rate had it been the same over all the years in question. Based on the assumed 30 percent increase until the end of the studied period, the CAGR regarding the drinking water demand development amounts to approximately 0.9 percent.

Regarding irrigation water, CONAGUA (2018a, 2016) reports that the water demand for irrigation in Irrigation District 01 amounted to 30.6 hm^3 during 2014-2015 and 30.8 hm^3 during 2015-2016. This difference represents an increase of approximately 0.65 percent between the years. Similarly, the FAO (2021) reports that the irrigation water withdrawal from surface and groundwater in Mexico amounted to 65.42 km^3 in 2017 and 65.87 km^3 in 2018. This difference represents a similar increase – approximately 0.69 percent – between the years. Thus, the annual increase in irrigation water demand is in this thesis assumed to be the average of the two previously presented numbers, i.e., 0.67 percent.

Of course, the increase in irrigation water demand is dependent on the expansion of agricultural land. According to the FAO (2009), the expansion of arable land will occur mostly in developing countries[12], and they mention Latin America as a region of example. Furthermore, the FAO projects that irrigated land will expand by 11 percent globally and that all the expansion will happen in developing countries. Therefore, it is assumed that the arable land in Mexico will grow by 11 percent until 2050. On an annual basis, the increase is computed using the CAGR (see equation 4). A CAGR of approximately 0.35 percent is used regarding the projected increase in agricultural land.

Furthermore, no previous studies have – to the author's knowledge – been carried out regarding the exact impact of the groundwater table depth on the fluoride concentration in the aquifer of Valle de Aguascalientes. Additionally, such data are highly context dependent, as the aquifer's specific geological conditions determine the 'normal' fluoride concentration. Also, Bhatnagar et al. (2011) mention that industry wastewater containing high levels of fluoride can affect the fluoride concentrations in the water. Fluoride-contaminated water can enter the aquifer through its recharge zones, where the geological conditions may not be able the reduce the fluoride concentration. These facts increase the importance of studying the specific aquifer in question and its recharge areas to learn about the actual relationship between the fluoride concentration and groundwater table in the aquifer.

Considering the aquifer of Valle de Aguascalientes, measurements of the fluoride level have been published annually since 2012 and show an increasing trend over the period (CONAGUA 2021b) (see

[12] Whether Mexico is defined as a developed or developing country differs between organisations (Investopedia 2021). Throughout this thesis, Mexico is defined as a developing country in accordance with the UN (2021).

Table 1). However, since data has not been kept over the changes in the groundwater table, the relationship between these two variables cannot be estimated. Nevertheless, CONAGUA (2020, 2015) reports that the deficit in disposable water resources in the aquifer of Valle de Aguascalientes between 2015 and 2020 increased, along with the water extraction rate. Based on these measurements, a relationship is assumed between the disposable water deficit and the fluoride concentration in the aquifer.

More specifically, CONAGUA (2020, 2015) report that the fluoride concentration increased from 1.74 mg/L in 2015 to 1.92 mg/L in 2020 (see

Table 1). They further report that the deficit in disposable water between the same years increased by 9 183 530 m^3. Combining these numbers provides the estimate that one m^3 of water saved in the aquifer reduces the fluoride levels by approximately 1.98×10^{-8} mg/L.

4. Results

This chapter summarises the main results of the respective CBA. As steps 1 and 2 of Boardman et al.s' (2014) recommended nine steps were thoroughly introduced in describing the projects in chapter 2, this chapter primarily regards steps 3-8. In sections 4.1 and 4.2, each cost and benefit included in the respective project are presented and shown in relation to its NPV (steps 3-7). Subsequently, a sensitivity analysis is presented for each project in section 4.3 (step 8). Note that step 9 is presented in relation to the discussion in chapter 5.

4.1. Project A: Installation of Fluoride Removal Units Using Electrocoagulation

The complete CBA for Project A can be found in Appendix 2. The results are based on the impacts and assumptions presented in the previous chapters. A summary of the costs and benefits included in the CBA and their associated NPVs is presented in Table 2.

Table 2: Summary of Costs and Benefits and their respective NPVs for Project A

	NPV[a]
Costs	
Capital (water treatment units)	- 881 384.10 USD
Installation	- 88 138.41 USD
Operational	- 7 009 698.46 USD
Fossil fuel emissions from energy consumption	- 250 689.17 USD
Benefits	
Dental care savings	167 491 943.31 USD
Total	159 262 033.17 USD

[a] Calculations are made using an SDR of 3 percent.

Haldar and Gupta (2020) present that apart from the electrocoagulation cell itself, the capital costs for electrocoagulation units include the cost of overhead tanks, sand, alumina, AC–DC power supply, minor electrical equipment, batteries, and inverters. The costs of any shed in which the unit is to be placed are excluded, as existing buildings that currently stand empty can be used. Furthermore, Haldar[13] claims that the material needed for the construction of the unit can be found at approximately the same prices in Mexico as in India. In general, he explains, the materials can be manufactured domestically at prices that are not significantly different between countries, or they are imported at similar costs. Therefore, the same capital cost as presented in Haldar and Gupta (2020) is used in this thesis. In addition, however, the costs of civil structure for installation are included in a separate impact category, as Haldar and Gupta exclude this cost. Haldar[14] estimates that this cost amounts to approximately 10 percent of the capital cost. The NPVs of the sum of the capital cost and installation cost over the 30 years considered amounts to 881 384.10 USD and 88 138.41 USD, respectively.

Additionally, Haldar and Gupta (2020) report that the operational costs include the cost of maintenance and minor repairs, the electricity cost, and the cost of operating the pump and electrocoagulation cell. Haldar[15] explains that as the maintenance and minor repairs requires little training, it can be performed by low-skilled workers. However, any potential social impact from employing additional low-skilled workers is omitted from this analysis due to time and financial constraints. Furthermore, because the electricity cost for this type of activity is lower in central Mexico than in Haldar and Guptas' experiment[16], Haldar[17] reports that the operational costs in Mexico are reduced by 8.8 percent per m^3 of water treated. The electricity cost is held constant at the current rate over the years considered in this thesis. In total, the NPV of the operational costs summed over the 30 years considered amounts to 7 009 698.46 USD.

The relatively high electricity consumption of electrocoagulation units is often mentioned as the main drawback of the fluoride removal method. However, the GHG emissions that the electricity generation gives rise to are rarely considered when the potential of the method is evaluated. Ritchie and Roser (2020b) report that approximately 0.20 kg emissions are created per kWh of energy in Mexico, and according to Haldar[18], 0.8-1 kWh of electricity is needed to treat one m^3 of water using their electrocoagulation units (excluding the energy needed to pump the groundwater from the aquifer). As an example of the amount of emissions that the electricity consumption of the electrocoagulation units give rise to, the emissions created in year 0 – considering the contemporary water demand – amount to 152.22 tonnes. This number is equivalent to the emissions created from approximately 55 round-trip flight journeys from Stockholm, Sweden (ARN) to Bangkok, Thailand (BKK)[19].

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[13] Arindam Haldar, PhD, Department of Civil Engineering, Indian Institute of Engineering Science and Technology, Shibpur. Interview 2021-11-16.
[14] Ibid.
[15] Ibid.
[16] The electricity cost in Mexico is approximately 0.10 USD/kWh (Castañeda et al. 2020), compared to 0.13 USD/kWh in India (Haldar & Gupta 2020).
[17] Arindam Haldar, PhD, Department of Civil Engineering, Indian Institute of Engineering Science and Technology, Shibpur. Interview 2021-11-16.
[18] Ibid.
[19] The calculation is based on the emissions for a round-trip journey in a reported by SAS (2021). The GHGs have been weighted by their respective global warming potential (GWP); nitrous oxide

In determining the social cost of the emissions generated by electrocoagulation, the social cost of carbon (SCC) is applied. The SCC is subject to uncertainty and is, therefore, a much-debated topic in the literature. The current and projected SCC values used in this thesis are retrieved from the baseline scenario presented by the OECD (2018), which are adapted from Nordhaus (2017). In the baseline scenario, the OECD (2018) explains that no new climate policies are adopted, and that the SCC thus increases from 36.43 USD per tonne CO_2 in 2015 to 119.69 USD per tonne in 2050[20]. Using the SCC to estimate the social cost of the emissions created over the considered period generates an NPV of 250 689.17 USD over the 30 years considered.

Moreover, the benefits occurring to the consumers of the cleaned water must be included. In this thesis, this benefit is estimated based on the expenses consumers save from not requiring dental care to treat dental fluorosis caused by intake of high-fluoride drinking water. The calculations on dental care savings are based on the young population in the state, specifically children between 0 and 11 years of age. Thus, the benefits will occur for the share of the population born in and after year 0. Because intake of high fluoride water is the primary source of dental fluorosis in Aguascalientes, this thesis assumes that no cases of dental fluorosis in children born after year 0 will occur after the implementation of Project A. The NPV of the dental care savings over the 30 years considered amounts to 167 491 943.31 USD.

With all the aforementioned costs and benefits considered, Project A produces an NPV of 159 262 033.17 USD in the CBA. Based on the NPV decision rule, the recommendation is to accept the project.

4.2. Project B: Implementation of Centre Pivot Irrigation Systems

The complete CBA for Project B can be found in Appendix 3. The results are based on the impacts and assumptions presented in the previous chapters. A summary of the costs and benefits included in the CBA and their associated NPVs is presented in

GWP = 298, hydrocarbons (ethane) GWP = 5.5, carbon monoxide = 1.9 (Forster et al. 2007). Emissions of sulphur dioxide and water vapor reported by SAS (2021) are omitted.

[20] The values have been converted from 2010 international dollar values to 2019 USD values.

Table 3: Summary of Costs and Benefits and their respective NPVs for

Table 3: Summary of Costs and Benefits and their respective NPVs for Project B

	NPV[a]
Costs	
Ownership cost – CPI system	- 32 614 305.46 USD
Labour	- 1 571 748.57 USD
Reparation and maintenance	- 4 268 096.40 USD
Energy	- 186 393 071.77 USD
Fossil fuel emissions from energy consumption	- 2 204 072.34 USD
Benefits	
Value of increased groundwater availability	63 008 708.13 USD
Dental care savings	40 178 011.06 USD
Total	- 123 864 575.35 USD

[a] Calculations are made using an SDR of 3 percent.

The ownership cost[21], as well as the operational and maintenance costs of CPI systems in this analysis are retrieved from RMCG's (2018) report from a semi-arid region in Australia. The ownership cost that RMCG reports is assumed to be the same for CPI systems installed in Aguascalientes. This assumption is made because the climate conditions are the same at the original study site as in Aguascalientes. Another reason for this assumption is that the RMCG takes no account of the crops cultivated in their study, which otherwise could have affected the ownership cost. RMCG reports that the capital cost for CPI systems equals approximately 4 849.73 USD/ha. As mentioned in section 3.3, it is assumed that the demand for agricultural land expands by 0.35 percent annually over the studied period. The useful life of CPI systems (15 years) and increasing demand for agricultural land give rise to annual ownership costs in this CBA. The NPV of the total ownership costs summed over the 30 years studied amounts to 32 614 305.46 USD.

The cost of labour to operate the CPI systems is calculated based on the labour demand per operated ha, the development of labour costs over the period considered, and the previously mentioned projected demand for agricultural land. According to RMCG (2018), the annual labour demand for operating one ha using a CPI system is two hours. It is assumed that the CPI systems can be operated by the same employees that operate the current irrigation systems. Thus, no additional social impacts caused by changes in the composition of the work force are included in this analysis. Based on the average hourly wage rate for a farm equipment operator in Aguascalientes of 4.99 USD[22] and a projected wage increase of 25 percent every five years (Economic Research Institute 2021), the annual labour cost increase is calculated to be 4.56 percent using the CAGR (see equation 4). The NPV of the total labour costs summed over the 30-year period amounts to 1 571 748.57 USD.

Regarding costs for reparation and maintenance, RMCG (2018) reports that the average annual costs equal 52.23 USD[23] per ha. This cost is held constant over the studied period. Combined with the projections for the agricultural land demand,

[21] Ownership costs refer to capital costs including interest and depreciation.

[22] The value is converted from MXN using a PPP for Mexico of 9.522 in 2020.

[23] The value is converted from AUD using a PPP for Australia of 1.452 in 2014.

the NPV of the total cost of reparation and maintenance summed over the 30 years studied amounts to 4 268 096.40 USD.

Furthermore, electricity is needed to pump groundwater from the aquifer to ground level and distribute it on the land via the CPI system. According to Roy et al. (2018), the variables determining the electricity consumption of a CPI system is the water table depth, system length, number of towers (i.e. ground points), operating pressure, well capacity, and application rate. Since these variables will vary from farm to farm, the variables used in Roy et al.s' example are utilised in this thesis in order to provide a feasible example of the electricity cost. Based on their calculations, applying water to crop land using CPI requires approximately 1.26 kWh/m^3 of water in total.

However, because the electricity needed to pump groundwater to above-ground levels is required regardless of the irrigation system used, this amount is subtracted from the energy required for operating the CPI systems before application in this analysis. Peacock (2005) explains that the energy required for groundwater pumping, assuming 100 percent pump efficiency, can be calculated by multiplying the weight of water by the lateral lift from the aquifer. However, Peacock states that a properly designed pump ordinarily operates at approximately 70 percent efficiency due to energy and friction losses. Thus, at least 30 percent should be added to the calculated energy consumption, he states.

Regarding the aquifer of Valle de Aguascalientes, Hernández-Marín et al. (2018), estimate that the water table has a maximum depth of 400 m. However, as the aquifer has a dynamic shape and the wells are distributed unevenly over different depths, the average depth of 200 m is used in calculating the electricity requirement of groundwater pumping. Multiplying the weight of water by the lateral lift and adding 30 percent to account for efficiency losses generates an energy requirement of approximately 0.71 kWh/m^3 of water pumped. Subtracting the energy required for pumping water from the total energy required, as reported by Roy et al. (2018), generates the energy required for the water distribution on the fields using CPI systems – approximately 0.55 kWh/m^3 of water.

Additionally, the electricity price must be incorporated. Rather than including the highly subsidised electricity rate that farmers pay for irrigation and the cost of the subsidies paid by the government as separate costs, the true cost of the necessary electricity (i.e., the sum of the two previously mentioned costs) is included in this CBA. According to Tellez Foster[24], the true cost of electricity for irrigation in Mexico is approximately 1.2 USD per kWh. Thereby, the NPV of the energy cost summed over the 30 years considered amounts to 186 393 071.77 USD.

The final cost included in this CBA is the cost of fossil fuel emissions from the energy consumption presented above. RMCG (2018) claims that switching from gravity-based irrigation systems – such as flood irrigation – to CPI systems will likely increase the energy required and thus the GHG emissions. As mentioned in section 4.1, approximately 0.20 kg emissions are created per kWh of energy consumed in Mexico (Ritchie & Roser 2020b). Multiplying this amount by the required electricity for distributing water and the SCC generates the NPV of the

[24] Edgar Tellez Foster, PhD, lecturer, University of California Riverside, Interview 2021-10-20.

total GHG emissions summed over the 30 years. The NPV amounts to 2 204 072.34 USD.

Regarding the benefits of implementing CPI systems on land previously managed using flood irrigation, the value of increasing the groundwater availability must be considered. Because no previous valuation study – to the author's knowledge – has been made regarding the value of this benefit in Aguascalientes, this CBA utilises unadjusted value transferring to estimate its magnitude. The values are retrieved from Suter et al. (2021), who study medium to large scale farmers' valuation of increased irrigation water availability. The majority of the farmers are located in cold semi-arid (BSk) areas. The farmers studied are dependent on water from the Ogallala aquifer, which is one of the most studied in the US, and it has long been in a state of deficit due to the unsustainable water withdrawal. The study was chosen for value transferring as the farmers face the same climate conditions, future climate challenges, and water scarcity problems as farmers in Aguascalientes.

Suter et al. (2021) performed a CVM-based study where the WTP for increased groundwater availability in the Ogallala aquifer was estimated as a function of the current availability and climate conditions. The respondents in the study were farmers utilising irrigation wells of > 200 gpm. Suter et al. found a median WTP for an additional 100 gpm of well capacity – provided by an aquifer recharge project – of 78.38 USD[25] per well. This WTP equals 3.94×10^{-4} USD per additional m^3 of water available per well per year. They state that the WTP is low because of the relatively small increase in well capacity proposed in the WTP question. However, they claim that the WTP "depends strongly" (p. 1) on the current well capacity and climate conditions.

Suter et al.s' (2021) results show that farmers in drier and hotter regions report a WTP of thousands of USD higher than the median. This result, they claim, suggests that the benefits of groundwater availability and WTP may increase drastically as climate change continues to alter the growing conditions. Based on their reported valuation of increased groundwater availability, the unadjusted value transfer generated an NPV of 63 008 708.13 USD for the saved water summed over the 30 years considered in this thesis.

Additionally, Morris and Gallardo Cabrera (2005) state that the high fluoride concentrations in the groundwater of Aguascalientes are directly related to the overexploitation of the resource and the subsequent extraction from deeper levels. However, as mentioned in section 3.3, no direct measurements of the exact relationship between fluoride concentration and water table depth have been found for the aquifer of Valle de Aguascalientes. Therefore, the strong assumption that a relationship exists between the two variables – where one m^3 of water saved in the aquifer reduces the fluoride levels by approximately 1.98×10^{-8} mg/L – has been made in this CBA in estimating this potential benefit.

Assuming that the above estimate holds, the annual water savings from switching irrigation systems would cause a decrease in the fluoride concentration. However, the decrease would not be sufficient to reduce the concentration to < 1.5 mg/L. Thus, it cannot be assumed that the general prevalence of dental fluorosis among children would decrease significantly. It can, however, be

[25] The values have been converted from 2018 USD values to 2019 USD values.

assumed that the cases of severe dental fluorosis are reduced substantially. As mentioned in chapter 1, the National Research Council (2006) report that the number of severe dental fluorosis cases rises sharply when the fluoride concentration in drinking water exceeds 2 mg/L, but are close to zero when the concentration is < 2 mg/L. Due to the assumed water savings from switching irrigation systems, the fluoride concentrations would be reduced to < 2 mg/L. Thus, it is assumed that all cases of severe dental fluorosis become moderate cases, for which treatment costs less. This cost reduction creates a benefit with an NPV of 40 178 011.06 USD.

In total, switching from flood irrigation to CPI systems in Irrigation District 01 generates an NPV of - 123 864 575.35 USD. Based on the NPV decision rule, the recommendation is that the project should not be accepted.

4.3. Sensitivity Analyses

Table 4 and Table 5 summarise the new total NPVs produced for the respective project when one variable is varied at a time. The analyses focus on the most uncertain variables where critical assumptions have been made. Because small variations in the included variables do not substantially affect the total NPV, larger and more feasible variations have been analysed. The results of the sensitivity analyses are discussed in chapter 5.

Table 4: Sensitivity Analysis for Project A

Variable varied	**Change**	**New Total NPV[a]**	**Difference from Original NPV**
Social discount rate	Increase from 3% to 10%	42 207 646.55 USD	- 117 054 386.62 USD
	Decrease from 3% to 1.5%	219 595 225.16 USD	+ 60 333 191.99 USD
Capital cost	+ / - 30%	158 971 176.42 USD / 159 552 889.92 USD	- / + 290 856.75 USD
Dental care treatment price	+ / - 30%	208 147 340.96 USD / 109 795 011.88 USD	+ / - 48 885 307.79 USD
Drinking water increase	Increase from 1% to 5%	165 905 380.12 USD	+ 6 643 346.95 USD
Electricity required for water treatment	+ / - 50%	158 845 831.83 USD / 159 096 521.00 USD	- / + 416 201.34 USD
Reference period	Increase from 30 to 60 years	212 030 019.52 USD	+ 52 767 986.35 USD

[a] Calculations are made using an SDR of 3 percent.

Table 5: Sensitivity Analysis for Project B

Variable varied	Change	New Total NPV[a]	Difference from Original NPV
Social discount rate	Increase from 3% to 10%	- 76 884 571.98 USD	+ 46 980 003.37 USD
	Decrease from 3% to 1.5%	- 42 126 530.30 USD	- 18 261 954.95 USD
Agricultural water demand annual increase	Increase from 1% to 5%	- 233 511 445.12 USD	- 109 646 869.77 USD
Ownership cost	+ / - 10%	- 127 126 005.90 USD / - 120 603 144.81 USD	- / + 3 261 430.55 USD
Electricity required for water distribution	+ / - 20%	- 161 584 004.18 USD / - 86 145 146.53 USD	- / + 37 719 428.83 USD
Valuation of increased water availability	+ / - 20%	- 111 262 833.73 USD / - 136 466 316.98 USD	- / + 12 601 741.62 USD
Dental care treatment price	+ / - 30%	- 111 811 172.04 USD / - 135 917 978.67 USD	+ / - 12 053 403.31 USD
Application efficiency	Increase from 70% to 83.13%	43 324.93 USD	+ 123 907 900.28 USD
Reference period	Increase from 30 to 60 years	- 178 053 999.69 USD	- 54 189 424.34 USD

[a] Calculations are made using an SDR of 3 percent.

5. Analysis and Discussion

According to the results presented in the previous section, only Project A generates positive net social benefits in the original CBA. As the sensitivity analysis for this project shows, the recommendations based on the NPV decision rule are robust, even at large variations in the included variables. Also, because of the fluoride removal efficiency of the electrocoagulation unit, the treated water would be safe to drink even at higher initial fluoride levels (Haldar[26]). The project also remains within the boundaries of the current state budget for rehabilitation, modernisation and technification efforts, which Project B does not. In fact, even if an update similar to that in 2020 were made, the estimated costs of Project B would exceed the current state budget for such projects. Thereby, this thesis indicates that Project A has potential to ensure that the water extracted from the aquifer of Valle de Aguascalientes is of good quality, and the probability of successful implementation is high.

However, due to the assumptions made in this thesis, there is uncertainty related to the estimated costs and benefits. Firstly, the assumptions impose uncertainty regarding the impact of Project A. For example, it has been assumed in this thesis that the electricity price will remain constant over the studied period. This assumption may not be correct considering the aim stated in the General Law on Climate Change of increasing the amount of electricity generated from renewable sources in the near future. With an increased amount of renewable energy in the national electricity mix, the cost of generating electricity will likely decrease (IEA & OECD/NEA 2020). Thus, the operational costs of fluoride removal using electrocoagulation – the most significant cost associated with the project – will likely decrease as well, making the net benefits of Project A even greater.

Furthermore, the actual benefits of a water quality improvement are most likely larger than those presented in this thesis for two reasons. Firstly, the actual benefits of decreased fluoride concentrations in the drinking water will occur to children born in the eight years before year 0 as well. Despite those children being further along in their enamel development, the reduction in their cumulative fluoride intake from drinking water will reduce their risk of suffering more severe forms of dental fluorosis. Nonetheless, this benefit has not been accounted for as it goes beyond the temporal scope of this CBA. Secondly, the intrinsic value of the improved water quality was omitted from the CBA due to the risk of double counting benefits. Nevertheless, this benefit is important to acknowledge,

[26] Arindam Haldar, PhD, Indian Institute of Engineering Science and Technology, Interview 2021-11-16.

primarily because of its potentially increasing value over time due to continued degradation of ecosystems.

The estimated benefit of saved expenses for dental care to treat dental fluorosis manifests the magnitude of the public health issue clearly. However, it should be noted that all cases of dental fluorosis in Aguascalientes may not vanish after the installation of electrocoagulation units, as this CBA assumes. The difference in outcome after adjustments is expected to be minor, as high-fluoride drinking water is concluded to be the leading cause of dental fluorosis in Aguascalientes (González Dávila 2021). Nevertheless, the current lack of knowledge regarding the percentage of dental fluorosis cases in Aguascalientes caused by excessive fluoride intake from other sources than drinking water hinders adjustment for such cases. Learning about the other sources of fluoride intake could increase the certainty of the magnitude of this benefit and improve public health recommendations.

Moreover, the assumptions made in this thesis also induces uncertainty related to the estimated costs and benefits of Project B. The presented results show that the estimated costs outweigh the estimated benefits. However, the costs would likely be even higher were CPI systems to be implemented in reality. As a new irrigation policy would most probably be implemented throughout all of Irrigation District 01, changes would, to some extent, be required also on the share of land already irrigated using CPI systems. Most importantly, the total costs would increase due to, among other things, the additional need for maintenance and replacement of worn-out equipment. The benefits, on the other hand, would not change significantly from considering the additional land area, as they arise mainly due to the switch from less efficient irrigation systems.

Considering the benefits of Project B, the robustness of the value transfer concerning the farmers' valuation of increased groundwater availability is uncertain. The primary reason for this uncertainty is that WTP varies with income level (Markandya & Ortiz 2011) and there is an expected difference in income levels between Suter et al.s' (2021) original study site and the study site considered in this thesis. Since the sampled farmers' incomes were not a variable of interest in the original study, they were not presented. Thus, no adjustments could be made to account for the expected difference in income level between the study sites. Thereby, the unadjusted value transfer method was utilised in this thesis, which fails to account for this important socio-economic difference between the study sites.

Had the income level and the effect of income on the WTP been presented in the original study, the adjusted value transfer approach could have been applied instead. The adjustment could imply, e.g., considering the farmers' stated WTP as a share of their income instead of solely considering the stated WTP amount. The difference in income between the sites could thereby have been accounted for, and hence, the accuracy of the value transfer could have increased.

Additionally, Suter et al.s' (2021) claim that farmers' valuation of increased groundwater availability depends on the current availability implies a potential change in the valuation over time. Suter et al.s' findings suggest that the valuation of availability would increase as the groundwater becomes scarcer due to hotter and drier growing conditions brought on by climate change. In turn, such a change implies a possibly increasing preservation value. This thesis does not include projections of how the valuation, nor the climate may change over the period considered, and thus, the benefit of increased groundwater availability may be underestimated.

As mentioned in section 2.2, Sainz-Santamaria and Martinez-Cruz (2019a) estimate that implementing CPI systems throughout Irrigation District 01 will decrease the expected net average water extraction because of the increase in application efficiency. However, they also note that there is agreement in the literature about the risk that the increase in application efficiency has the opposite effect. For example, Foster et al. (2004), claim that farmers have been observed to respond to increased water availability by planting more water demanding crops or increasing their irrigated land area. Therefore, they state that complementary policies that prevent such changes are necessary to ensure a net decrease in water extraction and the benefits that come with it.

Complementing policies may also be needed to ensure that unwanted socio-economic effects do not arise, Hrozencik et al. (2017) argue. They note that groundwater management policies shaped without consideration to the aquifer dynamics will have limited relevance. Similar to Suter et al. (2021), this thesis only includes the average of the values reported on increased availability, which is arguably unrealistic as the availability is affected by season and differs significantly across the aquifer (Guerrero et al. 2018). The approach also fails to account for distributional effects. Such effects may involve farmers in areas where the initial well capacity is low being able to increase their income security due to the decreased water stress. Conversely, effects may also involve enabling farmers in areas with a high initial capacity to benefit disproportionately due to their ability to, e.g., expand their irrigated land area.

The estimated benefits of switching irrigation systems build on the assumption that the water that is ‘saved’ from implementing Project B is kept in the aquifer. If this assumption holds, the only scenario where Project B generates a positive NPV is if the difference in application efficiency between flood irrigation and CPI systems is increased, as shown in the sensitivity analysis (see Table 5). More specifically, it is required that CPI systems are 66.26 percent more efficient than flood irrigation to reverse the policy recommendation. This difference is achieved if the application efficiency of the CPI systems is ensured at 83.13 percent, while the application efficiency of flood irrigation remains at 50 percent. With continued technical development, it is not unlikely that the lower bound application efficiency of the CPI systems increases, which would imply higher total net benefits.

If, on the other hand, the previously mentioned assumption does not hold, it can be argued that the potential of Project B alone to change the current extraction patterns and thereby the fluoride concentration is low. If, in addition, the assumption of fixed irrigation and pumping technology is relaxed, its potential will decrease even further. The same may be said regarding the political feasibility of successful project implementation. Tellez Foster[27] and Ortega Caldera (2010) explain that, in general, farmers in Mexico are resistant to government interventions that affect their operations. Muñoz-Piña et al. (2006) even suggest that a type of compensation may be needed in order to persuade the

[27] Edgar Tellez Foster, PhD, lecturer, University of California Riverside, Interview 2021-10-20.

farmers – as well as the strong lobbying industry working for their interests – to accept a new intervention. However, neither the required magnitude of such compensation nor the guarantee of its actual effects have been estimated in relation to CPI systems.

The fact that the results of this thesis show that Project A generates a positive NPV whereas Project B does not should be seen as an indication for at what end of the fluoride contamination problem spectra that future policy evaluation studies should focus to improve the public health in Aguascalientes. With the human health-centred perspective taken in this thesis along with the assumptions made, particularly regarding no technological development, it is clear that a policy project aiming to solve the underlying problem of aquifer overdraft is too costly. In comparison, the indication that an end-of-pipe solution offers greater benefits at lower costs motivates further investigations of the potential and feasibility of such a project. In that sense, the information presented in this thesis may be useful, despite its low level of accuracy (Brookshire 1992, see OECD 2018).

Furthermore, the insights gained in this thesis indicate that implementing policies aimed at reducing the fluoride concentration in the groundwater and reducing the groundwater extraction will produce a less damaging outcome than the baseline scenario. Considering the CBA presented in this thesis, it is clear that the benefits produced through implementing the evaluated policies become costs if the current groundwater management policies are not reshaped, or no new policies are implemented. An increase in the state budget for rehabilitation, modernisation and technification efforts of water related projects would allow the acquisition of the additional knowledge necessary to produce more precise estimates of the costs and benefits related to policy revision or implementation. Ultimately, this improvement in precision could facilitate the shaping of successful policies for ensuring safe and sustainable groundwater management.

Based on the discussion held previously in this chapter, along with the results presented in chapter 4, the author’s recommendation is to undertake more extensive studies focusing on improving the accuracy of the estimated net social benefits resulting from implementing Project A. Similar efforts should eventually be taken to evaluate the potential of Project B. However, as the initial estimates of the net social benefits presented in this thesis are higher and positive for Project A, Project A should be prioritised.

To the author’s knowledge, no previous valuation studies have been made in Aguascalientes regarding the net social benefits of the projects evaluated in this thesis. Due to the inability to travel because of the Covid-19 pandemic – in addition to the time and financial constraints – an original valuation study could not be performed for this thesis. Only to a certain degree can an understanding of the evaluated projects’ potential value to the population in Aguascalientes be gained by studying the literature previously produced on related subjects. Thereby, the accuracy of the policy evaluation presented in this thesis is limited. Future groundwater management policies should, therefore, not rely on the estimates of this thesis alone. Instead, this thesis should be considered to increase the understanding of the current obstacles to ensuring safe and sustainable long-term groundwater supply in Aguascalientes.

5.1. Further Research

In order for future CBAs considering the two policy projects evaluated in this thesis to inform policymaking, further research is essential and should consider various aspects. Firstly, additional studies should incorporate changing electricity prices when evaluating the potential of the two projects. It is likely that the expected changes in Mexico's electricity mix in the coming years will bring changes in the electricity prices, which in turn will bring changes to the estimated effects of the projects' operational costs. Additional studies should also opt to estimate the intrinsic value of improved water quality and account for the benefits occurring to children born before the implementation year for Project A.

Additionally, further studies should consider the social impact from potential changes in the labour demand caused by implementing the projects. Such changes are expected to be small as the labour currently employed would not need much special training to change their operations, although the assumption made in this thesis – that no change will occur – may be inadequate. Further research should also aim to improve the accuracy of the estimated benefit of increasing the water availability from Project B. A welcome development that may increase the robustness of such estimates is the increased availability of 'look-up values', i.e. standardised values and ranges for non-market impacts to use in policy evaluation studies (OECD 2018). If performing original valuation studies are deemed too costly, such values may allow utilisation of adjusted value transfers and value function transfers to a greater extent.

Also regarding Project B, future valuation studies should consider the distributional effects that the differences in the geological dynamic of the aquifer give rise to. Learning about these effects will enable an increased understanding of what complementary policies may be necessary to avoid unwanted socio-economic impacts and ensure actual net decreases in extraction, based on Hrozencik et al.s' (2017) and Foster et al.s' (2004) arguments. Ideally, the complementary policies should be included in a reshaped version of the suggested project. However, to predict the probability of successful implementation of such policies accurately, another objective of future studies should be to create a better understanding of the farmers' behaviour and attitudes towards CPI systems and increased groundwater availability.

Future valuation studies should also relax the assumption of fixed irrigation and pumping technology for Project B. Doing so would allow examination of whether the magnitude of a potential increase in application efficiency is sufficient to offset the negative impacts that continued global warming will most probably have on application efficiency over time. The assumption of fixed technology and number of pumps for Project A should also be relaxed in future studies. Haldar[28] states that experiments where technological improvements in terms of scale and fluoride removal efficiency of the electrocoagulation method are currently performed and look promising. Thus, he indicates, the probability of improved electrocoagulation units being available in the near future is high, which would increase the benefits received from installation.

[28] Arindam Haldar, PhD, Indian Institute of Engineering Science and Technology, Interview 2021-11-16.

Further studies should also aim to widen the perspective taken in order to provide a complete picture for policy evaluation. For example, if a perspective that also included the impacts to local ecosystems is taken, the actual net social benefits from Project B would likely be higher than those presented in this thesis. One reason for the expected higher benefits is the fact that groundwater supports the local ecosystems through replenishing rivers and streams, which provide water to plants and wildlife. By increasing the available groundwater quantity through improved aquifer management, the ability to thrive is increased for the species relying on the resource. As a result, the resilience of the local ecosystems is strengthened.

Another reason for the expected higher benefits from including the impacts on local ecosystems relies on the assumption that a groundwater quantity increase results in a decrease in the fluoride concentration. If this assumption holds, the quality of plants and irrigated crops as well as animal welfare would increase due to the decrease in fluoride concentration in the groundwater (Kessabi et al. 1984; Singh et al. 1995, 2018). Higher quality crops would, in extension, benefit the farmers through higher profits. In addition to benefiting the local ecosystems, these local benefits' global and intertemporal impacts should be included. However, such benefits are more complicated to estimate and may therefore not be possible to include even with the expected improvements of the CBA methodology (Boardman et al. 2014).

Lastly, other projects with the potential to increase the groundwater quality and reduce the aquifer overdraft in Aguascalientes should also be considered in future policy evaluation studies. Such projects should include other local initiatives – for example, installation of fluoride removal filters on taps destined for drinking water throughout the state – and national policy interventions – e.g., the innovative suggestion by Muñoz-Piña et al. (2006) to decouple the electricity subsidy for irrigation water[29].

[29] This suggestion, Muñoz-Piña et al. (2006) explain, would entail substituting the current subsidy for a cash transfer (i.e., a lump-sum subsidy). The energy prices for pumping irrigation water would thereby increase and cause a reduction in the water demand, they explain. However, they claim, the users would not experience the associated welfare loss as they simultaneously would receive a corresponding direct benefit in terms of the cash transfer. They also note that the compensation subsequently can be used to invest in more efficient irrigation technologies or switch to less water-demanding crops. If this situation plays out successfully, decoupling the energy subsidy would create a stable reduction in the water demand and allow the groundwater to recharge and reach sustainable levels. However, as the farmers in Mexico generally are resistant to changes (Ortega Caldera 2010), further studies must investigate the political feasibility of such an intervention.

6. Conclusions

The issues related to groundwater depletion and water quality degradation in the aquifer of Valle de Aguascalientes are of significant concern for the current and future population of the state. Due to the high reliance on the groundwater resources in Aguascalientes, it is likely that these issues become more prominent as the population growth and expansion of the industrial and agricultural sectors continue. Thus, there is an evident need for improving the current groundwater management policies. Additional policies may also be necessary to ensure quality and supply in the long run. The two policy projects evaluated in this thesis show little potential to reduce the water extraction from the aquifer of Valle de Aguascalientes and thereby improve the groundwater quality in the state. However, the results do indicate that installation of fluoride removal units which use electrocoagulation can potentially increase the quality of the drinking water consumed in the state and thereby create net benefits to the state inhabitants.

Increasing the drinking water quality by reducing the fluoride concentration would provide substantial social benefits to the population of Aguascalientes in the form of saved expenses on dental care. However, due to the scarcity of data on the aquifer in question, the estimations presented in this thesis relies on various strong assumptions. These assumptions induce uncertainty to the analysis. Thus, the recommendation of the CBA presented in this thesis is to not accept either of the evaluated projects until the certainty of the policy evaluation is increased. However, as Project A shows potential to increase the net social benefits of the inhabitants of Aguascalientes, further studies should first and foremost focus on increasing the certainty regarding the estimated costs and benefits related to this project.

The scarcity of data is a significant limitation in evaluating the actual social impacts of potential policies. Therefore, increasing the knowledge regarding the local groundwater resources is essential to shape targeted policies which are politically and financially viable. In order to provide the necessary knowledge, increased focus must be given to such efforts in the policy and research agenda, and the state and federal budgets. In extension, a better understanding of the critical variables may contribute to increasing the availability of ‘look-up values’ and thereby enable adjusted value transfers or value function transfers when evaluating the potential of similar projects in other semi-arid regions. Considering semi-arid regions’ potential future population growth and increasing vulnerability to climate change, informed groundwater policy decisions are vital to ensure the long-term water supply and drinking water quality. Increased knowledge of the groundwater resources and a larger role in the policy agenda for such matters may facilitate future policy evaluation studies and allow for more informed policy decisions regarding groundwater management in such regions.

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Popular Science Summary

Reductions in groundwater quality due to reductions in groundwater quantity is a growing issue globally and will become more prominent with continued climate change and population growth. Dry regions are particularly vulnerable to this issue due to their reliance on groundwater for water supply. Therefore, urgent attention to improving groundwater management in such areas is essential in regional budgets and policy agendas. This thesis aims to provide insight and initial estimates on the potential costs (monetary or otherwise) and benefits associated with two policy projects intended to increase the groundwater quality in the semi-dry state of Aguascalientes, Mexico. The focus lies on the water body of Valle de Aguascalientes, where fluoride contamination due to the overextraction of water is becoming increasingly problematic.

The projects evaluated are the installation of fluoride removal units using a technology called electrocoagulation (Project A), and the implementation centre pivot irrigation systems (Project B), which are more efficient than the most popular irrigation method currently used in the state. The evaluation of these policy projects is performed using cost-benefit analysis, where the sum of all costs valued in monetary terms over the 30 years studied are compared to the sum of all benefits valued in monetary terms over the same period. In the comparison, all values are expressed in present terms, i.e., in terms of today's value of money, in order to account for the preference for consumption now rather than later.

The results show that for Project A, the benefits outweigh the costs, meaning that the project is potentially beneficial for society. The estimated value of Project A to society amounts to 159 262 033.17 USD. For Project B, on the other hand, the costs outweigh the benefits, meaning that according to the estimates of this thesis, the project should not be implemented. The estimated value of Project A to society amounts to -123 864 575.35 USD. Due to the uncertainty associated with the estimates presented in this thesis, the author recommends that neither project should be implemented until the certainty of the estimates is increased. The author also recommends that policy implementation is not based on this thesis alone, but rather that this thesis is considered to increase the understanding of the current obstacles to ensuring safe and sustainable long-term groundwater supply in Aguascalientes. In that sense, the information provided in this thesis may be helpful in planning for future studies.

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Appendix 1: Complete List of Key Assumptions

Category	Assumption	Justification	Calculation(s)	Source(s)
Water consumption				
Total amount of water extracted from the Valle de Aguascalientes aquifer annually (m3)	347626050	The extraction is for the year 2020. Due to lack of information regarding annual extractions (data is only collected every fifth year), this value has been used to forecast the future water extraction from the aquifer in question.		Conagua (2020) https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdf
Share of the water extracted that is consumed by domestic users and livestock	0,006			Conagua (2020) https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdf
Extraction per pump (m3/year)	36592,22	Considering that livestock consume large quantities of water, only a fraction of this share is actually used for drinking purposes for humans. The measurement to the left is included to improve the precision of the amount of water consumedby humans for drinking purposes in Aguascalientes. Conagua (2020) present that out of the active water works (i.e. wells and norias), 31 units are destined for livestock and 26 units for domestic use. The assumption is made that each pump extracts the same amount of water and the calculation is based on the water demand in Aguascalientes for domestic and livestock use.	Amount of water extracted from the Valle de Aguascalientes aquifer annually (m3/year) * Share of the water extracted that is consumed by domestic users and livestock (%) / Total number of active water works destined for domestic use (i.e. livestock and drinking). The extraction per pump is calculated based on the numbers in the year 2020, i.e. 347626050 * 0,006 / (31 + 26) = 36592,22.	Conagua (2020) https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdf
Amount of water exctacted for domestic use/drinking in Aguascalientes 2020 (m3/year)	951397,61	Multiplying the extraction per pump by the 26 water works destined for domestic water use gives a reasonable estimate of the domestic water consumption per year in Aguascalientes. Further calculations are based on projections on the drinking water demand in a specific year.	Extraction per pump (m3/year) * Number of water works destined for drinking purposes (26 units).	Conagua (2020) https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdf
Share of the total water extracted from the aquifer that is consumed by domestic users	0,003		Total amount of water exctacted annually for domestic use/drinking in Aguascalientes 2020 (m3/year) / Amount of water extracted from the Valle de Aguascalientes aquifer annually (m3/year). The calculation is based on the numbers in the year 2020, i.e. 951397,61 /	Conagua (2020) https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdf
Amount of water consumed per person in Aguascalientes (m3/year)	0,667363173	Considering that 71% of the water consumed in Aguascalientes originates from groundwater and the rest from surface water (Conagua 2018), the annual water intake per person in Aguascalientes would (given that the number in the cell to the left is accurate) amount to 0,939948131 m3. Considering the recommended annual intake of 1,168 m3 per person, which is based on the recommended daily intake of 3,2 L on average (3,7 L for men and 2,7 L for women), the amount presented in the cell to the left may be an underestimate. However, it gives reason to assume that all the water consumed by domestic users is consumed for drinking (i.e. that the number does not include water consumption for dishwashing, showering etc.). Therefore, domestic water use and drinking water consumption will henceforth be used synonymously.	Annual water intake per person in Aguascalientes = 0,667363173 / 0,71 = 0,939948131. Recommended annual intake per person (NAP, nd) = 3,2 L * 0,001 * 365 days = 1,168 m3.	Conagua (2018) https://agua.org.mx/wp-content/uploads/2019/04/AAM_2018.pdf ; NAP (nd) (https://www.nap.edu/read/10925/chapter/6?term=3.7+litres#145)

Drinking water demand growth rate	1,008783829	The drinking water demand is dependent mainly on the population growth, economic development and water efficiency (Amarasinghe & Smakhtin 2014) . Most projections on the future water demand development were – to the best of the author's knowledge – published around the turn of the century, and therefore, their accuracy is subject for debate. According to Cosgrove and Rijsberman in source, the domestic water demand was projected to increase by 47% between the years 2000 and 2025. This rate is assumed to account for demographic dynamics and economic trends over the period. However, they report that already in 2005, the actual domestic water withdrawal had increased by 48%. Amarasinghe and Smakhtin (2014), however, suggest that the rapid historical growth presented by Cosgrove and Rijsberman is unlikely to be seen in the future. For the purpose of calculation, this analysis assumes a drinking water demand increase of 30% until the end of the period. This rate is arbitrarily chosen (although with guidance from the previously mentioned numbers and ideas) and has been included to illustrate the likely increases in future water demand. On an annual basis, the growth is given by the Compound Annual Growth Rate (CAGR) (Fernando 2021). The CAGR is to be seen as a representational figure which shows what the annual growth rate would be had it been the same over all years studied. Based on	Compund Annual Growth Rate (CAGR) = [Amount of water exctacted for drinking in Aguascalientes in 2020 (m3) * Increase until the end of the period (%) / Amount of water exctacted for drinking in Aguascalientes in 2020 (m3)]^(1 / Number of years that the increase concerns). The calculation is based on the numbers from 2020, i.e. (951397,61 * 1,3 / 951397,61)^(1/30) = 1,008783829	Amarasinghe & Smakhtin (2014) https://www.researchgate.net/publication/265186940_Global_Water_Demand_Projections_Past_Present_and_Future-_IWMI_Research_Report_series_156 ; Fernando (2021) https://www.investopedia.com/terms/c/cagr.asp
Amount of groundwater used for irrigation (m3)	30800000			Conagua (2018) https://agua.org.mx/wp-content/uploads/2019/04/AAM_2018.pdf
Annual increase in agricultural water demand	1,006707289	Conagua (2018; 2016) report that the water demand for irrigation in irrigation district 01 in Aguascalientes was 30,6 hm3 during 2014-2015, and 30,8 hm3 during 2015-2016. This represents an increase of 1,0065359477 between the years. Similarly, FAO Aquastat (2021) report that the irrigation water withdrawl from both surface and groundwater in Mexico was 65,42 km3 in 2017, and 65,87 km3 during 2018. This represents a similar increase of 1,0068786304 between the years. Thus, the annual increase in irrigation water demand is in this analysis assumed to be the average of the two previously presented numbers (see left cell).	Annual increase = [Increase between 2014-2015 and 2015-2016 according to Conagua (2018; 2016) (**1,0065359477**) + Increase between 2017 and 2018 according to FAO Aquastat (2021) (**1,0068786304**)] / Number of measurements (**2**)	Conagua (2018) https://agua.org.mx/wp-content/uploads/2019/04/AAM_2018.pdf ; Conagua (2016) http://201.116.60.25/publicaciones/AAM_2016.pdf ; FAO Aquastat (2021) https://www.fao.org/aquastat/statistics/query/results.html
Electrocoagulation				
Fluoride removal rate of electrocoagulation	0,5	Haldar and Gupta (2019) carried out experiments in Nalagola village, West Bengal, India. The area is located in a tropical savanna climate zone (Aw, according to Köppen's classification), which is fairly similar to the semi-arid climate zone (BSk) in which Aguascalientes is located. They installed a defluoridation unit, which operates using one electrocoagulation cell followed by one sand filter and one column of activated alumina. The unit decreases the fluoride levels in the groundwater from 2,1 mg/L to below 1 mg/L. In other words, it operates with a 50-60% efficiency (depending on seasonal variations in the water composition), according to the authors. In order to avoid overestimations, the lower bound is used when considering the efficiency of the treatment process. With this rate of removal, fluoride levels would be reduced to < 1,5 mg/L given current fluoride levels in the aquifer. Thus, It can be assumed that with fluoride removal using this technique will reduce the prevalance of dental fluorosis to negligable levels.		Haldar & Gupta (2019) https://link.springer.com/article/10.1007/s13762-019-02323-5

Capital cost per water treatment unit (USD)	5315,219	The authors divide the installation cost of the unit into capital cost and operational cost. The capital cost includes "the cost of electrocoagulation cell, overhead tanks, sand and alumina including columns, AC–DC power supply, minor electrical equipment (wires), battery and inverter, etc.". The total capital cost is reported to be around US$3850, "excluding the civil structure for placing the overhead tank and any shed (existing school building was used in this case)". The capital cost reported in Haldar and Gupta is used in this analysis. During an interview with Haldar (2021-11-16) explained that the prices and costs in their article are in 2016 USD values. Thus, the USD value has been converted to 2019 USD values. Furthermore, Haldar expressed that it is his belief that the material needed for the construction can be found at the same prices i Mexico as they can in India. In general, he explains, the material can be manufactured domestically at prices that are not significantly different between countries, or they are imported at similar costs. Therefore, the same capital cost as presented in Haldar and Gupta is used in this analysis. Haldar further explained during the interview that there are 3-4 other projects in the area, which operate using the same technology for fluoride removal. He mentions that the plant that has been running for the longest time has been operating for around 10 years. Currently, there are still funds		Haldar & Gupta (2019) https://link.springer.com/article/10.1007/s13762-019-02323-5
Operational cost per m3 treated per unit (USD)	0,3192	The operational cost presented in Haldar and Gupta includes "the cost of electricity (equivalent to US$0.12/KWh), operating the pump and EC cell as well as other maintenance costs (electrode replacement, minor repairs, etc.)". In total, it amounted to US$0.33 per m3 of water treated. Because the source article present prices in 2016 USD values, the USD value has been converted to 2019 USD values. Furthermore, because the electricity price per kWh is somewhat lower in Mexico according to Castaneda (2020), the operational costs are expected to be somewhat lower in Mexico. In fact, through personal communication (2021-11-19), Haldar shared the operational cost estimates with the Mexican electricity price instead of the Indian electricity price. He found that the operational costs decreased by 8,8% per m3 treated. Therefore, the per m3 operational cost presented in Haldar and Gupta has been scaled down by 8,8%.	Operational cost per m3 treated per unit presented in Haldar & Gupta (USD) * 0,912	Haldar & Gupta (2019) https://link.springer.com/article/10.1007/s13762-019-02323-5
Dental care savings		The savings have been calculated based on the total population in Aguascalientes between 0 and 11 years old (as dental fluorosis is primarily developed in children in their first 8 years of life) and the prevalance as well as the severity of dental fluorosis among the inhabitants. Furthermore, the cost of treatment is dependent on the severity of the disese. The treatments are based on the alternatives presented by Akpata (2001) and the costs have been collected from various sources. The different treatments and related costs (with sources) are presented in the section 'Treatments and Costs'. The costs have subsequently been weighted by the share of inhabitants suffering from dental fluorisis of a certain severity (mild, moderate or severe). Because the prices have been collected in MXN, conversion has been made to 2021 USD values using PPP. Adjustments have subsequently been made to express the prices in 2019 USD values. Furthermore, because the dental treatments require the patient to take leave from work, the forgone wages have been included for the share of cildren suffering from the disese in the state. The assumption is made that approximately 2 hours for the first (consultation) visit, and subsequently an additional half a day for the actual treatment. In total, this sums to 8 hours of forgone work. The forgone wages are based on the average monthly wages in Aguascalientes and the average work	Population in Ags (**1425600**) * Percentage with mild DF (**32,89%**)* (Cost for dental consultation (**77,5 USD**) + Average cost for procedure (**277,5 USD**)) + Population in Ags * Percentage with moderate DF (**8,37%**) * (Cost for dental consultation + Average cost for procedure (**1296,59 USD**)) + Population in Ags * Percentage with severe DF (**2%**) * (Cost for dental consultation + Average cost for procedure (**11302,86 USD**)) + Forgone wage due to work absence [exchange rate MXN to USD (**0,049 conversion factor** used currently) * Hours of work lost due to appointment/treatment (approx. 2 h for first visit + approx. half day for treatment = approximately **8 hours**) * Average monthly wage in Aguascalientes of **4460 MXN** according to https://datamexico.org/en/profile/geo/aguascalientes-ag#empleo-evolucion-poblacion-ocupada / Number of hours worked during one month (assuming a 43 hour work week as suggested in https://www.weforum.org/agenda/2018/01/the-countries-where-people-work-the-	Akpata (2001) https://www.sciencedirect.com/science/article/pii/S0020653920356550?via%3Dihub ; NHS (2018) https://www.nhs.uk/live-well/healthy-body/teeth-facts-and-figures/ ; National Research Council (2006).
Sprinkler irrigation				
Extent to which flood irrigation is used in Aguascalientes	0,678888889	Based on the expert elicitation study by Sainz-Santamaria and Martinez-Cruz (2019b, unpublished data), experts on water use within the agricultural sector in Aguascalientes were asked to provide estimates on to what extent flood irrigation is used throughout the sector. The experts answered between 46 and 90 percent (note: one experts estimate was discarded due to counting errors). In this analysis, the average of 67,88888889 percent will be used as the extent to which flood irrigation is used in Aguascalientes.	Average percentage of experts estimates = (80+45+50+82+54+90+80+40+90)/9	Sainz-Santamaria and Martinez-Cruz (2019b, unpublished data)
Number of wells destined for agricultural use connected to the aquifer of Valle de Aguascalientes (2020)	852			Conagua (2020) https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdf

Installation cost of center pivot irrigation system per ha	4849,73	RMCG reports the ownership costs (i.e. capital costs including interest and depreciation on the capital cost) and operational & maintenance costs (including power, repairs, motorbike, labour, and water costs) of centre pivot irrigation systems in a semi-arid region of Australia. The capital cost they include for sprinkler irrigation (which in their sample mostly consisted of centre pivot systems) is 6500 AUD/ha, equal to 4476,584021 USD/ha (assuming a PPP for Australia of 1,452) in 2014 USD values. Converted to 2019 USD values, this equals 4849,73 USD/ha. The useful life of the investment is expected to be 15 years. The assumption is made as the demand for agricultural land expands, additional irrigation devices are added so that the entire agricultural area is irrigated. Therefore, annual installation costs will appear in the analysis.		RMCG: https://www.gbcma.vic.gov.au/downloads/Farm_Water_Program/2019%20-%20Comparison%20of%20irrigation%20system%20costs.pdf
Annual increase in labour costs (USD/ha)	1,045639553	RMCG report that for a center pivot irrigation system, 2 hours of labour per ha is needed every year. Based on the average hourly wage rate for a farm equipment operator in Aguascalientes (48,09 MXN/h = 5,0504095778 USD/h using a PPP for Mexico in 2020 of 9,522) of 4,99 USD in 2019 USD values, it is assumed that the wage will increase with 25% every 5 years (Economic Research Institute 2021). On an annual basis, the growth is given by the Compound Annual Growth Rate. The evolution of labour cost per ha is presented in table 2 in the 'Forecasts' tab.	CAGR = [(Initial salary of farm equipment operator in Aguascalientes * 25 percent increase) / Initial salary of farm equipment operator in Aguascalientes]^(1/number of years during which the increase happens (5)). The calculation is based on the numbers for 2020, i.e. ((2,36*1,25)/2,36)^(1/5) = 1,045639553	Economic Research Institute (2021) https://www.salaryexpert.com/salary/job/farm-equipment-operator/mexico/aguascalientes
Reparation and maintenance cost (USD/ha/year)	52,23	RMCG report that the annual cost of repairs and maintenance for a center pivot irrigation system is 70 AUD/ha, equal to 48,20936638 USD/ha (assuming a PPP for Australia of 1,452) in 2014 USD values. In 2019 USD values, this equals 52,23 USD/ha/year.		RMGC (2018) https://www.gbcma.vic.gov.au/downloads/Farm_Water_Program/2019%20-%20Comparison%20of%20irrigation%20system%20costs.pdf
Electricity price in central Mexico (USD/kWh)	1,2			Interview with Edgar Tellez Foster and interview with Sara Avila
Electricity required to sprinkle 1 m3 of water to land using CPI system (kWh/m3 water)	1,259469028	According to Roy et al. (2018), the variables determining the electricity consumption of a CPI system is the water table level, system length, number of towers, gallons per minute of water and application rate. Since these variables are not known for the aquifer of Valle de Aguascalientes, the variables used in Roy et al. will be utilised here to provide an example of the power use.	According to Roy et al.'s calculations, it takes 1,145833 h to irrigate a 120 acre field with water measuring 1 inch in hight. Per day, 0,2086956522 inches of water is applied to the field, which requires on average 3242,0935 kWh. Using these numbers, we learn that to irrigate the 120 acre field with 1 inch water would require (1/0,2086956522)*3242,0935 = 15535,0313522248 kWh. Converted to the metric system, the 120 acre field is 485 613,6943061794 m2 and 1 inch water is 0,0254 m. In other words, to irrigate the 120 acre field with 1 inch water requires in total 485613,6943061794*0,0254=12334,587835377 m3 water and 15535,0313522248 kWh. This means that applying 1 m3 water to the land	Roy et al. (2018) https://www.researchgate.net/publication/323859023_A_Renewable_Solution_Approach_for_Center_Pivot_Irrigation_System
Energy required to lift 1 m3 of water from aquifer (kWh)	0,708223641		Peacock (2005) explains that the energy requirement to pump water is given by the formula Energy Required = weight of water x feet of lift to lift 1 acre-foot of water 1 foot requires 1,02 kWh of energy, assuming 100% efficiency of the pump. However, most pumps operate at 70% efficiency. Adding 30 percent of the energy requirement gives the real energy requirement to lift 1 acre-foot of water, which is 1,326 kwh. 1 acre-foot equals 1233,48184 m3. In other words, to lift 1 m3 of water 1 foot requires 1,326/1233,48184=0,001075005693 kWh. To lift 1 m3 water the 200 m that the aquifer of Valle de Aguascalientes on average is deep, on average, requires 0,708223641 kWh. This value is	Peacock (2005) https://cetulare.ucanr.edu/files/82040.pdf

Emissions per ha irrigated with center pivot irrigation system (tonne CO2-eq)	1	According to the RMCG and their assumtions of the energy consumption of the center pivot irrigation system, they state that "the green house gas emissions and energy requirements from pumping are likely to increase on conversion from an old style gravity system [such as flood irrigation systems] on perennial pasture". They present calculations of the difference in emissions per ha of land converted from gravity (flood) irrigation systems to center pivot irrigation systems. More precicely, they state that the difference would be 1000–2000 kg Co2-e per ha for a centre pivot sprinkler systems. They state that the lower-bound value reflect the emissions from systems working at their expected efficiency, whereas the higher-bound values are for systems operating at low efficiency. Because the systems implemented in Aguascalientes will be new, the assumption is made that the lower-bound values are more accurate for this analysis. The values have been converted into tonnes CO2-eq emissions per ha irrigated land.		RMGC (2018) https://www.gbcma.vic.gov.au/downloads/Farm_Water_Program/2019%20-%20Comparison%20of%20irrigation%20system%20costs.pdf
Annual increase in agricultural land (share)	1,003484725	According to FAO (2009), the expansion of arable land will take place mostly in developing countries. Furthermore, FAO states that "Land equipped for irrigation would expand by some [...] (11 percent)". Therefore, it will be assumed that the arable land in Mexico will grow by 11 percent until 2050. On an annual basis, the growth is given by the Compound Annual Growth Rate (CAGR).	CAGR = [Demand for arable land in 2020 (ha) * 11 percent increase / Demand for arable land in 2020 (ha)]^(1/ Number of years during which the increase will happen). Calculations are based on the numbers for 2020, i.e., (3794 * 1,11 / 3794)^(1/30) = 1,003484725	FAO (2009); https://www.investopedia.com/terms/a/aagr.asp
Difference in water application efficiency between center pivot and flood irrigation systems (share)	0,4	Accoding to Rogers et al. (1997), the application efficiency of flood irrigation ranges between 50-90%, whereas for center pivot irrigation systems, the same range is 70-90%. In this analysis, the lower bound values will be used to avoid overestimations.		Rogers et. Al (1997) https://bookstore.ksre.ksu.edu/pubs/MF2243.pdf; Pfeiffer and Cynthia Lin (2013) http://clinlawell.dyson.cornell.edu/PfeifferLin_irrigationtechnology_paper.pdf
Value of conserving groundwater (per m3 per year)	0,000393685	Suter et al. (2021) have performed a contingent valuation study to measure the WTP for additional groundwater in the Ogallala aquifer region. The aquifer is in a state of deficit, and is one of the most studied in the region. It stretches over a large area, and thus provides water to users in various different climates. Mostly, however, users operate in humid subtropical or cold semi-arid climates. They state that the counties which has been mostly focused on are located in the semi-arid areas, i.e. the areas whith the same climate as Aguascalientes. Respondents were farmers utilising irrigation wells of > 200 gpm. The WTP question asks respondents to consider the benefits of an aquifer recharge project. They find a median WTP for an additional 100 gallons per minute of well capacity (equl to approximately 199093,266 m3/year) of 77 USD per well (2018 USD values, i.e. 78,38 USD of 2019 USD values). In other words, for one additional gpm of well capacity, the respondents' WTP would be equal to 0,7838 USD in 2019 USD values (number for one additional m3 presented in the cell to the left). They state that this WTP value is low, and that a reason for this is the relatively small increase in well capacity that is proposed in the WTP question. However, they claim that the WTP "depends strongly" on the current well capacity and climate conditions, and that drier and hotter regions in their study report a WTP of thousands		Suter et al. (2021) https://www.sciencedirect.com/science/article/pii/S0928765518303403

Improved water quality (reduced fluoride levels per m3 water saved in aquifer)	1,98E-08	Since there are no annual historical records kept over the groundwater resources or consumption in Mexico (data is produced every 5-6 years), it is difficult to produce a precise estimate of the improvements in water quality that the increased water volumes from the "saved" water would produce. However, Conagua (2018, 2020) suggest that the fluoride concentrations (see tab 'GW qual. By Year Ags 2012-20') have increased in the Valle de aguascalientes aquifer simultaneously as the defecit in disposable water has increased. In fact, the defecit increased by 9183530 m3 from 2015 to 2020. During the same time period, the fluoride concentration in the groundwater increased (although fluctuating over the years) by 0,181395813 mg/L. Based on these numbers, it can be assumed that increasing the water volume in the aquifer by one m3 will reduce the fluoride concentrations by the number in the cell to the left.	Fluoride concentration increase in the groundwater between 2015 and 2020 (**0,181395813 mg/L**) / Change in deficit in the aquifer between 2015 and 2020 (**9183530 m3**)	Conagua 2018 (https://www.gob.mx/cms/uploads/attachment/file/329103/DR_.0101.pdf), conagua 2020 (https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/Aguascalientes/DR_0101.pdfl
Treatments and Costs				
Cost of treatment for mild dental fluorosis (per person)	$265,48	Calculations are based on the average prices presented by Dentaly.org (2021) for microabration and bleaching. These treatments are the most common for mild cases of dental fluorosis, according to the National Research Council (2006). Prices are converted from 2021 USD values to 2019 USD values.		Dentaly.org (2021) ; National Research Council (2006)
Cost of treatment for moderate dental fluorosis (per person)	$1 240,43	Calculations are based on the average prices presented by Mexico Dental (n.d.) for composite restorations. This treatment is the most common for moderate cases of dental fluorosis, according to the Sherwood (2010). Prices are converted from 2021 USD values to 2019 USD values.		Sherwood (2010) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2883808/ ; Mexico Dental (n.d.) https://mexicodental.co/prices-for/composite-filling/
Cost of treatment for severe dental fluorosis (per person)	$10 813,30	Calculations are based on the average prices presented by Dentaly.org (2021) for porcelain veneers and full crowns. These treatments are the most common for severe cases of dental fluorosis, according to the Sherwood (2010) and the National Research Council (2006). Prices are converted from 2021 USD values to 2019 USD values. Note, however, that depending on what material the veneers are made from, the cost differs. Most often, resin or porcelain laminate are used, according to Akpata (2001) . In this analysis, porcelain is chosen as the effects of treatment last longer if porcelain is used, according to Akpata (2014).		Sherwood (2010) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2883808/ ; National Research Council (2006) ; Akpata (2001) https://www.sciencedirect.com/science/article/pii/S0020653920356550?via%3Dihub ; Akpata (2014).
Cost for consultation visit at dentist	$74,14	Calculations are based on the average price presented by four different dentists.		https://www.driniguez.com/dental-treatments/cost-of-dental-treatments/ ; https://www.cancundentaldesign.com/dental-prices-mexico/ ; https://smilebuilders.net/price-list/#1634146640691-ef5d1a04-78ea ; https://oceandentalcancun.com/prices/

Appendix 2: Complete CBA for Project A

Cost-Benefit Analysis: Installation of Fluoride Removal Units Using Electrocoagulation										
Year										
	0	1	2	3	4	5	6	7	8	9
Costs										
Capital (water treatment units)	-$962 054,64	-$5 315,22	-$10 630,44	-$10 630,44	-$5 315,22	-$10 630,44	-$10 630,44	-$5 315,22	-$10 630,44	-$10 630,44
Installation	-$96 205,46	-$531,52	-$1 063,04	-$1 063,04	-$531,52	-$1 063,04	-$1 063,04	-$531,52	-$1 063,04	-$1 063,04
Operational	-$303 686,12	-$306 353,64	-$309 044,60	-$311 759,20	-$314 497,64	-$317 260,13	-$320 046,89	-$322 858,13	-$325 694,06	-$328 554,90
Fossil fuel emissions from energy consumption	-$6 653,57	-$6 910,32	-$7 184,32	-$7 475,98	-$7 785,69	-$8 113,88	-$8 460,96	-$8 827,36	-$9 213,51	-$9 619,86
Total costs	-$1 368 599,79	-$319 110,71	-$327 922,41	-$330 928,66	-$328 130,07	-$337 067,49	-$340 201,33	-$337 532,22	-$346 601,05	-$349 868,24
Benefits										
Dental care savings	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00
Total benefits	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00
Net benefits	-$1 368 599,79	-$319 110,71	-$327 922,41	-$330 928,66	-$328 130,07	-$337 067,49	-$340 201,33	-$337 532,22	-$346 601,05	-$349 868,24
Net present value	$158 971 176,42									

	10	11	12	13	14	15	16	17	18	19	20
Capital (water treatment units)	-$5 315,22	-$10 630,44	-$10 630,44	-$10 630,44	-$5 315,22	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$5 315,22
Installation	-$531,52	-$1 063,04	-$1 063,04	-$1 063,04	-$531,52	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$531,52
Operational	-$331 440,87	-$334 352,19	-$337 289,08	-$340 251,77	-$343 240,48	-$346 255,45	-$349 296,90	-$352 365,06	-$355 460,17	-$358 582,48	-$361 732,20
Fossil fuel emissions from energy consumption	-$10 046,86	-$10 494,95	-$10 964,61	-$11 456,31	-$11 970,52	-$12 507,73	-$13 068,44	-$13 653,15	-$14 262,36	-$14 896,61	-$15 556,42
Total costs	-$347 334,46	-$356 540,62	-$359 947,17	-$363 401,56	-$361 057,74	-$370 456,66	-$374 058,82	-$377 711,69	-$381 416,02	-$385 172,57	-$383 135,37
Dental care savings	$0,00	$0,00	$0,00	$0,00	$0,00	$155 290 517,27	$0,00	$0,00	$0,00	$0,00	$0,00
Total benefits	$0,00	$0,00	$0,00	$0,00	$0,00	$155 290 517,27	$0,00	$0,00	$0,00	$0,00	$0,00
Net benefits	-$347 334,46	-$356 540,62	-$359 947,17	-$363 401,56	-$361 057,74	$154 920 060,61	-$374 058,82	-$377 711,69	-$381 416,02	-$385 172,57	-$383 135,37

	21	22	23	24	25	26	27	28	29	30	Net present value
Capital (water treatment units)	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$10 630,44	-$1 145 799,33
Installation	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$1 063,04	-$114 579,93
Operational	-$364 909,60	-$368 114,90	-$371 348,36	-$374 610,22	-$377 900,73	-$381 220,15	-$384 568,72	-$387 946,71	-$391 354,36	-$394 791,95	-$7 009 698,46
Fossil fuel emissions from energy consumption	-$16 242,32	-$16 954,86	-$17 694,60	-$18 462,09	-$19 257,90	-$20 082,63	-$20 936,85	-$21 821,17	-$22 736,20	-$23 682,56	-$250 689,17
Total costs	-$392 845,40	-$396 763,25	-$400 736,44	-$404 765,79	-$408 852,12	-$412 996,26	-$417 199,05	-$421 461,36	-$425 784,05	-$430 167,99	
Dental care savings	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$164 609 342,21	$167 491 943,31
Total benefits	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$164 609 342,21	
Net benefits	-$392 845,40	-$396 763,25	-$400 736,44	-$404 765,79	-$408 852,12	-$412 996,26	-$417 199,05	-$421 461,36	-$425 784,05	$164 179 174,22	
Net present value											$158 971 176,42

Appendix 3: Complete CBA for Project B

Cost-Benefit Analysis: Implementation of Center Pivot Irrigation Systems										
Year	0	1	2	3	4	5	6	7	8	9
Costs										
Ownership cost – Centre pivot irrigation system	-$18 399 875,62	-$64 118,50	-$64 341,94	-$64 566,15	-$64 791,15	-$65 016,93	-$65 243,49	-$65 470,85	-$65 699,00	-$65 927,94
Labour	-$37 864,12	-$39 730,19	-$41 688,23	-$43 742,76	-$45 898,55	-$48 160,58	-$50 534,09	-$53 024,58	-$55 637,81	-$58 379,82
Reparation and maintenance	-$198 160,62	-$198 851,16	-$199 544,10	-$200 239,45	-$200 937,23	-$201 637,44	-$202 340,09	-$203 045,19	-$203 752,75	-$204 462,77
Energy	-$8 299 021,35	-$8 354 685,28	-$8 410 722,57	-$8 467 135,72	-$8 523 927,25	-$8 581 099,69	-$8 638 655,61	-$8 696 597,57	-$8 754 928,16	-$8 813 650,00
Fossil fuel emissions from energy consumption	-$60 457,26	-$62 660,94	-$65 011,42	-$67 511,37	-$70 163,50	-$72 970,55	-$75 935,31	-$79 060,59	-$82 349,25	-$85 804,16
Total costs	-$26 995 378,97	-$8 720 046,07	-$8 781 308,25	-$8 843 195,45	-$8 905 717,67	-$8 968 885,19	-$9 032 708,60	-$9 097 198,78	-$9 162 366,96	-$9 228 224,69
Benefits										
Value of increased groundwater availability	$2 805 418,73	$2 824 235,48	$2 843 178,44	$2 862 248,46	$2 881 446,39	$2 900 773,09	$2 920 229,41	$2 939 816,23	$2 959 534,43	$2 979 384,88
Dental care savings	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00
Total benefits	$2 805 418,73	$2 824 235,48	$2 843 178,44	$2 862 248,46	$2 881 446,39	$2 900 773,09	$2 920 229,41	$2 939 816,23	$2 959 534,43	$2 979 384,88
Net benefits	-$24 189 960,25	-$5 895 810,59	-$5 938 129,81	-$5 980 946,99	-$6 024 271,28	-$6 068 112,11	-$6 112 479,19	-$6 157 382,55	-$6 202 832,53	-$6 248 839,81
Net present value	-$123 864 575,35									

Year	10	11	12	13	14	15	16	17	18	19	20
Costs											
Ownership cost – Centre pivot irrigation system	-$66 157,68	-$66 388,22	-$66 619,57	-$66 851,72	-$67 084,68	-$19 385 471,86	-$131 671,54	-$132 130,38	-$132 590,81	-$133 052,86	-$133 516,51
Labour	-$61 256,98	-$64 275,92	-$67 443,65	-$70 767,50	-$74 255,16	-$77 914,70	-$81 754,59	-$85 783,73	-$90 011,44	-$94 447,50	-$99 102,19
Reparation and maintenance	-$205 175,27	-$205 890,25	-$206 607,72	-$207 327,69	-$208 050,17	-$208 775,17	-$209 502,69	-$210 232,75	-$210 965,35	-$211 700,51	-$212 438,23
Energy	-$8 872 765,69	-$8 932 277,90	-$8 992 189,27	-$9 052 502,48	-$9 113 220,23	-$9 174 345,23	-$9 235 880,22	-$9 297 827,94	-$9 360 191,16	-$9 422 972,66	-$9 486 175,27
Fossil fuel emissions from energy consumption	-$89 428,27	-$93 224,52	-$97 195,92	-$101 345,51	-$105 676,38	-$110 191,62	-$114 894,40	-$119 787,93	-$124 875,42	-$130 160,16	-$135 645,48
Total costs	-$9 294 783,88	-$9 362 056,81	-$9 430 056,13	-$9 498 794,90	-$9 568 286,61	-$28 956 698,58	-$9 773 703,44	-$9 845 762,72	-$9 918 634,18	-$9 992 333,69	-$10 066 877,67
Benefits											
Value of increased groundwater availability	$2 999 368,48	$3 019 486,11	$3 039 738,67	$3 060 127,08	$3 080 652,24	$3 101 315,06	$3 122 116,48	$3 143 057,42	$3 164 138,81	$3 185 361,61	$3 206 726,75
Dental care savings	$0,00	$0,00	$0,00	$0,00	$0,00	$37 251 129,80	$0,00	$0,00	$0,00	$0,00	$0,00
Total benefits	$2 999 368,48	$3 019 486,11	$3 039 738,67	$3 060 127,08	$3 080 652,24	$40 352 444,86	$3 122 116,48	$3 143 057,42	$3 164 138,81	$3 185 361,61	$3 206 726,75
Net benefits	-$6 295 415,41	-$6 342 570,70	-$6 390 317,45	-$6 438 667,82	-$6 487 634,37	$11 395 746,28	-$6 651 586,97	-$6 702 705,30	-$6 754 495,37	-$6 806 972,09	-$6 860 150,92
Net present value											

Year	21	22	23	24	25	26	27	28	29	30	Net present value
Costs											
Ownership cost – Centre pivot irrigation system	-$133 981,78	-$134 448,67	-$134 917,18	-$135 387,33	-$135 859,12	-$136 332,55	-$136 807,63	-$137 284,37	-$137 762,77	-$138 242,83	-$32 614 305,46
Labour	-$103 986,27	-$109 111,06	-$114 488,42	-$120 130,78	-$126 051,23	-$132 263,45	-$138 781,83	-$145 621,46	-$152 798,17	-$160 328,57	-$1 571 748,57
Reparation and maintenance	-$213 178,52	-$213 921,39	-$214 666,84	-$215 414,90	-$216 165,56	-$216 918,84	-$217 674,74	-$218 433,28	-$219 194,46	-$219 958,29	-$4 268 096,40
Energy	-$9 549 801,78	-$9 613 855,07	-$9 678 337,97	-$9 743 253,38	-$9 808 604,20	-$9 874 393,34	-$9 940 623,75	-$10 007 298,39	-$10 074 420,23	-$10 141 992,28	-$186 393 071,77
Fossil fuel emissions from energy consumption	-$141 334,72	-$147 231,29	-$153 338,64	-$159 660,26	-$166 199,67	-$172 960,45	-$179 946,22	-$187 160,65	-$194 607,45	-$202 290,37	-$2 204 072,34
Total costs	-$10 142 283,07	-$10 218 567,47	-$10 295 749,05	-$10 373 846,65	-$10 452 879,77	-$10 532 868,63	-$10 613 834,18	-$10 695 798,15	-$10 778 783,07	-$10 862 812,34	
Benefits											
Value of increased groundwater availability	$3 228 235,19	$3 249 887,90	$3 271 685,83	$3 293 629,98	$3 315 721,30	$3 337 960,81	$3 360 349,47	$3 382 888,31	$3 405 578,32	$3 428 420,52	$63 008 708,13
Dental care savings	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$39 486 531,96	$40 178 011,06
Total benefits	$3 228 235,19	$3 249 887,90	$3 271 685,83	$3 293 629,98	$3 315 721,30	$3 337 960,81	$3 360 349,47	$3 382 888,31	$3 405 578,32	$42 914 952,47	
Net benefits	-$6 914 047,88	-$6 968 679,57	-$7 024 063,22	-$7 080 216,68	-$7 137 158,47	-$7 194 907,82	-$7 253 484,70	-$7 312 909,84	-$7 373 204,76	$32 052 140,13	
Net present value											-$123 864 575,35