Reuse of treated wastewater for irrigation in Murcia, Spain

A comparison study of three different water sources

MSc. Thesis by Rob Sjoukes

February 2015

Water Resources Management group

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The photo on the front page shows three buildings. The (first) green building is the container with the IRIS treatment system. The second building is the control building, were the different irrigation waters are collected and fertilizers are added, and the third building is the greenhouse of this project. In this greenhouse peppers are irrigated with different water sources. The photo was taken by Francisco Pedrero Salcedo

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Master thesis Water Resources Management submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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February 2015

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Acknowledgements

I would like to thank several people that helped me during this thesis. Of course, I want to express my gratitude to my supervisors of Wageningen University Harm Boesveld and Katarzyna Kujawa. Their experience, substantive feedback, and discussions helped me to write this report.

I would like to express my gratitude towards Francisco Pedrero Salcedo for the opportunity to do this research at CEBAS-CSIC. I also want to thank him for supervising me during my stay in Spain. I would like to thank Antonio José García García for his help. He helped me a lot during measurements and with practical issues.

I also would like to thank Fatima Grajales Sarabia, my roommate in Mucia, for her help with my language problems.

Abstract

In the water scarce area of Murcia there are problems with the quality of surface water. To improve the quality of surface water, the Regional Government implemented a master plan, called The Master Plan for Urban Wastewater Sanitation and Treatment in the Murcia Region 2001-2010. The plan improved wastewater treatment, which resulted in improved surface water quality. Most of the treated water is reused in agriculture. The master plan focuses on the environment, however in this thesis the focus is on the farmers. The farmers are the end users of the treated wastewater and used as starting point of the reverse water chain approach. From the reverse water chain approach the following focus points emerged: nutrient concentrations of NO_3, P_2O_5, and K_2O in the water sources, the salinity level of the water sources, the safety of using the water sources, and the crop yield by using different water sources.

The focus points are part of the research project IRIS (Intelligent Reclaim Irrigation System). In this research three different water sources are used: (1) water from the Irrigation community (IC), this water is used by farmers in the area and is a mix of transfer water from the Tajo-Segura transfer, groundwater, surface water, reclaimed water from treated wastewater, and desalinated water; (2) effluent water of the wastewater treatment plant (WWTP) of Roldán-Balsicas, that uses tertiary treatment (TT); and (3) the effluent water of the new IRIS treatment system, which is designed to keep the valuable nutrients and reduce the salinity level. For the IRIS research, green bell pepper (Capsicum Annuum) is grown in a greenhouse, this is a common crop in the area. The peppers grow on two hydroponic substrates, rock wool and coconut fiber and are irrigated with drip irrigation.

The nutrient savings, for which the IRIS treatment system is designed, are not represented in the measurements. The measured concentrations of nutrients were not higher than concentrations in TT water. There can be made a small fertilizer savings when TT water is used instead of the now used IC water. The salinity level of IC water is better than the salinity level of TT water. For safety indication the E. coli concentrations of the different waters are measured. The concentration in IC and TT water are far below the regulations. There are measured E. coli concentrations above the regulation in the IRIS water. There was not a significant difference observed in pepper yield between TT and IC water irrigation. There was not a significant difference observed in yield between peppers growing on rock wool and pepper growing on coconut fiber. The IRIS treatment system did not function well, and therefore no conclusion can be made about the performance of the treatment system. The advantages of using TT water instead of IC water are little, especially when taken into account that the effluents WWTPs in the area cannot meet the irrigation water demand.

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List of abbreviations and units

µm	Micrometre (10^{-6} meter)
BOD	Biological Oxygen Demand
BOD_5	Is the Biochemical Oxygen Demand at 20 over 5 days and is a measure of the biodegradable organic matter in wastewater
CEBAS-CSIC	Centre of Edaphology and Applied Biology of the Segura River (National Council for Scientific Research
CF	Coconut fiber
CFU	Colony-forming unit, it is an estimation of the number of viable bacteria
COD	Chemical Oxygen Demand
CRCC	Comunidad de Regantes del Campo de Cartagena
dS	deci Siemens
dS/m	deci Siemens per meter,
E. coli	Escherichia coli
EC	Electrical Conductivity (dS/m)
EC_e	Electrical Conductivity of soil (dS/m)
EC_w	Electrical Conductivity of water (dS/m)
ESAMUR	Entity for Sanitation and Treatment in the Region of Murcia
ha	Hectare (10,000m^2)
Hm^3	Cubic hectometre (1,000,000 m^3)
IC	The water of Irrigation Community of Campo de Cartagena
IC-CF	Water from the Irrigation community of Campo de Cartagena irrigated on coconut fiber
IC-RW	Water from the Irrigation community of Campo de Cartagena irrigated on rock wool
IRIS	Intelligent Reclaim Irrigation System
K	Potassium
K_2O	Potassium oxide
LF	Leaching Fraction
N	Nitrogen
NH_4	Ammonium
NO_3	Nitrate
P	Phosphorus
P_2O_5	Phosphorus pentoxide
RW	Rock wool
TSS	Total Suspended Solids
TT	Tertiary treatment, the effluent of the wastewater treatment system of Roldán-Balsicas
TT-CF	Effluent of the wastewater treatment plant of Roldán-Balsicas irrigated on coconut fiber
TT-RW	Effluent of the wastewater treatment plant of Roldán-Balsicas irrigated on rock wool
WWTP	Wastewater treatment plant

1 Introduction

In the world there are many places with water scarcity. Water scarcity is encountered on all continents. According to the United Nations, water scarcity is one of the main problems of the 21st century. In the last century the water use is growing at twice the rate of the population growth. One of the places known for its water scarcity is Murcia, Spain.

The Murcia region is an important region for fruit and vegetable production of Spain; 20% of the fruits and vegetables that are exported from Spain are produced in the Murcia region (CARM, 2012). The water used for irrigation mainly comes from the Segura River (CARM, 2012). Murcia and the Segura river are part of the Segura basin (see Figure 1), which is the only basin in Spain whose natural water resources cannot cover the water demand (www.iris-project.eu).

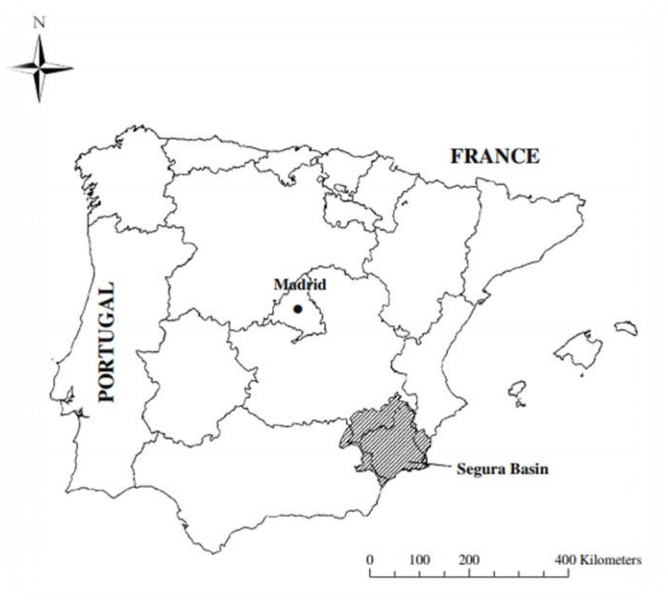

Figure 1: Segura Basin and Murcia Province (Martínez-Granados et al, 2011)

Figure 2: Murcia province with Campo de Cartagena (http://www.lascasasrurales.com 13-06-2014)

rainfall is very low, less than 300 mm per year, which is one of the lowest rainfall numbers in Europe (CARM, 2012). The low rainfall numbers require irrigation methods to practice agriculture. In the 1980s the irrigation activities increased in the area (CARM, 2012), resulting in a change from growing dry crops to intensively irrigated crops. So the water demand increased.

In the area of Campo de Cartagena (Murcia, Spain see Figure 1 and Figure 2) almost all treated wastewater is reused, because there is a water deficit of 460 Hm^3 per year in this region (see Figure 3). Agriculture is the main water consumer with 1660 Hm^3 per year in the Segura Basin (see Figure 3). Most of the treated wastewater is reused in agriculture. Other water sources that are used for agriculture are surface water, transfer water, groundwater and desalination water.

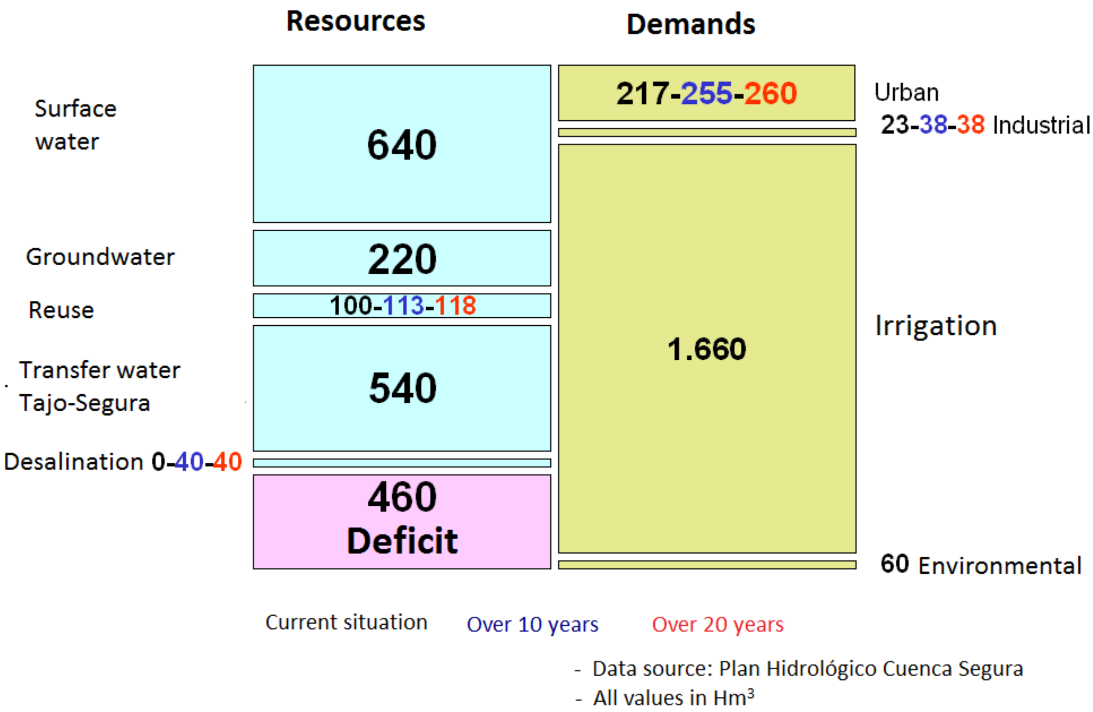

Figure 3: Water balance of the Segura Basin (CHS, 1998)

Figure 3 shows the water resources and water demands. Because of politics around water distribution and water rights there is no updated data available (F. Pedrero Salcedo personal communication July, 2014). However, the numbers in blue represent the expected values over 10 years and the red numbers the values over 20 years in Hm^3.

The increase in irrigation had two effects on the Segura river, on one hand the flow of the river decreased due to increase of water use and on the other hand the river received more nutrients and other pollutants from the agricultural industry and drainage water from irrigation. The river no longer had the self-purification capacity that was needed. Therefore the quality of the river deteriorated, with measured peak values of 250 mg/L BOD_5[1] in the river (CARM, 2012), this is higher than the allowed effluent BOD_5 concentration of WWTPs. The water was changed from moderately oligotrophic to relatively eutrophic (Velasco et al., 2006). The change from dry crop to intensively irrigated crops also had an effect on the amount of nutrients that the Mar Menor, a coastal lagoon, received by runoff (Velasco et al., 2006). The Mar Menor is one of the largest coastal lagoons in the Mediterranean with a surface of 135 km^2. The lagoon is an important place for tourism and for its biodiversity (LAGOONS, 2012). To improve the quality of the surface water, a master plan of 10 years was prepared and started in 2001 (CARM, 2012).

The master plan, called Master Plan for Urban Wastewater Sanitation and Treatment in the Murcia Region 2001-2010, was developed to improve the quality of surface water by improving wastewater treatment. In Campo de Cartagena 7 wastewater treatment plants (WWTPs) are situated. The treatment should comply with the European Directive on Urban Wastewater Treatment, the 91/271/EEC (CARM, 2012). This means that after the secondary treatment step effluent concentration limits are 25 mg/L BOD_5 and 125 mg/L COD, which are the European standards for

[1] BOD_5 is the biochemical oxygen demand at 20 over 5 days and is a measure of the biodegradable organic matter in wastewater (Pescod, 1992)

urban wastewater treatment according to the Directive 91/271/CEE. To remove the nutrients, a nitrification-denitrification process is carried out. The effluent concentration for total nitrogen is 15 mg/L for smaller WWTPs and 10mg/L for larger WWTPs (exceeding 100.000 population equivalents). The limits for phosphorus are 2 mg/L for smaller and 1 mg/L for larger plants, respectively. Those limits can be achieved by biological or chemical removal (CARM, 2012).

The objective of the master plan is to increase the surface water quality. This means that fewer nutrients are present in the water and that water in the Segura river is cleaner. Another effect is that valuable nutrients for irrigation are removed from the water. Those valuable nutrients are mainly coming from human excreta. Important nutrients for crop are nitrogen (N), phosphorus (P) and potassium (K). Phosphate is a nutrient that is getting scarce in the world. Phosphate that is used in fertilizer is mostly coming from phosphate rocks (Cordell, Drangert, & White, 2009). Most of the reserves phosphate rock are in China, the US and Morocco (Cordell et al., 2009). The phosphate rock is not a renewable source (Cordell et al., 2009) and therefore phosphate should be reused and recovered from other sources. One of those sources can be wastewater streams. Currently in the Murcia region, (valuable) nutrients in the wastewater are removed by treatment. Later on, farmers add fertilizer with the same nutrients to reach the right concentrations of nutrients. In this way (valuable) nutrients are lost. If this loss is to be avoided, other kind of treatment is necessary. In the project IRIS (Intelligent Reclaim Irrigation System) a treatment system is tested to reduce the loss of valuable nutrients.

Another problem in the area of Murcia is the salinity levels. The high salinity levels in the area are mainly due to poor quality of irrigation water (Acosta, Faz, Jansen, Kalbitz, & Martínez-Martínez, 2011). A second reason for the high salinity levels comes from sea water intrusion due to overexploitation of groundwater. In the area of Murcia, 91% of the treated wastewater has a salinity levels above 2 dS/m, and 31% above 3 dS/m (ESAMUR, 2005). A salinity level above 3 dS/m requires intensive management to avoid negative effects (Maas, 1993). The high salinity level in wastewater can be a problem for irrigation.

1.1 IRIS research

The IRIS research is a pilot project that wants to compare three different irrigation water sources. The three different water sources are: (1) effluent water from the WWTP of Roldán-Balsicas; (2) water from the Irrigation Community (IC); and (3) water from a new IRIS treatment system. The treatment system is designed in such a way that it should not remove all the important nutrients for irrigation from the water. However, it should remove the organics, suspended solids, pathogens and reduce the salinity by removing some salts. The treatment system treats domestic wastewater using electrochemical flocculation, filtration, ultrafiltration and nanofiltration (http://www.iris-project.eu/). Irrigation Community water is a mix of different water sources and can consist of groundwater, reclaimed wastewater, water from the Tajo-Segura transfer and desalination water. As a model crop green bell peppers is chosen for this project, (Capsicum Annuum) because it is an important crop in this area.

Involved in this project are:

- CEBAS-CSIC (Centro de Edafología y Biología Aplicada del Segura-Consejo Superior de Investigaciones Científicas), monitors the effect of irrigation with the effluent on two types of substrate crops and yield production (http://www.cebas.csic.es/)

- ESAMUR (Entity for Sanitation and Treatment in the Region of Murcia), they operate the WWTPs in the area (http://www.esamur.com/)
- Ritec, responsible for the irrigation system (http://www.ritec.es/)
- Rufepa, creating a new intelligent greenhouse (http://www.rufepa.com/)
- Capilix, are monitoring and measuring anion and cation concentrations (http://www.capilix.com/)
- Hellebrekers, designs and build the treatment system (http://www.hellebrekers.nl/)

1.2 Problem statement

With the master plan the quality of surface water in the area increased. However, with this plan the end-users (farmers) are not taken into account. Farmers do need water but also nutrients to grow crops. In the current legislation the WWTPs are removing most of the nutrients, which are important for the farmers. Therefore, it is evident to take the needs of farmers in the IRIS project.

1.3 Research questions

The main research question is:

What are the advantages and disadvantages for farmers in the area of Campo de Cartagena (Spain) by using either IRIS treated wastewater or direct effluent water of a conventional treated wastewater compared to water that the farmers are using now for irrigation (Irrigation Community water)?

To find an answer on the main question above, the following sub-questions need to be answered:

1. What can be the nutrient saving by making use of direct WWTP effluent and IRIS water compared to the Irrigation Community water?
    a. What are the current nutrient (NO_3, P_2O_5, and K_2O) concentrations of the different irrigation waters?
    b. How much of the nutrients (NO_3, P_2O_5, and K_2O) is currently added to the different waters?
    c. How much nutrients (NO_3, P_2O_5, and K_2O) can be saved by using direct the effluent of a conventional WWTP that is removing N and P, compared to using Irrigators Community water?
    d. How much nutrients can be saved by using the water of the IRIS treatment system, that is designed to remove less nutrients, compared to using Irrigators Community water?
    e. What is the nutrient demand for the selected model crop (pepper) focusing on NO_3, P_2O_5, and K_2O?

2. What are the salinity levels of the three different water sources?
    a. What is the salinity threshold for the green bell pepper?
    b. What are the salinity levels of the irrigation waters?

3. What are the safety standards for irrigation water and do the irrigation waters meet those standards?

4. What are the different yields of peppers by irrigating with effluent water of the WWTP and irrigating with IC water?
    a. What is the quantity of the yield of the two different waters?
    b. What is the difference between the yield of peppers growing on the different substrates rock wool and coconut fiber?

1.4 Thesis outline

This report is divided into seven chapters. Chapter 1 contains the introduction of the research, this includes background information on this research and also the research questions. Chapter 2 describes the methodology that is applied in this research. The methodology exists of two parts. It starts with explaining the theoretical framework used in this research, the Reverse Water Chain approach, and it describes the set up for the experiments and the measurements done in the IRIS pilot project. Chapter 3 gives more background information on the research in particular the three different water sources and the used hydroponic substrates. The results are described in chapter 4. The results of the four focus points are given: nutrients, salinity, safety, and yield. In chapter 5 the results are discussed. Chapter 6 gives the conclusion of this research and in chapter 7 are recommendations given for the next IRIS research and for further research.

2 Methodology

2.1 Conceptual framework

In the Master Plan the focus was to improve surface water quality. The improvements of the treatment were to improve the environment. In this research the Reverse Water Chain Approach is used. In this approach we will start looking at the needs of the end-users, which are the farmers/crops in this research. The Reverse Water Chain Approach is adopted from the Water Chain Approach.

2.1.1 Water Chain Approach

With the Water Chain Approach from Huibers and Van Lier (F. P. Huibers & Van Lier, 2005) we look at the water flow as a chain. The approach starts with clean (drinking) water that is polluted by the users. This wastewater is upgraded by treatment and used for agriculture purposes (F. P. Huibers & Van Lier, 2005). With this approach the different steps and water uses in the water flow become clear. In this approach, it is possible to investigate every step separately in the chain, and analyze the change in quality and function of water. Figure 4 applies Water Chain Approach to show the origin and destination of water in the IRIS project and Figure 5 shows the water chain for irrigators community water.

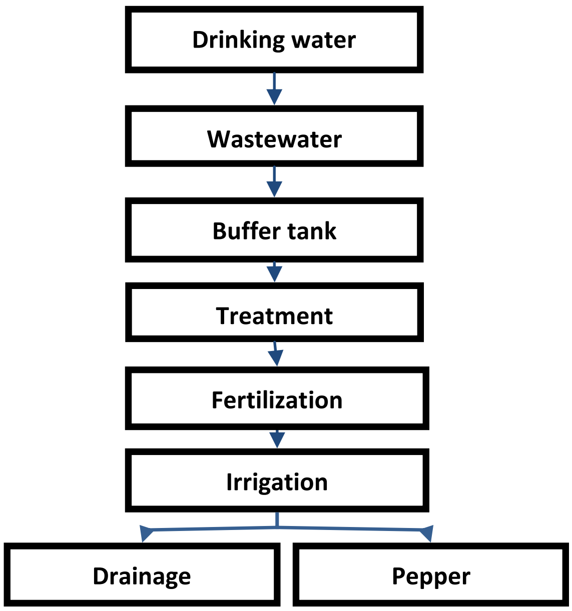

Figure 4: The Water Chain of IRIS project

Figure 4 shows the water chain of the IRIS project. People and companies are using clean drinking water. They produce wastewater, this wastewater is collected in buffer tanks. The wastewater is then treated by wastewater treatment plants. The treated water is used by farmers. The farmers are adding fertilizer before they use the water for irrigation. A part of the water flows towards the drainage and part of the water is taken up by the pepper plants.

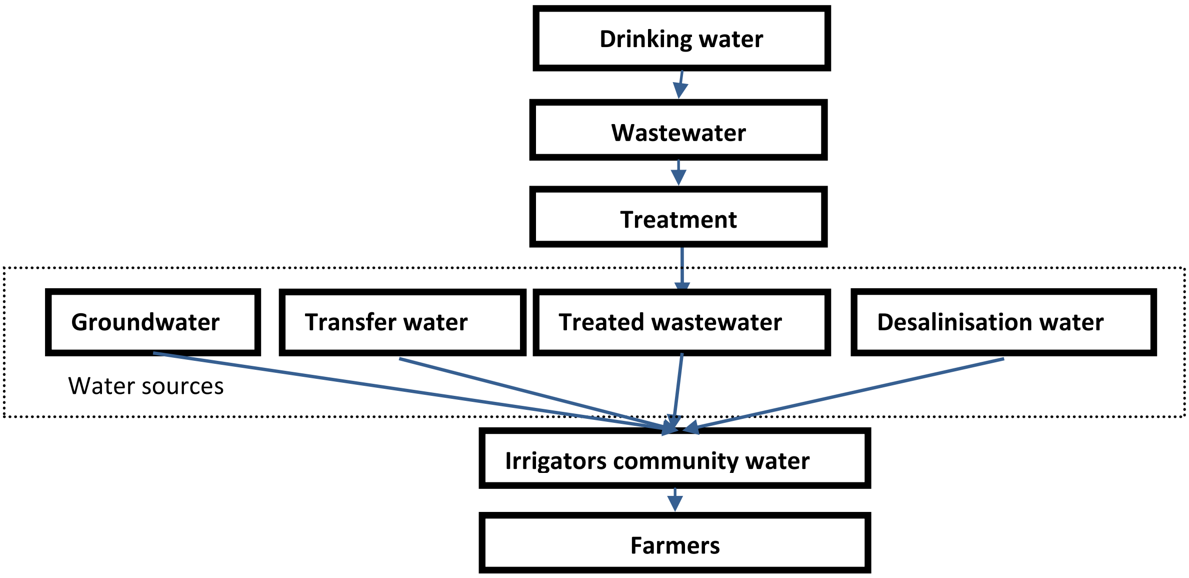

Figure 5: Water chain of Irrigators community water

Figure 5 shows the water chain of the Irrigators community. People and companies are using clean drinking water. They produce wastewater, this wastewater is treated by wastewater treatment plants. The treated wastewater is one of the water sources that is used by the Irrigators community. A mix of the different water sources is used as irrigation water by the farmers.

2.1.2 Reverse Water Chain Approach

The Water Chain Approach is following the water flow from upstream till downstream. Most conventional wastewater systems are designed and managed in this top-down manner. The end-users of a wastewater system are passive and not involved in the system and decision making process (F. Huibers, Redwood, & Raschid-Sally, 2009). The Reverse Water Chain Approach is based on the Water Chain Approach, but starts with the end-users. The starting point is the water quantity and quality that the end-user wants, and from that point the treatment system is designed upstream (van Lier & Huibers, 2010). The quality demanded by the end-user determines the treatment system. The Reverse Water Chain Approach is the approach used in this research. In Figure 6 the reverse water chain for this research is shown.

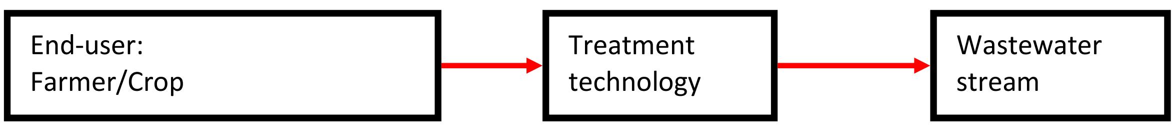

Figure 6: Reverse Water Chain (based on van Lier & Huibers, 2010)

2.1.3 The end-user demands

In this research the farmers that will use the water and the crops (pepper) that will receive the water will be taken as end-users. The following elements of the water are important for the end-user:

1. *Nutrient demand*, the crops need a certain amount of nutrients. Those nutrients can come from fertilizer or from the waste water. Therefore, the design criteria can be different compared to conventional WWTP (van Lier & Huibers, 2010).

2. *Salinity*, crops can handle a certain concentration of salinity. For higher salinity levels the crops cannot extract sufficient water from the soil anymore.
3. *Safety*, the water should be safe to use for farmers. The pathogens are considered to be one of the major risks in effluent use (van Lier & Huibers, 2010). The risk of contamination by pathogens does not only depend on the pathogens concentration in the water, however also on crop handling, type of crop and irrigation system (van Lier & Huibers, 2010).

The different water sources can lead to different crop yields, which is very important for the farmers. Therefore the *yield* is also taken into account in this research.

2.1.4 The treatment technology

The treatment technology should treat the wastewater in such a way that it meets the end-users demands. The technology should not only supply the most suitable water, but should also be cost efficient (van Lier & Huibers, 2010). In this research the costs of treatment are not taken into account. In this research the effluent water of a new treatment system (IRIS) is analyzed, other treatment systems are not analyzed.

2.1.5 The water stream

Water characteristics such as nutrient concentrations, pathogens, electroconductivity, are depended on the water source. Therefore, it is interesting for the end-user to look at the different water sources to see if a wastewater flow fits the demands of the end-users best. In this research the water of the Irrigation community, the effluent of the WWTP and the effluent of the IRIS treatment are analyzed.

2.2 Experimental setup

In this research three different water sources are used. The three different water sources are: effluent of the WWTP of Roldán-Balsicas. This WWTP makes use of Tertiary Treatment (TT). Another water source is the water of the Irrigation Community (IC). The third water source is effluent of a newly designed treatment system for this project, the IRIS treatment system. This water is called IRIS water. The three different waters (TT, IC and IRIS) are collected in buffer tanks (in Figure 7 the three buffer tanks are shown on the right).

The IRIS treatment system was not working constantly, which is necessary for irrigation, therefore this water is not used for irrigation.

From the buffer tanks the waters of TT and IC flow to fertigation tanks (see Figure 7). In those tanks fertilizers are added to get the demanded amount of nutrient in the irrigation waters, the requested amount of nutrients are shown in Appendix A: The requested nutrient concentrations. The fertilizers that are added are: $Ca(NO_3)_2$, KNO_3, and KH_2PO_4. Also iron with micro elements and acid are added (the fertilizer tanks are shown on the upside of Figure 7). The waters in the fertigation tanks are called TT-T and IC-T (the tanks on the left side of Figure 7).

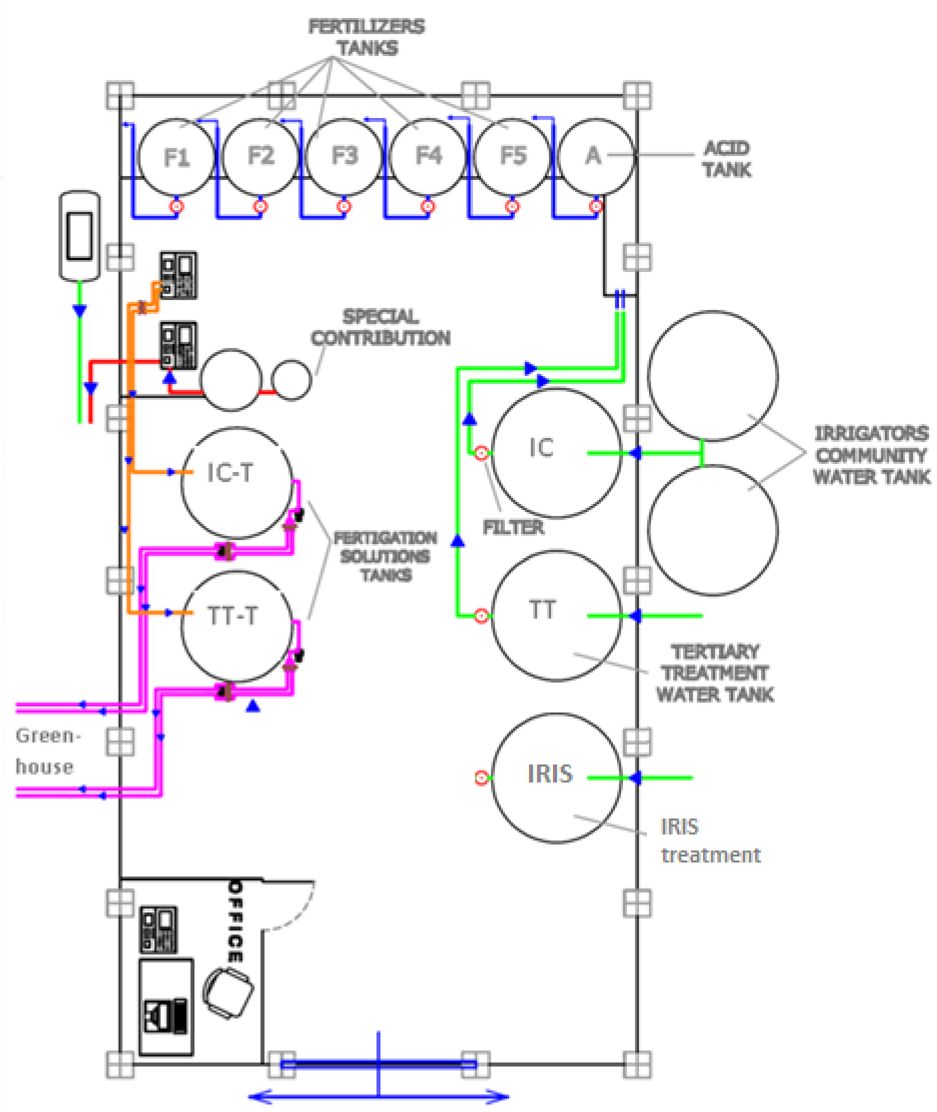

Figure 7: Schematic overview of irrigation waters and fertilization

In the overview of Figure 7 there are 5 fertilizer tanks, in practice only 4 were used.

The waters TT-T and IC-T are used for irrigation. The pepper specie that is used is the bell pepper called Capsicum Annuum. Pepper is chosen as a model crop in this research, because this is an important greenhouse crop in the area. The water is applied with drippers. The capacity of the drippers is 2 liters per hour. The peppers are growing hydroponically. In this research two types of hydroponic substrates are used: rock wool (in this report called RW) and coconut fiber (in this report called CF). The two irrigation waters (TT-T and IC-T) are irrigating peppers on the two substrates (RW and CF). This gives four different irrigation sections, defined by the type of irrigation water combined with the type of substrate. Peppers irrigated with TT water growing on rock wool irrigated (TT-RW), peppers irrigated with TT water growing on coconut fiber (TT-CF), peppers irrigated with IC water growing on rock wool (IC-RW), and peppers irrigated with IC water growing on coconut fiber (IC-CF) (see Figure 8 for an overview of the irrigation sections).

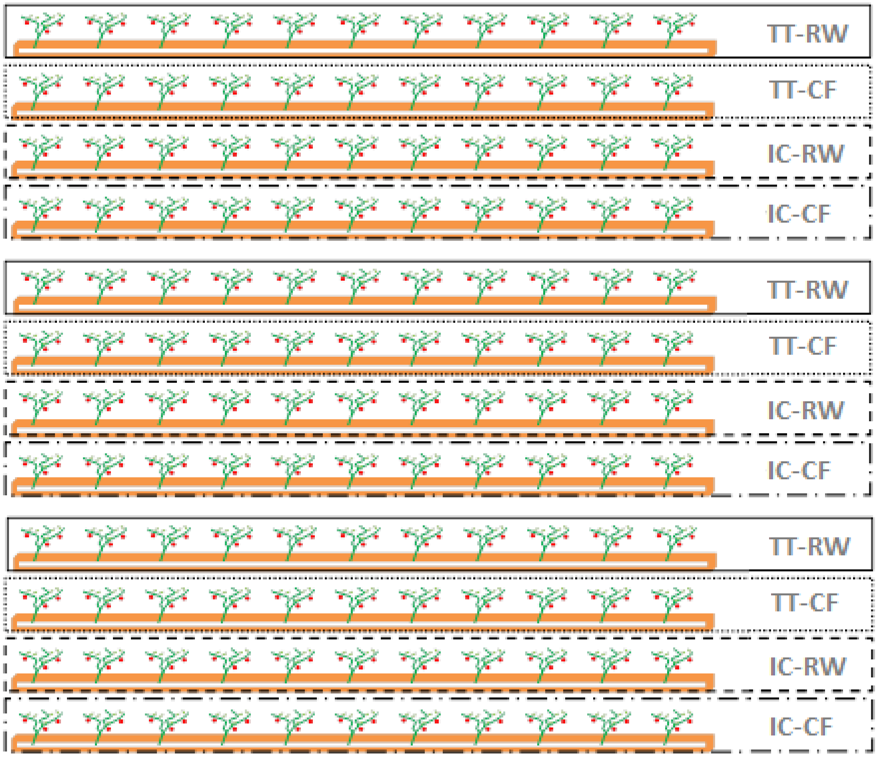

Figure 8: Overview of the irrigation sections

Figure 8 shows the irrigation sections with the different water sources and different hydroponic substrates that are used. As can be seen from Figure 8 there are three replicas of all irrigation sections. There are 20 pepper plants planted per irrigation section, with a density of 4 plants per meter. The distance between the irrigation sections is 1.6 meter. The plant density is 2.5 plants per m^2 (4 plants per meter divided by 1.6 meter).

The water supply is based on the drainage amount, the drainage amount is set on 30% of the irrigation water. The drainage is measured for the different irrigation sections. Those measurements are done by collecting the drainage water of the first meter of all irrigation sections in buckets.

2.2.1 Water analysis

To get insight in the concentrations of different nutrients in the water streams, water analyses are carried out. The water analyses are done at different locations in the system, those measurement locations are described in the next paragraph. Two different methods to analyze the concentrations of anions and cations in the different water streams are used. One is measuring with a measurement unit of Capilix, the other method of analysis is done by the lab of CEBAS-CSIC.

2.2.1.1 Measurement locations

In Figure 9 the measurement locations are indicated. In total there are 9 measurement locations:

- The three different waters sources:
    - Water from the IRIS treatment (IRIS)
    - Effluent water from the WWTP Roldán-Balsicas (TT)
    - Water from the Irrigation community (IC)
- The two waters with fertilizer:
    - Water from WWTP with fertilizer (TT-T)
    - Water from the IC with fertilizer (IC-T)
- The four drainage waters:
    - Drainage water from the WWTP on rock wool (TT-RW)
    - Drainage water from the WWTP on coconut fiber (TT-CF)
    - Drainage water from the IC on rock wool (IC-RW)
    - Drainage water from the IC on coconut fiber (IC-CF)

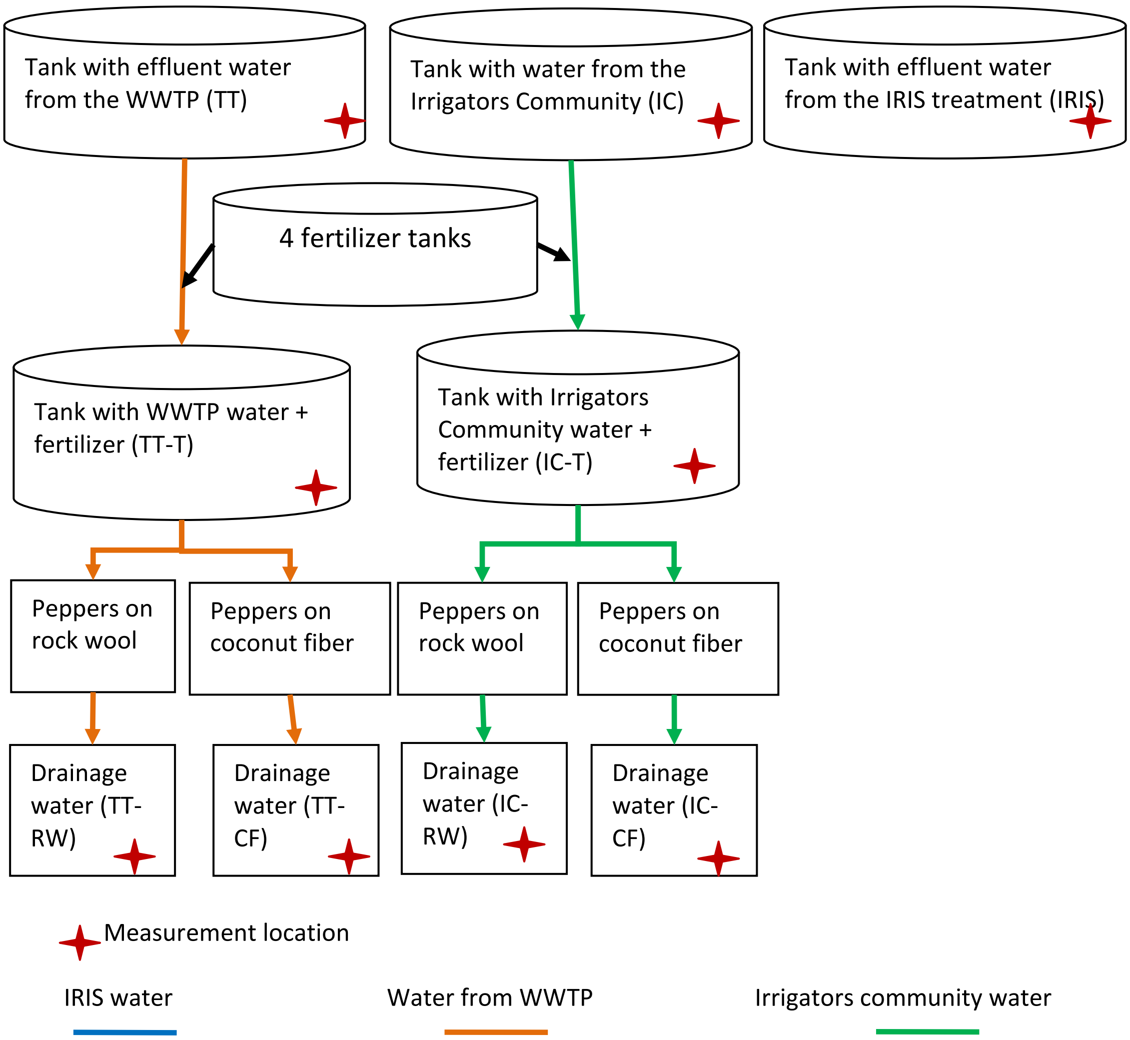

Figure 9: Measurement locations

Figure 9, shows the flowchart of the water flows and the water measurement locations. The idea is to irrigate with 3 different water sources. However, since the water supply from the IRIS treatment was not reliable, this water is not used for irrigation. For irrigation constant water availability is necessary. Therefore no measurement locations from the tank with IRIS water and fertilizer, and of the IRIS drainage water are present.

2.2.1.2 Water analyses with the Capilix measurement unit

The Capilix measurement unit (see Figure 10) analyze the water on the cations; NH_4^+, K^+, Na^+, Mg^{2+} and Ca^{2+} and on the anions; Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, and PO_4^{3-}. The Capilix measurement unit is a new measurement tool that works with micro-chip technology. The purpose of this machine is to do a quick and online measurement.

Figure 10: Capilix measurement unit

The procedure for a measurement is as follows: a water sample with a 1.5 liter bottle was always taken. This water is pumped through a filter, to filter out bigger parts like sand. Because there is always water in the filter from the sample that is used before, the first half of the sample was used to flush the filter. After this is done the Capilix machine takes a sample of the filtered water, which flows through a 0.45 mu filter. The machine takes a small amount of water, which then flows through the anion micro-chip. This chip measures voltages. After this is done, water flows through the cation micro-chip. The results are analyzed by the Capilix company and translated to a concentration of the different anions and cations. After a measurement the 0.45 µm filter was routinely replaced by a new filter.

2.2.1.3 Lab measurements of CEBAS-CSIC

The Capilix measurement machine is a new machine. To investigate if the Capilix machine functioned correct, the water samples were also analyzed by the lab of CEBAS-CSIC. The lab of CEBAS-CSIC makes use of inductively coupled plasma (ICP-ICAP 6500 DUO Thermo, England) and an ion chromatography (Metrohm, Switzerland). The lab analyzes cations; Al, As, Be, Bi, B, Ca, Cd Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, P, Sb, Se, S, Sr, Ti, Tl, V, Zn and anions: F, Cl, NO_2, Br, NO_3, PO_4^3 and SO_4^2. The water samples were taken from the same water from the Capilix analysis, the 1.5 l bottle. The water samples were filtered by a 0.45 mu filter.

2.2.2 Safety

In raw wastewater there can be pathogenic viruses, bacteria, protozoa, and helminthes present (Pescod, 1992). The most widely adopted indicator of faecal pollution is testing for Escherichia coli (E. coli) (Pescod, 1992). Therefore, water samples were taken every week to test on E. coli. Irrigation water was sampled before (IC and TT) and after fertilization (IC-T and TT-T) and it was also collected from the hydroponic substrate lines of coconut fiber (IC-CF and TT-CF). Only the drainage water of coconut fiber is analyzed, because in previous research with tomatoes E. coli was only found in the drainage water of coconut fiber. Also water samples in the different IRIS treatment steps are taken, as samples taken from the different fertilizers. Duplicate samples were taken for each type of water using sterile plastic jars. At each sampling week, two samples per water type were analyzed by direct plating for E. coli. The detection and quantification of E. coli is done according to the Royal Decree 1620/2007. For quantification of *E. coli* in water samples, filtrated and non-filtrated samples were plated in Chromocult coliform agar (Merck, Darmstadt, Germany). Plates were incubated for 24 h at 37 °C before interpretation. Dark blue-violet colonies were considered positives for *E. coli*. An overview of the sample points are shown in: Appendix B: Overview of sampling points for E. coli measurement.

2.2.3 Yield analysis

Yield was collected on 15 plants per irrigation section, so in total 45 plants per treatment (there are 3 repetitions of every irrigation section, see Figure 8). The following measurements were made: number of peppers, total kg and distribution in commercial weights using the following classification (UNECE, 2009):

- non commercial size
- industrial
- MM 90-119g
- M120-159g
- G 160-219g
- GG >120g

Figure 11: Yield analysis

Figure 11 shows an example of weight analysis of the peppers, every pepper is weighted and indicated to the classification above.

2.3 Nutrients calculations

In this report the nutrients are expressed as NO_3, P_2O_5, and K_2O. In literature and in measurements the nutrients are sometimes shown in different units. Therefore all the different units are converted to the same units in this report. For calculation of the converting rates, the difference in molar weight of the different nutrients and atoms should be known. The molar weights of the atoms are given in the table below.

Table 1: Molecular weights

Atom	Weight (g/mol)
N	14.0067
O	15.999
K	39.098
P	30.974

The molar weight of the nutrients (NO_3, P_2O_5, and K_2O) is the sum of the individual atoms of the nutrients. This calculation is done in Table 2.

Table 2: Nutrient weights

Nutrient	Molar weight		Calculation
NO_3	62.0037	g/mol	N (14) + 3 times O (16)
P_2O_5	141.943	g/mol	2 times P (31) + 5 times O (16)
PO_4	94.97	g/mol	P (31) + 4 times O (16)
K_2O	94.195	g/mol	2 times K (39) + O (16)

2.4 Nutrient conversion factors

The conversion rates give the ratio between the measured unit and the preferred unit. By multiplying the measured unit with the conversion rate, you get the preferred unit.

Nitrogen

NO_3 has a molar weight of 62 g/mol, N has a molar weight of 14. If N is measured and this should convert to NO_3, the value of N should be multiplied by 4.43 ($\frac{NO_3(62.0037)}{N\ (14.0067)} = 4.427$).

Phosphorus

P_2O_5 has a molar weight of 141 g/mol, PO_4 has a molar weight of 95. If PO_4 is measured and this should convert to P_2O_5, the value of P should be multiplied by 0.75. This because of the molar weight of 2 times PO_4 (there are 2 P's in P_2O_5) is 0.75 times smaller than the molar weight of P_2O_5 ($\frac{P_2O_5(141.943)}{2*PO_4\ (189.94)} = 0.7473$). This value is also found by Palintest (Palintest®). To convert from P to P_2O_5, the concentration of P should be multiplied by 2.29 ($\frac{P_2O_5(141.943)}{2*P\ (61.948)} = 2.2913$).

Potassium

K_2O has a molar weight of 94.195 g/mol, K has a molar weight of 39. If K is measured and this should convert to K_2O, the value of K should be multiplied by 1.20. This because of the molar weight of 2 times K (there are 2 K in K_2O) is 1.20 times smaller than the molar weight of K_2O ($\frac{K_2O(94.195)}{K_2\ (78.196)} = 1.204601$). This value is also found by Resh (Resh, 2004).

An overview of the converting rates:

- From N to NO_3 is multiplying by 4.43
- From PO_4 to P_2O_5 is multiplying by 0.75
- From P to P_2O_5 is multiplying by 2.29
- From K to K_2O is multiplying by 1.20

3 Background information

This chapter gives relevant background information on the IRIS project. The water sources and the hydroponic substrates that are used in this research are analysed in this chapter.

3.1 Water sources

Three water sources are used in this research; the effluent water from the WWTP Roldán-Balsicas, Irrigation community water, and water from the new IRIS treatment system.

3.1.1 Wastewater treatment plants

There are 7 WWTPs in the area of Campo de Cartagena. The 7 WWTPs are shown on the map of Figure 12. Those WWTPs are important for wastewater reuse and the quality of surface water. In this area most of the treated wastewater is reused for irrigation (greenhouses). However, through (heavy) precipitation the amount of water is too much for the irrigators, so a part of it flows to the surface water and ends in the Mar Menor. This is also happening in periods when the demand of the irrigators is lower than the supply of the treatment system. When the water is flowing to surface water it should meet the effluent regulations. Those regulations are made to protect the environment from wastewater. By discharging nutrient rich water to surface water there is a change on eutrophication. Smith (Smith, Tilman, & Nekola, 1998) describe eutrophication as "a process by which water bodies are made more eutrophic through an increase in their nutrient supply". This can result in water with low O_2 concentrations and also water with of algae, and smelly water. This is also what was happened with the Segura river in Murcia (CARM, 2012).The regulations for effluent discharge of waste water are described in the Urban Waste Water Directive (91/271/EEC). The directive was adopted in 1991 and is giving direction to treatment of urban waste-water. The directive advices that by a population equivalent[2] above 2.000 there should be collection and treatment of wastewater. This should be the secondary treatment. If the population equivalent is higher than 10.000 in a sensitive area, there should be more advanced treatment.

The effluent discharge limits for secondary treatment are 25 mg/L BOD_5 and 35 mg/L COD. For N is the limit 15 mg/L for small WWTPs (<100.000 people) and for big WWTPs (>100.000 people) the limit is 10 mg/L (CARM. 2012). For P the limit for a small WWTP is 2 mg/L and for a bigger WWTP 1mg/L (CARM. 2012)

[2] Population equivalent means the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day (91/271/EEC)

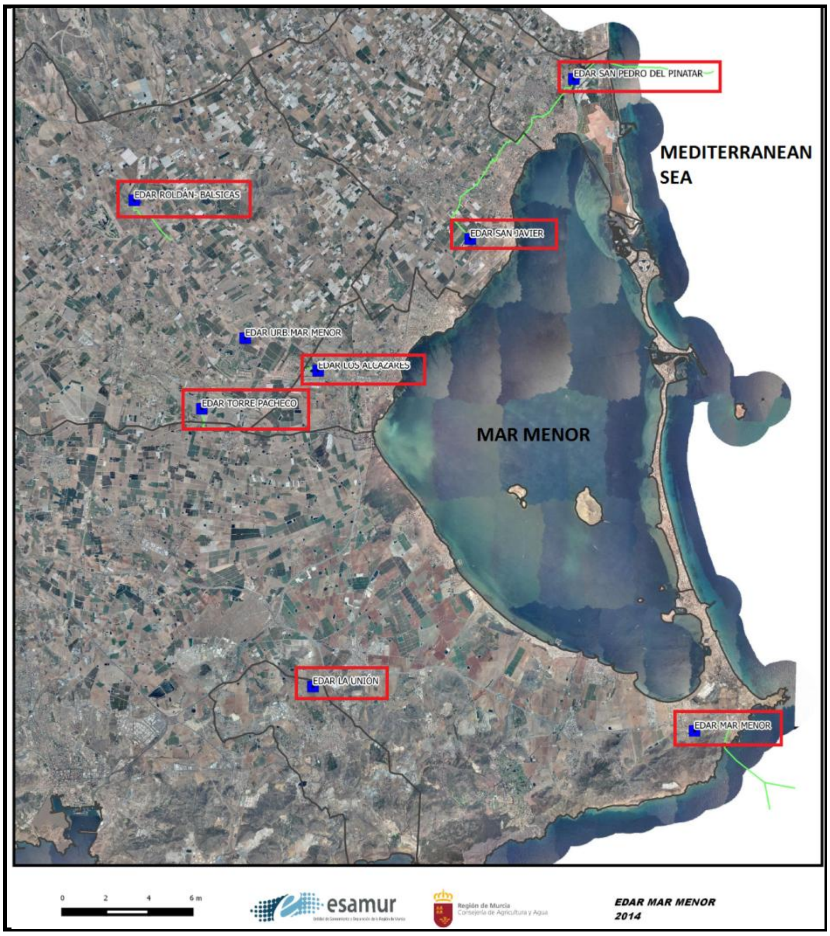

Figure 12: Locations of the 7 WWTPs near the Mar Menor

The characteristics of the 7 WWTPs in the area of Campo de Cartagena are shown in the table below, Table 3.

Table 3: The characteristics of the 7 WWTP near Mar Menor

WWTP	Year of building	Design flow m^3/day	Population equivalent	Treatment system
Mar Menor Sur	1998	50.000	541.667	Secondary treatment (activated sludge)
La Unión	2002	4.100	35.000	Secondary treatment (activated sludge) tertiary treatment and disinfection by sodium hypochlorite
Torre Pacheco	2004/2007	7.500	81.000	Secondary treatment (activated sludge), tertiary treatment and disinfection with UV light
Roldán-Balsicas	2006	5.500	59.600	Secondary treatment (activated sludge), tertiary treatment and disinfection by UV light
San Pedro del Pintar	2007	20.000	145.000	Biological membrane reactor
San Javier	2007	22.500	120.000	Secondary (activated sludge), tertiary treatment and disinfection with UV light
Los Alcázares	2008	22.500	120.000	Secondary (activated sludge), tertiary treatment and disinfection by UV light

Almost all the WWTPs, 6 out of 7, are using activated sludge. Activated sludge treatment is a biological treatment. Microorganisms are using the nutrients from wastewater to grow. Microorganisms needs oxygen for their growth, therefore wastewater is aerated. In another step in the treatment system the water and the microorganisms are separated. Tertiary treatment is an additional treatment, this is mostly done to improve the removal of nitrogen en phosphorus. The biological removal of nitrogen is a two-steps process. The first step is nitrification, this is the oxidation of ammonia (NH_4) to nitrate (NO_3). In this process there are two types of bacteria involved: Nitrosomonas, those bacteria are responsible for the oxidation of ammonia to nitrite and the Nitrobacter, those bacteria are responsible for the oxidation of nitrite to nitrate. The second step is the denitrification step. In an anaerobic situation bacteria are using the oxygen of nitrate, what is left is nitrogen gas (Metcalf and Eddy et al, 2003). Phosphorus is used by bacteria for cell synthesis and energy transport. There are bacteria (Acinetobacter) that can take up more phosphorus than other bacteria (Metcalf and Eddy et al, 2003). If those bacteria are more represent in the WWTP the phosphorus removal can be increased

Most of the WWTPs have a disinfection step, 5 out of 7 WWTPs. Disinfection is used for inactivation or destruction of pathogenic organism to prevent the spread of waterborne diseases to downstream users (EPA, 1999). Four of the WWTPs use UV light as a disinfection step. The two WWTPs that does not making use of a disinfection steps (Mar Menor Sur and San Pedro del Pintar) are the WWTPs close to the Mar Menor. Those waters are not reused in agriculture, and therefore there is no need for a disinfection step.

The effluent concentrations for the main parameters of the 7 WWTPs are shown in Table 4. These are average concentrations of the period from January 2013 till May 2014, 17 months in total. Every month one measurement was performed, so 17 measurements in total.

Table 4: Average effluent characteristics of the 7 WWTPs (ESAMUR)

	Conduc-tifity	BOD_5	COD	N-total	$N\text{-}NH_4$	NO_3	TKN	pH	PT Tot.	TSS	Turbi dity	E. coli
WWTP	dS/m	mg O_2/L	mg 2/L	mg N/L	mg N-NH_4/L	mg N-NO_3/L	mg /L	u. pH	mg P/L	mg/L	NTU	CFU[3]/ 100ml
Mar Menor Sur	9.417	2.5	26.2	19.9	2.3	15.5	4.1	7.8	3.4	4.8	2.5	7,019
La Unión	1.159	3.7	34.4	8.2	3.4	1.8	6.2	7.9	3.2	6.5	3.9	35
Torre Pacheco	1.408	2.2	23.9	7.7	2.3	2.8	4.8	7.9	1.9	3.0	2.2	5
Roldán-Balsicas	1.535	2.3	24.1	7.5	2.1	3.1	4.2	8.0	2.5	4.1	2.4	33
San Pedro del Pinatar	4.964	2.2	23.6	4.9	1.1	1.9	2.8	8.0	2.5	2.6	1.3	1
San Javier	6.641	2.2	24.1	7.4	1.2	4.0	3.4	8.1	2.9	3.4	2.2	76
Los Alcazares	5.041	2.5	26.2	5.7	2.1	1.4	4.0	8.0	1.6	3.3	2.4	13

The table above shows a difference in salinity levels of the 7 WWTPs in the area. The WWTPs with a high salinity level are closer to the Mar Menor (see Figure 12), which is a saline inland sea. The water from Mar Menor Sur is not reused in agriculture due to the high salinity level. The WWTPs have different flows, the concentrations of the table above can also be displayed in volumes of different salinity levels, the values are shown in Table 5.

[3] Cfu stands for Colony-forming unit, it is an estimation of the number of viable bacteria

Table 5: Volume percentages of the effluent salinity concentrations (ESAMUR, 2006)

dS/m	Volume %
1-2	9
2-3	60
3-5	16
>5	15

Most of the water has a salinity level that can be used direct for irrigation (ESAMUR, 2006), water which has a value below the 3 dS/m (69%). The main part of the water used for irrigation is mixed with other water with lower salinity levels, like transfer water from the Tajo-Segura transfer. This water has an EC value around the 1 ds/m (Pedrero et al, 2013).

Another difference between the WWTPs is the N concentrations, the concentrations from Mar Menor Sur and Urbanización Mar Menor are much higher (around 20-25 mg/L N-total) compared to the other WWTPs (around 5-8 mg/L N-total). Another element which stands out is the E. coli concentration. The E. coli concentrations for Mar Menor Sur is high compared to other WWTPs, >7,000 and the others between 1 and 76 CFU/100ml. The high concentration of Mar Menor Sur is due to the lack of tertiary treatment and a disinfection step. This water is not re-used due to the high salinity level, so there is no need to reduce the E. coli concentration.

3.1.1.1 Wastewater treatment plant of Roldán-Balsicas

The IRIS project is located on the WWTP area of Roldán-Balsicas. The effluent of this treatment plant is used as a water source for irrigation. In the 2 tables below (Table 6 and Table 7) the influent and effluent concentrations of different parameters are presented for the period January 2011 till June 2011.

Table 6: Influent characteristics of WWTP Roldán-Balsicas

Influent of Roldán-Balsicas										
	pH	Cond.	COD	BOD_5	TSS	N total	TKN	NO_3	NO_2	P Tot.
Date	u. pH	dS/m	mg O_2/l	mg O_2/l	mg/l	mg N/l	mg N/l	mg N-NO_3/l	mg N-NO_2/l	mg P/l
12-1-2011	7.4	2.453	833	416	428	102	98	3.9	0	12
27-1-2011	7.1	1.415	533	179	203	51	50	1.3	0	7.7
7-2-2011	7.7	1.874	437	197	203	56	55	1.1	0	9
22-2-2011	7.3	2.156	1321	637	470	108	104	3.1	0	12
7-3-2011	7.7	2.106	1298	345	840	97	96	0.96	0.01	21
22-3-2011	7.5	2.217	840	381	448	110	108	1.8	0	19
5-4-2011	7.5	2.424	1543	557	1027	123	120	2.7	0	20
28-4-2011	7.6	1.962	528	260	128	67	66	1.3	0.01	13
9-5-2011	7.8	1.977	668	338	243	89	88	1	0.01	8.3
25-5-2011	7.1	2.110	824	417	337	97	92	5.2	0	8.1
13-6-2011	7.8	2.102	871	291	485	93	90	2.8	0	13
27-6-2011	7.7	2.311	906	430	630	97	93	3.5	0	19
Average	7.5	2.092	884	371	454	91	88	2.39	0.00	13.51

Table 6 presents the characteristics of the influent water. The pH is constant around the 7.5. The conductivity of influent water is around the 2 dS/m, with the highest concentration of 2.5 dS/m. The average COD/BOD ratio is 2.4 (884/371). This indicates a high ratio for domestic wastewater (Henze et al, 2002). What stands out is that the COD concentration in some periods was almost 2 times higher (1543 mg O_2/L) than the average COD concentration. The BOD concentration in those periods are also higher, this might be due to industry in that time which did have high discharges. The total nitrogen is on average 91 m/L, this can be indicated as concentrated (Henze et al., 2002). The concentration of nitrogen reaches even the 123 mg N/L. The total Kjeldahl nitrogen (TKN) is on average 88 mg N/L. TKN is the organic N plus NH_3 and NH_4. A TKN concentration of 88 mg N/L is indicated as a concentrated wastewater stream (Henze et al., 2002). The NO_3 and NO_2 concentrations are low in influent data. The nitrogen in the wastewater is not yet oxidized to nitrate (NO_3) or nitrite (NO_2). The total phosphates concentration is on average 13.5 mg P/L, this is a concentration that is associated with a concentrated urban wastewater stream. The highest total phosphorus concentration is even up to 21 mg P/L. Overall, the influent data indicates that wastewater stream has high concentrations and can be indicated as a concentrated domestic wastewaters stream. The influent has periods with extra high concentrations, (22-2-2011, 7-3-2011, and 5-4-2011), this might be caused by high discharges of industry.

The influent is treated by an activated sludge treatment system, the effluent concentrations are shown in Table 7.

Table 7: Effluent characteristics of WWTP Roldán-Balsicas

Effluent of Roldán-Balsicas												
	pH	Cond.	Turbidity	COD	BOD_5	TSS	N total	TKN	N-NH_4	NO_3	NO_2	P Tot.
Date	pH	dS/m	UNT	mg O_2/l	mg O_2/l	mg/l	mg N/l	mg N/l	mg N-NH_4/l	mg N-NO_3/l	mg N-NO_2/l	mg P/l
12-1-2011	7.1	2.033	1	34	2	7	54	52	42	2	0.15	1.1
27-1-2011	7	1.731	4	48	6	8	21	9	8	12	0.04	0.86
7-2-2011	7.2	1.557	4	23	2	3	14	4	1	9.6	0.13	0.68
22-2-2011	7.3	1.687	4	29	3	6	14	5	1	8.6	0.05	0.83
7-3-2011	7.6	1.576	3	29	2	9	7	3	1	3.7	0.02	1.6
22-3-2011	7.8	1.450	5	28	2	5	10	2	1	7.7	0.06	1.3
5-4-2011	7.4	1.678	3	18	2	4	16	6	1	9.6	0.07	0.65
28-4-2011	7.8	1.360	1	31	2	2	11	4	1	7	0.03	0.96
9-5-2011	8.1	1.313	2	28	4	5	20	4	1	15	0.53	1.3
25-5-2011	7.3	1.674	2	55	4	3	23	4	2	19	0.32	1.8
13-6-2011	7.7	1.954	4	23	2	9	15	4	1	11	0.21	0.84
27-6-2011	7.8	1.916	2	17	2	5	14	4	2	10	0.27	1.8
Average	7.5	1.661	2.92	30	2.75	5.50	18	8.42	5.17	10	0.16	1.14

Table 7 does show that the pH is almost neutral in the influent and in the effluent (7.5). The conductivity reduces from 2.100 in the influent to 1.661 dS/m in the effluent. The treatment reduces the oxygen demand, the COD (Chemical Oxygen Demand) is going down from 884 to 30 mg O_2/L, and the BOD (Biological Oxygen Demand) from 370 to 3mg O_2/L. These are removal efficiencies of 97 for COD and 99 percent for BOD. The total suspended solids (TSS) reduces from 450 to 5.5 mg/L, a removal of 97%. In the influent there is about 90 mg N/L, the most of the N is part of TKN with 88 mg N/L, which is the sum of ammonium-nitrogen and the organically bounded nitrogen. The NO_3 (nitrate) and nitrite (NO_2) in the influent are low. In the effluent the concentration N-total is reduced to 18 mg N/L, the N removal is 80%. The nitrate concentration in increased from 2 till 10 mg N/L, this increase is due to nitrification, ammonium with oxygen is oxide to nitrate. From the NH_4

concentrations it seems that the nitrification did not work well by the measurement of 12 January 2011, the NH_4 concentration was 42 mg/L and the NO_3 concentration was low (2 mg N/L). This resulted in a high total N concentration of 54 mg N/L. The phosphorus is reduced from 13.5 mg P/L to 1 mg P/L, this is a removal of 93%.

3.1.2 Irrigation community water

One of the water sources is water from an irrigation community (IC). The IC where the water is coming from is Comunidad de Regantes del Campo de Cartagena (CRCC), in English Campo de Cartagena Irrigation Community. This is the largest IC of Spain, with an area of 41,065 hectares and has nearly 10,000 farmers. The water they provided to the farmers is coming from different sources. The water sources are: Tajo-Segura transfer water (122 Hm^3), surface water from the Segura river (4.2 Hm^3), reclaimed water from 7 WWTPs (13.2 Hm^3) and Mojón desalination plant where the water is coming from irrigation drainage (2.2 Hm^3) (http://www.crcc.es).

Almost all the water is irrigated with local irrigation. Most of the irrigation is done with drip irrigation (95%), the other 5% is irrigated with surface irrigation (2%) and sprinklers (3%). Most of the area is used for growing horticultural crops (59%), for growing citrus (30%), the other parts are used for greenhouses (7%) and fruit (4%) (http://www.crcc.es).

The water supply to the farmers is a complex system with many pipelines and hydrants. The main pipeline transfers the water over 65 km to the different irrigation sections, 18 in total. The total pipe length is 1,033 km and there are 25 reservoirs, in total they can store 2.5 Hm^3 of water. Everything is automated and controlled by over 1,000 remote stations in the area (http://www.crcc.es).

Table 8 does show the water characteristics of the IC water. These values are from a measurement on the 24th of March 2014, and are done by FITOSOIL.

Table 8: Characteristics of Irrigation community water

pH	Conductivity	NO_3-N	P_2O_5	K_2O
	dS/m	mg/L	mg/L	mg/L
8,7	1.23	<0.226	<1.14	10.2

3.1.3 IRIS water

The third water source is water that in this report is called IRIS water. This is water that is produced by a new pilot treatment system of Hellebrekers company. This treatment system is treating the same water which the WWTP of Roldán-Balsicas uses. The treatment system exists of the following treatment steps: anaerobic fermentation, electrofloculation, ultra filtration, and nano filtration (see Figure 13). The treatment system has a capacity of 5 m^3/day.

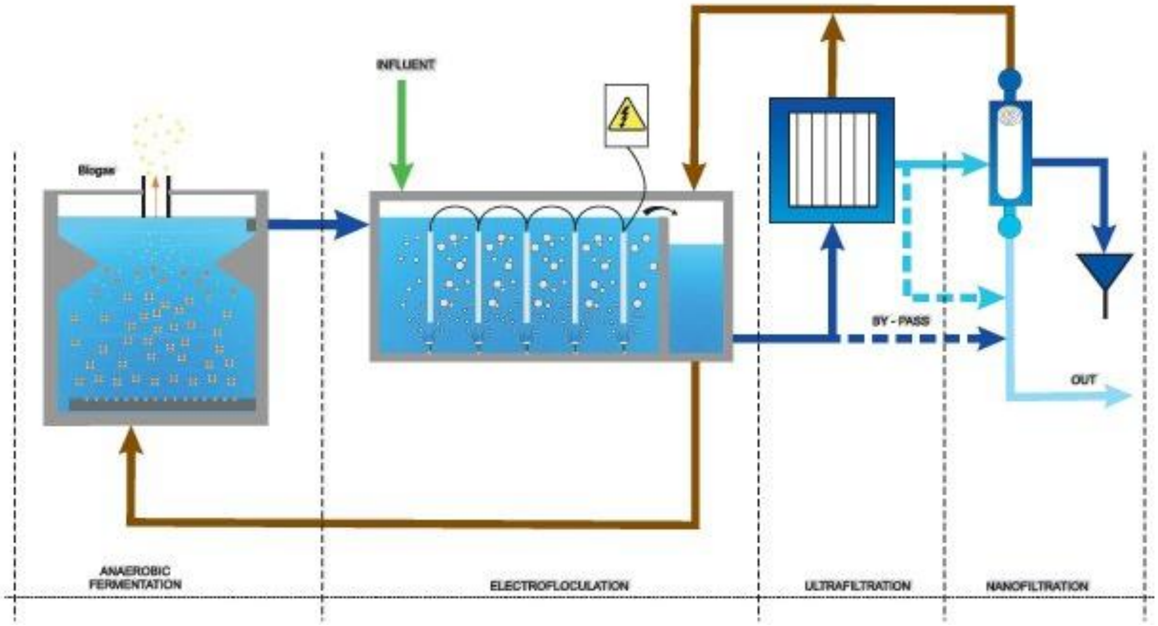

Figure 13: Treatment steps of IRIS treatment system (from www.iris-project.eu)

3.1.3.1 Anaerobic fermentation

In the anaerobic fermentation tank organic material breaks down by microorganisms (bacteria). This process is done in anaerobic conditions, which means that there is no oxygen present. Anaerobic fermentation process has three steps. The first step is hydrolysis. In the hydrolysis step complex organic substrates are converted to smaller compounds. Those smaller compounds can be taken up by micro-organisms. The second step is the fermentation step. In this step the amino acids, sugars, and some fatty acids are degraded further. The products of fermentation are acetate, hydrogen, CO_2, and propionate and butyrate. The last step is methanogenesis, in this step methane (CH_4) is produced. This is done from acetate ($CH_3COOH \rightarrow CH_4 + CO_2$) and from CO_2 and H_2 ($2\ H_2 + CO_2 \rightarrow CH_4 + H_2O$) (Metcalf & Eddy., Tchobanoglous, Burton, & Stensel, 2003).

3.1.3.2 Electrofloculation

Electroflocculation is a combination of electroflotation and electroprepitation (Koren & Syversen, 1995). Electroprecipitation is a flocculation process. Ions, coming from an anode, have a strong affinity for dispersed/dissolved substances, as well as counter-ions (Koren & Syversen, 1995). This lead to coagulation/adsorption (Cerqueira, Russo, & Marques, 2009). The best anodes that can be used are iron or aluminium, because they give trivalent ions ($^{+3}$). Those ions have a better ability to absorb onto particles than bivalent ions ($^{+2}$)(Cerqueira et al., 2009; Koren & Syversen, 1995). Electroflotation is a flotation process. This process exists of four steps: (1) gas or air bubbles are generated; (2) there is contact between the bubbles and particles in the liquid; (3) bubbles adsorption to the surface of the particles; and (4) the particles with the bubbles are floating to the surface (Koren & Syversen, 1995). The bubbles with the particles producing foam on the surface, which can be removed by skimming. Electroflocculation makes use of an anode and a cathode. By the cathode hydrogen gas evolves and by the anode oxygen gas evolves (Koren & Syversen, 1995).

3.1.3.3 Filtration: ultra and nano

The last two steps are filtration steps. By filtrations constituents that are bigger than the pores of the filter get stuck in front of the filter, smaller particles flows through the filter. The first filter step is ultra filtration. Ultra filtration filters out particles that are bigger than 0.005-0.2 µm (micrometre, 10^{-6} meter), depending on the filter (Metcalf & Eddy. et al., 2003). Nano filtration filters out particles that are bigger than 0.001-00.1 µm (Metcalf & Eddy. et al., 2003). Ultra filtration filters out macromolecules, biodegradable organics, most of the bacteria, TSS (total suspended solids) and some viruses. Nano filtration is removing small molecules, biodegradable organics, some hardness, heavy metals, nitrate, TDS (total dissolved solids), bacteria and viruses (Metcalf & Eddy. et al., 2003).

3.2 Hydroponic substrates

Hydroponic substrates are a replacement for soils. Plants are growing on the hydroponics and are feed with water that contains minerals and nutrients.

According to Savvas (Savvas et al., 2007) hydroponics have the following advantages relative to soils; hydroponics have no soils-borne pathogens, which can be a problem by growing on soils. By making longer use of the same crops on the soil, the soil structure declines and also the soil will lose fertility. The control of nutrient applications can be more precise, due to the homogenous constitution which is known by the growers. There is no need for preparation of the soil, which can save time and increase the length of cultivation time, which can results in higher yields. Also the drainage with nutrients can be recycled.

Savvas (2003) mentioned that the only disadvantage of hydroponics is the somewhat higher cost for the installation and the increased technical skills that are needed. There are many different kinds of hydroponic soils. In this research rock wool and coconut fiber are used. Rock wool is one of the most common hydroponic for commercial growers. Rock wool is made of a combination of basalt rock, limestone, and silica. It is a sterile, porous and non degradable hydroponic (Coene, 2000). Coconut fiber is a hydroponic which is becoming more popular. It is coming from the coconut industry, where it is a kind of waste. It is an organic hydroponic that have good performances. The oxygen capacity is larger compared to rock wool. Also the water holding capacity is better compared to rock wool (SimplyHydro, 2008).

4 Results

The results are split up into the four focus points of this research: nutrients, salinity, safety, and yield. For these focus points it is important to know the water supply to the different irrigation sections, therefore this chapter starts with that and then the results of the focus points.

4.1 Water supply to the irrigation sections

The water supply is measured with flow meters. The water supply is based on a drainage amount of 30%. The amount of water that is applied to the different irrigation sections is shown in Table 9, in L/m^2.

Table 9: Water supply to the irrigation sections (L/m^2)

Period	Irrigation days	TT-RW	TT-CF	IC-RW	IC-CF
24/12/2013 -26/01/2014	33	23	21	26	26
27/01/2014 - 10/03/2014	43	54	41	49	44
11/03/2014 -21/03/2014	11	18	26	17	26
22/03/2014 -29/07/2014	130	671	867	616	833
30/07/2014 - 07/08/2014	9	87	100	81	95
TOTAL	226	853	1054	787	1025

What stands out is that the amount of water applied for coconut fiber is much more than for rock wool. The irrigation period in this research is 226 days (from 24th of December 2013 till the 7th of August 2014). The maximum irrigated water is 1054 L/m^2, which is the same as 1054mm. The average irrigation is 4.7 mm/day (1054mm/226 days). Chartzoulakis and Drosos (Chartzoulakis & Drosos, 1997) studied the water requirements of the Capsicum Annuum in a greenhouse with drip irrigations. This research is done in Crete, Greece, the peppers were growing in on a soil existed of 68% sand, 20% silt, and 12% clay. They found that the peppers in their research needed 348mm during the whole growing season. This is three times less than the maximum water supply in this research (1054mm/348mm=3.0).

The evapotranspiration in the research of Chartzoulakis and Drosos varied between 0.5 and 4.0 mm/day. Evapotranspiration is the evaporation of moisture from the soil to the atmosphere and transpiration from plants. In the research of Sabli (2012) with peppers growing in a greenhouse on rock wool, there was evaporation between 0.1 and 5 mm per day. The water supply of 4.7 mm/day on average is high compared with those evapotranspiration numbers.

By fertigation (application of fertilizer through an irrigation system) not only the amount of water is important, but also the amount of irrigation schedule. Sabli (2012) found in their research that an increase in irrigations events form 5 times per day to 20 times per day, increased the yield by 22%. There was a better uptake of nutrients by 20 irrigation events per day. The total irrigation time was for all the experiments the same. In the IRIS research the irrigation times where varied in different growing periods.

4.2 Nutrients

This paragraph is focusing on the nutrients; this includes the regulation of the effluents of WWTPs, nutrient measurements, nutrient concentrations and loads.

4.2.1 Comparison between Capilix and lab measurements.

A comparison is done between the measurement results of nutrients from the Capilix measurement unit and with the result of the lab analysis of CEBAS-CSIC to see if the results of the Capilix are reliable. The analyses of CEBAS-CSIC are well established methods and use scientific accepted methods, so assumed are that those analyses are correct. In Table 10 the results of a comparison of K, PO_4 and NO_3 in mg/L. measurement of the 22th of July 2014 are presented. The first column are the samples that were measured. The second column are the measurement results of Caplix and the third column are the results of the lab analysis of K. The fourth column gives the difference between the measurement of Capilix and the lab in mg/L (the value of Capilix minus the value of the lab). The fifth column gives the difference between the measurement of Capilix and the lab in percentage (value of Capilix minus values of the lab divided by the value of the lab). This is also done for PO_4 and NO_3.

Table 10: Comparison between nutrient analysis of Capilix and lab analysis of CEBAS-CSIC on the 22th of July 2014

Sample	Capilix	Lab	Difference		Capilix	Lab	Difference		Capilix	Lab	Difference	
	K (mg/L)	K (mg/L)	mg/L	%	PO_4 (mg/L)	PO_4 (mg/L)	mg/L	%	NO_3 (mg/L)	NO_3 (mg/L)	mg/L	%
TT	37	34	3	9	15	6	9	138	61	32	29	90
IC	9	7	3	43	0	<1,0	<1	-	0	4	-4	-100
TT-T	155	232	-77	-33	115	139	-25	-18	545	623	-78	-13
IC-T	158	227	-69	-30	463	148	315	213	1749	674	1076	160
TT-RW	171	263	-92	-35	122	111	11	10	706	796	-90	-11
IC-CF	216	294	-78	-26	318	155	163	105	1658	781	878	112
IC-RW	210	302	-92	-31	266	142	124	87	1736	1026	709	69

From the table above it becomes evident that the difference between the Capilix measurements and the analyses of the lab of CEBAS-CSIC can be big, up to 1076 mg/L difference (IC-T NO_3). In percentage the difference are between 9% up to 213%. There is not a constant difference. If that was the case the results could be used if taken into account that the difference is a fixed percentage. Because of the big difference between the analyses and the fact that the Capilix is a new technology that is not yet well established, the analyses of CEBAS-CSIC are used in this research.

4.2.2 Nutrient demand for pepper according to literature

Crops need nutrients to grow and to produce yield. There is an optimum for those nutrients. In Figure 14 is shown how crop reacts on fertilizers. At low concentration, there is a small increase in availability, which results in large changes in growth (A). By further increase of fertilizer the maximum yield is achieved (B). By further increase of fertilizer the crops are not producing more yield, so this is a loss of fertilizers (C). At high concentrations of nutrients they can become toxic, and then the yield reduces (D) (Raviv & Lieth, 2008).

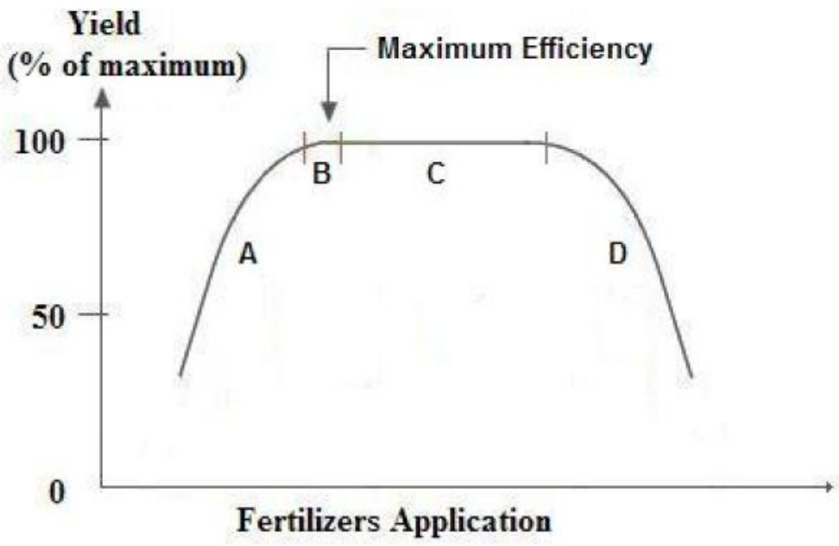

Figure 14: A nutrient response curve (Raviv & Lieth, 2008)

Fruiting plants, like pepper, are growing through three different growing phases: initial vegetative phase, flowering and fruit set phase and a fruit development phase (J. T. Calpas, 2002). The plants need different nutrient concentrations in those different phases.

Sabli (Sabli, 2012) did a research on the effect of N and K concentrations on the growth of Capsicum Annuum. In this research the peppers were growing in a greenhouse on rock wool. They used different NPK (nitrogen, phosphors and potassium) concentration for different growing phases. They had a control group that received a concentration of 126-55-106 mg NPK/L throughout the season (NPK is an abbreviation of NO_3-P_2O_5-K_2O (Maguire, Alley, & Flowers, 2009)). They found that an increase of NO_3 over the different growth phases from 126 mg/L to 265 mg/L and up to 385 mg/L and a concentration of K_2O form 106 mg/L to 214 mg/L and up to 321 mg/L did increase fruit yield significantly compared with the control. There was no further increase in yield if the fertilizers were increased to 500-55-625 mg NPK/L. The P_2O_5 concentration was always 55 mg/L, which is recommended by Calpas (J. T. Calpas, 2009).

4.2.3 Nitrogen

The NO_3 is measured in different time periods in 2014 on the different water streams. All the measurement results are shown in Table 11.

Table 11: NO_3 measurements in the water streams (in mg/L)

Water stream	10-jun	2-jul	14-jul	18-jul	22-jul	25-jul	**Average concentration**
TT	16.62	15.14	22.50	17.20	32.19	25.90	**21.59**
IC	1.40	1.25	3.70	<1.0	3.60	13.20	**4.63**
IRIS			1.00	4.00	2.60	2.50	**2.53**
TT-T	574.16	658.80	625.10	602.30	622.90	697.10	**630.06**
IC-T	630.01	687.90	756.10	658.00	673.70	699.10	**684.13**
TT-RW	693.39	891.20		662.30	796.30		**760.80**
TT-CF	663.81	807.70		602.40	780.70		**713.65**
IC-RW	818.62			890.30	1026.10		**911.67**
IC-CF	743.73			891.30	936.80		**857.28**

The concentrations of the irrigation waters (TT, IC, and IRIS) are low compared to the concentrations which are irrigated (TT-T and IC-T). The average irrigated concentration is 657 mg NO_3/L (TT-T of 630 mg/L and IC-T of 684 mg/L). The concentration in the TT water is 3.29% of the concentration which is irrigated, for IC water 0.70%, and for IRIS water 0.38%. The rest of the NO_3 is coming from the fertilizers. The concentrations in the drainage (TT-RW, TT-CF, IC-RW, and IC-CF) are higher than in the irrigated waters. This is possible because part of the nutrients is taken up by the plants, however also a part of the water is taken up by the plants. If the fraction of nutrients which is taken up by plants is lower compared to the fraction of water, the concentration of nutrients in the drainage water is higher compared to the irrigated water.

According to Sabli (2012) and Calpas (2009) the NO_3 concentration applied can be much lower than the applied concentration in this research. Sabli found an optimum NO_3 concentration of maximum 385 mg/L, this is almost half of the concentration that is applied in this research.

The concentrations of nitrogen are applied with an amount of water. The amount of water times the applied nutrient concentration results in the load of the nutrient. The applied waters are given in chapter 4.1 Water supply to the irrigation sections. In Figure 15 the NO_3 loads are given of the irrigation water, irrigation loads, drainage loads, and plant uptake loads. The loads of NO_3 in the irrigation water and the irrigated load are based on the measured concentrations times the applied water. The drainage load is based on the 30% drainage amount and the measured concentrations in the drainage waters. The plant uptake load is based on the irrigation load minus the drainage load, the NO_3 that is applied that is not in the drainage water is taken up by the pepper plants. The calculations are shown in Appendix C: Nutrient load calculations.

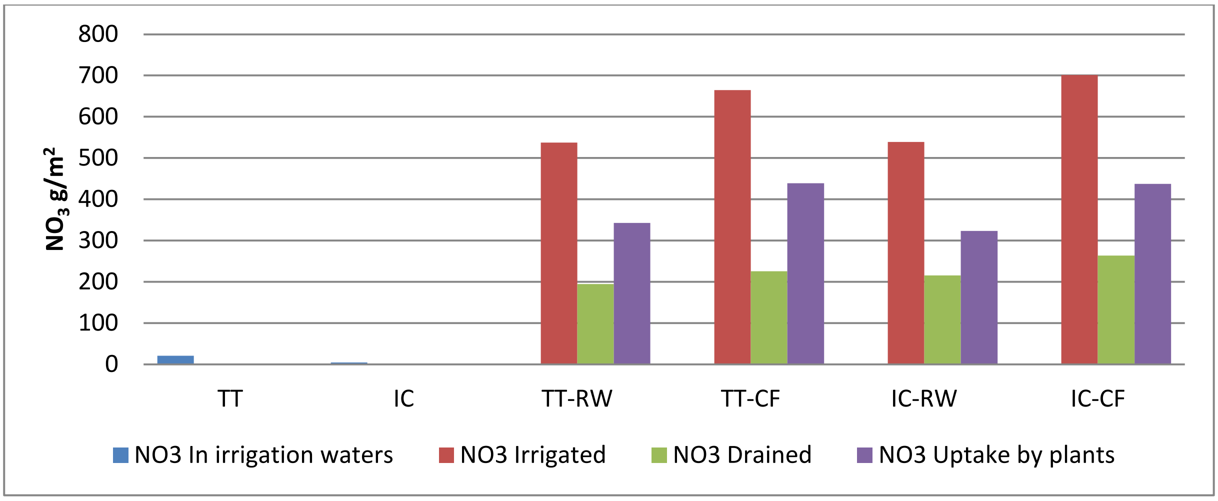

Figure 15: NO_3 loads of the water streams (g/m^2)

Figure 15 indicates that the NO_3 load in the irrigation waters TT and IC are very low compared with the irrigated loads. The NO_3 load of IC is even so low that it cannot be seen in the figure. The average irrigated load was 610 g/m^2. The TT had a load of 21 g NO_3/m^2, this is 3.4% of the irrigated load, and IC had a load of 4 g NO_3/m^2, this is 0.7% of the irrigated load. The NO_3 load of peppers growing on coconut fiber (CF) is higher compared to the NO_3 load of peppers growing on rock wool (RW). This difference is due to the difference in water supply, CF received more water than the peppers growing on RW. On average there is drained 225g NO_3/m^2, this is 37% of the irrigated load. The plant uptake is the difference between the irrigated load and the drained load. The average uptake was 385 g/m^2.

On average there were 2.5 plants per m^2 in this research. The NO_3 uptake per plant is 154 g/plant (385 g/m^2 divided by 2.5 plants per m^2). This uptake is high compared to the uptake that is found in the research of Sabli (2012) and in the research of Segura (et al, 2012). The uptake in their researches were 16.4 g NO_3/plant (Sabli) and 46.5 g NO_3/plant (this research used tickle irrigation and the peppers were grown on sandy loam soil).

4.2.4 Phosphorus

The phosphorus is measured in PO_4, those measurements are shown in Table 12. In the last column the PO_4 is multiplied by the convention rate of 0.75, this is the convention rate to convert PO_4 to P_2O_5, see chapter 2.4 Nutrient conversion .

Table 12: P_2O_5 measurements in the water flows (in mg/L)

Water stream	10-jun	14-jul	18-jul	22-jul	25-jul	Average concentration	**Average in P_2O_5**
TT	1.62	4.17	3.33	2.62	5.34	3.42	**2.55**
IC	0.60	0.32	0.26	0.29	0.36	0.37	**0.27**
IRIS		4.83	5.00	4.42	4.77	4.75	**3.55**
TT-T	72.95	53.23	52.80	50.79	57.33	57.42	**42.91**
IC-T	63.72	50.51	54.14	53.13	57.34	55.77	**41.68**
TT-RW	41.12		21.34	41.65		34.70	**25.93**
TT-CF	62.63		29.32	55.42		49.12	**36.71**
IC-RW	42.10		43.38	52.62		46.03	**34.40**
IC-CF	50.51		58.65	58.19		55.78	**41.69**

The concentrations of the irrigation waters (TT, IC, and IRIS) are low compared to the concentrations which are irrigated (TT-T and IC-T). The average irrigated concentration is 42 mg P_2O_5/L (TT-T of 42.9 mg/L and IC-T of 41.7 mg/L). The concentration in the TT water is 6.03% of the concentration which is irrigated, this is 0.65% for IC water, and 8.40% for IRIS water. The rest of the P_2O_5 is coming from fertilizers. The concentrations in the drainage are higher than in the irrigated waters.

According to Calpas (2009) the P_2O_5 concentration that should be applied for an optimum pepper yield is 55 mg P_2O_5/L. The applied concentration is 76% of the recommended concentration. The concentrations of phosphate are applied with an amount of water. The amount of water times the applied nutrient concentration results in the load of the nutrient. The applied waters are given in chapter 4.1 Water supply to the irrigation sections. In Figure 16 the P_2O_5 loads are given of the irrigation water, irrigation loads, drainage loads, and plant uptake loads. The loads of P_2O_5 in the irrigation water and the irrigated load are based on the measured concentrations times the applied water. The drainage load is based on the 30% drainage amount and the measured concentrations in the drainage waters. The plant uptake load is based on the irrigation load minus the drainage load, the P_2O_5 that is applied that is not in the drainage water is taken up by the pepper plants. The calculations are shown in Appendix C: Nutrient load calculations.

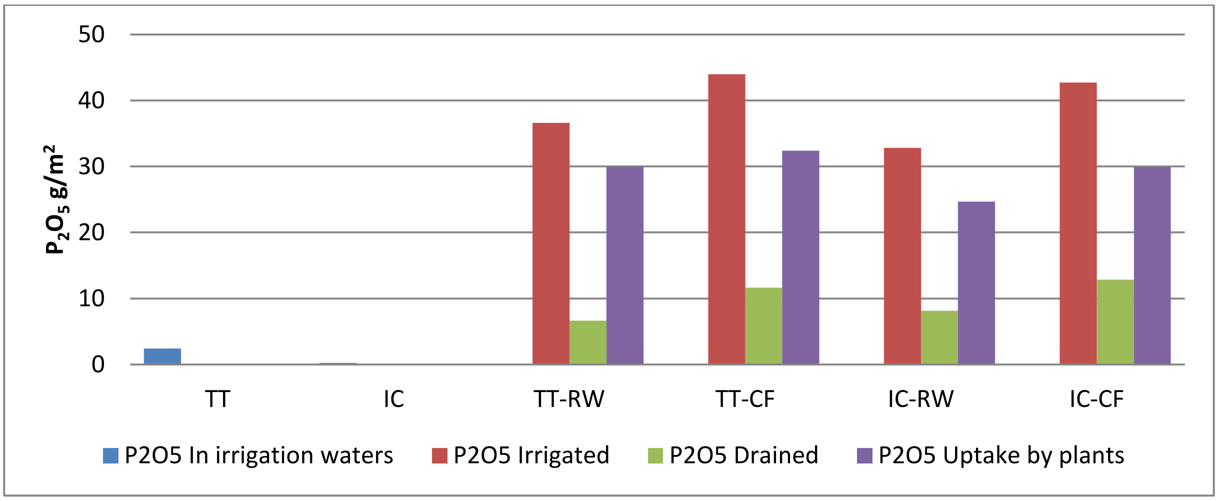

Figure 16: P_2O_5 loads of the water flows (g/m^2)

Figure 16 indicates that the P_2O_5 load in the irrigation waters TT and IC are very low compared with the irrigated loads. The average irrigated load was 39 g/m^2, the TT had a load of 2.4 g P_2O_5/m^2, this is 6.2% of the irrigated load, and IC had a load of 0.3 g P_2O_5/m^2, this is 0.6% of the irrigated load. The P_2O_5 load of peppers growing on CF is higher compared to the P_2O_5 load of peppers growing on RW. This difference is due to the difference in water supply, CF received more water than the peppers growing on RW. On average there is drained 10 g P_2O_5/m^2, this is 25% of the irrigated load. The plant uptake is the difference between the irrigated load and the drained load. The average uptake was 29 g/m^2.

On average there were 2.5 plants per m^2 in this research. The P_2O_5 uptake per plant is 11.7 g/plant (29 g/m^2 divided by 2.5 plants per m^2). This uptake is high compared to the uptake that is found in the research of Sabli (2012). The uptake in their researches was 0.07 g P_2O_5/plant.

4.2.5 Potassium

The phosphorus is measured in K those measurements are shown in Table 13. In the last column the K_2O is multiplied by the convention rate of 1.20, this is the convention rate to convert K to K_2O.

Table 13: K_2O measurements in the water flows (in mg/L)

Water stream	10-jun	14-jul	18-jul	22-jul	25-jul	Average	**Average in K_2O**
TT	32.04	35.80	37.43	33.79	34.02	35	**41.7**
IC	7.67	7.77	7.52	6.55	6.85	7	**8.8**
IRIS		28.61	35.93	26.61	27.40	30	**36**
TT-T	252.30	203.00	209.90	232.20	204.00	220	**265**
IC-T	230.90	200.30	219.30	227.10	203.30	216	**260**
TT-RW	261.60		233.60	263.00		253	**304**
TT-CF	261.90		241.70	296.70		267	**321**
IC-RW	233.30		262.70	302.10		266	**320**
IC-CF	225.90		277.40	294.20		266	**320**

The concentrations of the irrigation waters (TT, IC, and IRIS) are low compared to the concentrations which are irrigated (TT-T and IC-T). The average irrigated concentration is 263 mg K_2O/L (TT-T of 265 mg/L and IC-T of 260 mg/L). The concentration in the TT water is 15.9% of the concentration which is irrigated, this is 3.3% for IC water, and for IRIS water 13.6%. The rest of the K_2O is coming from the fertilizers. The concentrations in the drainage are higher than in the irrigated waters.

According to Sabli (2012) the K_2O concentration applied can a bit higher. Sabli found an optimum K_2O concentration of maximum 321 mg/L, the applied concentration is 82% of this (263 mg/L).

The concentrations of potassium are applied with an amount of water. The amount of water times the applied nutrient concentration results in the load of the nutrient. The applied waters are given in chapter 4.1 Water supply to the irrigation sections. In Figure 17 the K_2O loads are given of the irrigation water, irrigation loads, drainage loads, and plant uptake loads. The loads of K_2O in the irrigation water and the irrigated load are based on the measured concentrations times the applied water. The drainage load is based on the 30% drainage amount and the measured concentrations in the drainage waters. The plant uptake load is based on the irrigation load minus the drainage load, the K_2O that is applied that is not in the drainage water is taken up by the pepper plants. The calculations are shown in Appendix C: Nutrient load calculations.

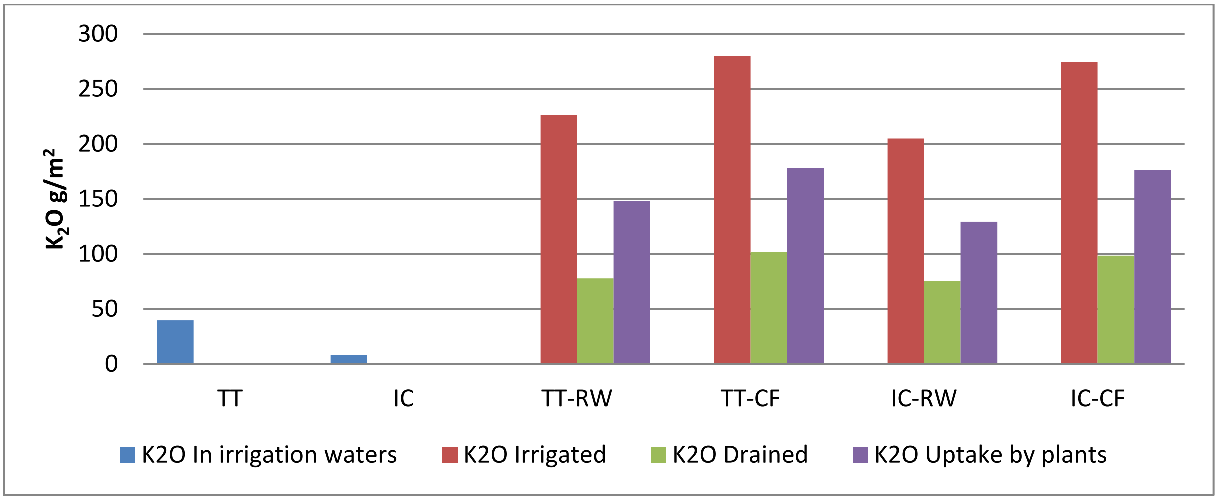

Figure 17: K_2O loads of the water flows (g/m^2)

Figure 17 indicates that the K_2O load in the irrigation waters TT and IC are low compared with the irrigated loads. The average irrigated load was 246 g/m^2, the TT had a load of 40 g K_2O/m^2, this is 16.1% of the irrigated load, and IC had a load of 8 g K_2O/m^2, this is 3.2% of the irrigated load. The K_2O load of peppers growing on CF is higher compared to K_2O load of peppers growing on RW, on average 60g K_2O/m^2. This difference is due to the difference in water supply, CF received more water than the peppers growing on RW. On average there is drained 88 g K_2O/m^2, this is 36% of the irrigated load. The plant uptake is the difference between the irrigated load and the drained load. The average uptake was 158 g/m^2.

On average there were 2.5 plants per m^2 in this research. The K_2O uptake per plant is 63 g/plant (158 g/m^2 divided by 2.5 plants per m^2). This uptake is high compared to the uptake that is found in the research of Sabli (2012). The uptake in their researches was 4.9 g K_2O/plant (Sabli 2012), what is 12 times less than the uptake calculated in this research.

4.3 Salinity

The salinity is an important element of irrigation water. To high salinity levels can reduce the yield or even prohibit the growth (Grattan, 2002). There are two ways to describe the salinity level, one is in total dissolved solids (TDS) and the other way is the electrical conductivity (EC). TDS are usually expressed in mg/L. EC is mainly expressed in decisiemens per meter (dS/m) or in millimhos per centimeter (mmhos/cm), (one mmhos/cm is one dS/m) (Grattan, 2002). The conversion between TDS and EC is, TDS (mg/l) is 640 times EC (dS/m). EC can be for more parameters, for irrigation water it is common to use ECw and for saturated soil extract it is common to use ECe.

4.3.1 Salinity tolerance

The salinity is not only important for the irrigation water, also the salinity of the soil is important. Salt accumulation in the soil is mainly coming from two processes. One process is the upward flowing of saline groundwater in the field and the other way is saline irrigation water (Grattan, 2002). Salt accumulation results in high salinity levels. Crops have different salinity threshold levels. Some crops are more tolerant for salinity than other crops. There is a difference in the threshold for ECw and ECe. In Figure 18, there are the thresholds for different salinity tolerant levels.

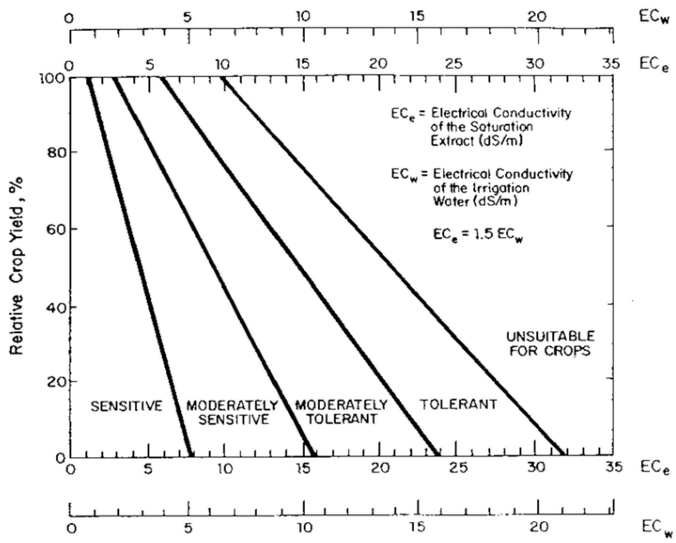

Figure 18: Divisions for relative salt tolerance ratings of agricultural crops (Maas, 1984)

Maas and Grattan (Maas & Grattan, 1999) have made a list of crops with the decline in yield according to the increase of salinity. This decline for the pepper Capsicum Annuum is shown in Table 14.

Table 14 estimate the yield of pepper with long-term use of irrigation water of different qualities (the potential yields are based on a LF between 15-20%) based on Maas and Grattan 1999.

Table 14: Yield reduction by different salinity levels

	EC (dS/m)									
	Yield potential									
	100%		90%		75%		50%		0%	
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw
Pepper (Capsicum Annuum)	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8

Table 14 shows that an ECw of 2.2 gives a yield potential of 75%, this means that Capsicum Annuum is moderately sensitive or salinity according to Figure 18.

To avoid problems with too saline irrigation water, more water than the crops need is irrigated. This process is called leaching. The extra water which is not taken up by the plants is drained. This drainage water can carry salts with it. The amount of water that is used for leaching is called the leaching fraction (LF). According to Ayers and Westcot (Ayers & Westcot, 1985) the following relations between LF, ECw and ECe are counting:

LF 10% leads to ECw x 2.1 = ECe
LF 15-20% leads to ECw x 1.5 = ECe
LF 30% leads to ECw = ECe

In the IRIS project there is applied a leaching fraction of 30%, this means that the ECe is the same as the ECw.

4.3.2 Salinity levels of the irrigation waters

The salinity levels are measured for IC and TT when the calculations for fertilizers were made. The measured concentrations are shown in Table 15.

Table 15: Salinity concentrations of IC and TT (dS/m)

Date	IC	TT
24-12-2013	1.913	2.357
27-02-2014	2.026	2.360
11-03-2014	1.695	2.185
22-03-2014	1.862	2.387
30-04-2014	2.276	2.404
12-07-2014	2.102	2.416
30-07-2014		2.225
Average	1.979	2.333

The salinity level of IC (1.98 dS/m) is lower than the salinity level of TT (2.33 dS/m). The IC water is a mix of different waters, the biggest part is Tajo-Segura transfer water. This water has a relatively low salinity level, lower than 1 dS/m (Pedrero et al., 2013).

According to Maas and Grattan (1999) the yield potential decreases to 75% by a salinity of the irrigation water of 2.2 dS/m. Lower salinity levels can increase the yield. Therefore the idea of the new treatment system to reduce the salinity can have an improvement in yield.

The drainage is 30% of the irrigation water, what results in a salinity level in the (hydroponic) soil that is the same as the salinity of the irrigation water according to Ayers and Westcot (1985).

4.4 Safety

An important parameter for safety is the E. coli (Escherichia coli) concentrations (Pescod, 1992). E. coli is a bacteria that normally lives in the intestines of people and animals. Most of the E. coli are harmless and are important for the health of human intestinal (NIH, 2011). However some E. coli bacteria are pathogenic, what means that they can cause illness. They can cause even bloody diarrhea and sometimes cause kidney failure and even death (NIH, 2014). By testing positive on E. coli it shows that there is E. coli, what does not mean that it is harmful, but it shows that it is contaminated. A source of E. coli can be inter alia contaminated water and contaminated food like raw vegetables. To avoid health problems there are regulations for the amount of E. coli in treated water.

4.4.1 Regulations

The Spanish regulations of E. coli in the water are described in the Royal Decree 1610/2007 of 7 December. The Royal Decree sets the legal framework for the reuse of treated wastewater. The Royal Decree overturns all other regulations of an equal or lesser legal status that contravene the provisions that are set out in the Royal Decree. The Royal Decree describes five intended water reuse purposes. For those different reuses, there are different standards. The five uses are; (1) urban uses, (2) agricultural uses, (3) industrial uses, (4) recreational uses, and (5) environmental uses. The three different water sources that are used in the research must meet the regulations that governing agricultural uses. The regulations for agricultural uses are split up in 3 quality categories. The 3 different categories are shown in Table 16 and the regulations related to those categories are shown in Table 17.

Table 16: Spanish wastewater reuse regulations (the Royal Decree 1610/2007)

Category	Description
1	a) Crop irrigation using a system whereby reclaimed water comes into direct contact with edible parts of the crops to be eaten raw
2	a) Irrigation of crops for human consumption using application methods that do not prevent direct contact of reclaimed with edible parts of the plants. which are not eaten raw but after an industrial treatment process. b) Irrigation of pasture land for milk- or meat-producing animals c) Aquaculture
3	a) Localized irrigation of tree crops whereby reclaimed water is not allowed to come into contact with fruit for human consumption. b) Irrigation of ornamental flowers, nurseries and greenhouses whereby reclaimed water does not come into contact with the crop. c) Irrigation of industrial non-food crops. Nurseries, silo fodder, cereals and oilseeds.

Every category has its own regulations, those regulations are shown in Table 17.

Table 17: Spanish wastewater reuse regulations (the Royal Decree 1610/2007)

Agricultural use	Intestinal nematodes	Escherichia coli	Suspended solids	Turbidity	Other criteria
1	1 egg/10L	1.000 CFU/100mL[4]	20 mg/L	10 NTU[5]	Legionella spp. 1.000 CFU/L. (if there is a risk of aerosolization) Discharge of contaminants to the environment must be limited
2	1 egg/10L	1.000 CFU/100mL	35 mg/L	No set limit	Taenia saginata and Taenia solium: 1 egg/L. (when irrigation pasture land for milk- or meat- producing animals) Discharge of contaminants to the environment must be limited
3	1 egg/ 10L	10.000 CFU/100mL	35 mg/L	No set limit	Legionella spp. 100 CFU/L Discharge of contaminants to the environment must be limited

The table shows that quality level depends on the risk of contamination. If there is a high risk (quality 1, where the raw eaten crops come in contact with the water) the regulations are stricter than where the crop does not come into contact with the water (quality 3).

In the IRIS project wastewater is reused for edible crop production in greenhouses. The water is applied by drip irrigation to the crops. By drip irrigation the treated wastewater does not come in direct contact with the crops. Quality 3b is valid for the IRIS project; greenhouses whereby reclaimed water does not come into contact with the crop. Therefore the regulations that count for agricultural use 3 are counting.

4.4.2 E. coli concentrations

The E. coli concentrations are measured by ESAMUR, the company that controls the WWTPs in the area, and by an extern company. From the drainage waters only the drainage on coconut fiber is measured, this is done because in the previous research with tomatoes there were found E. coli in

[4] CFU stands for Colony-forming unit, it is an estimation of the number of viable bacteria
[5] NTU stands for Nephelometric Turbidity Unit, gives the turbidity of a suspension

the drainage water of coconut fiber. The results of the measurements are shown in Appendix D: E.coli measurements

The concentrations of E. coli in the waters that are used (TT and IC) for irrigation are below the regulations. The maximum concentrations that are measured for TT water was 33 CFU/100mL and for IC 150 CFU/100mL. The limited concentration of E. coli according to the Royal Decree 1610/2007 is 10,000 CFU/100mL. When the fertilizers are added to the waters the concentrations are higher. For IC-T the concentration are up to 60 CFU/100mL and for TT-T 77 CFU/100mL. This assumes that there is E. coli in the fertilizers. Therefore the fertilizers are also measured. Most fertilizers have concentrations under the 10 CFU/100mL. However, the Fe + micro nutrients have higher concentrations, even up to 80.000 CFU/100ml. The concentrations of E. coli in the effluent of CF are low, the highest concentration that is measured is 54 CFU/100mL for TT-CF.

The concentrations of the IRIS water are most of the time much higher than the concentrations of IC and TT. Sometimes the concentrations are higher than 120,000 CFU/100mL. This is strange, because the IRIS treatment makes use of nano filtration, this should remove E. coli. Also it is strange that the measurement of 7 July show an increase in E. coli in the effluent (after the nano filtration) compared with the E. coli concentration after ultra filtration. The treatment system was most of the time not running, so the water was not treated well. Maybe, when the treatment system was not running there was flowing untreated water to the tank where the treated water was stored.

The regulation is that the concentration should be below 10,000 CFU/100mL. This means that the concentrations of E. coli for TT and IC are far below the regulations. However, the concentrations of E. coli in the IRIS water are sometimes far above the regulations.

Farmers that are using IC water are sometimes complaining about the quality of the reused water (Mariano Soto García, personal communication, June 25, 2014). For them it seems not to be save, but in a research that is done in Murcia is shown that the E. coli and fecal coliforms in the transfer water sometimes exceed the concentrations of tertiary-treated wastewater (Pedrero et al., 2013).

4.5 Yield

The peppers are harvested in three times. The yield is measured from the four different irrigation groups. There were two water sources used, the IC water and the TT water, both waters were used to irrigate two different hydroponics, rock wool (RW) and coconut fiber (CF). The yields are classified in different commercial weights. Table 18 shows the yields.

Table 18: Pepper yields

	GG (>190g)	G (160-219g)	M (120-159g)	MM (90-119g)	I (Industrial)	D (non commercial)	Total (kg/m2)
TT-RW	0.12	1.48	3.86	1.36	1.09	0.16	8.07
TT-CF	0.47	2.15	3.27	1.29	2.19	0.29	9.65
IC-RW	0.20	2.04	3.90	1.03	0.97	0.13	8.26
IC-CF	0.75	2.52	3.08	0.96	1.69	0.18	9.19

Table 18 indicates that the yield on RW are lower than on CF. The average yield of IC and TT are almost the same, 8.7 kg/m^2 for IC and 8.8 kg/m^2 for TT. If only the commercial yields are counting, so not the industrial (I) and non commercial (D), the results of this are shown in Table 19.

Table 19: Commercial pepper yields

Treatment	Total (kg/m2)
TT-RW	6.8
TT-CF	7.2
IC-RW	7.2
IC-CF	7.3

The commercial yield is between 6.8 and 7.3 kg/m2. This is lower than the maximum commercial yield that is found in other researches, up to 9 kg/m^2 (Jovicich et al, 2003). Grubben and Mohamed (Grubben & Mohamed, 2004) mention that the yield of pepper (Capsicum Annuum) can be up to 30 t/ha in the field and up to 100 t/ha (10 kg/m^2) in protected cultivation, like a greenhouse

The overall yield (also the industrial and non commercial yield included) were between 8.1 and 9.7 kg/m^2. The average commercial yield of peppers irrigated with IC water is 7.2 kg/m^2. This is the average of yield on coconut fiber and on rock wool. The difference between those is 0.1 kg/m^2 (IC-CF 7.3 and IC-RW 7.2 kg/m^2). For TT water is the average 7.0 kg/m^2 of commercial yield. The difference between rock wool and coconut fiber irrigated with TT water is 0.4 kg/m^2 (TT-CF 7.2 and TT-RW 6.8 kg/m^2). The difference between rock wool and coconut fiber with both irrigation waters is 0.25 kg/m^2. The difference between IC and TT water is on average 0.2 kg/m^2 (IC 7.2 and TT 7.0), which is a difference of 3%.

The average commercial yield on rock wool is 7.0 kg/m^2 and for coconut fiber 7.3 kg/m^2. The yields on coconut fiber have more big peppers. On rock wool the yield of big peppers (above 190 grams) was 0.12 kg/m^2 (TT-RW) and 0.20 kg/m^2 (IC-RW) and on coconut fiber was this 0.75 kg/m^2 (IC-CF) and 0.47 kg/m^2 (TT-CF). The non commercial yield on CF is much more than the non commercial yield on RW.

5 Discussion

5.1 Irrigation volumes

The amount of water applied in the IRIS project seems to be high. The applied amount of water is more than the applied amount of water in other researches. The amount of water supply is based on the drainage amount. The drainage amount in this research is 30%. The 30% is not an extremely amount, however if the drainage amount in reality was higher than the supposed 30%, the irrigation supply increased. Another cause of the higher irrigation volumes is that water is used for cleaning the drippers, but this is not enough to explain the high water supply.

The nutrient supply seems on the high end but the nutrient loads are high. The concentrations that are applied for P_2O_5 and K_2O are not higher compared to other researches. However, the concentration of NO_3 is higher compared with other researched. A possible explanation might be the higher water supply, which increases the amount of nutrient applied

The amount of nutrient uptake which is calculated seems not reliably. Compared with other researches the amount of uptake is far too high. The nutrient uptake is based on the nutrient applied and the nutrient that are drained. The applied nutrients minus the drained nutrients are the nutrients uptake. The drained nutrient is calculated with a drainage percentage of 30% of the irrigated water. If the drainage percentage was in reality more than 30%, the amounts of nutrients drained are more than was calculated. This results in a lower amount of nutrient uptake by the plants.

Based on the high irrigation supply, high nutrient supply and high nutrient uptake, it seems that the drainage amount was higher than the supposed 30%. To avoid mistakes and uncertainties about water supply in further research the water that is used for cleaning should not be measured as irrigation water and the drainage amount measurement should be checked.

5.2 Irrigation water demand

This research is located in a water shortage region where the wastewater is already reused. Only using treated wastewater is not enough to cover the irrigation demand, therefore there is also transfer water, groundwater, and desalination water. By implementing IRIS treatment systems instead of the conventional WWTPs that are used at the moment, there is still a need for those other water sources. However, by using water with a lower salinity level, where the IRIS treatment system is also designed for, the leaching fraction can be smaller. This results in a lower water demand.

5.3 E. coli concentrations

The high E. coli concentrations found in the different parts of the IRIS treatment system are remarkably. The IRIS treatment system makes use of nano filtration, this should remove the E. coli, however in some measurements the E. coli concentration increased after the nano filtration step. The samples were taken at the same time and same way as the other samples. Therefore, it is not likely that the way of sampling has an influence on the measured concentration. The treatment system was most of the time not working, it might be possible that if the treatment system is not working, untreated water is flowing to the effluent. So the treated water is mixed with untreated water. One day the water in the storage tank of IRIS treated water was black and not treated well. By trying to filter the water through a 0.45 µm filter, the filter was blocked directly which is not possible if the water is filtered by a nano filter. Therefore, it seems that untreated wastewater sometimes flows to the effluent storage tank. The IRIS treatment system is a pilot system, therefore it is normal that the system is not working fluently all the time.

5.4 Yield

The yield in this project was not as high as it could be according to other research. The yield is dependent on, among others the salinity level and nutrient concentrations of the irrigation water. According to literature, the salinity level of the irrigation waters was too high to get an optimum yield. The nutrient concentrations of P_2O_5 and K_2O were a bit low to get the maximum yield. One of those factors is likely the weakest link to get a maximum yield. On the salinity level there is no influence, the irrigation waters are coming from the Irrigation community and the effluent of a WWTP. In next research the nutrient concentrations of P_2O_5 and K_2O can be increased to see if this is the weakest link in the yield. One of the design objectives of the IRIS treatment system was to reduce the salinity level. It would be interesting to see if the yield will increase when the system is working well because of the lower salinity level.

5.5 Location

The conventional WWTPs in the area improved in the period of the master plan in 2001-2010. These are big investments and also the infrastructure which was made for all the different water sources. Therefore, it seems not realistic that those WWTPs will be replaced in the coming years by other technologies. The IRIS treatment system with the connected greenhouse and fertilization techniques might be interesting for areas were wastewater treatment is not yet sufficient. The IRIS treatment system is compact, one container, and could be placed in areas without a connection to a sewage system, like outlying villages. The capacity of the pilot project is $5m^3$/day, but according to the company the capacity can be increased.

5.6 Infrastructure by implementing IRIS treatment systems

If the irrigation demand is lower compared to the produced effluent of the IRIS treatment system there should be storage. Otherwise the effluent of the IRIS treatment system flows to the surface waters. The IRIS treatment system is designed in such a way that this water has higher nutrients concentrations. If this flows to surface waters the nutrient concentration in those waters will increase. If that is the case the situation can become the same as the situation before implementing the Master Plan for Urban Wastewater Sanitation and Treatment in the Murcia Region 2001-2010, with dirty and smelly surface waters. The irrigation infrastructure that is now used has storage ponds. Those storage ponds are not covered. The problem with storage of nutrient rich water in those ponds is that there is a big change on algae growth, especially with the high temperatures in the area. The algae in the irrigation waters can cause problems with clogging the pumps, the pipelines, and drippers. Therefore, a solution should be made in order to deal with the produced water if it is not used directly before implementing treatment systems with nutrient rich effluents.

5.7 Nutrient measurements

The idea was to do a lot of measurement with the Caplix measurement unit. This unit is designed to do quick analysis, in one morning you can measure all the water streams. This measurement unit is a pilot unit, there were still some starting problems. In the beginning of the research most of the measurements were done with the Capilix. Later on, when it became clear that the results were not always reliable, water samples were analysed in the lab. If the pilot measurement unit is better calibrated and functioning well there is a big advantage of using it. There can be done more measurements and even online measurements, so the fertilization can be adjusted better.

5.8 Legislations

The legislations for effluent water should be changed if a treatment system is used that produce effluent waters with high nutrient concentrations. At the moment, the concentrations of the effluent are based on surface waters, to avoid environmental problems like eutrophication. The WWTPs are designed to meet the concentrations of those legislations, but by using treatment systems with the goal to produce the best water for irrigation, the legislations should be changed.

6 Conclusion

The different water sources TT, IC and IRIS do not differ much in nutrient concentrations. The concentrations of NO_3, P_2O_5, and K_2O in the water sources are a small fraction of the nutrient concentrations which are used for irrigation. The highest fraction for NO_3 (3.3%) and K_2O (15.9%) are found in the TT water. The highest fraction of P_2O_5 (13.6%) of the irrigated water is found in the IRIS water, the fraction in the TT water was a bit lower (6.0%) The IRIS treatment system does not leave more nutrients in the water than the effluent of the conventional WWTP of Roldán-Balsicas (TT). If TT water is used instead of the IC water which is used for irrigation currently, the fertilizer savings of NO_3 can be 2.5%, for P_2O_5 5.4% and for K_2O 12.5%. However, the WWTPs in the area do not produce enough water to cover the irrigation demand, therefore other water sources are still necessary.

The salinity level of TT is 2.3 dS/m and from IC 2.0 dS/m. A salinity level above the 1.0 dS/m decreases the yield of bell peppers (Capsicum Annuum). Therefore the salinity level of IC is better for irrigation than TT. The lower salinity level of IC is explained due to the transfer water of Tajo-Segura which is used in this water, with a salinity level below 1 dS/m. The IRIS water was not used for irrigation and not measured. Therefore, it is not know if the IRIS treatment reduces the salinity level.

For the safety of using the irrigation water E. coli concentrations in the waters are measured. The concentration of E. coli in the TT and IC water are far below the regulations of 10,000 CFU/100mL. However, the concentrations measured in the IRIS water are sometimes far above the regulations up to >120,000 CFU/100mL. The high E. coli concentrations are not possible after the filtrations steps that are taken in the IRIS treatment system. It is likely that there was contamination with untreated wastewater when the pilot treatment system was not running.

The difference in yield between TT and IC water is negligible, 3% to the advantages of IC. The difference in yield between the different hydroponic substrates rock wool and coconut fiber is small.

In conclusion, the IRIS treatment system did not show that it improves the quality of irrigation water in this research. This is mainly due to malfunctioning of the treatment system, the treatment system was most of the time not running. The advantage of using TT water instead of IC water is to have some more nutrients, especially K_2O, in TT water. However, there is not enough water produced by WWTPs in area to meet the irrigation demand, therefore IC water is always necessary. For farmers it is good to know that the TT water is safe to use for irrigation.

7 Recommendations

The recommendations are divided in recommendation for the next research on the IRIS project and in recommendations for further research.

7.1 Recommendations for the next research on the IRIS project

Working treatment system

For analysing a treatment system it should be working. Therefore there is need for a reliable treatment system or at least a person from the company that can fix the problems quickly. Because now is the treatment system most of the time not working and is it not known if the water that is produced is treated as it should be.

Reusing drainage water

Another element that is interesting to implement in a next research is the drainage water. The measurements make clear that the nutrient concentrations in the drainage waters are much higher than the concentrations of nutrients in the irrigation waters. The drainage water is not reused in this research. The nutrient saving that can be made by reusing drainage water seems much more than the nutrient saving by making use of the IRIS treatment system. By reusing drainage water, the salinity level should be taken into account. Because of evapotranspiration of water, the salinity levels in the drainage water are higher than of the irrigated water. The drainage water is now flowing to the WWTP of Roldán-Balsicas and treated there. If the IRIS treatment system is implemented the drainage water should be treated. The concentrations of nutrient in the drainage are too high for surface water

7.2 Recommendations for further researches

Water use efficiency of the hydroponic substrates

Research should be done to the water use efficiencies of the hydroponic substrate. The area of Murcia is a dry and water shortage area, so the most water use efficient hydroponic substrate should be used in the area.

Infrastructure

There should be thought about how a new treatment system can be implemented in the infrastructure that is used now. Who will be connected to the effluent of the new treatment systems, or is the effluent flowing to the mix water of the irrigators community? Because of the higher nutrient concentrations it cannot flow to the surface water, so what should be done with the effluent in periods when the water is not needed?

E. coli concentration in the iron with micro elements

In the iron with micro elements that is applied to the irrigation waters is found an E. coli concentration of 80,000 CFU/100 mL. This is above the regulations for irrigation water, this concentration reduce by dilution with the irrigation water. But it is interesting to know where this high concentration is coming from.

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Appendices

Appendix A: The requested nutrient concentrations

The fertilizers applied to the irrigation water are based on the nutrient concentrations that farmers are using in the area. The concentrations that are requested are shown in Table 20. The concentrations are given in mmol/L and in mg/L. To convert the concentrations from mmol/L to mg/L the mmol should be multiplied by the molar weight.

Table 20: The concentrations that should be applied in mmol/L and mg/L

Period	mmol/L NO_3	mg/L NO_3	mmol/L P_2O_5	mg/L P_2O_5	mmol/L K_2O	mg/L K_2O
24/12/2013 -26/01/2014	10	620	1,5	213	5,5	518
27/01/2014 - 10/03/2014	11	682	1,8	255	5,5	518
11/03/2014 -21/03/2014	12	744	1,6	227	6,6	622
22/03/2014 -29/07/2014	14	868	1,6	227	6	565
30/07/2014 - 07/08/2014	12	744	1,6	227	6	565

Appendix B: Overview of sampling points for E. coli measurement

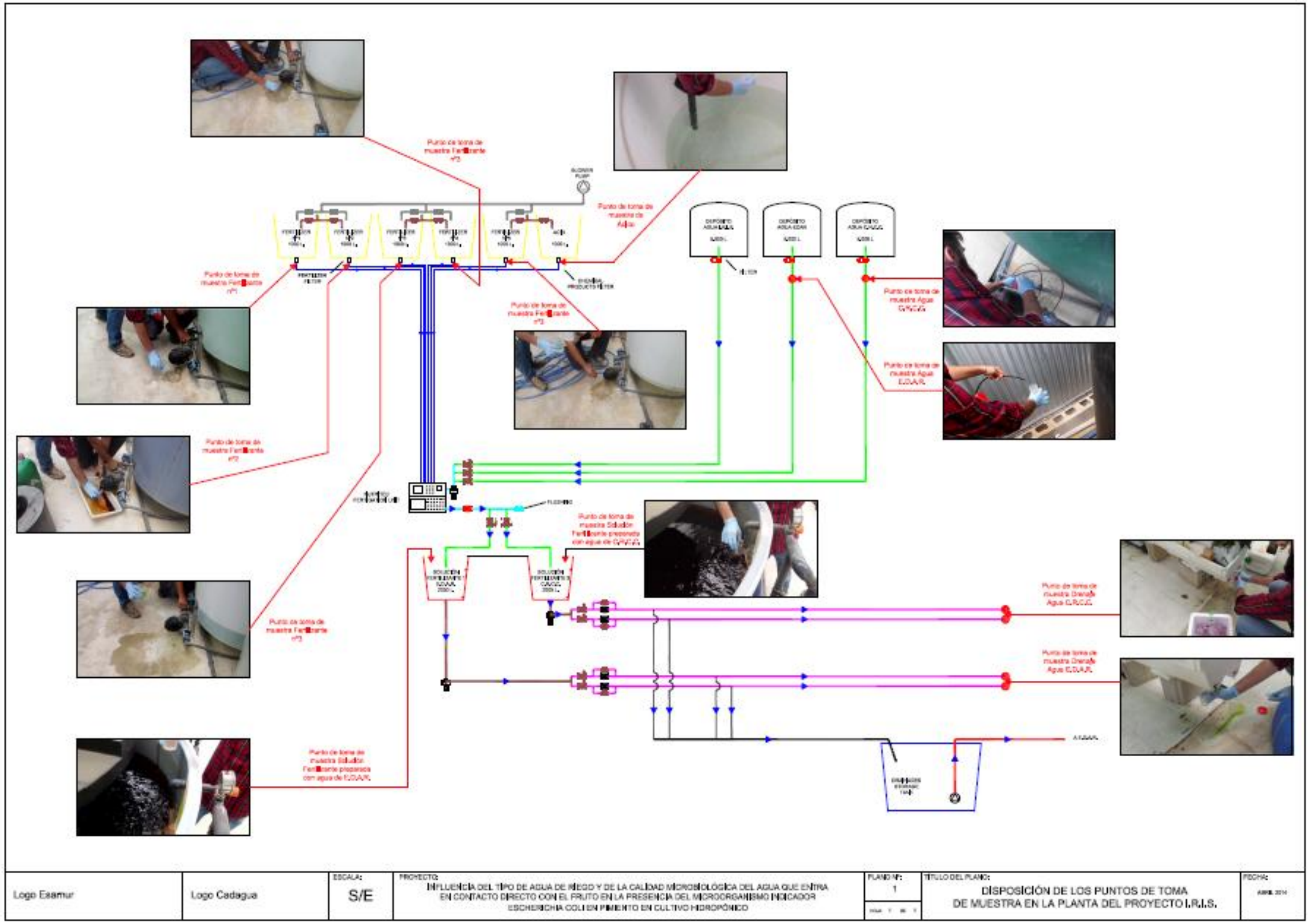

Figure 19: Sampling points for E. coli measurements

Appendix C: Nutrient load calculations

The loads are the concentrations times the amount of water. The amount of water that is applied to the different irrigation section is measured. The measured values are given in the table below in L/m^2.

Table 21: Water supply (L/m^2)

Period	TT-RW	TT-CF	IC-RW	IC-CF
24/12/2013 -26/01/2014	23	21	26	26
27/01/2014 - 10/03/2014	54	41	49	44
11/03/2014 -21/03/2014	18	26	17	26
22/03/2014 -29/07/2014	671	867	616	833
30/07/2014 - 07/08/2014	87	100	81	95
TOTAL	**853**	**1054**	**787**	**1025**

On average there is 954 L/m^2 ((853+1054)/2) of TT water supplied and 906 L/m^2 ((787+1025)/2) of IC water supplied.

The load calculation of NO_3 is done in Table 22. The amount of water supplied (column 3) times the concentration (column 4) gives the load (column 5). The water supply is given in L/m^2 and the concentration in mg/L, this gives mg/m^2, because of the high values than, this is divided by 1000, to get g/m^2. The concentrations of the irrigation water that are flowing to TT-RW and TT-CF are the concentration that is measured in the fertilizer tank TT-T. The same counts for IC-RW and IC-CF, this is the concentration that is measured in the fertilizer tank IC-T.

Table 22: NO_3 loads in the different water flows (g/m^2)

Waters		Water supply (L/m^2)	Concentration NO_3 mg/L	Load NO_3 g/m^2
TT	Water source	954	21.59	21
IC	Water source	906	4.63	4
TT-RW	Irrigation water	853	630.06	537
TT-CF	Irrigation water	1054	630.06	664
IC-RW	Irrigation water	787	684.13	539
IC-CF	Irrigation water	1025	684.13	701

The same calculations are done for phosphorus and potassium, see Table 23 for phosphorus and Table 24 for potassium.

Table 23: P_2O_5 loads in the different water flows (g/m^2)

Waters		Water supply (L/m^2)	Concentration P_2O_5 mg/L	Load P_2O_5 g/m^2
TT	Water source	954	21.59	2.43
IC	Water source	906	4.63	0.25
TT-RW	Irrigation water	853	630.06	36.59
TT-CF	Irrigation water	1054	630.06	43.97
IC-RW	Irrigation water	787	684.13	32.82
IC-CF	Irrigation water	1025	684.13	42.70

Table 24: K_2O loads in the different water flows (g/m^2)

Waters		Water supply (L/m^2)	Concentration K_2O mg/L	Load K_2O g/m^2
TT	Water source	954	21.59	40
IC	Water source	906	4.63	8
TT-RW	Irrigation water	853	630.06	226
TT-CF	Irrigation water	1054	630.06	280
IC-RW	Irrigation water	787	684.13	205
IC-CF	Irrigation water	1025	684.13	275

Nutrient loads in the drainage waters

The drainage amount is 30% of the irrigated amount of water. The amounts of drainage are shown in Table 25.

Table 25: Amount of drainage water (L/m^2)

Waters		Water supply (L/m^2)	Calculation
TT-RW	Drainage water	236	0.3 times 853
TT-CF	Drainage water	307	0.3 times 1054
IC-RW	Drainage water	256	0.3 times 787
IC-CF	Drainage water	316	0.3 times 1025

The amount of drainage water times the concentration of the nutrients in the drainage waters gives the loads of nutrients in the drainage water.

Table 26: Nutrient loads in the drainage water (g/m^2)

Drainage waters	Concentration NO_3 (mg/L)	Load NO_3 (g/m^2)	Concentration P_2O_5 (mg/L)	Load P_2O_5 (g/m^2)	Concentration K_2O (mg/L)	Load K_2O (g/m^2)
TT-RW	760.80	215	26	8,13	304	76
TT-CF	713.65	264	37	12,81	321	98
IC-RW	911.67	195	34	6,63	320	78
IC-CF	857.28	226	42	11,61	320	102

Nutrient uptake by the pepper plants

The nutrients that are irrigated and are not in the drainage waters are taken up by the pepper plants. The amounts of nutrients irrigated are known and the amounts of nutrients in the drainage are known (see the calculations above). The amount of nutrients irrigated minus the amount of nutrients in the drainage water is the uptake.

The uptake of NO_3 is calculated in Table 27 below in g/m^2.

Table 27: NO_3 uptake by the pepper plants

	NO_3 Irrigated	NO_3 Drained	NO_3 Uptake by plants
TT-RW	537	215	343
TT-CF	664	264	439
IC-RW	539	195	323
IC-CF	701	226	437

The uptake of P_2O_5 is calculated in the Table 28 below in g/m^2.

Table 28: P_2O_5 uptake by the pepper plants

	P_2O_5 Irrigated	P_2O_5 Drained	P_2O_5 Uptake by plants
TT-RW	36,59	8,13	29,95
TT-CF	43,97	12,81	32,35
IC-RW	32,82	6,63	24,69
IC-CF	42,70	11,61	29,89

The uptake of K_2O is calculated in the Table 29 below in g/m^2.

Table 29: K_2O uptake by the pepper plants

	K_2O Irrigated	K_2O Drained	K_2O Uptake by plants
TT-RW	226	76	148
TT-CF	280	98	178
IC-RW	205	78	129
IC-CF	275	102	176

Appendix D: E.coli measurements

Table 30 shows the E. coli concentrations in the water flows and the fertilizers. Measurements are done by ESAMUR and by a extern company.

Table 30: E. coli concentrations in the water flows and fertilizers (CFU/100 mL)

Date	28-04		07-05		14-05		22-05		26-05		30-05		03-06		05-06		11-06		17-06		25-06		02-07		07-07
	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR
TT	<10	<10	<10		<10		12	<10	<10		14		<10		<10		25		<10		33		<10	<10	<10
IC	56	120	59	150	32	31	29	72	22	20	20	15	99		53		25	43	<10		114		<10		<10
IC-T	<10		27		36	31	50		424	620	30	30	115	200	38		18		10		106	180	113		11
TT-T	<10		<10		<10		15	20	<10		15		<10		<10		<10		29		<10		57	77	15
Fe+micro elements	104		46		<10	30	35		654		63		> 500	80,000	<10		<10		31	230	12		<10		<10
$Ca(NO_3)_2$	<10		<10		<10		<10		<10		<10		45		<10		<10	<10	<10		<10		<10		<10
KNO_3	<10		<10		<10		<10		<10		<10	<10	<10		<10		<10		<10		<10		<10		<10
KH_2PO_4	<10		<10		<10		<10		<10		<10		<10		<10		<10		<10		<10		<10		<10
Acid	<10		<10		<10		<10		<10		<10		<10		<10		<10		<10		<10		<10		<10
IC-CF	18		<10	3	<10		<10	<10	13		<10	<10	<10		<10		<10		<10	<10	<10		<10	18	<10
TT-CF	<10		<10		<10		16		<10	<10	<10		<10		21		54		<10		<10		<10		<10

Table 31 shows the E. coli concentrations of the IRIS waters. This are measurements are done after different treatment steps of the IRIS treatment system. The measurements are done by ESAMUR and a extern company.

Table 31: E. coli concentrations of IRIS waters (CFU/100mL)

Date	22-05		26-05		30-05		07-07
	ESAMUR	Extern	ESAMUR	Extern	ESAMUR	Extern	ESAMUR
IRIS treatment after electrofloculation	<100,000		>120,000		>100,000		8,700
IRIS treatment After ultra filtration	>120,000		>100,000		>100,000		412
Effluent of IRIS treatment	≈119,200	>120,000	>80,000	88,000	>100,000	>120,000	2,100