Universidade do Minho
Escola de Engenharia

Kelly Ann Rodrigues

The efficient use of water in the context of climate change

julho de 2015

Kelly Ann Rodrigues   The efficient use of water in the context of climate change

UMinho | 2015

Universidade do Minho
Escola de Engenharia

Kelly Ann Rodrigues

The efficient use of water in the context of climate change

Dissertação de Mestrado
Ciclo de Estudos Integrados Conducentes ao
Grau de Mestre em Engenharia Civil

Trabalho efetuado sob a orientação do
Professor Doutor Naim Haie

julho de 2015

ACKNOLOWGEMENT

My dearest Mum, for all her never ending support and all her kind words that never seem to run out. And of course my Dad and Brother.

And by all means, the person I found so interesting since the first lesson of AIA, Professor Naim. I thank for always being available, advice and so much support.

ABSTRACT

As the world's population grows, so do the water demands to fit everyone's needs. This problematic topic is affecting many areas of the world and making its population experience severe water scarcity. As our Planet is changing at a rapid speed it's up to us do something about it and this is when water efficiency starts to get a new meaning. So in order to try to minimize the damage that this boosting problem is causing, enhancing the efficiency of water use and therefore understand that its management is important to increase the beneficial utilization of water.

We have witnessed that up to date water management only allowed so much growth to be sustained, so if water management has a proper approach towards efficiency, naturally it will enable a broader level of sustainable growth.

Another problem regarding the shortage of water the world faces is climate change. This subject plays an important role in the present dissertation as it's around it that the efficient use of water will be analyzed, through three Water Use Systems which consist of three plots of agricultural land located throughout the Guadiana River. This study will be conducive to the understanding of the Sefficiency concept as well as water allocation policies, as these were the two methods used to analyze the Water Use System. The results showed how crucial it is to take into consideration the use of different tools, when regarding natural resources, providing the stakeholder with several alternatives to ultimately make the best decision, in the context of climate change.

Keywords: Sefficiency, Climate Change, Water Allocation Policy, Efficiency, Water Management

RESUMO

À medida que a população mundial cresce a demanda de água acompanha de modo a satisfazer as necessidades de todos. Este tópico problemático está a afetar diversas áreas do mundo fazendo com que a sua população enfrente severa escassez de água. Conforme o nosso planeta está rapidamente a mudar depende de nós fazer algo para poder alterar isso e assim, o conceito de eficiência da água começa a ganhar outro significado. Deste modo, para tentar atenuar os estragos causados por este problema cada vez maior será necessário aumentar uso eficente da água e portanto perceber que a sua gestão é crucial para aumentar o seu uso benéfico.

Pelo que é possível constatar, ao longo dos anos a gestão da água apenas permitiu um crescimento sustentável até um certo ponto. Assim, uma abordagem correta perante a gestão da água, irá permitir um maior crescimento sustentável.

Contudo, entre outros problemas, existe a escassez da água que o mundo enfrenta devido às alterações climáticas. Este tópico terá uma grande importância na presente dissertação, uma vez que é à volta deste, que o uso eficiente da água será analisado, através de sistemas de uso de água que consiste em três lotes de terreno para fins agrícolas localizados ao longo do rio Guadiana. Este estudo será conducente à compreensão do termo Seficiência assim como políticas de alocação de água, tendo sido estes os métodos utilizados para analisar os sistemas de uso de água. Os resultados mostraram a importância da utilização de diferentes ferramentas, respeitando recursos naturais, fornecendo às partes interessadas diversas alternativas para posteriormente tomar a melhor decisão, no contexto de alterações climáticas.

Palavras-chave: Seficiência, Alterações Climáticas, Política de Alocação de água, Eficiência, Gestão da Água

LIST OF CONTENTS

TABLE OF ACRONYMS

FAO – Food and Agriculture Organization

UN – United Nations

IPPC - Intergovernmental Panel on Climate Change

UNESCO - United Nations Educational, Scientific and Cultural Organization

UNDP – United Nations Development Programme

WUS – Water Use System

W_q – Quality Weights

W_b – Beneficial Weights

pp- percentage points

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Context

Contrary to popular belief water is a scarce natural resource and it’s reaching a point of no return. Freshwater is beginning to be a very problematic topic throughout the world and for it to continue to be a reliable supply for future growth it must be available to local populations in sufficient quantity and quality, without compromising local ecosystems. Even though the access to drinkable water was declared a Human right (UNESCO, 2010), it’s lack in quantity and quality is one of the biggest problems worldwide.

With that in mind the word efficiency takes a big part in all that relates to something so important to us Humans. Not only regarding water there’s a known way to calculate efficiency, through Classical Efficiency, which relates input with output. Throughout the years this has been the way to calculate efficiency; however it may sometimes lead to error (Haie & Keller, 2012) as there’s much more to water then one simple equation. It’s important to acknowledge that water has several different purposes in which its efficiency should be looked at in several ways. This leads up to Sefficiency, in which all different factors such as quality and benefits, as well as specific variables, intervene allowing a more complete approach to the term efficiency and water management.

According to the United States Environmental Protection Agency increasing water efficiency can help a water system deal with critical issues such as:

- Decreasing availability and quality of water sources;
- Increasing costs of treating and providing water;
- Aging infrastructure in service beyond its useful life;
- Growing demands for an improved level of service placed on the system by customers;
- Reducing or delaying the need for expensive capital projects and important environmental sustainability benefits, including reduced energy use and reduced pressure on water resources.

Achieving higher water productivity levels and reducing stress is possible by practicing simple things such as polluting less, wasting less, reusing more, managing more effectively and becoming more efficient in all uses of water.

In order to understand the Sefficiency concept the present dissertation will analyze three different Water Use Systems throughout the Guadiana River, using different irrigation systems as well different crop types and assume a water allocation policy.

1.2. Objective

The drive of this dissertation is to understand how severe water scarcity is and how it’s quickly and surely affecting the world and its population. Even though there are many causes that point to this lack of water, climate change is the focus of this study. It will be shown that climate change is a topic that shouldn’t be overlooked and should definitely be taken into everyone’s consideration. So in order to overcome these drastic impacts there must be an appreciation about efficiency and how it should work towards water. The overall objective is to understand how efficiency and sustainability come together and form the Sefficiency concept and subsequently to comprehend how it works and in which circumstances it can be applied.

1.3. Study Outline

This dissertation begins with a Literature Review that covers all important aspects regarding water by approaching what’s happing in the world and in the area being studied. This section also specifies and explains all the different methods that were applied in the next section. So in the section called Methods, it can be find all the methods explained previously and its application towards Sefficiency and water policy allocations. The fourth section describes all the results obtained by using the previously characterized methods. Ultimately, all the conclusions provided from the results.

2. LITERATURE REVIEW

2.1. Climate Change

Even though we can't really see, so to speak, our planet is changing right before our eyes. Human and natural activities have caused a vast quantity of various types of gas to exchange between the earth and its atmosphere. One of the natural causes to aggravate this phenomenon is water vapor. The so called "Greenhouse gases" Carbone dioxide (CO2), methane (CH4), nitrous oxide (N2O) and water vapor absorb radiation off the Earth's surface, gas molecules and the clouds retain it in the form of heat in the lower levels of the atmosphere which assist in maintaining a constant temperature that can and does preserve life on Earth. As result of this, the gases permit radiation from the sun to traverse the atmosphere thus heating the earth and impeding any heat getting back out into space. Despite this alleged "Greenhouse effect" being a natural phenomenon, and the result disturbing the natural balance and impacting global climate, Scientists believe the cause is due to human activity which has increased the atmospheric greenhouse gases. (R. Lal, et al. 2004). A good example of this is when the heat is caught within the atmosphere, Global climate is affected by alterations occurring and having a major impact on the ocean's temperature, wind patterns, and the Earth's water cycle.

Rainfall changes have been seen in many parts of the world, which have resulted in more intense rain, floods, drought, and severe heat waves have now become a more frequent occurrence. Sea levels are rising, ice caps melting, and oceans are becoming much more acidic. It has nearly become a daily normality to learn about some sort of natural disaster happening somewhere in the world. So much destruction to people's lives and all due to something that has been provoked throughout the years, we are slowly paying for our careless and selfish ways. As Mother Nature is giving us a warning, the impact on food and nutritional security are aggravated and undermining the rights of marginalized and vulnerable people.

The comparatively recent growth of populations and activities due to agricultural development, industrialization, deforestation, oil from the burning of fossil fuels, coal and gas, have caused much larger quantities of greenhouse gases and at a much faster rate than their natural processes to be released. There has been an increase of 40% of Carbon dioxide since pre-industrial times (Spotlight IPCC, 2013). Taking into account the destruction that has already been done to the environment, nature is starting to dictate the course, which will soon be of no return.

In accordance to the global poverty project there will be a decline in agricultural productivity, an example of this will be that some African countries could eventually see their agricultural harvests decrease by 50% by the year 2050 which would all be due to the impacts of climate change. Affirmed by an Oxfam report (Oxfam media briefing 9/2014) also as a result of climate change, by 2050 there could 50 million more hungry people and an extra 25 million malnutrition children under the age of five. As always the most vulnerable and poorest people are being affected first and in the worst possible of ways. Grave risks to human health and threats to ecosystems and biodiversity are due to climate change, because of rising sea levels and an increase in water stress.

The United Nations Development Programme released a report in 2006, stating that in the slums of developing countries, people will typically pay up to five to ten times more per unit of water than those who have access to piped water (UNDP, 2006). Current projections (UN World Water Development Report, 2015), say that with an increase emission of greenhouse gases there will be crucial changes in temporal and spatial distributing of water resources, and there will be a significant rise in the frequency and intensity of water-related disasters.

According to IPCC sea level has risen 17 centimeters in the past one hundred years and since the industrial revolution the Planet’s temperature has risen 0.8 degrees and between 2016 and 2035 it will rise between 0.4 to 1 degree. Nevertheless 25% of global emissions are due to agriculture and deforestation. Another direct link to climate change has been the expansion of global meat and dairy products and is something many people aren’t even aware of. According to the FAO the livestock sector are responsible for approximately 18 percent of global greenhouse gas emissions.

With this being said, it’s important to first understand what it is that we are facing so then take action, and as engineers try to solve the problem by coming up with an efficient solution.

“You must be the change you want to see in the world” – Mahatma Ghandi 1869-1948

2.2. Water

In the world, there is no force that has a greater power over us than the power of water. It is the basis for sustainable development, and its vast range is responsible for environmental sustainability, economic growth, and the reduction of poverty in many countries. Despite our planet being covered by 70% water, it is misleading to think that it is bountiful. Water for millions of people in developing countries is not as easy as it is for most of us, simply a tap away. Women and children have to walk for miles every day to get some water. Human and animal waste often contaminates their water, which is a cause for much illness and death. If there is a problem, it has to do with economics and politics. In the developed world there isn't a water shortage; technology and wealth provide clean water for everyone but at an increasing cost. According to the UN, in 2006 the problem for the undeveloped world was caused by corruption, mismanagement, lack of investment, and the shortage of appropriate institutions which all leads to poor sanitation and unsafe water.

400 million people in India live along the Ganges River, which is one of the five most polluted rivers in the world. Many of the poorer population use the river daily for washing clothes, bathing, cooking and much more. Even though released into the river every day is industrial waste, human sewage, religious offerings and even partially cremated Human bodies it does not stop them from using the river.

In Yemen, the groundwater is being extracted four times the rate of natural recharge (International Crisis Group, 2003). This crisis is yet and another example of the adverse effect of climate change. The main reason for the increase demand in water is the because of population growth, thus cause this crisis. Underwater exploitation is getting out of hand. Agriculture plays a big role in Yemen's economy, adding to the hardships this country is going through.

Investing in water and sanitation yields would show health benefits, according to a 2014 UN Report (GLAAS 2014 Report). Millions of children would be saved from malnutrition illnesses, water-borne diseases and premature deaths. Better care for newborns, maternal health, and adults would live a healthier and longer life. The quality of life would also be greatly improved from using unsafe facilities and time would be saved from searching for and carrying water. With a reduction in the pollution of water and land resources, there would be a positive impact on coastal fisheries and broader water ecosystems, which lie in the heart of the global water cycle. Also an important aspect is Energy. Water is required to generate energy and energy is required to deliver water. Water is heated to create steam to drive electrical generators (UN -Water, 2015). Over 80% of today's power is produced by thermal electricity.

An opportunity for the growth of new industries, greater involvement in the workplace due to improved access facilities, and better productivity. There would be a sense of well-being and dignity for all with improved school attendance and completion. Freshwater fundamentally depends on the continued healthy operating of the ecosystems and acknowledging the importance of the water cycle as essential to achieving sustainable water management.

2.2.1. Food and Water Security

Food Security is when all the people have safe, nutritious and enough food all the time to be able to live a healthy life. Food is a basic human need, yet millions of people in the world are going to bed hungry every day. This problem is exacerbated by the population growth and hence the population demand for food. On the other hand water security is defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (UN-Water, 2013). Investing in water security is a long-term pay-off for human development and economic growth, with immediate visible short-term gains.

2.2.2. Water Management

Another very critical factor linked to water is its appropriate management. As the scarcity of water becomes more and more of a concern so does the importance of how it is managed. Minimizing the environmental impact and optimizing the use of water on the natural environment leads to successful management of any resources. Our failure to meet basic human needs is the root of all these problems. As a result of our in ability to balance human need with the needs of the natural world, and inappropriate or ineffective institutions and management. “Many issues have been over looked” according to the Pacific Institute research, for example: water as a basic human right, the importance of efficiency and conservation of water, the impact of climate change, the privatization and globalization of water, and the role of water in conflict.

The sustainability of the current and future water resource allocation is one of the largest concerns related to water in the future. An important step in the sustainability of water resources is to find a balance between what is needed in the environment and what is needed by humans. The decision making will not get any easier with the ongoing climate change, and all its uncertainty, which will lead to a never before encountered situation.

“The objective of sustainable water management is to promote water use in such a way that society’s need is both met to the extent possible now in the future. This tool allows adequate, inexpensive and sustainable supplies and qualities of water.” András Szollosi-Nagy, 2005.

2.2.3. Water Quality

It’s important to understand that water quality is just as important as water quantity for satisfying basic human needs and environmental needs. It’s of great concern to know the water which is about to be used or even drunk. It is measured by several factors, such as the concentration of dissolved oxygen, bacteria levels, the amount of salt or the amount of material suspended in the water, depending mainly of the purpose of that water. So it’s fundamental for good river health and sustains ecological processes that support native fish population, vegetation, wetlands and birdlife. Also, many of our own uses depend on water quality that is suitable of irrigation, watering stock, drinking, fishing, recreation and to meet cultural needs.

According to the World Water Development Report 2012, nearly 3.5 million deaths are related to inadequate water supply, sanitation and hygiene happen each year mainly in developing countries. Poor water quality incurs many economic costs such as degradation of ecosystem services; health related costs, agriculture, industrial production and tourism, increased water treatment costs and reduced poverty, for example.

2.3. Sefficiency: What does it mean?

First of all there must be an understanding about the meaning of Sustainability and Efficiency. Sustainability is a concept which is based on our natural environment, meaning that everything that us humans need for our own survival and well-being depends in some way of that same natural environment. It’s important to remember ourselves that we all live on common ground, our forests exhale the air we breathe and connect us all. Every living creator, no matter how small, sustains the whole. Even though there are many who believe that we belong to the planet others feel that the planet belongs to us and this is what brings us to the unsustainable planet we live in.

On the other hand we have Efficiency, which represents a level of performance that describes processes that uses the lowest amount of inputs to create the greatest amount of outputs, reducing the amount of waste of the inputs. In this context efficiency improvements of the irrigation system, which is what is being dealt with, are important water saving measures as they result in water loss reduction.

Water efficiency has become a growing concern worldwide and Organizations like UNESCO, World Water Council, and The International Water Management Institute have been promoting water efficiency alongside water conservation.

There must be an understanding that water is reaching a critical point and there’s more to it than the classical efficiency or trying use water in a more sustainable manner. Linking these two concepts allows a more complete and accurate view on what’s needed for water. From what was previously mentioned it’s possible to conclude that both sustainability and efficiency should meet half way. A more complete approach to the efficiency concept, which also includes sustainability, is called Sefficiency. This term is the main focus of this thesis and will be exemplified through three different Water Use Systems.

2.4. Guadiana Basin

The Guadiana river basin covers 66.800 km^2 of which 11.580 km^2 are located in Portugal.
The largest dam along the Guadiana River is Alqueva. This river source is from Spain in Ruidera at an altitude of about 1.7 km, and stretches over a total length of 810 km making its way to Vila Real de Santo Antonio, where it meets the sea. In Portugal, the river has a total length of 260 km, of which 110 km correspond to the border between Portugal and Spain.

The Guadiana River has a Mediterranean fluvial regime where floods alternate with dry spells. It represents a typical semi-arid region where there is increasing water scarcity due to human activity and the modification of the hydrological regime over previous decades. During the drought years this kind of climate needs some level of irrigation to maximize crop yields. It also is an area with an ageing population because of unemployment and progressive population loss over the decades.

Both in Spain and Portugal the land has a predominantly rural occupation, some of the water quality issues are due to sewage water discharges from agro-industrial units and to agricultural activity.

The agricultural sector which is very important in this area is going through a big change.
Climate change may affect directly or indirectly the water quality of the Guadiana river, according to the Portuguese Environmental Agency, as the rising temperature can lead to a decrease on the levels of saturation of the dissolved oxygen in the water and biological and chemical processes may be harmed, altering the ecosystem’s behavior; An alteration in the precipitation could cause more pollution, as the fertilizers and pesticides used in agricultural activities could be dragged to the river and a flow reduction may cause a larger concentration of pollutants.

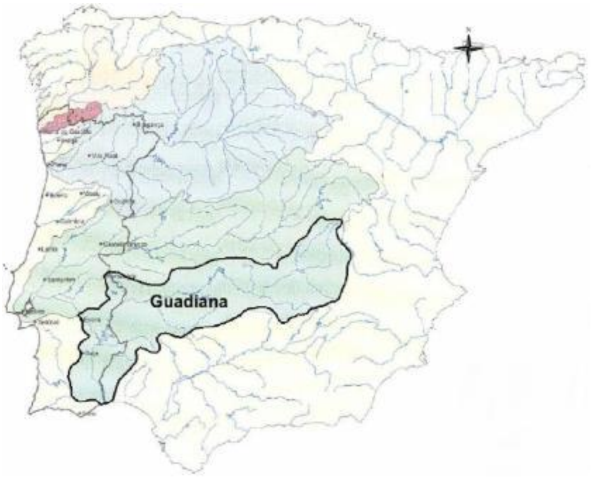


Figure 1- This figure shows both location and extent of the Guadiana River Basin (http://environ.chemeng.ntua.gr/)

The Portuguese Environmental Agency states that the objectives to obey the Law of Water must be attained during the present year. These goals consist of achieving a good or potentially good state of the water mass. More specifically, according to the Management Plans of the River Basin Region the superficial water must carry out these next objectives:

- Prevent the bodies of water from deteriorating;
- Protect, improve and recover all mass of water with the objective of achieving the good state of water – Chemically and ecologically;
- Protect and improve the mass of water that was strongly modified and artificial with the purpose of attaining a good ecological potential as well as a good chemical state;
- Gradually decrease the pollution cause by dangerous substances and eliminate emissions and discharges.

2.5. Agriculture

Controlling nature to allow cities and empires to grow and satisfying human needs involves high quantities of water in order to obtain all produce wanted and needed which is the main part of agriculture. Industrial agriculture dominates and sustains a large part of the world. Food has become abundant and affordable to all through the use of chemical pesticides, fertilizers, biotechnology and mechanization. Resulting in a system of chemically intensive food production developed after the Second World War.

Monoculture is the practice of growing single crops intensively on a very large scale, year after year and relies heavily on chemical inputs such as synthetic fertilizers and pesticides.
This system of planting the same crop year after year leaves the soil very weak and unable to support healthy plant growth. Farmers are forced to use chemical fertilizers to encourage plant growth as the soil quality and structure is so poor, however this practice adds to nutrient depletion. Planting diverse plant species so that crops will be able to withstand attacks from pests and insects can avoid this problem and eliminate the need to use pesticides. Using organic pesticides will reduce the amount of pollution. Also to help improve soil fertility the use of composted manure and other natural materials should be used, as well as crop rotation. All these practices result in protecting ground water supplies, and avoid runoff of chemicals that can cause dead zones and poisoned aquatic life.

According to a statement by the UN in 2013 (State of the World's land and water resources for food and agriculture, FAO 2013) meeting agricultural needs through organic farming is a possibility, as the social and ecological price has been high: deforestation, depleted and contaminated soil and water resources, erosion, loss of biodiversity, the decline in family farming, and labor abuses.

Encouraging healthy soil by planting different crops in fields every year and also incorporating croplands with grazing livestock; avoiding the use of pesticide by nurturing the presence of organisms that control crop-destroying pests. Nevertheless, critics of sustainable agriculture claim that among other things, this method results in higher land use and lower crop yields.

Both food security and food production are linked to the availability of water and water security. High efficiency reflects in low losses, losses are non-recoverable waste of resources; reductions in losses will mean more is available for alternative uses and by implication high efficiency is good.

Producing food that respects natural life cycles is called Organic farming, and it minimizes the human impact on the environment. To ensure that resources are used efficiently crops are rotated, synthetic fertilizers, chemical pesticides, antibiotics and other substances are severely restricted, genetically modified organisms are banned, disease-resistant plant and animal species adapted to the local environment are used and livestock are raised in a free-range, open-air environment and are fed on organic fodder.

Concerns about water scarcity make us focus our attention on irrigation. Irrigation requires a great amount of water, being the largest water-using sector across the world (Perry, 2007). In many developing nations, irrigation accounts for over 90% of water withdrawn from available sources for use. Water used for irrigation in Spain, Portugal and Greece exceeds 70% of total usage (UN-Water, 2006). Irrigation has been the reason which enabled many developing countries to produce enough food to feed everyone.

As reported by the UN World Water Development Report 2015, by 2050 agriculture will need to produce 60% more food globally, and 100% more in devolving countries. As the current growth rates of global agricultural water demand are unsustainable, the sector will need to increase its water use efficiency by reducing water losses and increase crop productivity with respect to water. Agricultural water pollution, which may worsen with increased intensive agriculture.

2.5.1.Desertification

Even though desertification has a greater impact in developing countries it is an increasing problem in Portugal, as it’s the most affected country in the European Union (FAO, 2002). Human activities, over-exploitation of water and soil, uncontrolled wood-cutting, mining and excessive use of chemicals are the main cause of desertification. In the Alentejo region, the extensive agriculture mechanization and shortage of land resting periods and intensive erosion processes resulted on soil fertility loss. Another example that may cause this problem is salinization. Water for irrigation purposes contain dissolved salts which may vary according to the origin of the water. The soil becomes concentrated with salt as the plants remove water through evapotranspiration (Letey, John, 2000). In arid or semi-arid regions salinization is a common phenomenon, meaning that this occurs in the Alentejo region, which is being studied. The increase in the salt levels in the soil affects the plant growth and kills them. Desertification in the Alentejo has been through a series of fazes, one of the most important one was in the XVII century when forests were destroyed to give place to cereal cultivation. During the world wars, due to fuel stocks running out, trees and scrub to produce coal, which lead to a massive destruction of nearly all natural vegetation (http://geografia.fcsh.unl.pt/lucinda/Leaflets/A2_Leaflet_PT.pdf).

The IPPC has acknowledged desertification as one of the biggest environmental challenge of our days. In 2012 the UN made aware that every year 23 hectares are transformed into deserts every minute, covering 40% of our planet. Desertification represents a big ecologic and economic problem that affects the whole world. Once rural areas are no longer productive the people who lived in those areas tend to head towards the cities, causing not only an economic problem but also a social problem. The image below represents the harsh reality that is faced right here in Portugal.

Figure 2 - Desertification in the Alentejo region (http://meioambiente.culturamix.com)

2.5.2. Drip Irrigation

This type of irrigation will be used in one of the Water Use System. In drip irrigation the water is passed through the field through a system of pipes where a tube is installed next to a row of plants or trees. The tube has a hole made at regular intervals and it is also equipped with an emitter. The water then slowly comes out of the emitter in drops and waters the plants. The water drips out of the emitter and provides deep watering and a microclimate (Bamouni, Souleymane, 2011). Drip irrigation objectives are: low-flow supplying allows a low variation of moisture, providing water locally in the root zone, ensures the supply in a high frequency. Only a limited area of soil is wet. The higher degree of inbuilt management that drip irrigation offers substantially reduces deep percolation and runoff losses, attaining higher irrigation efficiencies, as the water soaks into the soil before it runs off or evaporates. The high efficiency is also due to the fact that the water is only applied to where it is needed rather than sprayed randomly.

The image below depicts drip irrigation being applied to Olive Trees.

Figure 3 – Drip Irrigation applied to Olive trees (http://homeguides.sfgate.com)

2.5.3. Surface Irrigation

Surface irrigation is the oldest type of irrigation. Once this water irrigation system is constructed it is easy to maintain and to operate. The water runs over the soil to either wet it completely or only partially. Despite surface irrigation being the most common type of irrigation it is also the most inefficient. The disadvantages being potentially wasteful run offs and over watering (Bamouni, Souleymane, 2011). If the soil cannot readily absorb water or lacks proper sloping this can lead to standing water which damages plants and reduces yields for edible crops.

The three types of existing surface irrigation are the following:

- Furrow Irrigation: where narrow ditches are dug in the field between rows of crops. Here the water runs along the ditches as it moves down the slope.
- Border Irrigation: depends on the topography of the field, which determines the possible width that can be obtained while keeping a horizontal cross-section without requiring too much soil movement. The field to be irrigated is divided into strips by parallel dykes or border ridges.
- Basin Irrigation; these are horizontal flat plots of land which are surrounded by small dykes, that prevent water from flowing over to the surrounding fields.

The image below represents a vineyard using furrow irrigation, showing excessive water application in South Australia.

Figure 4 - Furrow Irrigation in vineyard in Australia (http://pir.sa.gov.au)

Although the type of irrigation depends on the characteristics of the soil, the slope of the land, the kind of crops intended to plant, the climate, among other factors, the objective of this thesis takes in to account the obvious flaws and benefits of each one as there would be a need for a more detailed and cautious study of all the mentioned factors. So the main difference considered was regarding the benefit weights that are explained in section 4.

3. METHODS

3.1. Sefficiency

In order to comprehend Sefficiency, a Water Use System must be characterized, along with its variables and respective value and it also must include water quantity, quality and benefits (Haie & Keller, 2012).

The terms Macro, Meso and Micro efficiencies are a vital point of this dissertation. These are integrated indicators that should reflect dynamics of different scales, such as a farm and a basin, alongside with the law of conservation of mass. A set of variables which define the WUS must abide to the water totals: Total inflow and total consumption.

Every variable must have a beneficial dimension as well as a quality dimension to provide it with useful criteria. The boundaries of the WUS must be known to the manager and the analyst.

According to Haie and Keller (2012) the definitions of the previously mentioned integrated indicators are:

- Micro-Efficiency (MicroE): This is the relationship between useful outflow and total flow within a WUS. It also indicates the useful outflow generated by a WUS for itself.

- Macro-Efficiency (MacroE): This is the relationship between useful outflow and total flow as related to a river basin. MacroE indicates the impact of a WUS on a basin.

- Meso-Efficiency (MesoE): This is the relationship between useful outflow and total flow as related to a situation between Macro e Micro-levels.

One of the mathematical views on these three concepts is called full models and can be represented by these next three equations ((i,c) = (0,1) gives the percentage of total consumption that is useful consumption and (i,c) = (1,0) gives the percentage of total useful inflow that is useful outflow):

$$\mathrm{MacroEs} = \left[\frac{\mathrm{ET+NR+i(VD+RP)}}{\mathrm{VU+OS+PP-c(VD+RP)}}\right]\mathrm{s} \quad \mathrm{i,c=0\ or\ ,\ i+c=1} \tag{1}$$

$$\mathrm{MesoEs} = \left[\frac{\mathrm{ET+NR+i(RF+RP)}}{\mathrm{VA+OS+PP-c(RF+RP)}}\right]\mathrm{s} \tag{2}$$

$$\mathrm{MicroEs} = \left[\frac{\mathrm{ET+NR}}{\mathrm{VA+OS+PP}}\right]\mathrm{s} \tag{3}$$

As explained above there are three different approaches and levels to understand Sefficiency. However, the present dissertation will focus only on MesoE, ignoring the volume upstream and downstream of the river, as both those variables are related to MarcoE. In order comprehend Meso-Efficiency in a more basic level there must be an understanding about Classical Efficiency, which basically represents the division between total output and total input in the system. However, when referring to water efficiency it's difficult to bear in mind all the different aspects that water involves and so classical efficiency is seen as less complete as it's defined more specifically as $\frac{ETb}{VA}$ (Beneficial weight of Evapotranspiration and Volume of water downstream after RF in main source).

Given the preview equations it's possible to calculate in a more complete way the water efficiency acknowledging all variables that belong and influence a Water Use System as well as quality and beneficial weights associated to each one of those variables.

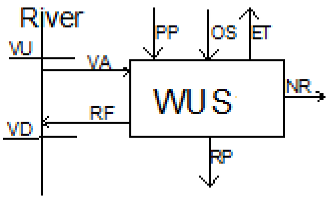


Figure 5 - General schematic of a Water Use System

In order to characterize a Water Use System water flow paths and attributes such as quality and benefits must be defined allowing the use of the law of conservation of mass. The figure above shows all the water flow paths that must be considered in a WUS. The present dissertation will have three WUS throughout the Guadiana River, which will be considered the main source. It’s important to keep in mind that these WUS are hypothetical, even though the values obtained are as close to reality as possible. With an area of about a hectare each and although the main objective is to understand how Sefficiency works, it will be possible to understand how it can vary differently according to the type of irrigation used and the crops being cultivated. So, oranges, grapes and olives were chosen for the crop and drip irrigation and surface irrigation, as mentioned before.

Table 1 - Variables included in 3ME and description

Variable	Description
ET	Evapotranspiration
NR	Nonreusable, water consumption
OS	Water from other sources
PP	Total precipitation
RF	Return flows
RP	Potential return (does not return to the main source)
VA	Abstracted water from the main source
VD	Volume of water downstream after RF in the main source
VU	Volume of water upstream before abstraction in the main source
V1	Volume of water at section 1 (VU or VA)
V2	Volume of water at section 2 (VD or RF)

The final results presented in the fourth section are either full models or quantity models. The main difference between them is that full models attend to both beneficial (b) and quality (q) dimensions of the variables. The product of both these dimensions is called Usefulness Criterion (s). However, the quantity models attend only to the beneficial dimension (b) of the variables.

A full model is represented through equation (2). When i = 0 and c = 1 then equation (2) has this appearance:

$$cMesoEs = \left[\frac{ET+NR}{VA+OS+PP-(RF+RP)}\right]s \qquad (4)$$

The numerator of equation (4) which is (ET+NR) represents the consumption of the WUS. (RF + RP) represents the return flow and (VA+OS+PP) the total inflow in the system. Overall, when dealing with full models and c=1, which can also be presented as cMesoEs, means the effective consumption that is useful consumption.

On the other hand when i=1 and c=0, equation (2) has the following appearance:

$$\mathrm{iMesoEs} = \left[\frac{\mathrm{ET+NR+(RF+RP)}}{\mathrm{VA+OS+PP}}\right]\mathrm{s} \qquad (5)$$

In this case the numerator of equation (5) is the total outflow and the denominator (VA + OS + PP) means the total inflow in the system. So iMesoEs give us the useful inflow that is useful outflow.

Equation (6) is an example of the value of ET would be calculated, considering a full model.

$$\mathrm{ETs} = \mathrm{ET}_{wq} \times \mathrm{ET}_{wb} \times \text{Water Balance Quantity of ET} \qquad (6)$$

Wq: Quality Weight
Wb: Beneficial Weight
All the remaining variables are calculated the same way, according to their respective value.

Regarding the quantity models when c=1 and i=0, equation (2) becomes the following equation:

$$\mathrm{cMesoEb} = \left[\frac{\mathrm{ET+NR}}{\mathrm{VA+OS+PP-(RF+RP)}}\right]\mathrm{b} \qquad (7)$$

Even though both the numerator and denominator are the same as equation (4) the final result gains a different meaning as it’s regarding a beneficial dimension. cMesoEb represents the effective beneficial consumption that is beneficial consumption.

In this case, and using the same example regarding ET but now referring to a quantity model, the way of calculating ET is shown in the next equation.

$$\text{ETb} = \text{ET}_{wb} \times \text{Water Balance Quantity of ET} \qquad (7)$$

Again respecting quantity models but now when c=0 and i=1, equation (2) becomes the equation below:

$$\text{iMesoEb} = \left\lceil \frac{\text{ET}+\text{NR}+(\text{RF}+\text{RP})}{\text{VA}+\text{OS}+\text{PP}} \right\rfloor \text{b} \qquad (8)$$

Once again both the numerator and denominator are the same as equation (5) however; as it's referring to a quantity model the final result has a different meaning. iMesoEb represents the effective beneficial consumption that is beneficial consumption.

3.2.WUS variables

As mentioned above the variables that define the Water Use System must be defined according the reality that surrounds it. Having in mind the definition of each one (table 1) the outflow variables are: ET, NR, RP and RF and on the other hand the inflow variables are: VA, PP and OS. These must have the same unit, such as volume, depth, percentage of fraction. In the present case all units are presented in millimeters per day. As previously mentioned the variables VU and VD were ignored as the present study is at a Meso-Efficiency level. Both OS and NR are zero as it was considered that there wasn't any water provided from another source besides the river and all the water was reusable.

3.2.1. Evapotranspiration

Evapotranspiration (ET) is one the variables defined in a WUS. This term represents the sum of the plants evaporation and transpiration and in order for this to occur water is needed. The plant roots extract water from the soil to live and grow. The main part of this water doesn't remain in the plant as it escapes to the atmosphere as vapor through the leaves and stems, called transpiration, which happens mainly during the day. The water on the soils surface leaves and stem escape as vapor to the atmosphere as the phenomenon called evaporation. The figure (from the site water.usgs.gov) below represents all the process described above.

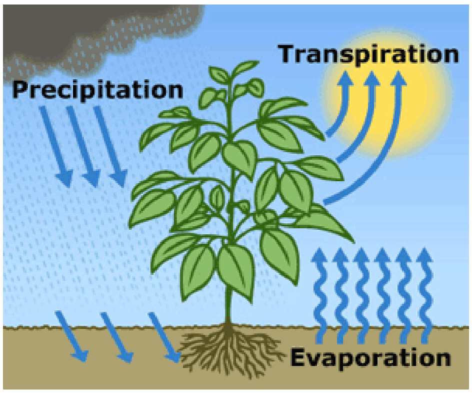


Figure 6 – Evapotranspiration. Image from site water.usgs.gov

It’s important to understand that the water the plant needs for evapotranspiration may be stored in the root zone and used when needed. This means that even though the plant needs a certain amount of water a day for this phenomenon to happen the excess or lack of water a day will not interfere negatively. The water that the crop needs mainly depends on the climate (hot climate crops need more water per day than crops in a cloudy and cool climate), humidity, wind speed, the crop type and growth stage.

The FAO Corporate Document Repository, Irrigation Water Management, provides the reader with a great amount of information regarding the determination of the reference crop evapotranspiration (ETo), the crop water need (ETcrop) and the irrigation water need. The definition of the reference crop evapotranspiration (ETo), conforming to the FAO Natural Resources Management and Environment Department is that ETo is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. Even though there are several methods to determine ETo (as experimental, using an evaporation pan or theoretical, using measured climatic data, e.g. the Blaney-Criddle method) it goes beyond the purpose of the present thesis, so indicative values were used, depending on the climatic zone (Arid, semi-arid, sub-humid, humid) and mean daily temperature (Low, medium and high). In the Guadiana case as the climatic zone is semi-arid and the mean daily temperature is medium (15/25 ºC) the indicative value of ETo is 5.

Once ETo is defined the next step is to find the value of Kc (crop factor), which depends on the climate, type of crop and growth stage of the crop, in order to obtain ETcrop. The relationship between the reference grass crop and the crop actually grown is given by the crop factor, Kc, through the next equation:

$$\mathrm{ETo} \times \mathrm{Kc} = \mathrm{ETcrop} \qquad (9)$$

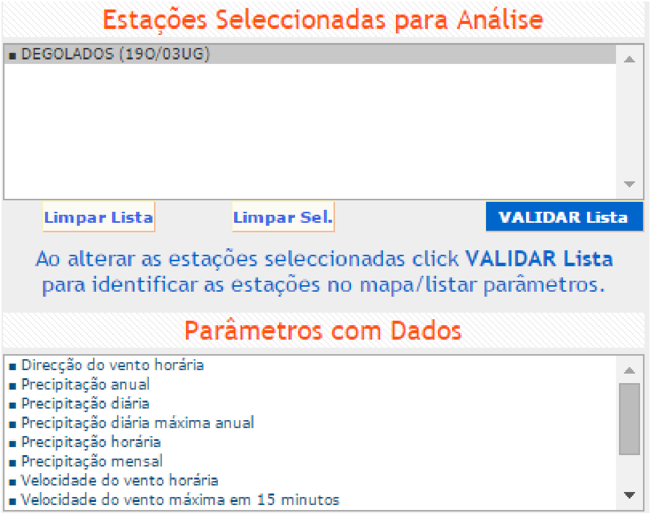
With ETcrop: Crop evapotranspiration (mm/day)
Kc: Crop factor
ETo: Reference evapotranspiration (mm/day)

Once again the values for Kc were provided by the FAO Natural Resources Management and Environment Department. These values vary from crop to crop and as all three WUS have different types of crop (Oranges, Olives and Grapes) hence the value of ETcrop will differ from WUS to WUS.

3.2.2. Total Precipitation

The variable total precipitation (PP) allows the use of less VA, once it’s also another source of water. Increased heating due to climate change leads to greater evaporation and thus surface drying, increasing the intensity and duration of drought. However, the water holding capacity of air increases, which leads to increased water vapor in the atmosphere. Hence, storms with increased moisture produce more intense precipitation events, increasing the risk of floods. With modest changes in wind, patterns of precipitation do not change much, but result in dry areas becoming drier and wet areas becoming wetter. (Trenberth, Kevin E. 2011).

In order to obtain information regarding the precipitation values in the area being studied, the SNIRH website (http://snirh.apambiente.pt) provides the user with a great amount of information about precipitation values in various different regions. Once the river basin is selected it’s easy to obtain information about a particular area, in this case the WUS. The figure below is an example of how the information about total precipitation was obtained through the meteorological station called Degolados of the Water Use System 1. The period of time selected for all three WUS was the average value of ten years, for a more precise result, using the daily precipitation.



Ao alterar as estações seleccionadas click **VALIDAR Lista** para identificar as estações no mapa/listar parâmetros.

- Direcção do vento horária
- Precipitação anual
- Precipitação diária
- Precipitação diária máxima anual
- Precipitação horária
- Precipitação mensal
- Velocidade do vento horária
- Velocidade do vento máxima em 15 minutos

Figure 7 - Example of how the values of precipitation were obtained through SNIRH

The image below allows a more visual understanding of how the precipitation varies during a period of ten years in the WUS 1 area.

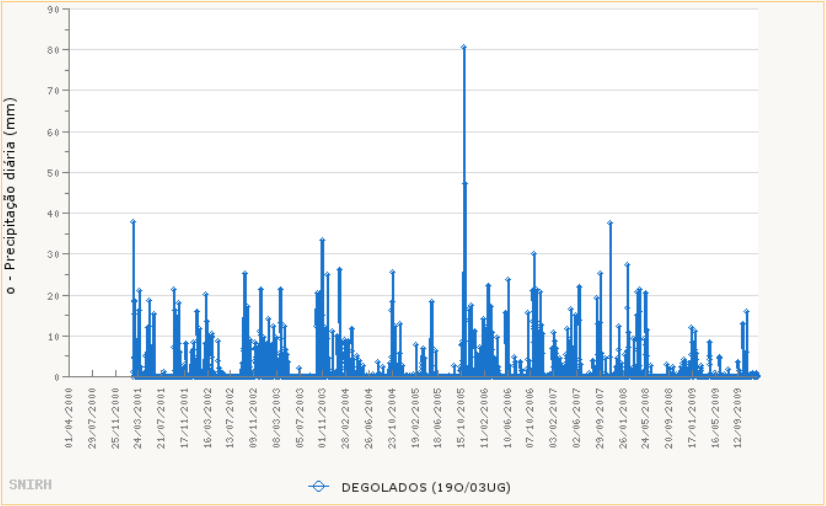


Figure 8 - Image with corresponding graph of precipitation obtained from SNIRH

3.2.3. Abstracted water from the main source

The abstracted water from the main source also known as the variable VA was determined according to the amount of water each WUS needed. The quantity of VA decreases as PP increases as there’s no need for more water to be abstracted when there’s another source involved. However, the opposite happens to VA when the value of ET increases, as the variable ET represents the quantity of water that the crop needs for Evaporation and Transpiration as mentioned in section 4.1.1. Having in mind that there’s no other source of water as OS is considered to be zero.

3.2.4. Return Flow

The value of the Return Flow variable (RF) was based on the type of irrigation considered for that particular WUS. The type of irrigation chosen influences runoff losses and deep percolation, for instances, which influences the amount of water that returns to the main source and also its quality and benefits. Having in mind that there must be water balance at all times.

3.2.5. Potential Return

The Potential Return (RP) represents all the water that doesn’t return back to the main source. It’s for example the water that infiltrates the soil and wonders off to neighbors land. The values were also obtained having in mind the type of irrigation for that particular WUS, as depending on the irrigation type the probability of occurring deep percolation or runoff losses are higher or lower. Based on that the quantities were estimated, always maintaining water balance. Both quality and benefit weights were also estimated according to irrigation type.

3.2.6. Volume Upstream and Volume Downstream

As it was mentioned previously the present thesis the WUS at a Meso-Efficiency level. With that in mind only equation (2) will be used. In this equation all variables are used except the Volume Upstream (VU) and the Volume Downstream (VD) so their values are irrelevant for this present study.

3.2.7. Other Sources and Non-Reusable

The present study does not consider that there's water provided from any other source but the rivers (main source) and there's no non-reusable water, which means that both OS and NR are considered to be zero.

3.3. Calculating Water Quality through the Canadian Water Quality Index

In order to analyze the water's quality we are given a great amount of parameters regarding the water quality. However, the CCME (Canadian Council of Ministers of the Environment) Water Quality Index compiles all the complicated data, providing an easier way to overcome the complex information regarding water quality parameters, which is based on a formula developed by the British Columbia Ministry of Environments, Lands and Parks and modified by Alberta Environment. Through the process mentioned below, it's possible to summarize a great amount of information into a single value and easy for anyone to interpret.

Through this index it will be possible to understand if the water in cause is actually good enough to be used for a determined purpose, which in this particular case is irrigation. However, all the necessary information, such as time period, variables and objectives must be gathered beforehand.

To calculate the water quality index one must attend to the factors below:

1. F1(Scope) During a considered period of time F1 is the percentage of variables that do not meet their objectives at least once, relative to the total number of variables measured:

$$\mathrm{F1} = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100 \qquad (10)$$

2. F2 (Frequency) represents the percentage of individual tests that do not meet the objectives:

$$\mathrm{F2} = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) \times 100 \qquad (11)$$

3. F3 (Amplitude) represents the amount by which failed test values do not meet their objectives. F3 is calculated in three steps.

i) The number of times by which an individual concentration is greater than the objective is called an excursion

$$\text{excursion}_i = \left(\frac{\text{Failed Test Valuei}}{\text{Objectivej}}\right) - 1 \qquad (12)$$

For the cases in which the test value must not fall below:

$$excursion_i = \left(\frac{Objectivej}{Failed\ Test\ Valuei}\right) - 1 \qquad (13)$$

ii) Summing the excursions of individual tests from their objectives and diving by the total number of tests.

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursioni}}{\text{number of tests}} \qquad (14)$$

Finally to calculate F3:

$$\text{F3} = \left(\frac{\text{nse}}{0.01\text{nse}+0.01} \right) \qquad (15)$$

After all three factors have been calculated, it’s possible to obtain the index by summing these factors, through the next equation:

$$\text{CCMEWQI} = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732} \right) \qquad (16)$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the worst water quality and 100 represent the best water quality.

Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories:

- Excellent: (CCME WQI Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

- Good: (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

- Fair: (CCME WQI Value 65-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

- Marginal: (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

- Poor: (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Given the previously mentioned process of calculating the water quality it’s now possible to analyze the water of the river in hand. As the purpose of this water is entirely for irrigation it’s easier organize all the different parameters that make the water suitable for irrigation or not. The Portuguese law defines several parameters for various different ends, so in case of irrigation Decree Law 236/98 Annex XVI allows the user to know if that particular water obeys or not the precise Law regarding irrigation. This Annex contains 29 different parameters which include, for example: pH, Nickel, Zinc, Salinity, Copper, Lead, Cobalt, among others.

For each Water Use System the nearest Hydrometric Station was selected (All this information was provided by the site SNIRH – Portuguese Environmental Agency) in order to obtain all the parameters necessary to obey the irrigation law as well as enough information to use the Canadian Quality Index mathematical framework.

The figure below was obtain from the previously mentioned site SNIRH and has an example of Hydrometric Station selected for WUS 2 called Monte Vinha – Jusante, which can be observed in the first box as the second one has all the parameters, with their respective unit, related to that station and consequently that water.

Estações Seleccionadas para Análise

- MONTE VINHA - JUSANTE (20O/05)

Ao alterar as estações seleccionadas click **VALIDAR Lista** para identificar as estações no mapa/listar parâmetros.

Parâmetros com Dados

- Tetracloroetileno ou Percloroetileno ou Tetracloroeteno (ug/l)
- Tolueno (ug/l)
- Triclorobenzeno ou TCB (ug/l)
- Tricloroetileno ou Tricloroeteno (ug/l)
- Trifluralina (ug/l)
- Xilenos - mistura de isómeros (ug/l)
- Zinco total (mg/l)
- pH - lab.

Figure 9 - Example of how data was obtained for WUS 2 figure from SNIRH

3.4. Water Allocation Policy

Due to several factors such as climate change, which is one the main focus of this dissertation, that make water scarcity a great problem there is an increased concern about how water should be distributed according to need and priority, for example to guarantee enough water for all demands. So economic consideration has developed a big part in all that’s of public concern, such as reallocation proposals and other water policies and water projects. (Dinar, Ariel et al. 1997). When done correctly it’s possible to take a great advantage of its benefits, like achieving higher levels of efficiency and equity satisfying the needs of those whom are involved.

Based on an example given by Loucks, D.P. & Van Beek, E. (2005) about a water allocation problem, four different Policies were defined, such as:

- Policy 1: The minimum amount of water in the river is 2 units;
- Policy 2: WUS 3 is the only one that receives water and it can go up to 2 units;
- Policy 3: WUS 1 and WUS 2 are able to receive water in equal amounts until both have also 2 units;
- Policy 4: After all three WUS have two units all receive water equally until the maximum value of VA is met and all the excess water remains in the river.

All quantities units used in the previous sections were defined in millimeters per day however, for a better understanding they will be called only units.

In other words and according to the hypothetical Water Allocation Policy considered:

- At all times there must be 2 units in the river;
- VD1=VU2 and VD2=VU3 which means that there won't be any other source of water entering the river;
- WUS 3 has priority over the two remaining WUS, meaning that it will be the first one to receive water;
- Once WUS 3 receives a total of 2 units, the remaining two will receive equally the same amount;
- When all tree WUS achieve 2 units they all start to receive equally;
- WUS 3 will be the first one to receive its total amount of 3 units, as VA3 = 3;
- As WUS 3 won't need to receive any more as its total amount was satisfied, WUS 1 and WUS 2 will continue to receive equal amounts until they fulfil their goals of 4 units each;
- Any excess flow will remain in the stream.

The figure below allows a more visual understanding of what has been said.

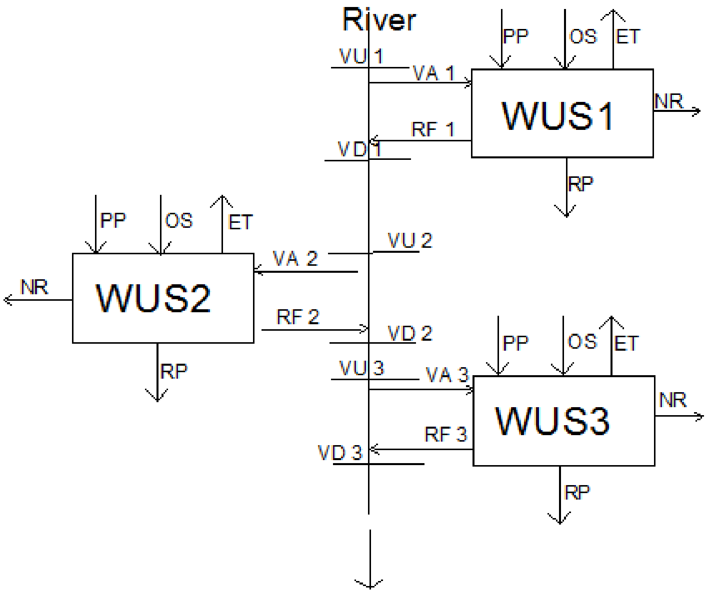


Figure 10 – General schematic of the WUS display throughout the main source with all variables defined.

Table 2 - Description of all variables represented in figure 9

Variable	Description
ET	Evapotranspiration
NR	Nonreusable,water consumption
OS	Water from other sources
PP	Total precipitation
RF	Return flows
RP	Potential return (does not return to the main source)
VA	Abstracted water from the main source
VD	Volume of water downstream after RF in the main source
VU	Volume of water upstream before abstraction in the main source

4. RESULTS

The Figure below shows the location of all three WUS that were considered for this study – Sefficiency and represents a more visual form of what is present in the general schematic in figure 9. Throughout the Guadiana River which is the main source, three plots of land with different crops, which are oranges, olives and grapes, were studied.

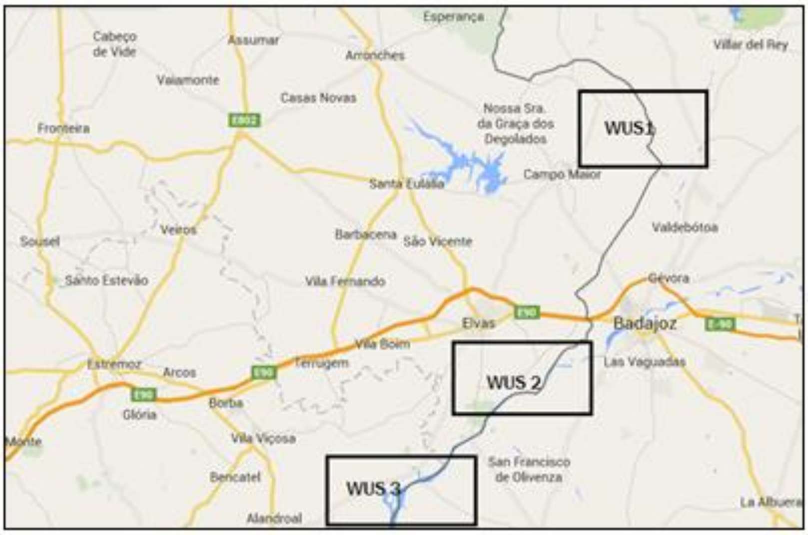


Figure 11 - Image obtained from Google maps with the WUS localization

4.1. Water Use System 1

In order to analyze Sefficiency the first Water Use System will be considered a small agricultural land of about a hectare. This land produces olives which are of a great importance in the Mediterranean region as the source of olive oil.

In Portugal the main region of olive trees cultivation is where WUS is localized which is in the Alentejo (42%) (INE, 2009). As an example, during the year of 2009 in all of Portugal 362.600 tons of olives were produced with 380.700 ha of cultivated area and 0.95 Ton/ha yield (OLIVAE, Official magazine of the international Olive Council / FAOSTAT).

For this case, the previously explained drip irrigation will be the type of irrigation chosen.

4.1.1. Evapotranspiration WUS1

According to the information granted by the FAO Natural Resources Management and Environment Department about olives the values of Kc for wide spacing of trees is 0.4 and for close spacing of trees is 0.7. In this particular case, it was considered close spacing of trees, so Kc = 0.7. As the climatic zone of area being studied is semi-arid and the mean daily temperature is medium the value given for ET0 is 5 mm/day. In consonance with the equations mentioned in section 3.2.1. the value for the variable ET for the olive trees is 3.5 mm/day.

$$E\text{T crop} = 5 \times 0.7 = 3.5\ \text{mm/day} \qquad (17)$$

4.1.2. Total Precipitation WUS1

There's a particular time of the year when the olive trees, in this case, need water, this is, during the growing season. For them the growing season is from April to December, so the values of precipitation only have interest if they're during these months. For the sake of being a bit more precise an interval of ten years was considered in order to achieve the average precipitation value.

As mentioned above the total precipitation value was obtained from SNIRH and in this case for WUS 1 the meteorological station with the daily precipitation is called Degolados. The next table contains the minimum, maximum and average value of daily precipitation during ten years.

Table 3 - Values of PP for WUS 1

Total Precipitation PP (mm/day)		
Minimum	Maximum	Average
0	80.8	1.1

4.1.3. Water Quality

To analyze the water quality according to the Canadian Water Quality Index there was a need to understand the Portuguese law regarding crop irrigation. Decree law number 236/98 Annex XVI attends to all specific parameters related to this topic allowing the reader to know if the water in hand may or may not be used for irrigation, as specified in section 3.3.

The site SNIRH from the *Agencia Portuguesa do Ambiente* (Portuguese Environmental Agency) provides a wide range of information about different parameters regarding the water quality of the desired river. The closest Hydrometric station to the WUS 1 is called Xevora and allowed the water quality to be analyzed.

Once all variables were obtained (pH, arsenic, cadmium, lead, chromium, iron, manganese, nickel, zinc, nitrates and total suspended solids – eleven variables-) and compared to the Portuguese Decree Law mentioned above only one parameter didn't meet the objective out of a total of 62 tests. The failed parameter was total suspended solids with 61 mg/L which the objective failed to meet was of 60 mg/L. (See Annex A)

Section 3.3. explains each equation in more detail.

$$F1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) \times 100 \ \leftrightarrow \ F1 = \left(\frac{1}{11}\right) \times 100 \leftrightarrow \ F1 = 9.090909 \qquad (18)$$

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) \times 100 \leftrightarrow \ F2 = \left(\frac{1}{62}\right) \times 100 \leftrightarrow \ F2 = 1.612903 \qquad (19)$$

$$\text{Excursion}_1 = \left(\frac{Failed\ Test\ Valuei}{Objectivej}\right) - 1 \ \leftrightarrow \text{excursion}_1 = \left(\frac{61}{60}\right) - 1 \leftrightarrow \ \text{excursion}_1 = 0.016667 \ (20)$$

$$nse = \frac{\sum_{i=1}^{n} excursioni}{number\ of\ tests} \leftrightarrow nse = \frac{0.016667}{62} \leftrightarrow nse = 0.000269 \qquad (21)$$

$$F3 = \left(\frac{nse}{0.01nse+0.01}\right) \leftrightarrow F3 = \left(\frac{0.000269}{0.01\times 0.000269+0.01}\right) \leftrightarrow F3 = 0.026874 \qquad (22)$$

$$CCMEWQI = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right) \leftrightarrow$$

$$\leftrightarrow CCMEWQI = 100 - \left(\frac{\sqrt{9.090909^2+1.612903^2+0.026874^2}}{1.732}\right) \leftrightarrow CCMEWQI = 90.7671 \text{ GOOD!} \quad (23)$$

4.1.4. Variable Values

Once the values that needed to be calculated are obtained, the remaining are assumed and explained below.

Table 4 - Water Balance Quantities

Variable	Value (mm/day)
VA	4
RF	1.4
NR	0
RP	0.2
ET	3.5
PP	1.1
OS	0
VU	1
VD	1

Both outflow and inflow must represent water balance (Mass Conservation) meaning that all that enters must leave. According to the data found regarding VA and PP the total inflow is 5 mm/day and considered that OS is 0 mm/day, meaning that there isn’t another source that can provide inflow. Also the data found for ET is 3.5 mm/day and the remaining outflow variables where assumed due to the fact that the system is hypothetical. As drip irrigation is assumed leads us to attribute a small value for RP 0.2 mm/day, once deep percolation is prevented by this irrigation method, and consequently the return flow to the main source is 1.3 mm/day, mainly through the root area. Once all quantities are defined the next stage is to define the usefulness of the variables, in quality and benefits.

Table 5 - Quality Weights Wq

Variable	Value (mm/day)
VA	0.97

RF	0.78
NR	0
RP	0.78
ET	1
PP	1
OS	0
VU	1
VD	1

As mentioned in section 3.2.6. VU and VD are untouched or in this case meaningless variables as they don't provide any useful information when only meso efficiency is being analyzed. On the other hand OS and NR are irrelevant once their corresponding quantity is zero. The quality weight attributed to VA was calculated through the Canadian Water Quality Index which was 0.97. The remaining variables RP and RF were given a value of 0.78. These values were attributed taking into account the possible pollution the main source might suffer.

Table 6 - Beneficial Weights Wb

Variable	Value (mm/day)
VA	1
RF	0.7
NR	0
RP	0.7
ET	1
PP	1
OS	0
VU	1
VD	1

The beneficial weights give the beneficial component of the variable which is defined by the managers, consultants and decision makers and depends on the intent of an intervention and societal priorities. Having in mind this definition of beneficial weight it’s possible to attribute values to the different variables according to what is considered beneficial or less beneficial for the system in hand. Considering that all the water entering the system is beneficial means that VA is 1, so is ET and PP. Even though the return flow (RF) is harmless for the system it isn’t entirely beneficial for the main source, which is in this case the Guadiana river, as the water has suffered alteration. The same goes to the variable RP, even though the water doesn’t go back to main source, it may interfere in other agriculture lands and may not be welcome. OS and NR are zero once there’s no quantity value, as mentioned above.

Table 7 - Final Results WUS1

MesoEs for WUS 1		
	i=1, c=0	i=0, c=1
Full Model	88.5%	86.2%
Quantity Model	91%	88.6%

The results presented in table 6 have the following meaning:

- iMesoEs: 88.5 % of useful inflow is useful outflow.
- iMesoEb: 91% of beneficial inflow is beneficial outflow.
- cMesoEs: 86.2 % of effective consumption that is useful consumption.
- cMesoEb: 8.6% of effective beneficial consumption that is beneficial consumption.

4.2. Water Use System 2

As a reminder of what was mentioned above there were defined three levels of analysis in relation to water flows and areal scales. The present case refers to Meso-Efficiency, as what will be analyzed is the impact of return flows generated by the WUS. In order to obtain this important performance indicator all the variables used in equation (2) must be defined.
The second Water Use System analyzes the Sefficiency of a plot of land with about a hectare which produces oranges.

Orange trees need humidity in the first 5 cm of the soil and can adapt to any kind of soil. Valencia Oranges are common in Portugal and these were the type of oranges considered for this plot of land.

4.2.1. Evapotranspiration WUS2

Once again through the information provided by the FAO Natural Resources Management and Environment Department about oranges the values of Kc for large mature trees covering 70% of the ground surface is 0.7 and when there’s no weed control 0.9 . For this particular case, the first value for Kc was considered so Kc = 0.7. As the climatic zone of area being studied is semi-arid and the mean daily temperature is medium the value given for ET0 is 5 mm/day. In consonance with the equations mentioned in section 3.2.1 the value for the variable ET for the olive trees is 3.5 mm/day.

$$E\text{T crop } = 5 \times 0.7 = 3.5 \text{ mm/day} \tag{24}$$

4.2.2. Total Precipitation WUS2

The Valencia Oranges growing season is from April to December and once again a period of ten years was considered for a more precise value. It’s important to mention that the years treated are the same in all three WUS. The website SNIRH provided the information regarding the total precipitation through the meteorological station called Caia, as observed in table 2. The value considered to calculate the Sefficiency is the average value of 1.1 mm/day.

Table 8 - Values of PP for WUS2

Total Precipitation PP (mm/day)		
Minimum	Maximum	Average
0	62.8	1.1

4.2.3. Water Quality

In order to determine the water quality through the Canadian Quality Index, the closest hydrometric station selected was Monte Vinha- Jusante. Variables such as pH, arsenic, cadmium, lead, copper, chromium, nickel, nitrates, zinc and total suspended solids were selected in order to provide the necessary results. With a total of 47 tests and comparing them with the Portuguese Decree Law only one parameter didn't meet the objective. (See Annex B). The following equations are explained in detail in section 3.3.

$$F1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) \times 100 \leftrightarrow \quad F1 = \left(\frac{1}{10}\right) \times 100 \leftrightarrow\ F1 = 10 \qquad (25)$$

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) \times 100 \leftrightarrow \quad F2 = \left(\frac{1}{47}\right) \times 100 \leftrightarrow\ F2 = 2.12766 \qquad (26)$$

$$\text{Excursion}_1 = \left(\frac{Failed\ Test\ Valuei}{Objectivej}\right) - 1 \leftrightarrow \text{excursion}_1 = \left(\frac{61}{60}\right) - 1 \leftrightarrow\ \text{excursion}_1 = 0.016667 \quad (27)$$

$$nse = \frac{\sum_{i=1}^{n} excursioni}{number\ of\ tests} \leftrightarrow nse = \frac{0.016667}{47} \leftrightarrow nse = 0.000355 \qquad (28)$$

$$F3 = \left(\frac{nse}{0.01nse+0.01}\right) \leftrightarrow F3 = \left(\frac{0.000355}{0.01\times 0.000355+0.01}\right) \leftrightarrow F3 = 0.035448 \qquad (29)$$

$$CCMEWQI = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right) \leftrightarrow$$

$$\leftrightarrow CCMEWQI = 100 - \left(\frac{\sqrt{10^2+2.12766^2+ 0.035448^2}}{1.732}\right) \leftrightarrow CCMEWQI = 89.77612 \quad \text{GOOD!} \quad (30)$$

4.2.4. Variable Values

Table 9 - Water Balance Quantities

Variable	Value (mm/day)
VA	4
RF	1.1

NR	0
RP	0.5
ET	3.5
PP	1.1
OS	0
VU	1
VD	1

Considering that the Water Use System 2 has a different type of irrigation from WUS 1, which is surface irrigation, meaning that the values of RF and RP will differ, maintaining the water balance RF will be lower and RP will increase.

Table 10 - Water Quality Weights Wq

Variable	Value (mm/day)
VA	0.89
RF	0.6
NR	0
RP	0.78
ET	1
PP	1
OS	0
VU	1
VD	1

For VA the quality weight was calculated previously through the Canadian Water Quality Index, as explained above. The type of irrigation is different so the quantity of the superficial water may be enough to drag unwanted substances that prevail on the land into the river, meaning that the Quality weight of RF will decrease. Even though deep percolation may occur and is related to RP, its quality weight will maintain the same

Table 11 - Beneficial Weights Wb

Variable	Value (mm/day)
VA	1
RF	0.5
NR	0
RP	0.5
ET	1
PP	1
OS	0
VU	1
VD	1

Having in mind that the values of RP rose and the possibility of it reaching a neighbors land and not being welcome, decreases its beneficial weight. Also, the value of RF will decrease due to the type of irrigation that will cause runoff losses, causing the entrance of unwanted substances in the river. The remaining variables won't be altered once they continue to have the same beneficial weight as WUS 1.

Table 12 - Final Results WUS 2

MesoE for WUS 2		
	i=1, c=0	i=0, c=1
Full Model	87.4%	85.9%
Quantity Model	85%	82.4%

The results presented in table 11 have the following meaning:

- iMesoEs: 87.4 % of useful inflow is useful outflow.
- iMesboEb: 85% of beneficial inflow is beneficial outflow.
- cMesoEs: 85.9 % of effective consumption that is useful consumption.
- cMEsoEb: 82.4%of effective beneficial consumption that is beneficial consumption.

The main difference between WUS1 and WUS2 is the irrigation type. The percentage has diminished from WUS 1 to WUS 2 as the irrigation is less efficient and brings fewer benefits to the Water Use System.

4.3. Water Use System 3

The third and final Water Use System will analyze a plot of land used for the cultivation of grapes, which's process takes place in the vineyard.

Each year begins with bud break in the spring and culminating in leaf fall in autumn followed by winter dormancy.

4.3.1. Evapotranspiration WUS3

Anew the information regarding ET values were obtained from the FAO Natural Resources Management and Environment Department. For grapes the value of Kc is 0.54, assuming that the grape harvest starts 5 months after the first leaf appears. The climatic zone is semi-arid and as the mean daily temperature is medium ET0= 5 mm/day, so the crop evapotranspiration value is 2.7 mm/day.

$$ET\text{ crop } = 5 \times 0.7 = 3.5\text{ mm/day} \qquad (31)$$

4.3.2. Total Precipitation WUS3

Considering that the grapevines require irrigation from March to November, its average precipitation will be during those months for a period of ten years. So in order to obtain the total precipitation value, consulting the website SNIRH (http://snirh.apambiente.pt) and the meteorological station (daily precipitation) called Juromenha throughout the mentioned ten years. As attended to table 13 the average value of PP is 1.2 mm/day.

Table 13 - Values of PP for WUS 3

Total Precipitation PP (mm/day)		
Minimum	Maximum	Average
0	45.5	1.2

4.3.3. Water Quality WUS3

The Alqueva-Juromenha hydrometric station provided several parameters which were used to analyze the water quality, such as the pH, arsenic, lead, cadmium, chromium, zinc, nitrates, copper and suspended solids (total of 9 variables). The variables that didn't meet their objective were the pH and the suspended solids, according to the Portuguese Decree Law. The total number of tests was 61. (See Annex C). The equations that follow are explained in more detail in section 3.3.

$$F1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) \times 100 \leftrightarrow \quad F1 = \left(\frac{2}{9}\right) \times 100 \leftrightarrow\ F1 = 22.222 \tag{32}$$

$$F2 = (\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}) \times 100 \leftrightarrow \quad F2 = \left(\frac{1}{61}\right) \times 100 \leftrightarrow\ F2 = 1.639 \tag{33}$$

$$\text{Excursion}_1 = \left(\frac{Failed\ Test\ Valuei}{Objectivej}\right) - \leftrightarrow \text{excursion}_1 = \left(\frac{73.6}{60}\right) - 1 \leftrightarrow \text{excursion}_1 = 0.226 \tag{34}$$

$$\text{Excursion}_2 = \left(\frac{Failed\ Test\ Valuei}{Objectivej}\right) - 1 \leftrightarrow \text{excursion}_2 = \left(\frac{97.6}{60}\right) - 1 \leftrightarrow \text{excursion}_2 = 0.626 \tag{35}$$

$$\text{Excursion}_3 = \left(\frac{Failed\ Test\ Valuei}{Objectivej}\right) - 1 \leftrightarrow \text{excursion}_3 = \left(\frac{9.2}{9}\right) - 1 \leftrightarrow \text{excursion}_3 = 0.022 \tag{36}$$

$$nse = \frac{\sum_{i=1}^{n} excursioni}{number\ of\ tests} \leftrightarrow nse = \frac{0.226+0.62667+0.022}{61} \leftrightarrow nse = 0.014 \tag{37}$$

$$F3 = \left(\frac{nse}{0{,}01nse+0{,}01}\right) \leftrightarrow F3 = \left(\frac{0.014}{0.01\times 0.014+0.01}\right) \leftrightarrow F3 = 1.414 \tag{38}$$

$$CCMEWQI = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right) \leftrightarrow$$

$$\leftrightarrow CCMEWQI = 100 - \left(\frac{\sqrt{22.222^2+1.639^2+1.414^2}}{1.732}\right) \leftrightarrow CCMEWQI = 87.109 \text{ GOOD!} \tag{39}$$

4.3.4. Variable Values

The type of irrigation considered for the third WUS was drip irrigation as it prevents runoff losses which avoid river pollution and deep percolation, as mentioned before and as used in WUS 1. There must be a distinction between young vines and older ones, as the younger ones need more water. In this case, older vines were considered.

Table 14- Water Balance Quantities

Variable	Value (mm/day)
VA	3
RF	1.3
NR	0
RP	0.2
ET	2.7
PP	1.2
OS	0
VU	1
VD	1

The water quantities for WUS 3 mainly differ in the value of ET. As this variable represents a smaller quantity VA will also decrease, even though PP is slightly higher.

Table 15 - Quality Weights Wq

Variable	Value (mm/day)
VA	0.87
RF	0.78
NR	0
RP	0.78
ET	1
PP	1

OS	0
VU	1
VD	1

Once again the value of VA was obtained through the Canadian Water Quality Index, calculated above. It’s evident that quality of the water’s river in this area isn’t as good, even though it’s a high value, which leads to believe that the water quality decreases downstream.

Table 16 - Beneficial Weights Wb

Variable	Value (mm/day)
VA	1
RF	0.7
NR	0
RP	0.7
ET	1
PP	1
OS	0
VU	1
VD	1

The beneficial weight was assumed according to the type of irrigation considered. As the irrigation type considered for this particular case was the same as the one considered for WUS 1, the beneficial weights were assumed equal.

Table 17 - Final Results WUS3

MesoE for WUS 3		
	i=1, c=0	i=0, c=1
Full Model	92.4%	90.3%
Quantity Model	89.3%	85.7%

The results presented in table 17 have the following meaning:

- iMesoEs: 92.4 % of useful inflow is useful outflow.
- iMesoEb: 89.3% of beneficial inflow is beneficial outflow.
- cMesoEs: 90.3% of effective consumption that is useful consumption.
- cMesoEb: 85.7% of effective beneficial consumption that is beneficial consumption

4.4. Water Policy

Through the water policies defined in section 3.4. It is possible to observe that the maximum values of VA are obtained sooner than expected. It’s wrong to assume that the quantity of water needed are 11 units (as the sum of all three VA is 11), even though it seems correct and somehow obvious. However, the hypothetical water policy assumed shows that it’s possible to obtain the maximum value for all three VA with much less quantity of water than the one that was predicted.

Annex D has the table with all the water policies that were applied. VU1 represents the water quantity entering the river (first column). As the water quantities increase, but still below the 2 minimum units, the water remains in the river which means that VU1=VD1=VU2=VD2=VU3=VD3. After reaching Policy 1, VA3 starts receiving water when there´s 2.2 units in the river. WUS 3 stops receiving when the water quantity is 4.2 units (Policy 2) and this is when WUS 1 and 2 begin to receive equally. At a quantity of 4.2 units of water there was a need to distribute as much water as possible between VA1 and VA2, equally, but always obeying the water policies previously defined.

By keeping a value of 4 units in VD2 allows VA3 to maintain its 2 units of water and consequently utilize as much water as possible for both WUS 1 and WUS 2.

Once all three WUS have 2 units (when the water quantity is 6.8 units) they all receive the same amount until they reach their maximum VA value and stop receiving when the water quantity is 9.2. So, in this case Policy 1 is met when the water quantity is 2 units, Policy 2 at 2.2 units, Policy 3 when the water quantity is 4.2 units and finally Policy 4 when the water quantity is 6.8 units.

The graph bellow represents the variation of ET as the quantity of water in the river increases. The horizontal axis represents the quantity of water that exists in the river, with a corresponding value of ET.

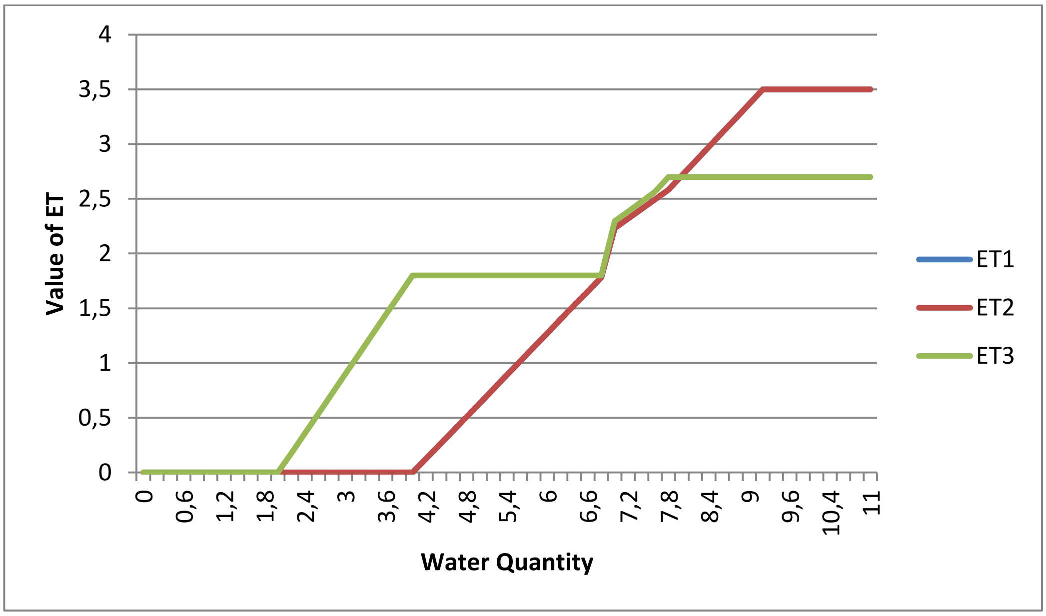


Figure 12 – Graph represents the variation of ET according to the water quantities

ET1 and ET2 are overlapped as they have the same values. As expected all the values initially are zero and only rise when VA starts capturing water. If the existence of PP is ignored then VA is the only source of water, which means that the value of ET depends entirely on VA. ET3 reaches a constant value when WUS3 stops receiving water, once VA3 reaches 2 units, it’s ate this point when the values of ET1 and ET2 start to rise.

On the other hand the graph bellow represents the variation of RF as the quantity of water in the river increases. The horizontal axis represents the quantity of water that exists in the river, with a corresponding value of RF.

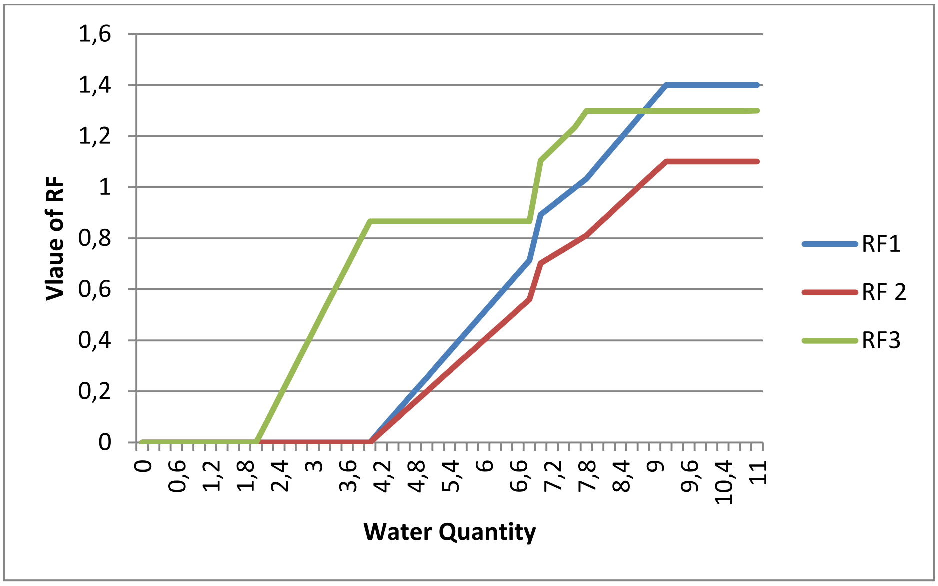


Figure 13 – Graph represents the variation of the variable RF according to the water quantities

The value of RF depends not only on VA but also ET. Three different percentages were defined to set the value of RF as the water quantity varied. The horizontal line in RF3 means that WUS 3 stopped receiving water as it reached its 2 units. It's when RF3 becomes a horizontal line that both RF1 and RF2 start to increase. All three reach stable levels when its corresponding VA reaches its maximum value.

4.5. Water Allocation Policy and Sefficiency

In order to combine both Water Allocation Policies and Sefficiency, MesoE was calculated for every meaningful value of the river units. For each WUS a graph was obtained, which makes it possible to visualize how the values of iMesoEs, iMesoEb, cMesoEs and cMesoEb vary according to the amount of water units that exist in the river. Annex E, F and G show each one of those values.

4.5.1. Water Use System 1

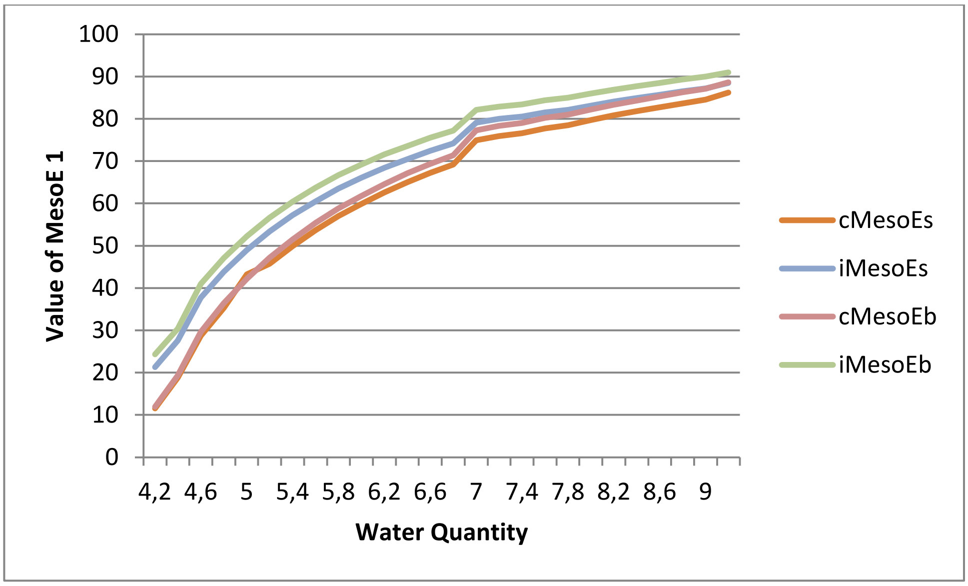


Figure 14 – Graph represents the variation of Meso-Efficiency in WUS 1 according to the existing units

For WUS 1, Meso-Efficiency starts to occur when the system starts to receive units. Having in mind that cMesoEs takes into account both quality and benefit weights and cMesoEb acknowledges only the benefit weights, this means that when the river achieves 4.2 units the quality weights aren’t as meaningful. Throughout the graph cMesoEs and cMesoEb seem to have similar values until about 5.6 units when cMesoEb attains higher values than cMesoEs, which means that the effective consumption that is beneficial consumption is higher than the useful consumption. The benefit weights have a greater impact than the quality weights in the WUS as this happens until VA reaches its maximum value. The graph seems to have a smooth increase through until the quantity reaches 7 units. At this point all efficiencies increase to higher values than before. This can be explained through the gain in the value of VA. The graph also shows that the beneficial outflow is at all times higher than the useful outflow. All values of iMesoEb are greater than iMesoEs, as the part of the numerator regarding ET and NR of the equation are the same in both cases, RF and RP for the quantity model is higher, once the value of the Useful Criterion is lower than the benefits. Also, the denominator has a greater value for the quantity model for the same reasons. The values that vary and influence the results are RF, RP and VA, which causes the beneficial outflow to always to be of a greater value than what is useful outflow.

4.5.2. Water Use System 2

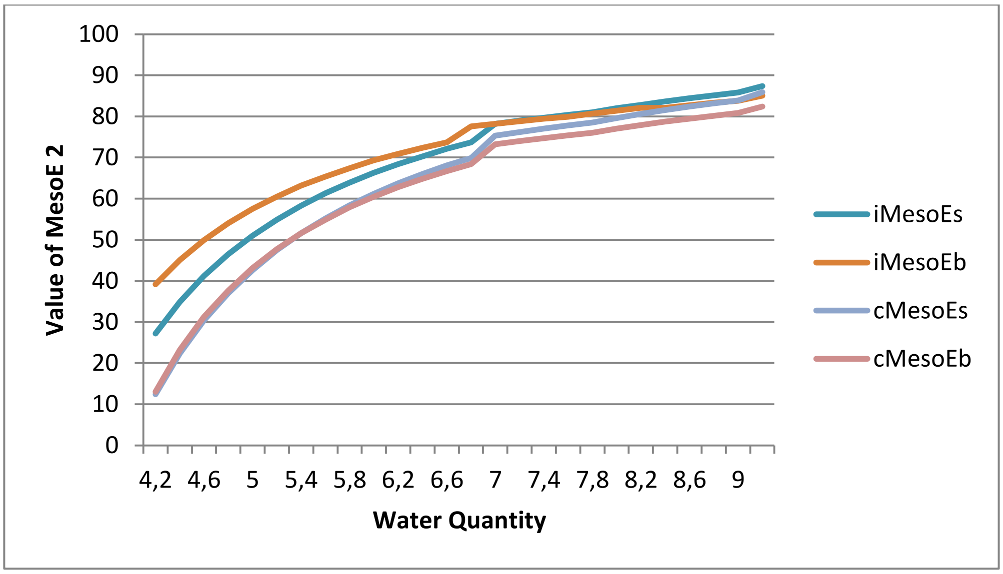


Figure 15 - Graph represents the variation of Meso-Efficiency in WUS 2 according to the existing units

In WUS 2, the values of cMesoEb and cMesoEs are very similar. The difference in values begins to be obvious when 7 units are achieved; cMesoEs starts to obtain greater values than cMesoEb, until VA reaches its maximum value. Both numerators are the same, either regarding a full model or a quantity model (ET+NR). However, the denominator for the full quantity models is less and the one for the quantity models, which implies that final result of the full models, is always greater than the quantity model. Meaning that the useful consumption is higher than the beneficial consumption.

Another particular point that stands out in the graph is at 6.8 units, when Policy 3 is reached, meaning that from this point forward all three WUS start to receive equal amounts of water. On the other hand, iMesoEs initially has a lower value than iMesoEb, which means that even though the numerator is the same, the value (RP + RF)b is higher than (RP+RF)s, which provides higher values once the difference both denominator is very low.

However, when reaching 8.2 units the opposite happens, as the denominator for iMesoEb has a greater value, which makes its final result to be lower than iMesoEs, meaning that the useful outflow is higher than the beneficial outflow.

4.5.3. Water Use System 3

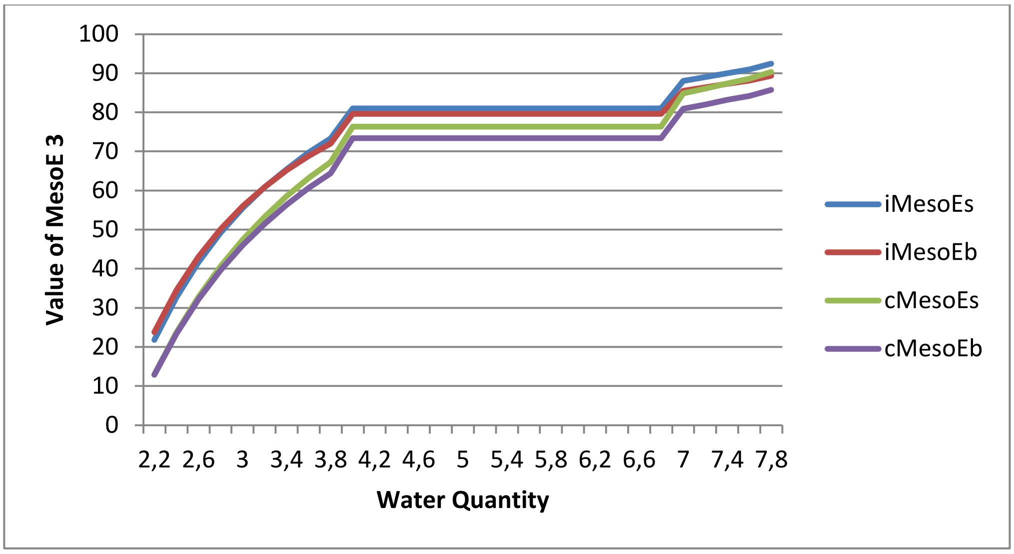


Figure 16 - Graph represents the variation of Meso-Efficiency in WUS 3 according to the existing units

As was defined in the water allocation policy, it had priority over the remaining WUS. So at 2.2 units the system started to receive water. Initially cMesoEs is very similar to cMesoEb, the same happens to the value of iMesoEs and iMesoEb. At about 3units cMesoEs and cMesoEb start not to have as similar values as previously. Seems that at this point, the Useful Criterion diminishes the final value of the equation. Even though the benefit weights may have a greater value, how it's applied to the cMesoE equation is what dictates whether the useful outflow higher or not than the beneficial outflow. However, when regarding to consumption at 3 units the values continue with very similar values. This means that either the beneficial part or the useful part has the same impact on the system. When the units reach a total of 4, the efficiency values remain at a constant value, as this represents the second policy when WUS 3 stops receiving to allow the remaining two systems to receive. Once all three systems attain 2 units for VA, all three start to receive equally and this is when the values on the graph start to grow again. At this point the Useful Criterion has a greater impact on the final result than the benefit weights, which means that the effective consumption that is useful consumption is bigger than the beneficial consumption. The same happens to iMesoEb and iMesoEs, meaning that once again the Useful Criterion has a bigger impact in the equation and consequently reflects on the system.

5. CONCLUSIONS

In order to understand the meaning of each value the table below allows an easier way to view and compare all values obtained for each WUS.

Table 18 - Final view of all results

	WUS1	WUS2	WUS3
iMesoEs	88,5%	87,4%	92,4%
iMesoEb	91%	85%	89,3%
cMesoEs	86,2%	85,9%	90,3%
cMesoEb	88,6%	82,4%	85,7%

Taking into consideration iMesoEs the values that outstand are the difference between WUS2 and WUS3 of 5 pp. The quantities of water are greater for WUS 2 however; the usefulness criterion is greater for WUS 3 so it’s logical that WUS3 assumes a bigger value regarding iMesoEs, once that it refers to a smaller amount of water but with higher qualities and benefits. So as a result of a comparison between all three Water Use Systems, regarding a full and an inflow model, WUS 3 has a higher Sefficiency value, meaning that the useful inflow that is useful outflow is greater.

For the second line of table 17, the first impression is that there’s a significant difference between iMesoEb1 and iMesoEb2. This difference is of 6 pp. The water quantities in both WUS are very similar however; the beneficial part is what distinguishes them. iMesoEb1 has a higher numerator than iMesoEb2 and have a common denominator which consequently will provide larger results for iMesoEb1. Even though the total inflow and outflow of both systems are equal the benefits are not. Higher benefits are attributed to higher quantities of water in WUS1, although the beneficial inflow is the same in both, what differentiates them is the greater beneficial outflow provided by WUS1.

In regards to consumption there’s cMesoEs and the most distinctive values are between WUS 2 and WUS 3 with a difference of 4.4 pp. Through a similar approach to iMesoEs what distinguishes both is that now there’s a value subtracted in the denominator, which means that if the subtraction is bigger, the denominator will also decrease, enhancing the final value.

So, as it was said before for WUS 3 the usefulness criterion is greater which implies that the subtraction is also greater, meaning that the effective consumption that is useful consumption is higher WUS 3 and in WUS 2.

Once again when regarding quantity models the main difference is between WUS1 and WUS2 which confirms the low benefits of WUS 2 and can be explained the same way as iMesoEb. However, in this particular case the higher value of WUS1 represents a greater effective beneficial consumption that is beneficial consumption than WUS 2.
These results can also be explained through what actually causes the benefits to be lower, which comes from the irrigation type that was elucidated in the previous section.

It's important to understand the importance of decision making and management as they may influence the whole Sefficiency process. The intention and objective of the stakeholder will decide on what is or not acceptable for the system. Depending on the purpose and the interest of the decision maker, it's possible to understand what they should or shouldn't do based on that mathematical framework for managing water resources.

On the other hand, there's the water policy allocation, which is in regard to more than one system. It's another meaningful way of making decisions. With no water allocation policy defined and applied there wouldn't be any fairness. Efficiency and equity are two principles which are combined in water allocation.

In this particular policy (see Annex D) when WUS 3 started to receive units there was in the remaining flow more than 2 units, which means that both WUS 1 and WUS 2 could have also started to receive water earlier than they actually did. For example when VU1 = 2.4 units VD3=2.173 units, which means that there's an extra 0.173 units that could have been equally distributed through WUS 1 and WUS 2.
However, the policy didn't allow that to happen. Instead of the maximum VA being achieved at 9.2 units it could have happened sooner which means less quantity of water would have been spent.

When regarding to Climate Change and hence the lack of water, it's important to take into account the several parameters than can be easily overlooked. Changes in precipitation, temperature and longer dryer seasons may alter the quantity and quality of the water that surrounds us. It’s important to remember, for example, that if the dryer seasons are longer then the value of the abstracted water from the main source will have to be higher and consequently the amount of water spent will be greater. Sefficiency values all details that intervene in a Water Use System and so the user may alter according to its need and makes the decision process easier. What’s considered to be a useful application or even beneficial depends on the stakeholder and its interest on the subject. All the benefits considered could easily be changed if the purpose of the WUS was different. Anyhow, this particular example of Sefficiency application tries to consider water use in the most efficient way possible due to climate change. When combining the Water Allocation Policy to Sefficiency it’s possible to achieve even higher values of efficient water use, as it’s possible to attain the maximum value of VA with less amounts of water. This particular Water Allocation Policy has its flaws as it was previously mentioned, however, if there had been a different approach, the units of water would have been less and that would benefit the water scarcity problem, as well as reducing costs.

It’s not possible to go back in time and alter people’s behavior towards the planet or even tell those people that the water will lack and thousands of children, men and women will indeed suffer. But there’re many tools that can at least help to use water in a more efficient way, and not spend unnecessary amounts of such a precious gift. When regarding water there must be a consideration of all possible alternatives involved and ultimately choose the one that suits our particular interest.

REFERENCES AND BIBLIOGRAPHY

Dinar, A., Rosegrand, Mark W. and Meinzen-Dick, Ruth (1997). Water Allocations Mechanisms: Principles and examples. The World Bank. Agriculture and Natural Resources Department, Washington. 1779, 2:16

Arnell, Nigel W. (1999). Climate Change and Global Water Resources: Global Environmental Change. Department Of Geography, Southampton. Elsevier Science Ltd, UK. 31:49

Vörösmarty, Charles J. et al., (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth. Department Of Geosciences, Penn State University, USA. 289, 284-288

Letey, John. (2000). Soil salinity poses challenges for sustainable agriculture and wildlife. California Agriculture.

Canadian Council of Ministers of the Environment. Canadian Environmental Quality Guidelines for the Protection of Aquatic Life (2001): CCME Water Quality index 1.0 User’s Manual.

Malashkhia, Nino (2003) Social and Environmental Constraints to the irrigation Water Conservation Measures in Egypt. Lund University, Sweden. Pages: 17, 23.

R. Lal, et al. (2004) Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science: American Association of the Advancement of Science, New York Avenue. 304: 1623-1626

Loucks, D.P. & Van Beek, E. (2005) Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications, UNESCO, Paris. Chapter 8 pages 4 and 5.

Perry, Chris (2007). Efficient Irrigation, Inefficient Communication and Flawed Recommendations. WaterWatch, Generaal Foulkesweg, the Netherlands. 56: 367-378

Schnoor, Jerald L., (2010) Water Sustainability in a Changing World. National Water Research Institute*:* The 2010 Clarke Prize Lecture. 1-20

Trenberth, Kevin E. (2011) Changes in precipitation with climate change. National Center for Atmospheric Research, Colorado, USA, 47: 123-138

Garcia, António de Aragão Cravo (2011) Enrelvamento no olival – Efeito da rega no crescimento vegetatito, na produção e na qualidade do azeite. Intituto Superior de Agronomia da Universidade Técnica de Lisboa. Pages: 2, 12, 14.

FAO (Food and Agriculture Organization). (2011). Biodiversity for Food and Agriculture. Contributing to food security and sustainability in a changing world. The Food and Agriculture Organization of the United Nations and the Platform for Agrobiodiversity Research. Rome, Italy. Pages: 11, 14, 15

Haie, N. & Keller, A. A. (2012). Macro, Meso, and Micro Efficiencies in Water Resources Management: A New Framework Using Water Balance. Journal Of The American Water Resources Association (JAWRA), Wiley, 48:2, 235-243

Papatsie, Leesee, Ellsworth Leanna, Meakin Stephanie (2013) The Right to Food Security in a Changing Artic. Case Studies: Local Solutions. A New Diologue: Putting People at the Heart of a Global Development. Dublin, Ireland. 75-82

IPCC (Intergovernmental Panel on Climate Change). (2013). Climate Change 2013 – The physical Science Basis. Fifth Assessment Report, Working Group I.

Investing in Water and Sanitation: Increasing Access, Reducing Inequalities. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water. GLAAS 2014 Report

Hassen, Yusuf Kedir (2014) Assessment of small scale irrigation using comparative performance indicators on two selected schemes in upper awash river valley. Alemaya University. Pages: 23, 26.

Haie, N. & Keller, A. A. (2014). Macro, meso, and Micro Efficiencies and Terminologies in Water Resources Management: a Look at Urban and Agricultural Differences. Water International, Taylor & Francis Ltd, UK. 39:1, 35-48

UNDP (United Nations Development Report). (2015). Water for a Sustainable World. UN-Water Report. Paris, France.

Weiss, Matthew L. (2015). A Perfect Storm: The causes and consequences of severe water scarcity, institutional breakdown and conflict in Yemen. Water International, Taylor & Francis Ltd, UK. 40:2, 251-272

LIST OF WEBSITES

United States Environmental Agency (2012). National Water Program 2012 Strategy: Response to Climate Change. Available:< http://water.epa.gov/scitech/climatechange/2012-National-Water-Program-Strategy.cfm> Accessed: 1st of June 2015

Growing blue. Water in 2050. Available: < http://growingblue.com/water-in-2050/ > Accessed: 24th of May 2015

Sistema Nacional de Informação de Recursos Hídricos: Agência Portuguesa do Ambiente. Available: < http://snirh.apambiente.pt/index.php?idMain=2&idItem=1> Accessed: 3rd of May 2015

Brandt, Jane and Geeson, Nichola. Land Care In Desertification Areas. Available: <http://geografia.fcsh.unl.pt/lucinda/Leaflets/A2_Leaflet_PT.pdf> Accessed: 16th of May 2015

ANNEX

Annex A

Water Quality WUS1: Hydrometric Station Xevora

		mg/L	ug/L	ug/L	mg/L	mg/L	mg/L	ug/L	mg/L	mg/L	mg/L
	pH	Arsenic	Cadmium	Lead	Chromium	Iron	manganese	nickle	nitrates	zinc	TSS
April		0,003	L15	L3	L0,005	L0,005	L0,002	L5	8,8	L0,002	10
May								L5	4,2		39
June						L0,015	0,3	L5	3,85	L0,006	6,05
July			L15	L9	L0,015			L5	L2		L5
August						L0,015	0,28	L5	2,65	L0,006	24,55
September			L15	L9	L0,015			L5	L2		L5
October						L0,015	0,26	L5	L2	L0,006	17
November								L5	L2		9,2
December						0,6	0,24		L2	0,02	11
January					L0,015				L2		17
February						0,16	0,02		L2	0,04	8,4
March									3		**61**
April	7,7										
Objective	6,5-8,4	0,1	50	500	0,1	5	0,2	500	50	2	60
	ok!	ok!	ok!	ok!	ok!	ok!	ok!	ok!	ok!	ok!	**ko!**

L less than

Annex B

Water Quality WUS2: Hydrometric Station Monte-Vinha Jusante

		mg/L	ug/L	ug/L	mg/L	mg/L	ug/L	mg/L	mg/L	mg/L
	pH	Arsenic	Cadmium	Lead	Copper	Chromium	Nickel	Nitrates	Zinc	TSS
April	8,3							4,2		44
May										
June			L15	L90						
July	7,7		L5	L30				15		17
August			L5	L30						
September		0,003	L5	L30	L0,025	0,002	L5		0,06	
October	7,6		L5	L30			L5	14		**61**
November			L15	L90			L5			
December			L15	L90			L5			
January	8,2		L15	L90			L5	16		42
February		0,005	L15	L90			L5			
March	8,1		L15	L90			L5	7,4		42
April										
Objective	6,5-8,4	0,1	50	500	0,2	0,1	500	50	2	60
	ok!	ok!	ok!	ok!	ok!	ok!	ok!	ok!	ok!	**ko!**

L less than

Annex C

Water Quality WUS3: Hydrometric Station Juromenha

		mg/L	ug/L	ug/L	mg/L	mg/L	mg/L	mg/L	mg/L
	pH	Arsenic	Cadmium	Lead	Copper	Chromium	Nitrates	Zinc	TSS
March	7,9				0,003		9,27	0,022	48,8
April	8,1						4,72		34,2
May	8,3				L0,003		5,05	L0,019	35,6
June	8,1						2,02		41,6
July	**9,2**				L0,003		0,7	L0,019	24,4
August	7,5						1,97		10,4
September	7,5	L0,004	L0,5	L4	L0,003	L0,002	3,23	L0,019	19,2
October	8,4						4,2		30,6
November	7,8	L0,005	L0,5	L4	L0,003	L0,002	18,1	L0,019	**73,6**
December	6,7						14,1		L10
January	8,1						16,5		22,4
February	7,5	0,007	L0,5	L5	0,005	L0,002	8,1	L0,014	**97,6**
March	7,1						5		38,4
Objective	6,5-8,4	0,1	50	500	0,2	0,1	50	2	60
	ko!	ok!	ok!	ok!	ok!	ok!	ok!	ok!	**ko!**

L less than

Annex D

Water Allocation Policy

VU 1	VA 1	ET 1	RF 1	VD 1	VU 2	VA 2	ET 2	RF 2	VD 2	VU 3	VA 3	ET 3	RF3	VD 3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,2	0	0	0	0,2	0,2	0	0	0	0,2	0,2	0	0	0	0,2
0,4	0	0	0	0,4	0,4	0	0	0	0,4	0,4	0	0	0	0,4
0,6	0	0	0	0,6	0,6	0	0	0	0,6	0,6	0	0	0	0,6
0,8	0	0	0	0,8	0,8	0	0	0	0,8	0,8	0	0	0	0,8
1	0	0	0	1	1	0	0	0	1	1	0	0	0	1
1,2	0	0	0	1,2	1,2	0	0	0	1,2	1,2	0	0	0	1,2
1,4	0	0	0	1,4	1,4	0	0	0	1,4	1,4	0	0	0	1,4
1,6	0	0	0	1,6	1,6	0	0	0	1,6	1,6	0	0	0	1,6
1,8	0,000	0,000	0,000	1,800	1,800	0,000	0,000	0,000	1,800	1,800	0,000	0,000	0,000	1,800
2	0,000	0,000	0,000	2,000	2,000	0,000	0,000	0,000	2,000	2,000	0,000	0,000	0,000	2,000
2,2	0,000	0,000	0,000	2,200	2,200	0,000	0,000	0,000	2,200	2,200	0,200	0,180	0,087	2,087
2,4	0,000	0,000	0,000	2,400	2,400	0,000	0,000	0,000	2,400	2,400	0,400	0,360	0,173	2,173
2,6	0,000	0,000	0,000	2,600	2,600	0,000	0,000	0,000	2,600	2,600	0,600	0,540	0,260	2,260
2,8	0,000	0,000	0,000	2,800	2,800	0,000	0,000	0,000	2,800	2,800	0,800	0,720	0,346	2,346
3	0,000	0,000	0,000	3,000	3,000	0,000	0,000	0,000	3,000	3,000	1,000	0,900	0,433	2,433
3,2	0,000	0,000	0,000	3,200	3,200	0,000	0,000	0,000	3,200	3,200	1,200	1,080	0,520	2,520
3,4	0,000	0,000	0,000	3,400	3,400	0,000	0,000	0,000	3,400	3,400	1,400	1,260	0,606	2,606

3,6	0,000	0,000	0,000	3,600	3,600	0,000	0,000	0,000	3,600	3,600	1,600	1,440	0,693	2,693
3,8	0,000	0,000	0,000	3,800	3,800	0,000	0,000	0,000	3,800	3,800	1,800	1,620	0,779	2,779
4	0,000	0,000	0,000	4,000	4,000	0,000	0,000	0,000	4,000	4,000	2,000	1,800	0,866	2,866
4,2	0,145	0,127	0,051	4,106	4,106	0,145	0,127	0,040	4,001	4,001	2,000	1,800	0,866	2,867
4,4	0,291	0,255	0,102	4,211	4,211	0,291	0,255	0,080	4,000	4,000	2,000	1,800	0,866	2,866
4,6	0,436	0,382	0,153	4,316	4,316	0,436	0,382	0,120	4,000	4,000	2,000	1,800	0,866	2,866
4,8	0,582	0,509	0,204	4,422	4,422	0,582	0,509	0,160	4,000	4,000	2,000	1,800	0,866	2,866
5	0,727	0,636	0,255	4,527	4,527	0,727	0,636	0,200	4,000	4,000	2,000	1,800	0,866	2,866
5,2	0,873	0,764	0,305	4,633	4,633	0,873	0,764	0,240	4,000	4,000	2,000	1,800	0,866	2,866
5,4	1,018	0,891	0,356	4,738	4,738	1,018	0,891	0,280	4,000	4,000	2,000	1,800	0,866	2,866
5,6	1,164	1,018	0,407	4,844	4,844	1,164	1,018	0,320	4,000	4,000	2,000	1,800	0,866	2,866
5,8	1,309	1,145	0,458	4,949	4,949	1,309	1,145	0,360	4,000	4,000	2,000	1,800	0,866	2,866
6	1,455	1,273	0,509	5,055	5,055	1,455	1,273	0,400	4,000	4,000	2,000	1,800	0,866	2,866
6,2	1,600	1,400	0,560	5,160	5,160	1,600	1,400	0,440	4,000	4,000	2,000	1,800	0,866	2,866
6,4	1,745	1,527	0,611	5,265	5,265	1,745	1,527	0,480	4,000	4,000	2,000	1,800	0,866	2,866
6,6	1,891	1,655	0,662	5,371	5,371	1,891	1,655	0,520	4,000	4,000	2,000	1,800	0,866	2,866
6,8	2,036	1,782	0,713	5,476	5,476	2,036	1,782	0,560	4,000	4,000	2,000	1,800	0,866	2,866
7	2,550	2,231	0,893	5,343	5,343	2,550	2,231	0,701	3,494	3,494	2,550	2,295	1,104	2,048
7,2	2,650	2,319	0,928	5,478	5,478	2,650	2,319	0,729	3,556	3,556	2,650	2,385	1,147	2,054
7,4	2,750	2,406	0,963	5,613	5,613	2,750	2,406	0,756	3,619	3,619	2,750	2,475	1,191	2,060
7,6	2,850	2,494	0,998	5,748	5,748	2,850	2,494	0,784	3,681	3,681	2,850	2,565	1,234	2,065
7,8	2,950	2,581	1,033	5,883	5,883	2,950	2,581	0,811	3,744	3,744	3,000	2,700	1,299	2,043
8	3,100	2,713	1,085	5,985	5,985	3,100	2,713	0,853	3,738	3,738	3,000	2,700	1,299	2,037
8,2	3,250	2,844	1,138	6,088	6,088	3,250	2,844	0,894	3,731	3,731	3,000	2,700	1,299	2,030
8,4	3,400	2,975	1,190	6,190	6,190	3,400	2,975	0,935	3,725	3,725	3,000	2,700	1,299	2,024
8,6	3,550	3,106	1,243	6,293	6,293	3,550	3,106	0,976	3,719	3,719	3,000	2,700	1,299	2,018
8,8	3,700	3,238	1,295	6,395	6,395	3,700	3,238	1,018	3,713	3,713	3,000	2,700	1,299	2,012
9	3,850	3,369	1,348	6,498	6,498	3,850	3,369	1,059	3,706	3,706	3,000	2,700	1,299	2,005

9,2	4,000	3,500	1,400	6,600	6,600	4,000	3,500	1,100	3,700	3,700	3,000	2,700	1,299	1,999
9,4	4,000	3,500	1,400	6,800	6,800	4,000	3,500	1,100	3,900	3,900	3,000	2,700	1,299	2,199
9,8	4,000	3,500	1,400	7,200	7,200	4,000	3,500	1,100	4,300	4,300	3,000	2,700	1,299	2,599
10	4,000	3,500	1,400	7,400	7,400	4,000	3,500	1,100	4,500	4,500	3,000	2,700	1,299	2,799
10,2	4,000	3,500	1,400	7,600	7,600	4,000	3,500	1,100	4,700	4,700	3,000	2,700	1,299	2,999
10,4	4,000	3,500	1,400	7,800	7,800	4,000	3,500	1,100	4,900	4,900	3,000	2,700	1,299	3,199
10,6	4,000	3,500	1,400	8,000	8,000	4,000	3,500	1,100	5,100	5,100	3,000	2,700	1,299	3,399
10,8	4,000	3,500	1,400	8,200	8,200	4,000	3,500	1,100	5,300	5,300	3,000	2,700	1,299	3,599
11	4,000	3,500	1,400	8,400	8,400	4,000	3,500	1,100	5,500	5,500	3,000	2,700	1,300	3,800

Annex E

Water Allocation Policy and Sefficiency WUS 1

VU 1	VA 1	ET 1	RF 1	VD 1	cMesoEs	iMesoEs	cMesoEb	iMesoEb
4,2	0,145	0,127	0,051	4,106	11,5	21,3	11,9	24,3
4,4	0,291	0,255	0,102	4,211	18,8	27,6	19,3	30,4
4,6	0,436	0,382	0,153	4,316	37,7	41	28,7	29,6
4,8	0,582	0,509	0,204	4,422	35,3	43,8	36,4	47,1
5	0,727	0,636	0,255	4,527	43,2	54,2	43,2	54,2
5,2	0,873	0,764	0,305	4,633	45,7	53,4	47,2	56,6
5,4	1,018	0,891	0,356	4,738	49,9	57,2	51,5	60,4
5,6	1,164	1,018	0,407	4,844	53,7	60,5	55,4	63,7
5,8	1,309	1,145	0,458	4,949	57	63,5	58,8	66,7
6	1,455	1,273	0,509	5,055	68,5	73,4	70,7	76,4
6,2	1,600	1,400	0,560	5,160	62,6	68,4	64,6	71,6
6,4	1,745	1,527	0,611	5,265	65	70,5	67,1	73,6
6,6	1,891	1,655	0,662	5,371	67,2	72,4	69,3	75,5
6,8	2,036	1,782	0,713	5,476	69,2	74,2	71,4	77,2
7	2,550	2,331	0,893	5,343	74,9	79,1	77,3	82,1
7,2	2,650	2,319	0,928	5,478	75,9	80	78,3	82,9

7,4	2,750	2,406	0,963	5,613	76,6	80,5	79	83,4
7,6	2,850	2,494	0,998	5,748	77,7	81,5	80,2	84,4
7,8	2,950	2,581	1,033	5,883	78,5	82,1	81	85
8	3,100	2,713	1,085	5,985	79,7	83,1	82,2	86
8,2	3,250	2,844	1,138	6,088	80,8	84,1	83,3	86,9
8,4	3,400	2,975	1,190	6,190	81,8	84,9	84,3	87,7
8,6	3,55	3,106	1,243	6,293	82,7	85,7	85,3	88,5
8,8	3,7	3,238	1,295	6,395	83,6	86,5	86,3	89,3
9	3,85	3,369	1,348	6,498	84,5	87,2	87,1	90
9,2	4	3,500	1,400	6,600	86,2	88,5	88,6	91

Annex F

Water Allocation Policy and Sefficiency WUS 2

VU1	VA 2	ET 2	RF2	iMesoEs	iMesoEb	cMesoEs	cMesoEb
4,2	0,145	0,127	0,04	27,2	39,2	12,4	13
4,4	0,291	0,255	0,08	34,9	45,1	22,4	23,2
4,6	0,436	0,382	0,12	41,2	49,9	30,4	31,2
4,8	0,582	0,509	0,16	46,5	54	37	37,6
5	0,727	0,636	0,2	51	57,5	42,6	43,1
5,2	0,873	0,764	0,24	54,9	60,5	47,5	47,7
5,4	1,018	0,891	0,28	58,3	63,2	51,6	51,6
5,6	1,164	1,018	0,32	61,3	65,4	55,2	54,9
5,8	1,309	1,145	0,36	63,9	67,4	58,4	57,9
6	1,455	1,273	0,4	66,3	69,3	61,2	60,5
6,2	1,600	1,400	0,44	68,4	70,9	63,7	62,8
6,4	1,745	1,527	0,48	70,3	72,4	66	64,8
6,6	1,891	1,655	0,52	72,1	73,7	68,1	66,7
6,8	2,036	1,782	0,56	73,7	77,6	69,9	68,4
7	2,550	2,331	0,701	78,2	78,2	75,3	73,2
7,2	2,650	2,319	0,729	79	78,8	76,2	74

7,4	2,750	2,406	0,756	79,7	79,4	77	74,7
7,6	2,850	2,494	0,784	80,4	79,9	77,8	75,4
7,8	2,950	2,581	0,811	81	80,7	78,5	76
8	3,100	2,713	0,853	82	81,4	79,6	77
8,2	3,250	2,844	0,894	82,8	82,1	80,6	77,9
8,4	3,400	2,975	0,935	83,6	82,1	81,5	78,7
8,6	3,55	3,106	0,976	84,4	82,7	82,4	79,4
8,8	3,7	3,238	1,018	85,1	83,3	83,2	80,1
9	3,85	3,369	1,059	85,8	83,8	83,9	80,8
9,2	4	3,500	1,1	87,4	85	85,9	82,4

Annex G

Water Allocation Policy and Sefficiency WUS 3

VU 1	VA3	ET3	RF3	iMesoEs	iMesoEb	cMesoEs	cMesoEb
2,2	0,4	0,18	0,087	21,8	23,8	12,9	12,9
2,4	0,6	0,36	0,173	32,7	34,5	23,7	23,4
2,6	0,8	0,54	0,26	41,7	43,1	32,8	32,2
2,8	1	0,72	0,346	49,2	50,1	40,6	39,6
3	1,2	0,9	0,433	55,5	56	47,4	46
3,2	1,4	1,08	0,52	60,9	60,9	53,3	51,5
3,4	1,6	1,26	0,606	65,5	65,2	58,6	56,4
3,6	1,8	1,44	0,693	69,7	68,8	63,2	60,6
3,8	2	1,62	0,779	73,3	72	67,3	64,4
4	2	1,8	0,866	81	79,6	76,3	73,4
4,2	2	1,8	0,866	81	79,6	76,3	73,4
4,4	2	1,8	0,866	81	79,6	76,3	73,4
4,6	2	1,8	0,866	81	79,6	76,3	73,4
4,8	2	1,8	0,866	81	79,6	76,3	73,4
5	2	1,8	0,866	81	79,6	76,3	73,4
5,2	2	1,8	0,866	81	79,6	76,3	73,4

5,4	2	1,8	0,866	81	79,6	76,3	73,4
5,6	2	1,8	0,866	81	79,6	76,3	73,4
5,8	2	1,8	0,866	81	79,6	76,3	73,4
6	2	1,8	0,866	81	79,6	76,3	73,4
6,2	2	1,8	0,866	81	79,6	76,3	73,4
6,4	2	1,8	0,866	81	79,6	76,3	73,4
6,6	2	1,8	0,866	81	79,6	76,3	73,4
6,8	2	1,8	0,866	81	79,6	76,3	73,4
7	2,55	2,295	1,104	88	85,5	84,8	80,9
7,2	2,65	2,385	1,147	89	86,4	86,1	82
7,4	2,75	2,475	1,191	90	87,3	87,4	83,2
7,6	2,85	2,565	1,234	91	88,1	88,6	84,2
7,8	3	2,7	1,299	92,4	89,3	90,3	85,7