José Benito de Andrade Vieira

Adaptation to climate change in irrigated agriculture: An evolutive water footprint approach.

Campina Grande - PB

February, 2020

José Benito de Andrade Vieira

Adaptation to climate change in irrigated agriculture: An evolutive water footprint approach.

Dissertation presented to the Graduate Program in Civil and Environmental Engineering in compliance with the requirements to obtain the Master's Degree.

Federal University of Campina Grande - UFCG

Graduate Program in Civil and Environmental Engineering

Supervisor: Carlos de Oliveira Galvão

Co-supervisor: Érica Cristine Medeiros Machado

Campina Grande - PB

February, 2020

José Benito de Andrade Vieira
Adaptation to climate change in irrigated agriculture: An evolutive water footprint approach./ José Benito de Andrade Vieira. – Campina Grande - PB, February, 2020-
215p. : il. (algumas color.) ; 30 cm.

Supervisor: Carlos de Oliveira Galvão
Co-Supervisor: Érica Cristine Medeiros Machado

Dissertation – Federal University of Campina Grande - UFCG
Graduate Program in Civil and Environmental Engineering, February, 2020.

1. Pegada Hídrica. 2. Algoritmos Genéticos. 2. Estratégias de Adaptação. II. Universidade Federal de Campina Grande. III. Programa de Pós Graduação em Engenharia Civil e Ambiental. IV. Pegada hídrica como guia para o desenvolvimento de estratégias de adaptação em recursos hídricos: Uma abordagem evolutiva.

José Benito de Andrade Vieira

Adaptation to climate change in irrigated agriculture: An evolutive water footprint approach.

Dissertation presented to the Graduate Program in Civil and Environmental Engineering in compliance with the requirements to obtain the Master's Degree.

Campina Grande - PB, 19 February, 2020:

Carlos de Oliveira Galvão
Supervisor

Érica Cristine Medeiros Machado
Co-Supervisor

John Elton de Brito Leite Cunha
Internal Examiner

Camilo Allyson Simões de Farias
External Examiner

Campina Grande - PB
February, 2020

Este trabalho é dedicado aos meus pais, Benedito e Raimunda, pelo apoio incondicional em todos os momentos da minha vida.

Acknowledgements

Primeiramente a Deus, pela vida que tenho, pela saúde que nunca faltou, pela força de correr atrás dos meus objetivos, pelas oportunidades colocadas no meu caminho, por errar e poder tentar novamente e, acima de tudo, pela paz.

Aos meus pais e familiares, por terem me ensinado a ser tudo que eu sou hoje e pelo apoio, carinho e dedicação que me foram dados.

Aos meus orientadores, Carlos e Érica, pela paciência de me explicar aquilo que eu não compreendia (muitas vezes mais de uma vez), pela sempre disponibilidade de me orientar, pela humildade de repassar seu conhecimento e pela modéstia com que conversavam com os alunos na hora do café.

Aos meus colegas do Laboratório de Hidráulica II (a.k.a. BU), pelo apoio, pelas trocas de conhecimento e pelos momentos de descontração que vivemos juntos ao longo deste dois anos de mestrado.

Aos professores e funcionários do Programa de Pós Graduação em Engenharia Civil e Ambiental, pela qualidade dos serviços prestados e pela disposição em compartilhar todo este vasto e precioso conhecimento que lhes é tido.

A CAPES, pelo financiamento desta pesquisa.

A todos aqueles que não foram mencionados diretamente, mas que, de alguma forma, contribuíram para a realização este trabalho.

Muito Obrigado!

"isso de querer
ser exatamente aquilo
que a gente é
ainda vai
nos levar além"
(Paulo Leminski)

Resumo

Em um cenário global em constante alteração devido às mudanças climáticas, surge a necessidade de se melhorar a maneira como usamos os nossos cada vez mais escassos recursos naturais. Como a agricultura é o setor produtivo que consome mais água no mundo, esta torna-se um foco prioritário destes esforços. Muitos trabalhos já apontaram quais seriam as melhores medidas de adaptação aos impactos das mudanças climáticas na agricultura, porém pouco se sabe sobre quais são as melhores maneiras de implementar essas medidas, especialmente quando se inclui nesta problemática variáveis como: limitações financeiras, disparidades de poder entre grandes e pequenos agricultores, e perdas de produtividade devido à diminuição da disponibilidade de água. Este trabalho objetivou desenvolver uma metodologia para determinar estratégias ótimas de adaptação para o uso da água na agricultura irrigada, utilizando a pegada hídrica como indicador de eficiência/sustentabilidade para guiar o processo. O SPEA2, um algoritmo evolutivo de segunda geração, foi usado para encontrar soluções ótimas, enquanto o software Aquacrop OS foi usado para estimar a pegada hídrica de cada agricultor. Com isso, é possível determinar um conjunto de soluções ótimas de Pareto, a partir dos dois principais objetivos deste processo de adaptação: aumentar a eficiência/sustentabilidade do uso da água e minimizar o custo para fazer isso. A estratégia de adaptação, segundo a metodologia proposta, é gerada em várias etapas, de maneira que a mesma importância é dada aos estágios intermediários e ao resultado final do processo. Com o objetivo de testar a metodologia desenvolvida, um caso de estudo prático foi realizado, utilizando como exemplo a Bacia do Rio Mamuaba (uma sub bacia da bacia do Rio Gramame), localizada no estado da Paraíba, nordeste do Brasil. Para o caso de estudo, observando-se todas as fronteiras de Pareto obtidas no processo, algumas recomendações gerais puderam ser extraídas para os agricultores. Nas primeiras décadas, até um certo custo, a redução na pegada hídrica por unidade de dinheiro investida é mais proveitosa do que além desse ponto, enquanto no final do período de adaptação é melhor escolher medidas mais baratas. Também foi sugerido fazer mais alterações que aprimoram a eficiência do sistema do que alterações que substituem diferentes tipos de culturas. Pequenos agricultores foram priorizados no processo de adaptação, tornando a abordagem mais holística. Também foram sugeridos valores de referência de Pegada Hídrica com o objetivo de servir como metas de redução para orientar e ajudar a monitorar o processo de implementação da estratégia de adaptação no campo.

Palavras-chave: otimização sequencial; equidade; gestão adaptativa.

Abstract

In a rapidly changing global scenario due to climate change, there is a need to improve the way we treat our increasingly scarce natural resources. As agriculture is the most water-consuming productive sector in the world, it becomes a priority focus on these efforts. A lot of works had pointed out what are the best adaptation measures to climate change impacts on agriculture, however little is known about what are the best ways to implement these measures, especially when are included in the problem variables such: financial limitations, power gaps between large and smallholder farmers, and losses in productivity due to decreases in water availability. This work aims to develop a methodology to determine optimal adaptation strategies for water use in irrigated agriculture using the water footprint as an efficiency/sustainability indicator to guide the process. SPEA2, a second-generation evolutionary algorithm, was used to find optimal solutions, and Aquacrop OS was used to estimate the farmer's water footprint. Through this, it is possible to determine a set of Pareto solutions with the two main objectives of the adaptation process: increase water use efficiency/sustainability and minimize the cost to do so. The adaptation strategy is generated in several steps, in a way that the same importance is given to the mid rages and the final result of the process. To test the develop methodology, a practical study case was simulated using River Mamuaba basin (a sub basin from River Gramame basin), located in the Paraiba state in northeast Brazil. For the study case, observing the Pareto frontiers for all decades, some general recommendations could be extracted to the farmers. For the firsts decades, until a certain cost, the reduction in water footprint per unit of money invested is more gainfull than beyond that point, while at the end of the adaptation period, it is better to choose cheaper measures. It was also suggested to make more changes that enhance the system's efficiency than changes that replace different kinds of crops. Very small and small farmers were prioritized in the adaptation process, making the approach more holistic. Water Footprint benchmarks are also suggested to serve as reduction targets to guide and helps to monitor the adaptation strategy implementation process on the ground.

Keywords: sequential optimization; equity; adaptative management

List of Figures

List of Tables

Contents

1 Introduction

1.1 Problem

Climate change has been cited by IPCC (2014) as a phenomenon of relevant importance in short and long term projections. Projected variations are mainly associated with an increase in temperatures and a decrease in average rainfall. In addition, there is also a high probability of intensification of extreme events, such droughts. This conjuncture emphasizes the need to take measures to address the risks related to climate change, taking into account the scale of the analysis and the local particularities (MIRZABAEV; NKONYA; BRAUN, 2015).

In recent decades, a large number of studies have indicated that rural areas are particularly vulnerable to climate change, that is because plant growth can be severely affected by rising temperatures and decreasing rainfall, compromising agricultural production and food security both globally and locally (WHEELER; BRAUN, 2013). According to Challinor et al. (2014), for each degree increased in the historical average temperature, a decrease of 5 % in agricultural production is expected. Still according to the same authors, crops that have undergone some measure of adaptation to climate change have a yield about 7 % higher than non-adapted ones. For this reason, maintaining the sustainability of this sector in an ever-changing scenario has become a staple on the agenda of farmers, politicians, and government agencies (DUBEY; SINGH; ABHILASH, 2016; MORTON, 2007).

Householders farmers living in underdeveloped countries are the most vulnerable to these impacts. For this group, even small changes in climate can result in disastrous impacts on their lives and livelihoods. The main aggravating factors are: unfavorable geographical positions, low income, high dependence on agriculture for subsistence, and limited ability to look for alternative forms of livelihood (KIMBALL, 2008). In this context, considerable effort has been made to determine what are the best ways to adapt to future climate conditions, taking into account all uncertainties associated with climate projections (DESSAI et al., 2009; SWART et al., 2009). Speaking of agriculture in particular, several adaptation strategies have been proposed by several authors, among them: increase water use efficiency, increase soil water retention capacity, and biodiversity (IGLESIAS; GARROTE, 2015; ALTIERI et al., 2015; ALTIERI; NICHOLLS, 2017; VARELA-ORTEGA et al., 2016; DOUXCHAMPS et al., 2016).

In addition to these, more specific strategies have been proposed. Parker et al. (2016) studied the main crops of Central Europe and suggested better agricultural management and genetic improvement as ways to confront climate change. Yoon et al. (2019) used a multi-purpose genetic algorithm to generate climate resilient land use compositions. Rippke et al. (2016) has created a three-step adaptation strategy for an agricultural area in sub-Saharan Africa, where for each location and each time period one type of adaptive measure would be most appropriate. Douxchamps et al. (2016) studied the relationship between adaptation strategies, food security, agricultural production and the type of production (subsistence, diversified, extensive or intensive). The conclusion was that, depending on the type and size of the producer, different adaptation strategies are more appropriate.

After analyzing several papers related to this theme (including those already mentioned above), it was possible to realize that the main focus of these is, in the vast majority of cases, the determination of what measures can be taken to make a region less vulnerable to the effects of climate change, hence little was said about how these measures would be implemented (the transition process) on the ground. Taking into account the information mentioned above, one of the innovations that this work aims to present refers to the focus that is given to the elaboration of an optimized transition process between the current state of a given region and the so-called ideal state (a state that is adapted to the impacts of climate change), caring about the transition process as much as its the end result. Besides that, when looking for the best ways to adapt, the factors listed below are taken into account:

- Budgetary limitations, which indirectly dictate what action can be taken and the speed with which it will happen.
- Mixed groups of farmers, ranging from small families who see agriculture as their livelihood to large intensive farming, where a clear power difference can be identified between the parties.
- Loss in production due to decreased water availability coupled with the impossibility of applying an adaptive measure in a timely manner.

Thus, this work proposes to answer the following questions: What must be done so that the adaptation process occur as best as possible, considering local financial constraints? Is it possible to maintain equity during this whole process since there are such power asymmetry involved? What is the most appropriate (cost-effective) adaptation strategy that compensates for the reduction in water availability (over a certain period of time) and does not undermine farmer's production? What goals can be set to assess whether adequate effort is being employed in adopting such measures over time?

It is critical to be concerned about the applicability of the adaptation measures from the point of view of those who will apply them if they are ever expected to come out of paper and become a reality, as the negative impacts of climate change are already occurring.

1.2 Proposed Solution

There are two main ways to deal with decreasing water availability. The first would be to reduce cultivated area, which would not require any other measure, but which, on the other hand, would reduce food production, a fact that should be avoided as much as possible. The second way would be to increase water use efficiency, which would not require a reduction in the cultivated area, but which, on the other hand, would incur extra costs for the farmer, who would have to modernize his irrigation and soil management system. It is also possible to employ both strategies together.

What will determine in practice which strategy is going to be employed is the amount of money available to invest. In an utopian scenario with unlimited funding and unlimited technology, no reduction in productivity would be required and all adaptation would be done by increasing system's efficiency. In a real scenario, where funding and technology is limited, especially in developing countries like Brazil, it is not always possible to do this.

Therefore, it is essential to optimize the decision-making process so that the limited money is spent in order to produce the best outcome, so that the impact of climate change on agricultural production is minimal. Besides cost and productivity, it is essential to consider the social aspect as well. The adaptation strategy should, in addition to fulfilling the objectives mentioned above, favor the adaptation of small farmers, because, as we have seen, they are the most vulnerable.

Assuming that the available budget for adaptation is finite and renewable over time and knowing that climate change is a dynamic phenomenon and will continue to affect the planet's climate for several decades, the adaptation strategy has been subdivided into several stages (or steps), each step is product of an independent optimization process, so that the adaptation strategy can change over time, adjusting to the dynamic aspect of the process. The evolutionary approach of the adaptation strategy proposed by the suggested methodology can be seen as another innovation of this research, since none of the papers researched in this works presented an approach similar to what was done in this work. Due to the progressive aspect of the adaptation strategy, it will be possible to establish sustainability goals to be achieved over time. These goals will serve as a means of monitoring and evaluating if the adaptation strategy is being effectively implemented on the ground. It is necessary to make it clear that the main objective of this work is to propose a generic methodology for the generation of adaptation strategies for different cases and locations around the world. At the end of the work, the methodology developed was applied to a local case study, with the aim of demonstrating the performance of the method in concrete case.

To guide the optimization process it is necessary to quantify the sustainability/efficiency of the system, in order to aim for the highest efficiency increases at the lowest costs. In the literature there are a large number of indicators that could serve to this purpose, among them, this research proposes to use the water footprint, due to its use in other works as an aid in the decision making process (PAHLOW; SNOWBALL; FRASER, 2015) and as a tool to encourage the replacement of less efficient methods by more efficient ones (LU et al., 2016).

The optimization method used in this work was a type of evolutionary algorithm known as genetic algorithm. This method was chosen due to several factors. In general, these algorithms can work very well together with other models, since they use only objective function's information and suitability of the solutions; They are also highly capable of optimizing objective functions with complex surfaces, reducing problems related to convergence to local minimum points, are less susceptible to the shape or continuity of the Pareto Frontier, and are simpler to impose qualitative constraints (COELLO, 2006).

The genetic algorithm, like most multiobjective methods, uses Pareto's dominance concept, which is the search not only for a single optimal solution but for a set of favorable solutions for all goals. According to Coello, Veldhuizen and Lamont (2002) Pareto's optimal solutions are those in which one goal can only be improved by causing a simultaneous worsening to another, and that are better than the others in at least one goal. Through the Pareto optimality concept a set of optimized solutions can be determined, which can serve as scenario options. This opens the possibility of having a meeting between the farmers participants in the process to define, in a participatory way, which option is the most advantageous for the group. Since all options results from a optimization process, they are all able to solve the adaptation problem in different ways.

2 Objectives

2.1 General Objective

Determine medium to long-term adaptation strategies for increasing water use sustainability of a group of farmers that shares the same water source.

2.2 Specific Objectives

- Assess whether that strategies contribute positively or negatively to mitigate the power and opportunity differences that exist between small and large farmers.
- Identify through the adaptation strategies general recommendations to be followed by the farmers
- Set sustainability goals based on local characteristics, which could serve for monitoring and evaluating the implementation of adaptation strategies on the ground.

3 Literature Review

3.1 The History of Environmental Issues and the Decision Making Process in Environmental Management

Since the 1960s, environmental issues were evident and caused concern among state leaders and the scientific community. In the following years, this concern only increased due an increasing number of disasters and the worsening of environmental imbalances. This fear for the worrisome future of the planet motivated the first global environmental conference, known as the Stockholm Conference, held in 1972 in Stockholm, Sweden. It was considered an international political milestone, as it has played a decisive role in directing the world's eyes to environmental issues and, consequently, enabling the emergence of environmental management policies (GRIEGER, 2012).

In 1974 a meeting between UNCTAD (United Nations Conferences on Trade-Development) and UNEP (United Nations Environment Program) resulted in Cocoyok's statement, which contributed to the discussion about the relationship between the level of development of countries and the environment. Among the conclusions of this meeting there as: 1) Environmental destruction is caused, among other factors, by poverty, which leads the needy population to overuse the soil and native vegetation; 2) There is not only a minimum of resources necessary for the welfare of an person; there is also a maximum (BRÜSEKE, 1994).

In 1975, the final report of a Dag-Hammarskjöld Foundation project involving researchers and politicians from 48 countries was presented, reinforcing and deepening the points presented at Cocoyok. This report shows the relationship between power abuse and ecological degradation. In it is possible to see how the colonial system concentrated the most suitable soils for agriculture in the hands of a social minority, while the large mass of the original population was expelled, marginalized and forced to use lower quality lands. This has devastated many landscapes in South Africa, Morocco, and many other locations (BRÜSEKE, 1994).

Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This concept of sustainable development was first introduced to the world in 1987 with the publication of "Our Common Future Report" by the World Commission on Environment and Development(WCED) (BRUNDTLAND, 1987).

In 1992, in Rio de Janeiro took place the Earth Conference, also known as Eco-92, where sustainable development was recognized as a goal to be pursued by all nations. This conference gave rise to Agenda 21, a document that systematizes an action plan that has been helping many country to achieve a more sustainable development and to improve environmental and life quality of the population (BARBOSA, 2007).

After these, other meetings were held and other environmental documents were published to discuss and reaffirm the commitment to sustainable development. These include the Earth Charter (in Paris in 2000), the Johannesburg Declaration (in South Africa in 2002) and the Rio +20 (in Rio de Janeiro in 2012).

It is important to present this background to show how the concern with sustainability and sustainable development has grown and become more relevant to national leaders over the years. It is important to mention as well, however, that the decision-making process in environmental management is complex, interdisciplinary and fraught with uncertainty, especially when considering climate change scenarios (POLASKY et al., 2011).

To deal with these complexities and uncertainties, it is important that the approaches developed to assist in the decision-making process are multidisciplinary and allow the participation of all parties involved (LUCA et al., 2015). According to Hurlbert and Gupta (2015), social participation is essential for solving unstructured (climate change and adaptation) or moderately structured problems, although less necessary for well-structured problems.

Fish, Ioris and Watson (2016) recognizes that the lack of articulation between stakeholders is still a reality in natural resources management, constituting the biggest obstacle for sustainable development. The same author also points out that collaborative management is essential to deal with complex problems.

Organizations must adapt to cope with change, since this changes can become a serious problem if not addressed properly. Many organizations are unable to adapt efficiently or quickly enough due to its stifled standards, institutional arrangement and governance. Janssen and Voort (2016) presents the concept of adaptive governance, which aims to increase an organization's ability to adapt to change. Adaptive governance strategies include utilizing internal and external resources, decentralizing the decision-making process, and seeking to convey decision-making information bottom-up.

3.2 Climate Change and its Implications for Water Availability

Global warming continues to dominate the global political and scientific agenda, mainly due to the changes it is causing in the behavior of the various planet's ecosystems. Water's vapor saturation pressure in the atmosphere is highly sensitive to temperature, so it can be said that the warming of the planet causes changes in the water cycle. Imbalances in the hydrological cycle will reflect in rainfall and river flow on many parts of the world, where will be expected an increase in some places and decrease in others (MILLY; DUNNE; VECCHIA, 2005).

A key concern is the impact of climate change on global water availability. Studies such as Vorosmarty (2000) already pointed, a few decades ago, that a significant portion of the population was already living in areas where there was water deficit and that this situation would only worsen in the future, mainly due to global warming and increasing water demands.

According to Gosling and Arnell (2016), between 1.6 and 2.4 billion people currently live in river basins that suffer from water scarcity. According to these authors, by 2050, it is estimated that this range will increase to between 0.5 and 3.1 billion due to climate change. Another important conclusion from this study is that in the future the world will see more areas entering in water scarcity scenarios than getting out of them.

Other studies also reveals that climate change will cause an increase in the demand for water, especially in the agricultural sector. As irrigation accounts for the biggest part of the global water consumption, an increase in the water demand of this sector can cause severe stress on water resources. Just proper management of the water sources will not be enough to adapt to this new reality, water management on the demand-side is also needed in order to adapt to this new uncertain and constantly changing environment (WANG et al., 2016).

Elliott et al. (2014) shows the consequences that global warming will provoke on irrigated agriculture. According to them, in some regions of the United States, China and Asia, it will be necessary to convert between $20 - 60Mha$ from irrigated crops to rainfed crops by the end of the century. This will represent a loss of between $600 - 2900Pcal$ [1] in agricultural production.

In China, over the past decade, global warming is estimated to have caused a loss of about 820 million in the maize and soybean sectors. In addition, the production of these two sectors are expected to fall between $3 - 12$ % and $7 - 19$ %, respectively, by the year of 2100, for the same reason (CHEN; CHEN; XU, 2016).

3.3 Climate Change Adaptation

There are two main ways for society to respond to the consequences of climate change: Mitigation or adaptation. Mitigation means reducing the impacts caused by climate change through the reduction of greenhouse gases emissions, ie by addressing the

[1] $Pcal$: Peta Calories, $1Pcal$is equals to10^{15} Calories

problem directly at its source. Adaptation means acting on a particular vulnerable system in response to current or projected climate change in order to minimize the impact on this system, ie dealing with the symptoms of the problem (MCCARTHY et al., 2001).

Mitigation has received far more attention than adaptation, both politically and scientifically. That is because mitigation, by focusing on addressing the cause of the problem, reduces the impacts of climate change everywhere, including the locations where adaptation is hard to implement due to local constraints. In addition, greenhouse gas emissions are easier to be monitored quantitatively than the effectiveness of an adaptive measure, in terms of future impacts avoided (FÜSSEL, 2007).

Despite the obvious need for mitigation, there are also good arguments for the adoption of adaptive measures. Firstly, greenhouse gas emissions are already affecting climate conditions, meaning that mitigating measures will not soften the impacts that are already happening (FRANCE et al., 2007). Secondly, climate will continue to change in the near future, due to the accumulation of greenhouse gases and the inertia of the climate system (MEEHL et al., 2007). Thirdly, the effect of reducing greenhouse gas emissions will take decades to produce concrete results, while adaptive measures pay off in a much shorter period. Fourthly, adaptation can be implemented on a local/regional scale, making its effectiveness less dependent on external actions (FÜSSEL, 2007).

Adaptation and mitigation are not mutually exclusive alternatives, on the contrary, these are complementary to each other. This is because their have distinct characteristics, timescales and steakholders.

According to Füssel (2007), the process of planning climate change adaptation strategies is the act of using current and future climate information to review the appropriateness of current practices, policies and structures. Planning adaptation strategies involves asking questions such as: How do climatic and non-climatic conditions of the future differ from those of the past? Do these changes interfere in the current decision making process? What is the ideal balance between the risks of acting too soon or too late? The process of adaptation comes down to making recommendations about what should be done more, less or different, and with what resources it will be done.

According to Füssel (2007) and Smit et al. (1999) the process of adaptation to climate change has several key dimensions, which are as follows:

- **Climate Sensitive Domains:** Adaptation is relevant to all climate related domains. (Agriculture, forestry, water management, public health, disaster prevention, etc.)

- **Types of climate disasters:** Adaptation can be motivated by several types of climate disasters, the ones that are already occurring or the ones that will occur in the future.

- **Predictability of climate change:** Some aspects of climate change can be predicted with a reasonable degree of confidence (eg variation in average temperatures), while others have a high degree of uncertainty in their prediction (eg changes in routes and intensity of hurricanes).
- **Conditions not related to the weather:** The adaptation process should not only consider the variables related to climate, but also the environment, politics and culture of the place where it is being implemented.
- **Intentionality:** Adaptation can be autonomous (when individuals act individually without an upper control over them) or intentionally planned (when there is institutional control over the measures being taken).
- **Time:** Adaptation can be reactive (happens after impacts occurrence) or proactive (when the adaptation is done before major damages occurs).
- **Planning horizon:** The adaptation planning horizon can vary substantially, from a few months to several decades.
- **Form:** The adaptation process is interdisciplinary and involves technical, institutional, legal, educational and behavioral measures. Research and data collection can also be considered adaptive measures (in a general context) as they facilitate the implementation of effective actions to reduce climate risks.
- **Actors:** Adaptation involves a large number of people of different hierarchical levels, as well as various public and private institutions.

Based on the work of Last (1998), Füssel and Klein (2004) suggested some prerequisites for climate change adaptation to be effective. The following list presents these prerequisites and what should be done to achieve each one:

- **Be aware of the problem:** Measuring vulnerability to climate change.
- **Availability of adaptation measures:** Encouraging researches that leads to the development of new adaptation options.
- **Information about these measures:** Identifying and measuring the effectiveness of adaptive measures.
- **Availability of resources to implement these measures:** Assessing the benefits of adaptation, identifying ways to increase resource efficiency, and provision of additional resources.
- **Cultural acceptance of these measures:** Informing people about the risks and about the adaptation measures to increase the acceptability of unfamiliar measures.

- **Incentives for the implementation of these measures:** Identifying obstacles to the implementation of effective measures and suggesting options for overcoming these obstacles.

As mentioned earlier, the process of designing and implementing policies that aims to reduce vulnerability to climate change involves a large number of people from different ranks. For Füssel (2007), the participation of the following groups is essential to the success of this process:

- **Scientists:** Scientists produce essential knowledge, which shows us why current policies, practices and infrastructures are no longer appropriate for the future.

- **Professionals:** These are the people who really implement the recommended changes. They can provide information on how things are currently being done and why they are done in that way. This information is the starting point for planning change.

- **Decision makers:** Leaders of government agencies, business managers and other decision makers are critical parts to the adaptation process. They are the people who define what are the priorities and who decide which measures will be implemented and which not.

- **Analysts:** Political analysts and economists can help to choose which adaptation measures are priorities based on a cost-benefit analysis or any other criteria defined by decision makers.

Due to resource constraints, in some cases, adaptive measures can not be implemented immediately and a slower adaptation process is therefore required. Several authors have identified criteria for prioritizing adaptation measures (SMITH; LENHART, 1996; SMITH, 1997; FANKHAUSER; SMITH; TOL, 1999; REILLY; SCHIMMELPFENNIG, 2000). There is an general agreement that anticipating adaptation is particularly favorable if:

- There is urgency for risk mitigation.

- There is a assurance that these risks will increase in the future (with high degree of reliability).

- Future impacts are potentially catastrophic or irreversible.

- Decisions have long-term effect.

- The adaptation takes a long time to be implemented and start to produce results.

In contrast, delaying the adaptation process may be viable if:

- Current and future risks are moderate.
- The adaptation process is very expensive.
- Options that produce quick responses are evaluable.

3.4 Adaptation Strategies for Agricultural Water Management

Agriculture is the most water consuming sector in the world. Conducting water management for this sector is becoming an increasingly complex work, as now this must be done within the context of the progressive reduction of water availability. On the past years, several studies have been conducted to identify the main impacts caused by climate change on agriculture, as well as what would be the most appropriate measures to be taken to adapt to this new scenario (IGLESIAS; GARROTE, 2015).

The implementation of adaptive measures should vary according to local conditions. For example, in areas where there is significant economic and social inequality and water scarcity has not become a matter of urgency yet, water management should focus primarily on ensuring equal access to water (IGLESIAS et al., 2011).

Interventions should be made not only on the supply side, but also on the demand side. On the supply side, changes can be made to increase reservoir storage capacity or to find alternative water sources. On the demand side, what can be done is to prioritize the allocation of water to sectors that use it most efficiently (GLEICK, 2003; GLEICK; PALANIAPPAN, 2010). Science has to adapt as well, more multidisciplinary approaches needs to be done in order to deal with multidisciplinary issues; science also have to strengthen the comunication with decision makers (HOWDEN et al., 2007).

An optimistic future will depend on whether agriculture will be able to consume water on an sustainability way or not. This will depend on a set of actions that may not produce results in the short-term. Ensuring economically efficient water use and promoting water and soil conservation are the priority areas of action (IGLESIAS; GARROTE, 2015).

Even when policies are well defined, user's training and/or orientation is required. For example, improving the efficiency of irrigation methods is only an option for groups that already have a certain understanding of what alternative technologies are and how important are to implement these in practice (QUEVAUVILLER et al., 2005; HOWDEN et al., 2007).

Implementing adaptive measures can be challenging for both farmers and managers. In the short term, cultural and financial barriers may limit adaptation to the adoption of low cost and ease to implement measures. Long-term measures that requires changes in infrastructure, technology or governance are more difficult to implement (QUEVAUVILLER et al., 2005).

Iglesias and Garrote (2015) evaluated various types of adaptation strategies for agricultural water management. As a result, the authors were able to summarize what are the main objectives that the adaptation process should achieve, the main adaptive measures that can be used to achieve these objectives, and the main mechanisms to address the impacts of climate change. This information can be viewed in the Figure 1.

In irrigated agriculture, a change in an irrigation method can cause a significant reduction in water footprint and ,thus, in water consuption. Using dripping irrigation instead of sprinkler irrigation can result in a water savings of over 30 % (KOLOKYTHA, 2014). According to Tsakmakis et al. (2018) drip technology could reduce the total water footprint by 5%, when compared to sprinkler. According to Wang et al. (2019) China's average water footprint per ton of wheat under sprinkler irrigation was 21% higher than that under micro-irrigation in 2014. Improving the irrigation efficiency has been identified as a major strategy to adapt to future climate and socioeconomic change globally and in major arid regions (FADER et al., 2016; MALEK; VERBURG, 2018; KANBER et al., 2019; ASHOFTEH; BOZORG-HADDAD; LOÁICIGA, 2017). However, more efficient irrigation is only one aspect of adaptation to global change, others improvements are necessary to ensure food security and mitigates impacts in agriculture, for instance the use of mulching and cover crops (KAYE; QUEMADA, 2017; BIRD et al., 2016).

Figure 1 – Adaptation measures that offsets the potential negative impact of climate change for agricultural water management. Source: (IGLESIAS; GARROTE, 2015)

Adaptation needs	Measure	Mechanism to overcome the impacts of climate change
I. Improve resiliency and adaptive capacity	(1) Implement regional adaptation plans	Enhances effectiveness of adaptation measures
	(2) Improved monitoring and early warning	Mitigates consequences of adverse events
	(3) Improve coordination planning	Enhances effectiveness of adaptation measures
	(4) Innovation and technology	Improves effectiveness of adaptation measures and reduces costs
II. Response to changes in water availability	(5) Innovation: water use efficiency	Increases water availability
	(6) Improve soil moisture retention capacity	Increases water use efficiency
	(7) Small-scale water reservoirs on farmland	Increases water management flexibility at the local level
	(8) Improve the reservoir capacity	Increases management flexibility and water availability at regional level
	(9) Water reutilisation	Increases water availability
	(10) Improve water charging and trade	Decreases inefficient use of water
	(11) Re-negotiation of allocation agreements	Improves water use efficiency
	(12) Set clear water use priorities	Improves water use efficiency
	(13) Integrate demands in conjunctive systems	Increases management flexibility and water availability
III. Response to floods and droughts	(14) Create/restore wetlands	Reduces flood peaks
	(15) Enhance flood plain management	Reduces flood vulnerability
	(16) Improve drainage systems	Reduces extent and duration of flooding
	(17) Farmers as 'custodians' of floodplains	Decreases risk of flood damages
	(18) Hard defences	Decreases risk of flood damages
	(19) Increase rainfall interception capacity	Reduces flood peaks at the local level
	(20) Introduce drought resistant crops	Improves agronomic water use efficiency
	(21) Insurance to floods or drought	Decreases economic losses to the farmer
IV. Response to increased irrigation requirements	(22) Change in crops and cropping patterns	Decreases economic risk to farmers
	(23) Improve practices to retain soil moisture	Decreases the need for additional water to crops
	(24) Develop climate change resilient crops	Mitigates impacts of climate change
V. Response to changes in agricultural land use	(25) Relocation of farm processing industry	Maintains industrial activity
	(26) Addition of organic material into soils	Recovers soil functions
	(27) Introduce new irrigation areas	Develops new agricultural land
VI. Response to deterioration of water and soil quality	(28) Improve nitrogen fertilisation efficiency	Reduces agricultural diffuse pollution
	(29) Soil carbon management and zero tillage	Reduces soil erosion and improves soil water retention capacity
	(30) Protect against soil erosion	Reduces land degradation
VII. Response to loss of biodiversity	(31) Increase water allocation for ecosystems	Improves ecosystem services, effective at the global level
	(32) Maintain ecological corridors	Improves biodiversity with positive global consequences
	(33) Improve crop diversification	Improves biodiversity

3.5 Injustice, Equity and Adaptation

According to Acselrad, Mello and Bezerra (2009) environmental injustice can be understood in two ways: the first would be related to the implementation of policies - or their omission - causing disproportionate risks to those most in need of financial and political resources; and the second would represent unequal access to environmental resources, expressed in both production and consumption of these resources.

Physical water scarcity and poor access to water are often mistaken for the same thing, but they are not. Access to water and water services are aspects of water security, but they do not depend solely on physical water scarcity, although this is often cited as the only reason. In most cases, what we have are consequences of mismanagement, bad political or economic policies masked as water scarcity. In this context, people who are mostly geographically, economically, institutionally and socially marginalized do not have or have poorly access to water (WATKINS, 2006).

According to Mukheibir (2010) water scarcity is mainly caused by a combination of three principal factors: power, poverty and inequality and not only by lack of physical water availability. The same author also pointed out depletion and degradation of the resource caused by non sustainable exploitation, population growth and unequal distribution or access to water was driven forces of scarcity, besides recognizes the role of institutions and politicians in this process. Phansalkar (2007) studied water access equity in India and concluded that the current social and institutional arrangement was creating inequities in the access to water for sheer survival in several locations and for specific social groups. The same author also found several factors that contributes for the enlargement of the inequities, some of they are: the enlargement of water scarcity, the use of the water for economic activities (such agriculture), the exploitation of water by large industries, and the action of of economic actors within industrial sector.

Goff and Crow (2014) suggest that access to water is justiciable for at least three reasons:

- If water access was seen, as income and wealth, as a prerequisite for business and livelihood opportunities
- Water plays a key role in domestic work. Without easy access to water, the tasks of maintaining a home and bringing up children are constrained.
- The time spend in water collection deprives a part of the population of opportunities to live other aspects of life. Water equity cannot be judged only by the material circumstances of access, such as quantity of potable water available. Equity must be understood more holistically. It is the capabilities enabled by water access that really matter.

The impacts of climate change are contributing to exacerbate the problems of scarcity and equitable access to water, but when we talk about scarcity, equitable access and climate change impacts, little synergy is seen between this three different issues, then a more holistic view is needed wherefore appropriate adaptation strategies are adopted and resilience is built (MUKHEIBIR, 2010). International conventions are increasingly recognizing the need to engage resource stakeholders in agendas in order to achieve their desired aims, as part of more holistic approaches to sustainable development (THOMAS; TWYMAN, 2005).

The issue of equity and justice, in the context of climate change, is discussed more on an international scale than on smaller scales, that often receive insufficient attention. This is worrying, as it is at these smaller scales that the process of adaptation potentially widens inequalities by creating winners and losers (KATES, 2000).

Climate change adaptation process, in some cases, may present significant dilemmas about justice, as the impacts of climate change contribute to the worsening of the already existing cases of injustice. These problems become even more prominent in highly resource-dependent communities, scenarios that are quite common in under developed countries (ADGER et al., 2003; PAAVOLA; ADGER, 2002; THOMAS; TWYMAN, 2005). In general, poorer communities will be most severely affected by the impacts of climate change, but not necessarily because of the impacts themselves, but because these communities are less resilient (MUKHEIBIR et al., 2010; THOMAS; TWYMAN, 2005).

Adger, Arnell and Tompkins (2005) studied the implications of different spatial scales for the adaptation process, and developed a set of normative evaluative criteria for judging the success of adaptations at this different scales. They argued that, among other factors, the equity is a important element for judging success in terms of the sustainability of development pathways into an uncertain future.

3.6 Methods for Sustainability Assessment

In the last few decades, there have been extensive efforts on measuring sustainability. One example is the development of assessment tools based on sustainability indicators, known as sustainability indices. These sustainability indices have a common purpose: to measure the sustainability (JUWANA; MUTTIL; PERERA, 2012). Well-developed indicators ought to condense and unscramble significant information by measuring, quantifying/qualifying, and transmitting data in a way that is simple to understand (KURKA; BLACKWOOD, 2013). However, in their definition process, it should not only consider the technological issue, it should also take into consideration the environmental, social, institutional, and economic aspects related to sustainability (SPANGENBERG, 2004).

Some authors have developed general sustainability indices, such as the Environmental Sustainability Index (ESTY et al., 2005), Corporate Sustainability Indicators (SPANGENBERG; BONNIOT, 1998), the Barometer of Sustainability (PRESCOTT-ALLEN, 1997), Environmental Pressure Indices (JESINGHAUS, 1999), Taking Sustainability Seriously (PORTNEY, 2003), Sustainability Indicator Systems (SPANGENBERG; BONNIOT, 1998). Some sustainability indices are field-specific, such as indicators for environment (ESTY et al., 2005), agriculture (ITTERSUM et al., 2008), fossil fuel (EDIGER et al., 2007). Indices for water resource sustainability, for example, are the Water Poverty Index WPI (LAWRENCE et al., 2002), Canadian Water Sustainability Index CWSI (INITIATIVE et al., 2007), Watershed Sustainability Index WSI (CHAVES; ALIPAZ, 2007) and West Java Water Sustainability Index WJWSI (JUWANA; PERERA; MUTTIL, 2010). The main goal of all these indices is to measure sustainability, which can be used after that to help decision makers and other stakeholders accomplishing sustainable development. Additionally, the indices can also be used to communicate the progress of sustainability to wider community (JUWANA; MUTTIL; PERERA, 2012).

One important aspect of sustainability assessment is to set targets and then measure the distance between the target and the current state or trend (MOLDAN; JANOUŠKOVÁ; HÁK, 2012). In terms of interpretation, if the indicator was applied over a long period of time, it can be used to determine a trend. In this case, we use reference points to measure the proportion of the change. The simplest reference point is the baseline. Baselines are starting points for measuring change from a certain state or date (BRINK, 2010). We can also utilize absolute values, although them, by their own, may not entirely matter, since we need a notion of what is admissible. So the called reference values has the purpose of giving a meaning to absolutes values, establishing what is admissible, and differentiating them from raw data (GALLOPIN, 1997).

The scientific community emphatically suggests the adoption of indicators for the assessment and monitoring of advances towards sustainable development. Besides it, international organizations consider that indicators are effective decision-making instruments. The pertinence of indicators for the decision-making process is one of the most vital features of the indicators in relation to other forms of information. In any case, the quality and reliability of the indicators depends on the application of satisfactory and fitting criteria to evaluate them (PIRES et al., 2017; NICHOLSON et al., 2012).

The selection of a appropriate indicator is extremely important. Liverman et al. (1988) suggested observing the aspects listed below during the selection of an indicator.

- **Sensitive to change in time:** An indicator should be usable along a time series of data, so it can be possible to see how the indicator have changed over time.

- **Sensitive to change across space or within groups:** An indicator must represent the changes occurred across space or within groups.

- **Predictive or anticipatory:** An indicator should be capable of predict or anticipate the signs of unsustainable conditions, and once the signal is received, the indicators can be used to identify the main causes for the unsustainable signal.

- **Reference or threshold values available:** Indicators will be more useful if reference or threshold values to assess them are available.

- **Unbiased:** Biases in the selection of sustainability indicators may occur due to various reasons, such as the existing knowledge of the index developer, political interests, and the background given in the existing literature.

- **Appropriate data transformation:** For most indicators, the identified indicator is not the raw data. Therefore, to obtain the value for the indicator, appropriate data transformations or calculations are needed. It is important to carefully develop or adopt the appropriate method for transforming the data into the meaningful indicator value.

- **Integrative:** The main causes that lead to the not sustainable conditions must be known so the process could be understood as a whole.

The increasing of sustainable development concepts and environmental concerns has been leading to a broad and strongly application of indicators by a large number of users in different contexts, including water resources (JUWANA; MUTTIL; PERERA, 2012; SPANGENBERG, 2008; MCCOOL; STANKEY, 2004). The United Nations World Water Assessment Programme (WWAP, 2012) comments that "a staggeringly extensive array of indicators have been developed, or are proposed, to monitor the state, use and management of water resources, for a wide range of purposes." These indicators can give information on current conditions of water resources, including recognizing all components contributing to the enhancement of water resources management. This data can be utilized to communicate the current status of existing water resources to the wider community and are powerful decision making tools and key components to monitor advances towards sustainable development within the water sector (JUWANA; MUTTIL; PERERA, 2012).

Pires et al. (2017) identified 170 indicators related to water use and management and evaluate how each one of them perform against a set of sustainability criteria. They found that only 24 indicators fulfill the majority of the sustainability criterias. Among the 24 sustainable indicators, is the Water Footprint (HOEKSTRA, 2003). Pellicer-Martínez and Martínez-Paz (2016) points that water footprint is an indicator that allows a comprehensive view of the sustainability of water use and can be assessed within the framework of IWRM. In the next section, the Water Footprint indicator will be explained in a more detailed way.

3.7 Water Footprint

The concept of water footprint was first introduced by Hoekstra (2003) who, inspired by the concept of the ecological footprint by Wachernagel and Rees (1996), developed an indicator to investigate water consumption and pollution along supply chains. Today water footprint has taken on a far greater role than that, becoming a powerful tool for assessing the sustainability of water use, exploring the possibility of water use reduction and encouraging the replacement of inefficient and polluting methods with more efficient and cleaner ones (HOEKSTRA, 2017).

Basically, the water footprint expresses the human appropriation of water in terms of volume. Comparing this water footprint with the water availability of the study area, it is possible to evaluate the sustainability of this appropriation, so that is possible, thus, to improve the decision-making process in water resources (HOEKSTRA et al., 2011).

Hoekstra (2014) presents the three pillars of smart water allocation:

- **Water footprint benchmarks per basin:** Establish maximum volumes of water that can be consumed or polluted by human activities per basin. Aims to ensure water sustainability within each basin.
- **Reference water footprints for products:** Aims to encourage producers to reduce the water footprint of their products to a reasonable reference level.
- **Fair sharing of water footprint between communities:** It aims to contribute to the debate on social equity. Water allocation must be ecologically sustainable and resource efficient, but only this does not guarantee that it is socially fair. There is a need to be an international consensus on what makes the water footprint of a community fair or acceptable given the maximum value of sustainable water footprint per global citizen.

Using the water footprint indicator provides valuable information to facilitate the water allocation process, both economically and environmentally, as it provides new data to address water scarcity and pollution issues (GALVAO et al., 2018).

Water footprint has already been proven useful in assessing risks related to water scarcity and pollution. It can be used together with economic instruments to gauge the implications of a water scarcity scenario on the economic development of a certain region. Thus, the water footprint should be used by decision makers to communicate with a wider audience, beyond the scientific community (KOLOKYTHA, 2014).

There are three types of water footprint: green, blue and gray. The green water footprint refers to the use by humans of water that evaporates from the soil surface (mainly due to the growth of crops and forests used for logging). The blue footprint refers to the consumptive use of superficial runoff water, in other words, it is the volume collected from some water source (surface or groundwater reservoir) that does not return to its original source. The gray footprint refers to the appropriation of the ability to assimilate pollutants from a given water source, ie, it measures the volume of water needed to dilute a particular polluting load dumped in a water body (HOEKSTRA et al., 2011).

How the water footprint will be expressed will depend on the focus of the work. It is possible to calculate the water footprint of a specific process within a production chain, product, consumer, consumer group, producer, an entire economic sector, geographical area (rural property, watershed, municipality, state, country, or even the entire planet) (SILVA et al., 2015; ALDAYA; HOEKSTRA, 2010; DAVIS; GEPHART; GUNDA, 2016; BOSIRE et al., 2015; LI; CHEN, 2014; FRANCKE; CASTRO, 2013).

The water footprint can be estimated by various methods, each with different degrees of accuracy and specific limitations. Hoekstra et al. (2011) present a series of equations for calculating the footprint of various services, products, groups of people, etc. Romaguera et al. (2010) developed a way of estimating agriculture's water footprint using only remote sensing data. Mekonnen and Hoekstra (2011) used the CROPWAT model as an auxiliary tool to calculate the water footprint of various crops.

In the subsection below will be presented the calculation methodology proposed by Hoekstra et al. (2011) for estimating agriculture's water footprint (regardless of the type of crop).

Green Water Footprint Calculation

Green water footprint is calculated as the ratio of the volume of "green water" used for crop production $CWU_g(m^3/m^2)$ to its yield $Y(ton/m^2)$ (Equation 3.1).

$$WF_{green} = \frac{CWU_g}{Y} \tag{3.1}$$

"Total green water" is calculated as the sum of the "green water" used in each month $u_g(mm/month)$ over the entire growing season. Assuming that the water demand of the crop is fully met, the monthly green water use will be the smallest value between the effective rainfall (P_{eff}) and crop evapotranspiration (ET_c) (Equation 3.2).

$$u_g = min(P_{eff}, ET_c) \tag{3.2}$$

There are several methods available for estimating evapotranspiration. Charchousi, Tsoukala and Papadopoulou (2015) calculated the water footprint using different evapotranspiration estimation methods to determine the difference in the WF values obtained by the different methods. His conclusion was that the method chosen for estimating evapotranspiration (and then using it to estimate water footprint) does not significantly alter decisions at the policy level related to water resource management, thus it is possible to use any of the estimation methods without prejudice to the final decision.

Blue Water Footprint Calculation

The blue water footprint (m^3/ton) is calculated by Equation 3.3, in a similar way to the green water footprint.

$$WF_{blue} = \frac{CWU_b}{Y} \tag{3.3}$$

Blue water u_b is defined as the water used for irrigating the plantation. On a monthly scale, assuming that the irrigation water demand will be fully met, blue water will be equal to the highest value between zero and the difference between crop evapotranspiration and effective rainfall (Equation 3.4).

$$u_b = max(0, ET_c - P_{eff}) \tag{3.4}$$

Gray Water Footprint Calculation

The gray water footprint (m^3/ton) of a crop (Equation 3.5) depends on the amount of fertilizer applied on it per square meter (kg/m^2), where $alpha$ is the fraction of fertilizer carried by the runoff. $c_{max}(mgl^{-1})$ is the maximum acceptable concentration, $c_{nat}(mgl^{-1})$ is the natural concentration of the pollutant in the receiving body of water, and Y is the crop yield.

$$WF_{grey} = \frac{\alpha.AR.Y}{c_{max} - c_{nat}} \tag{3.5}$$

Total Water Footprint Calculation

The total water footprint is calculated by the sum of the three types of water footprint (green, blue and gray) (Equation 3.6).

$$WF = WF_{green} + WF_{blue} + WF_{grey} \tag{3.6}$$

3.8 Uncertainties and the Decision Making Process

According to Andrade (1998) the rational decision making process is one that can achieve the pre-set objectives effectively and efficiently. Bazerman (2015) divides the rational decision making process into 6 steps, they are:

1. Problem Definition
2. Criteria Identification
3. Weighting of criterias
4. Generation of alternatives
5. Classification of alternatives according to the criteria
6. Optimal solution identification

However, the decision maker can exchange the best solution for one deemed acceptable or reasonable based on his own rationality or interest (BAZERMAN, 2015).

It is essential that the social dimension is also included in the decision-making process. Walgenbach, Parentoni and Barbosa (2000) observed that, in developed countries, the quality of decision-making increased when social impact assessment began to be done, which can be understood as the process of identifying future consequences for individuals, organizations or macro-social systems of actions that can be taken in the present.

One of the major difficulties of the decision making process in water resources is the uncertainties associated with the behavior of the systems under study, especially those associated with the random behavior of hydrological events. Vicens, Rodriguez-Iturbe and Schaake (1975) classify the uncertainties inherent in mathematical modeling of hydrological systems into three types:

Type I uncertainties: These are those caused by ignorance and/or difficulties in natural process representation. So far, they are impossible to avoid, since every model is just a simplification of what happens in reality. The greater the sophistication of the model, the lower is this type of uncertainty.

Type II uncertainties: They occur due to the determination of model parameters from inadequate field samples. They can be decreased by increasing the amount of information collected.

Type III uncertainties: They are inherent in natural processes. Since it is impossible to reduce them, the only thing you can do is to know them and incorporate them into the planning.

Vieira (2001) points out several factors that generate uncertainties in the management of water resources, they are: randomness of hydrological events, adoption of inaccurate models, simplifying hypotheses, relativity of the principles adopted and connection with environmental and socioeconomic components which present great variability.

Another type of decision-making uncertainty that has not been mentioned above is future-related uncertainty (or randomness), it happens because decision-making process occur to meet a multiple number of objectives and that complex negotiations will be necessary for the decision-making process to take place (LANNA, 1997).

According to Lanna (1997), there are two types of approaches to dealing with future randomness related to hydrological uncertainties:

1. **Explicitly stochastic approaches:** use probabilistic models to simulate future-related randomness. Decision making is solved by optimization

2. **Implicitly Stochastic Approaches:** Its use is more common than the previous approach. It is assumed that future hydrological events are known before the decision-making process.

Canter (1996) points out four steps that can be taken when facing a uncertainty scenario:

1. Ignoring uncertainties, which is not a prudent attitude, because it generates many associated risks

2. Avoid uncertainties through mitigating measures. This reduces the negative impacts caused by them, although it does not eliminate the problem source.

3. Reduce uncertainties by deepening research and collecting more data and information.

Knowing the uncertainties embedded in the models is very important, as uncertainties generate risks that hinder the rational decision making process. According to Freitas (2003), the 4 steps for risk management analysis are:

1. Risk identification

2. Risk Qualification

3. Risk Minimization

4. Mitigation or remediation of risk effects

There are three criteria for uncertainty decision making (FREITAS, 2003; SOUZA, 2005):

1. MaxMin Criterion: It is supposed that the worst case scenario will happen
2. MaxMax Criterion: It is supposed that the best case scenario will happen
3. Hurwicz Criterion: It's a middle ground between the previous ones, in it the least regrets are calculated

The most used criterion in the area of water resources has been MaxMin, where decisions are made taking into consideration that the worst scenario (extreme drought) will happen (FILHO; PORTO, 2003).

3.9 Multi-objective Optimization Models

Multi-objective optimization has a huge practical importance, since nearly all real-world optimization problems and most practical decision-making problems are ideally suited to be modeled utilizing multiple conflicting objectives. However, in the past, due to lack of suitable solution methodologies, these problems were solved by transforming the multiples objectives into a single objective. In a single-objective optimization problem, the task is to find one solution and, extending that idea to multi-objective optimization, it may be wrongly assumed that the task in a multi-objective optimization is also to find an optimal solution. This type of approach was not satisfactory, because multi-objective optimization problems often have not only one solution, but several (known as Pareto-optimal solutions, if we have conflicting objectives), so it is important to find as many optimal solutions as possible and not just one single solution (DEB, 2014).

Another difference between single-objective and multi-objective optimization is that in the latter there is an additional multi-dimensional space in addition to the search space common to all optimization problems. This additional space is called objective space; For each point in the search space, there is a corresponding point in the objective space (DEB, 2014). Figure 2 shows the representation of the decision variable space and the corresponding objective space.

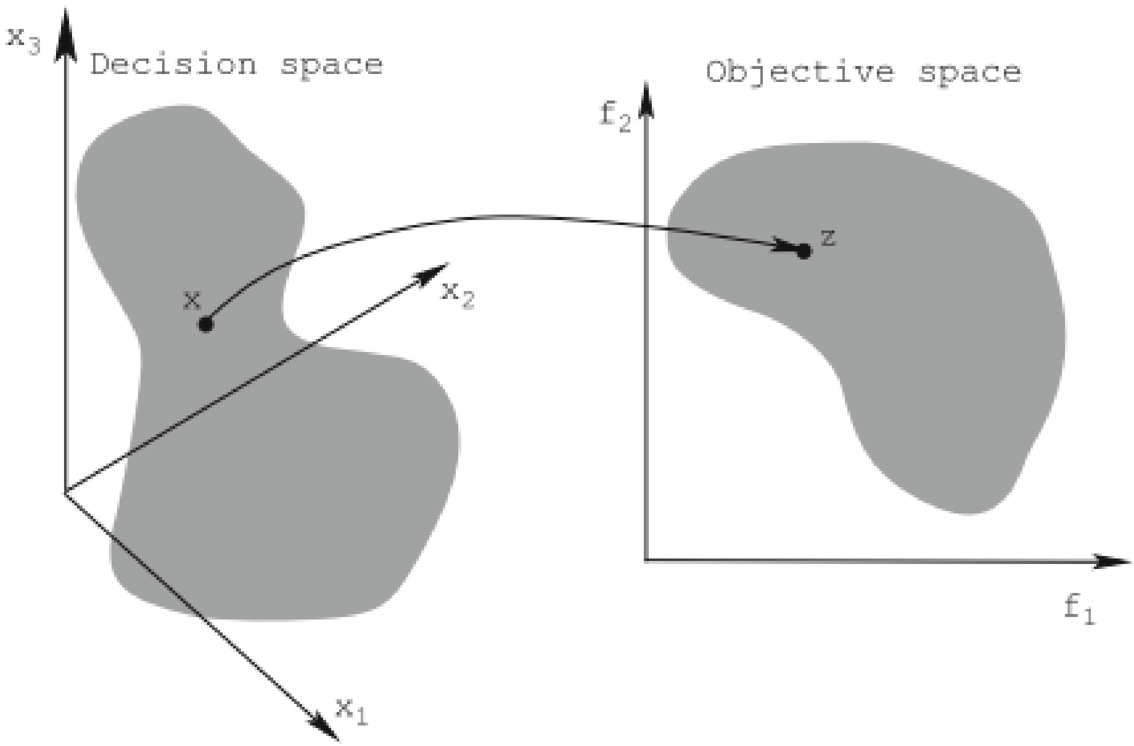
Several multi-objective optimization algorithms make use of the dominance concept. In these algorithms, two solutions are compared based on whether one dominates the other or not. According to Deb (2014) we can say that a solution x_1 dominates another solution x_2 if the following conditions are true

1. The solution x_1 is no worse than x_2 in all objectives.

2. The solution x_1 is strictly better than x_2 in at least one objective.

As mentioned earlier there is usually not only a single solution to multi-objective optimization problems, but a set of solutions. According to Marler and Arora (2004) the concept most commonly used to define this optimal solution set is the Pareto Optimality (PARETO, 1906) which is defined by:

Figure 2 – Representation of the decision variable space and the corresponding objective space. Source: (DEB, 2014)



Pareto Optimal Definition: A point, $x^* \in X$, is Pareto optimal if there does not exist another point, $x \in X$ such that $F(x) \leq F(x^*)$, and $F_i(x) \leq F_i(x^*)$ for at least one function.

Where:

x: is a vector of decision variables

X: is the search space (often called the feasible decision space)

$F(x)$: is a vector of objective functions $F(x) = [F_1(x), F_2(x), ..., F_i(x)]$ which we want to minimize.

$F_i(x)$: is a objective function, also called criteria, payoff functions, cost functions, or value functions.

There are several methods used to solve multi-objetive optimization problems. Among them we can cite:

- **Weighted-Sum Approach**: The weighted-sum method, as the name suggests, join a set of objectives into a single objective by pre-multiplying each objective with a weight (MARLER; ARORA, 2010).
- **ε-Constraint Method**: Used for solving problems that have non-convex objective spaces, which weighted-sum approach faces difficulties (DEB, 2014).
- **Simulated Annealing**: This approach is used usually to solve large scale combinatorial optimization problems (SERAFINI, 1994).
- **Quantum Annealing**: Similar to the Simulated Annealing, Quantum Annealing uses quantum algorithm and Quantum Adiabatic Computers to solve multi-objective combinatorial optimization (BARÁN; VILLAGRA, 2016).
- **Evolutionary Multi-objective Optimization (EMO) Method**: The algorithms that have propose to to deal with multi-objective optimization using evolutionary computation. There are several algorithms within this group, for instance: Strength Pareto Evolutionary algorithm (SPEA), Non-dominated Sorting Genetic Algorithm (NSGA), Vector-Evaluated Genetic Algorithm (VEGA), Pareto Archived Evolution Strategy (PAES), Particle Swarm Optimization, Artificial Immune Systems Algorithm, Estimation Distribution Algorithm, etc (BROWNLEE, 2011; MAO-GUO et al., 2009).

In this work, we choose to utilize SPEA2, a kind of genetic algorithm that belongs to the group of the evolutionary algorithms (EAs). During the last two decades, it was possible to see a dramatic increase in the development and application of various types of evolutionary algorithms, especially the genetic algorithms, undoubtedly the most popular of the several types of EAs. EAs have proven to be flexible and powerful tools for solving complex water resources problems and have been applied and different researches have been done in the water resource optimization (TYAGI et al., 2019; TANG; REED; KOLLAT, 2007; REED et al., 2013), including the optimization of the water use for agricultural irrigation (ARIF et al., 2019). According to Nicklow et al. (2009), evolutionary computation will continue to evolve in the future as problems become more complex, uncertainties increases and social pressure for more innovative and efficient solutions increases.

4 Methodology

4.1 Strenght Pareto Evolutionary Algorithm 2 (SPEA2)

The Strength Pareto Evolutionary Algorithm (SPEA) is an algorithm for multiobjective optimization and an evolutionary algorithm of the field of evolutionary computing. It belongs to the field of evolutionary multi-object algorithms (EMO). SPEA is an extension of genetic algorithms used to solve multiobjective optimization problems. Other evolutionary algorithms similar to it are: Non-dominated Sorting Genetic Algorithm (NSGA), Vector-Evaluated Genetic Algorithm (VEGA), and Pareto Archived Evolution Strategy (PAES). There are two versions of SPEA, the original SPEA and its successor, SPEA2. It can be also mention two extensions, SPEA + and iSPEA (BROWNLEE, 2011).

The purpose of this algorithm is to locate and maintain a boundary of non-dominated solutions, also known as the Pareto Frontier. To do this it uses an evolutionary process (which includes procedures for genetic recombination and mutation) and a process that uses a combination of the concept of solution dominance with the neighborhood density concept (BROWNLEE, 2011).

Before detailing the operation of SPEA2, it is important to give a general explanation of the genetic algorithm, predecessor of SPEA. Genetic algorithms were first introduced by John Holland (HOLLAND, 1975) and popularized by one of his students, David Goldberg (GOLDBERG, 1989).

These algorithms are inspired by the principle of natural selection and survival of the fittest, first introduced to the world in 1859 by English naturalist and physiologist Charles Darwin in his book "The Origin of Species." In his work, Darwin argues that, within a population, the fittest individuals are more likely to survive and, consequently, leave more offspring that will carry their genes and take them to future generations. Coupled with this process of natural selection are the phenomena of genetic recombination (also called "crossover") and mutation, which occur during the reproduction process and are vital to ensuring diversity among individuals and allowing fitters individuals to emerge in future generations.

According to Goldberg (1989), there are basic procedures that are common to the implementation of any genetic algorithm, these are:

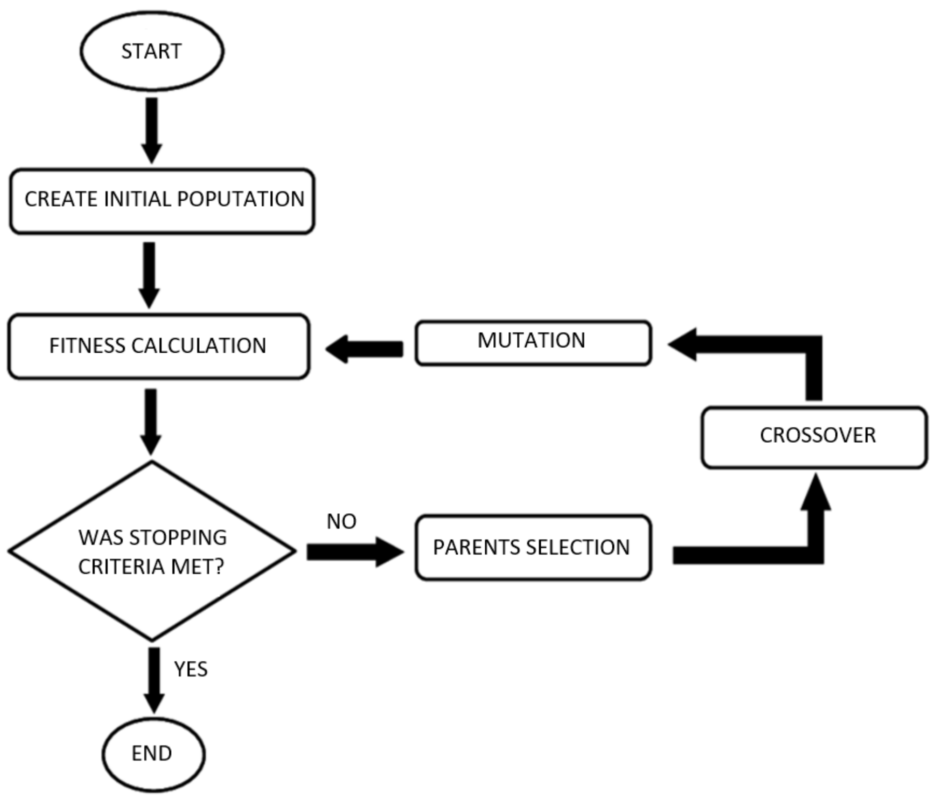
1. Choice of decision variables representation system

2. Generation of an initial population, containing various solutions to the problem.

3. Definition of one or more objective functions
4. Specification of genetic operators for selection, recombination and mutation mechanisms
5. Determination of various vestments (initial population size, probability of recombination and mutation, termination condition, etc.)

The first version of the genetic algorithm, proposed by Holland (1975), works in a relatively simple way to understand. First, possible solutions were represented in the form of "chromosomes", which are nothing less than strings of bits. The initial population consists of several randomly generated chromosomes from the search space (region where all solutions to the problem are contained). The next step is to evaluate the suitability of each solution using the objective function and then sort the solutions from the most fit to the least fit. The best chromosomes in the population are then transferred to an intermediate population, while the rest are discarded. A new generation of individuals is then produced by recombining the chromosomes of the intermediate population. A small percentage of the child chromosomes is modified by the mutation operator. This whole process is repeated, producing populations with increasingly fit individuals to the point where some termination criteria is met. This process is shown in Figure 3.

Figure 3 – Genetic Algorithm.

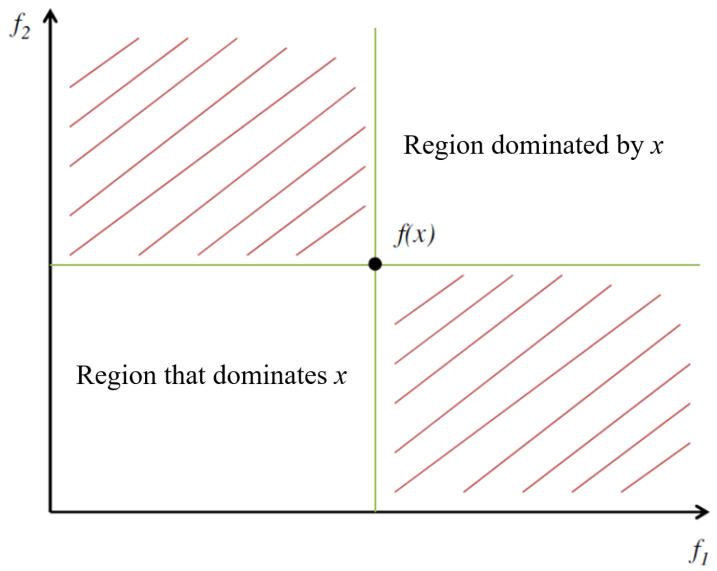


SPEA2 works similarly to Holland's original version, although it has some differences from it. Like Holland's algorithm, SPEA2 starts by generating an initial population composed of random individuals produced from the search space. After that, each individual's fitness is calculated (each individual has a fitness value for each objective function). These fitness values are subsequently used to analyze dominance relationships between individuals.

Consider a multiobjective optimization problem with r objectives, where we simultaneously want to minimize the r objective functions $f(x) = f_1(x), ..., f_r(x)$. One solution x is said to dominate another solution y if and only if $f_i(x) \leq f_i(y)$ to $i = 1, ..., r$ and $f_i(x) < f_i(y)$ for at least one objective function i.

Figure 4 presents, for a problem with two objectives, the region dominated by solution x, the region that dominates this solution, and the regions that neither dominate nor are dominated by it.

Figure 4 – Representation of the dominance concept in the objetctive's space.



A Strength value is calculated for each individual in the initial population, which is equal to the number of individuals dominated by the individual under analysis. Then, the Raw Fitness value is calculated, which is the sum of the Strengths of the individuals who dominate the individual under analysis. The more solutions dominated by an individual, the greater the value of their Strength, while the fewer individuals dominate the solution under analysis the lower their value of Raw Fitness. Therefore, if a solution is not dominated, the value of its Raw Fitness will be zero. When individuals are indifferent to each other (neither dominate nor are dominated by each other), no conclusion can be drawn from the concepts of dominance.

Since all non-dominated individuals will have the same value of Raw Fitness (zero), some additional information is needed to differentiate them. In this case, the concept of neighborhood density is used to determine, among these individuals, which are the most fit. Neighborhood density is a decreasing function of the distance of the k nearest neighbor of the individual under analysis. In this study we considered $k = 1$. Equation 4.1 shows the formula for calculating neighborhood density.

$$D = \frac{1}{\sigma^k + 2} \tag{4.1}$$

Where:

D: Neighborhood Density

σ^k: Euclidean distance between individuals or, for $k = 1$, is Euclidean distance to nearest neighbor.

The neighborhood density value ranges from 0 to 0.5, where the highest value represents the case where the two individuals are equal (the Euclidean distance between them is zero). The lower the neighborhood density, the more isolated the solution is in relation to others, so it is more important to preserve it in order to maintain diversity among solutions (critical to helping the optimization method converge to the global optimum).

An individual's fitness will then be given by the sum of his Raw Fitness value and neighborhood density, as shown in Equation 4.2. Then, the lower the value of fitness, the more fit the individual is, and the more likely they are to pass on their characteristics to the next generation.

$$F = RF + D \tag{4.2}$$

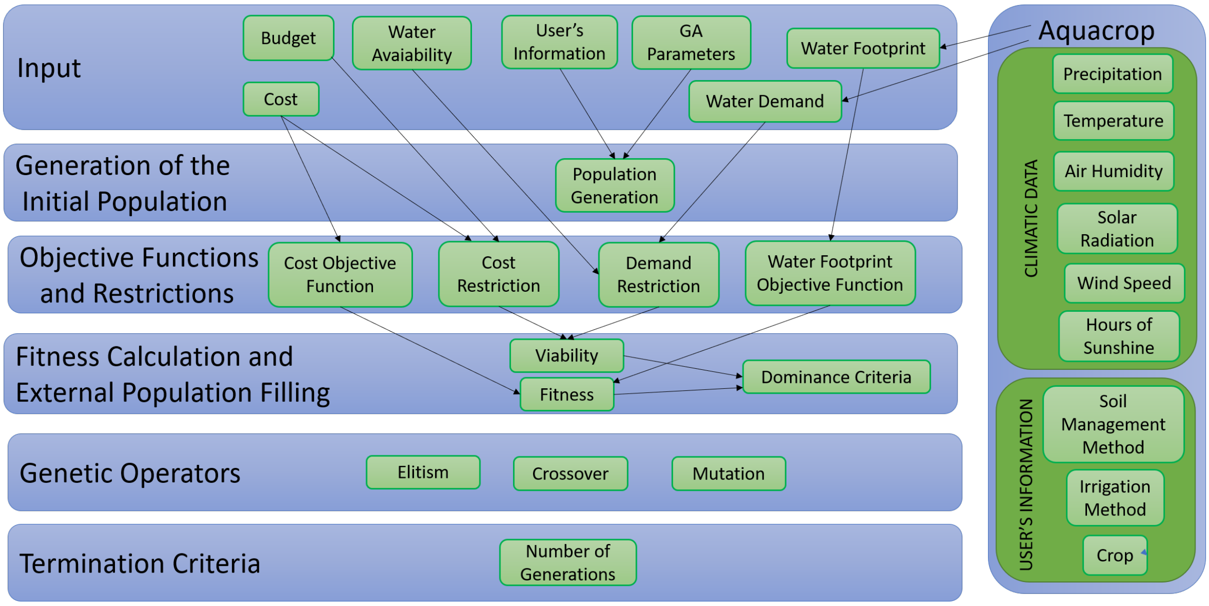
All non-dominated individuals in the population are transferred to the external population (population smaller than the initial population, which contains the best individuals and where the parents of the next generation will come from). If the external population is not fully populated, it is completed with dominated individuals, ranked in ascending order of Fitness value. If the number of non-dominated individuals exceeds the size of the external population, surplus solutions will be excluded in decreasing order of neighborhood density.

If the termination criterion is not met, individuals from the external population will be sent to genetic operators, where they will generate individuals for the new population, restarting the process, which will continue until a certain number of generations are reached or until termination criteria are met.

4.2 Optimization Algorithm

In order to obtain an algorithm that was capable of producing strategies for adapting to climate changes along the lines presented in this work, some adaptations were made to the original SPEA2 code. A code produced by MACHADO et al. (2011) (that is a adaptation of SPEA2 as well) was used as a basis for the development of the present source code. Figure 5 presents the general structure of the optimization algorithm, that will be detailed step by step into the following subsections. The code is presented integrally on Appendix A.

Figure 5 – General representation of the optimization algorithm.



4.2.1 Input

In order to the algorithm to work properly, a series of information should be provided either directly to the genetic algorithm (GA) or indirectly through Aquacrop. The data provided directly to the GA are the following:

- **Budget:** The maximum value that should be expend on adaptation strategies.
- **Cost information:** The cost to make changes (in R$/m^2$) for each measure that could be taken.
- **Water availability:** The water availability (l/s) for all users considered into the adaptation process.
- **Users information:** Such as crop, irrigation method, and soil management method, provided according with the mathematical representation presented in the next topic.

- **GA parameters:** Number of individual in the initial and external population, probability of occurrence of crossover and mutations, and termination criteria.
- **Water demand:** It will be estimated by Aquacrop.
- **Water footprint :** It will be estimated by Aquacrop.

4.2.2 Mathematical Representation of the Problem

We choose to represent the problem mathematically through a two-dimensional matrix, where each column represents a user (u_n) and each row provides information about it. The first line contains information about the type of crop planted by that user (C_n), the second is the irrigation method used by him (MI_n) and the third is the soil management method practiced by him (MI_n). Figure 6 shows an example of a generic solution.

Figure 6 – Generic mathematical representation of a solution.

$$
\begin{matrix} u_1 & u_2 & \ldots & u_n \end{matrix}
$$
$$
\begin{bmatrix} C_{u1} & C_{u2} & \ldots & C_{un} \\ IM_{u1} & IM_{u2} & \ldots & IM_{un} \\ SM_{u1} & SM_{u2} & \ldots & SM_{un} \end{bmatrix}
$$

u – FARMERS
C – CROP ($1 \leq C \leq c$)
IM – IRRIGATION METHOD ($1 \leq IM \leq im$)
SM – SOIL MANEGEMENT ($1 \leq SM \leq sm$)

In order for the optimization algorithm to work properly, all information in the mathematical matrix must be numeric, so data on crop type, irrigation method and soil management had to be represented by numbers as explained below:

Crop Type: Crops suitable for cultivation in the study area were divided into c groups according to their water footprints. The value of the first row of the solution matrix ranges from 1 to c and indicates which crop group the user irrigates in their property. Where 1 represents the group that contains the crops with the largest water footprint and c is the group that has the lowest water footprint.

Irrigation Method: We considered the irrigation methods that are already used by the farmers and the most efficient ones. The total number of methods available for use (im) were identified by values ranging from 1 to (im), where, as for crops, they were organized according to their efficiency (here we consider the most efficient method as the one that wastes less water). The most inefficient method was identified by number 1, while the most efficient by the number im.

Soil management: The *sm* soil management strategies that could be implemented in the study area were identified and, as well as the previous characteristics, organized according to their effectiveness in saving water and consequently reducing the water footprint. The value 1 was attributed to the no adoption of soil management methods, while the *sm* value was attributed to the most efficient soil management method.

4.2.3 Generation of the Initial Population

Before generating the initial population individuals, the study area current configuration was represented through the matrix presented in the previous section (same representation that will be adopted for the solutions). After that, initial population individuals were generated from the following rule: In each cell of the matrix, a random integer number will be stored. The value of that random integer number shall vary between the value stored in that same cell in the matrix that represents the current study area configuration and the maximum value that cell can get (c, im, or sm, for rows 1, 2, and 3 respectively).

Thus, the solutions generated will always be better (more efficient) or equal than the current configuration of the study area, therefore not allowing setbacks to be made. Limiting the maximum value of cells also prevents the suggestion of solutions that do not correspond to any methods (for instance, preventing a solution from suggesting that user x changes its irrigation method to method number 7, as there are only 6 methods available (ie method 7 does not exist)).

4.2.4 Aquacrop OS and the Water Footprint Calculation

Before initiating the optimization algorithm, the code uses Aquacrop OS software to calculate crop's water footprint. In the subsection below we will explain, in a general way, how Aquacrop works, how it differs from Aquacrop OS and how the genetic algorithm exchange information with this model.

4.2.5 Aquacrop

AquaCrop is a model for crop growth simulation, created by FAO to ensure food security and proper management of agriculture. It simulates the agricultural productivity of a given crop if a certain amount of water is supplied to it during its growing season. AquaCrop is particularly useful in cases where water is the limiting factor for crop yield.

There are a large number of crop growth simulation models available in the literature. Examples: DSSAT (JONES et al., 2003); CropSyst (STÖCKLE; DONATELLI; NELSON, 2003); Hybrid-Maize (YANG et al., 2004). However, a problem common to the vast majority of these models is the demand for a high amount of input data with high level of details, which is not available for the most part of the planet.

Aquacrop stands out from other models that serve for the same purpose as it because it requires a relatively smaller number of parameters to be set by the user, and has been validated and applied to various crop types in multiple climate types and in different locations (VANUYTRECHT et al., 2014).

Tsakmakis et al. (2018) compared the performance of AquaCrop with CROPWAT (older version of AquaCrop) for estimating the water footprint of cotton in a region of northern Greece. The results showed superiority of AquaCrop in relation to the other model in this regard.

Currently, AquaCrop is one of the main tools used to calculate the water footprint of irrigated agriculture. It is possible to cite several works where this model was used for this purpose, among them we have: Nouri et al. (2019), Zhuo, Mekonnen and Hoekstra (2016a) and Chukalla, Krol and Hoekstra (2015).

AquaCrop is available in three versions: A standalone Windows application, a GIS plugin and an open-source version for Matlab. In this work, we will use the Matlab version.

The following description of how AquaCrop works was based on its reference manual, available at Raes et al. (2018).

Similar to other crop growth models, AquaCrop is composed of a set of sub-models that simulates: the soil (and its water balance), the crops (its growth, development and yield), the atmosphere (its temperature, precipitation , evaporation, and concentration of carbon dioxide), and soil and crop management practices (irrigation and soil fertilization, for instance).

AquaCrop simulations are done on a daily time scale and can be represented by calendar days or growing degree days. AquaCrop simulates the soil water balance by accounting for the inlet and outlet water flows of a control volume, as shown by Equation 4.3.

$$S_{[t]} = S_{[t+1]} + PR_{[t]} + IRR_{[t]} + CR_{[t]} - ET_{[t]} - RO_{[t]} - DP_{[t]} \tag{4.3}$$

Onde:

$S_{[t]}(mm)$ - Water stored in the soil at the end of the day t

$S_{[t+1]}(mm)$ - Water stored in the soil at the beginning of the day t

$PR_{[t]}(mm)$ - Daily rainfall t

$IRR_{[t]}(mm)$ - Irrigation water applied in a day t

$CR_{[t]}(mm)$ - Deep aquifer capillary rise in a day t

$ET_{[t]}(mm)$ - Daily actual evapotranspiration t

$RO_{[t]}(mm)$ - Daily surface runoff t
$DP_{[t]}(mm)$ - Percolation to deep aquifer in a day t

To calculate effective precipitation, surface runoff and soil water infiltration, AquaCrop uses the Soil Conservation Service (SCS) method. Actual evapotranspiration is separated into two parts: one non-productive (evaporation of water from the soil surface) and one productive (transpiration from plants). Thus, it is possible to simulate the effect of management practices on these two plots separately. This program feature is fundamental for estimating the water footprint.

Evaporation from soil surface is calculated by multiplying potential evapotranspiration by factors that take into account soil water availability and the fraction of the soil surface that is covered by the leaves (canopy cover). The calculation of water evaporation over the uncovered soil surface is done in two steps. In the first step, which occurs whenever the soil is wet due to rain or irrigation, the evaporation rate is determined solely by the energy available to evaporate water. In the second, evaporation ceases to depend only on available energy, and now also depends on the hydraulic properties of the soil.

To estimate the biomass production (B) of a given crop, AquaCrop take into account two parameters: water productivity (WP) and crop transpiration (Tr) (Equation 4.4). Water productivity is a parameter that expresses biomass production (kg) per m^2 of area, per mm of transpirated water, adjusted according to the evaporative demand of the atmosphere and the concentration of CO_2 in the air.

$$B = WP \times \sum Tr \tag{4.4}$$

It is possible to simulate various options of water supply, ranging from rainfed agriculture to fully irrigation. It is also possible to choose between different types of irrigation methods (surface, sprinkler or drip) and soil management practices (soil fertilization, plastic or organic mulch, barriers to reduce runoff, and plant control). The impact of water stress on plant growth is modeled with three types of response: change in leaf growth rate, stomatal closure and senescence acceleration.

Biomass production can be reduced by the action of some external agents, they are:

- **Temperature:** Extreme temperatures (too high or too low) affects crop growth
- **Soil Salinity:** High salinity soils have a negative influence on plant growth
- **Water stress:** Lack of water, especially at some stages of plant growth, can cause a significant decrease in productivity

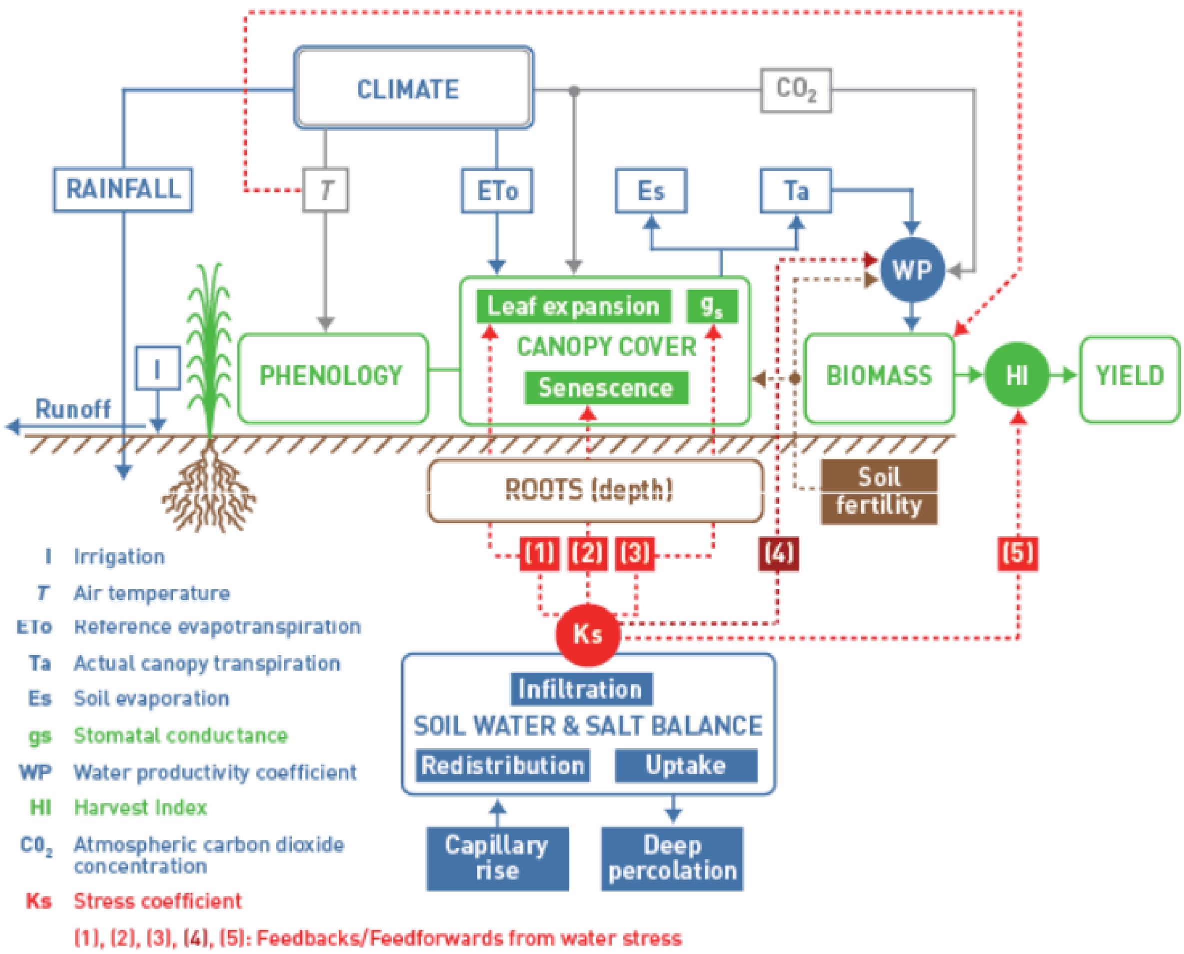
- **Soil fertility:** Poorly fertile soils are limiting factors in crop growth

After estimating biomass, it is multiplied by the HI factor to obtain crop's yield Y. HI (harvest index) is the harvest factor and represents the percentage of biomass that actually becomes harvest. HI varies from culture to culture and is adjusted according to water and temperature stress, depending on how long the crop is exposed to stress and how intense it is. For this, the harvest index reference value HI_0 is multiplied by an adjustment factor f_{HI}, as shown by Equation 4.5.

$$HI = f_{HI} \times HI_0 \tag{4.5}$$

The overall structure of AquaCrop, including its main components, as well as the relationship between them, can be seen in Figure 7.

Figure 7 – General operating structure of AquaCrop. Source:(RAES et al., 2018)



4.2.6 AquaCrop-OS

AquaCrop OpenSource (or AquaCrop OS) is an open-source version of AquaCrop, implemented in Matlab and also compatible with the free GNU Octave language. Unlike its original version, which was developed in Delphi and distributed only for Windows, AquaCrop OS can run on Windows, Macintosh and Lixus operating systems.

An additional feature of AquaCrop OS is the ability to perform multiple simulations simultaneously (Batch run), significantly reducing the total processing time for large or complex projects.

Among all the features of AquaCrop OS, perhaps the one that is most relevant to this work is its ease of integration with other models. AquaCrop OS follows the OpenMI (Open Modeling Interface) standard, which is basically an interface standard designed to allow data to be exchanged between different models at runtime. This ease of connection allows AquaCrop OS to be part of integrated models for water resources management.

4.2.7 GA - Aquacrop OS Interaction

Both input and output data from Aquacrop OS are done via text files (extension .txt). This feature has made it much easier to integrate AquaCrop OS with the genetic algorithm, as this file extension is very simple to open, read and edit in Matlab. Input files can be divided into two categories, essential and optional. The essentials files are the ones required to make the model work, while the optional ones may or may not be necessary, depending on the type of simulation you want to perform.

Essential input files include information such as: simulation's start and end date, climate data on daily basis (precipitation, temperature, air humidity, solar radiation, wind speed, hour of sunshine on a day, etc.), soil profile data, crop data, information on irrigation methods used, information on soil management strategies used, aquifer data (if present), and initial soil water content data. Optional input files may include data about: soil texture, soil hydraulics, crop rotation calendar and irrigation calendar.

Among all input files, GA received permission to edit the following parameters in the following files:

- **Crop parameters file:** All parameters can be edited.
- **Irrigation methods parameters file:** The parameters concerning the efficiency of the method and the percentage of soil surface that is wetted can be changed.
- **Soil management methods parameters file:** Two parameters can be changed. The first indicates whether or not there is mulching on the soil, while the second

specifies the reduction in soil water evaporation due to the presence of mulching (the plastic mulching causes a greater reduction in evaporation than the organic).

After running Aquacrop, the results produced are written in the output files. Among the miscellaneous data provided by the program, only four variables are imported and used by the GA to calculate the water footprint and water demanded for irrigation, they are:

- Water evaporation from soil surface (Es) [mm]
- Crop transpiration (Tr) [mm]
- Crop Yield ($Yield$) [ton/ha]
- Water used for irrigation ($TotIrr$) [mm/m^2]: This data is used to calculate the farmer's water demand for irrigation

4.2.8 Water Footprint Calculation

Based on the data provided by Aquacrop, it is possible to calculate the water footprint (WF) in liters per kilogram (l/kg) using the Equation 4.6. In this work only the blue and green portions of the water footprint were considered.

$$WF = 10 * \frac{Es + Tr}{Yield} \tag{4.6}$$

Before starting the interactive process, GA calculates the water footprint for all combinations of crop type, irrigation method and soil management. As this work considers six types of crops, six types of irrigation methods and three soil management possibilities (totaling 108 possible combinations, ie 108 WF calculations), it was realized that it was much faster (in processing time) to calculate the footprint of all possible scenarios than individually calculate the footprint of all users of all individuals of all generations (considering 1000 generations, 500 individuals per population and 27 users, there are 13.5 million WF calculations).

In this work, to estimate the water footprint of each farmer, a simulation of one year long as performed. The sowing data was always put in the begging of the dry period (were the demand for water for irrigation is bigger). So, the water footprint was estimated based on the amount of water needed to supply a specific crop along a year, divided by the annual yield of that same crop.

4.2.9 Optimization Objectives and Constrains

We define two objective functions for the adaptation process: one to minimize the system's WF, and another to minimize adaptation's financial cost. A set of Pareto solutions considering the two main objectives of the adaptation process, since these two main objectives are opposed (the more the efficiency increases, the more it costs) was also generated. The intention is to present this set of Pareto solutions to the users as a list of options from where they can choose one solution, in a participatory process, and implement it on the ground.

Objective # 1 Minimization of the water footprint

This objective function aims the maximization of the water use efficiency through the minimization of the sum of all users water footprint, as shown in Equation 4.7.

$$f_1 = \sum_{i=1}^{u_n} WF_i \tag{4.7}$$

Where:

f_1: First objective function fitness value

u_n: : Number of users

WF_i Water footprint of user i (l/kg)

The formulation of this function has the purpose of inducing the optimization algorithm to prioritize smallholder users. This is possible because a reduction of the WF of a smallholder user has the same impact in the fitness value of the same reduction to a larger user. Reducing the WF of a large user costs more than reducing the WF of a small user, then it is more advantageous (for the optimization algorithm) to adapt the smaller user first.

Objective # 2 Minimization of the adaptation monetary cost

This objective function aims to minimize the monetary cost to implement the adaptation strategies. It is calculated based on what changes from one time step to the next and the cost to do so. Equation 4.8 shows the second objective function.

$$f_2 = \sum_{i=1}^{u_n} (c(MI_i) + c(MS_i)) * A_i \tag{4.8}$$

Where:

f_2: Second objective function fitness value

u_n: Number of users

$c(MI_i)$: Unitary cost ($R\$/m^2$) to implement user's i new irrigation method

$c(MS_i)$: Unitary cost ($R\$/m^2$) to implement user's i new soil management method

A_i: User's i irrigated area (m^2)

Variables $c(MI_i)$ and $c(MS_i)$ vary according to the different options of methods that the user could choose (each option has its specific cost). The value of these two variables is assumed to be equal to zero if there is no change in irrigation method or soil management method of the user i in the time step since we want to calculate the cost to change. The cost to change crop type was not taken into consideration in this work but in further research, it could be inserted through a $c(C_i)$v term into the equation.

Besides these two objectives, two constraints were imposed to ensure that the adaptation cost does not assume too high values and that the demand does not overcome water availability. Solutions that violates at least one constraint are considered unviable.

Restriction # 1: If the cost to implement a solution is bigger than a previously established value (budget), that solution is considered unviable. This constraint aims to prevent the suggestion of adaptation strategies that are out of the local user's financial capability.

Restriction # 2: If the total water demand (of all users) is bigger than the water availability for the time period, that solution is considered unfeasible. This constraint aims to prevent the algorithm to suggest solutions that are in controversy with the potential impacts of climate change.

In the study area, the adaptation strategies focus on more efficient irrigation methods, soil management methods and changes in irrigated area. Among the farmers considered, none currently uses improved soil management practices, so all the surveyed methods are suggestions for future adoption during the adaptation process. Among all practices, only the mulching practices were considered, since they are the only ones that are simultaneously simulated by Aquacrop OS and are compatible with local crops.

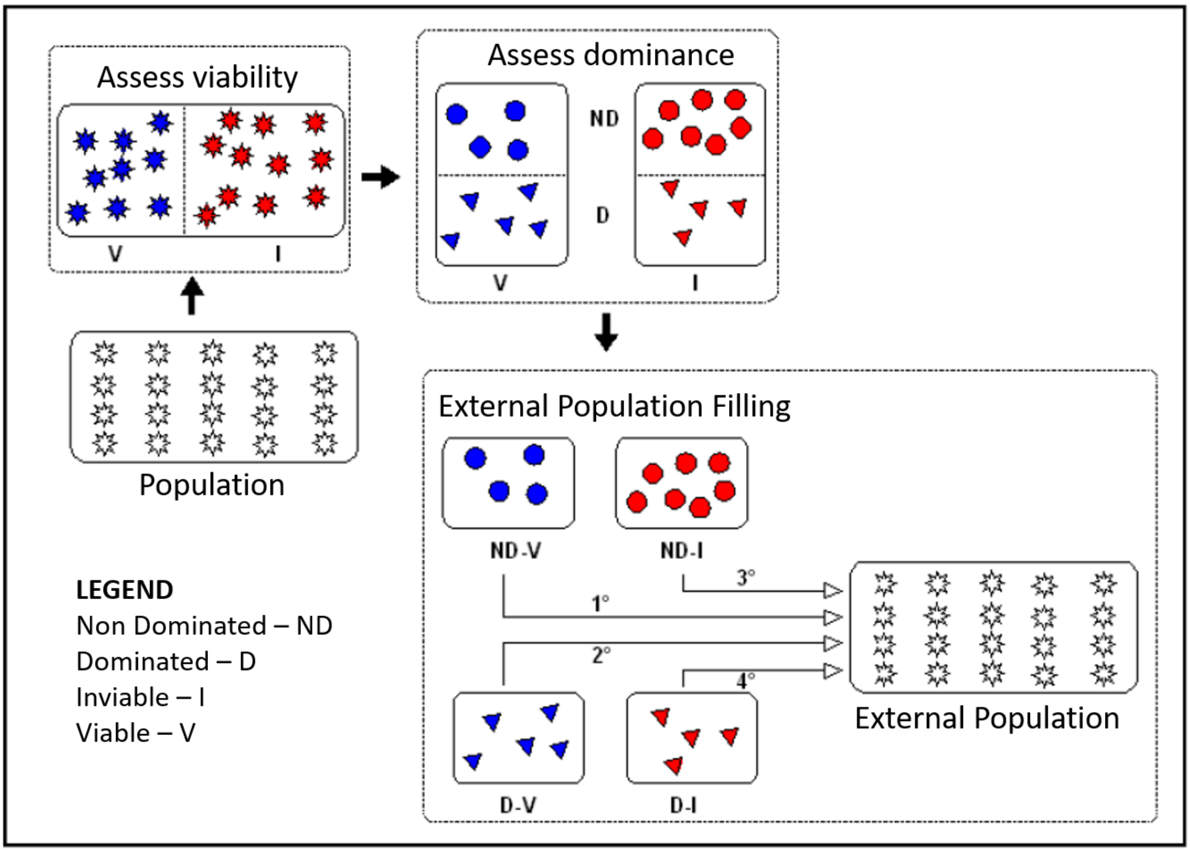
4.2.10 External Population Filling

After being divided into viable and unviable, the solutions are evaluated separately into each subgroup according to the concepts of dominance and neighborhood density, discussed earlier in this work. There is also the option of evaluating individuals firstly through the concept of dominance and then dividing them according to viability. However, in this paper we chose to use the first form because, in this case, it is more important that an individual is viable than not dominated.

After separating individuals by viability and dominance criteria, the external population is filled following the order of priority listed below and illustrated in Figure 8. If it is not possible to allocate all individuals from the same subgroup into the external population, priority will be given to those with the lowest *Fitness* value.

1. Viable and non-dominated individuals
2. Viable and dominated individuals
3. Inviable and non-dominated individuals
4. Inviable and dominated individuals

Figure 8 – External population filling according to the concepts of viability and dominance. Source: (MACHADO, 2006)



4.2.11 Selection of Individuals and Genetic Operators

The Tournament Method was used to select individuals for reproduction. This method begins randomly selecting two individuals from the external population, choosing the most suitable between this two and forwarding it to the reproduction mechanism. To determine which individual is more fit, we used the same criteria that was utilized to fill the external population as shown in Figure 8. Thus, the best individuals and those who are in greater quantity in population are more likely to generate offspring.

The genetic operator used in this work was *Crossover* average (GALVAO, 1999). In this operator, the son is generated by the arithmetic mean of his two parents, as shown by Equation 4.9. As in this work the solutions could only assume integer values, if the result is a decimal number, then it is rounded to the nearest integer.

$$Son_{i,j} = round\left(\frac{Father_{i,j} + Mother_{i,j}}{2}\right) \tag{4.9}$$

Where:

$Son_{i,j}$ is the element of line i and column j of son solution

$round()$ is the function that rounds a decimal number to its nearest integer

$Father_{i,j}$ is the element of line i and column j of father solution

$Mother_{i,j}$ is the element of line i and column j of mother solution

Both the genetic operator and the mutations were associated with a probability of occurrence. As in nature, reproduction by *Crossover* had a high probability of occurrence, while mutations had low probability. If the probability of occurrence was not met, the reproduction would not occur and the son would be considered as a identical copy of his father or mother (the one who had the highest fitness considering the same criteria previously mentioned).

Two types of mutation were used, one is a uniform mutation and the other is a directed mutation. The uniform mutation could be applied to all individuals if, of course, the probability of occurrence was met. Directed mutation was applied only to unviable individuals, in order to accelerate the convergence of the algorithm.

If the probability of occurrence of the uniform mutation would been met, the son solution was entirely replaced by a random solution generated in the same way as the individuals of the initial population, as explained in session 4.2.3.

Directed mutation, unlike uniform mutation, was not applied to the sons, but to the parents. If the probability of occurrence of the mutation was reached and one of the parents was not viable, this individual was modified as shown by Equation 4.10.

$$Father_{i,j} = round\Big(Father_{i,j} - (Father_{i,j} - IniConfig_{i,j}) * k\Big) \tag{4.10}$$

Where:

$Father_{i,j}$ is the element of line i and column j of father/mother solution

$round()$ is the function that rounds a decimal number to its nearest integer

$IniConfig_{i,j}$ is the element of line i and column j of study area current configuration matrix

k is a random number between 0 and 1.

This mutation works by lowering the cost to implement the adaptation strategy while decreases the reduction in water footprint. Thus, an solution that was previously considered unviable, because it had a higher cost than the previously established budget, may now be viable. However, a viable individual under the second constraint (which considers unviable all individuals who has demand greater than availability), may become unviable.

There is no directed mutation that can act simultaneously in favor of both constraints, since an improve in one represents an worsen in the other. In our case, it is more difficult to obtain solutions that comply with restriction 1 (cost) than with restriction 2 (availability), so it was decided to implement a mutation that would lower the cost, even if this would lead to an increase in demand.

4.2.12 Termination Criteria

The termination criteria defined is quite simple. The algorithm continues to make interactions (generations) indefinitely until the first viable solution is found, after that a predefined number of interactions (generations) are performed before the algorithm stops.

4.2.13 Seeding

A well-known heuristic technique in genetic algorithms used to accelerate the convergence process is *Seeding*. The *Seeding* process involves inserting one or more than one solutions that are potentially good candidates for solving the problem into the initial population (EIBEN; SMITH, 2015). In this work, two simulations were made, one with *Seeding* and one without it, to determine if the use of this technique would produce any significant difference in the algorithm performance. The simulations were done in duplicate to ensure that the method converged.

Comparing simulations results with and without *Seeding*, it can be observed that the use of this technique made no difference in the number of generations, in other words it did not decrease the processing time. This may be due to the fact that directed mutation is already accelerating this process, making *Seeding* not very effective.

Looking at the Pareto frontier graphs without (Figure 9) and with *Seeding* (Figure 10), no significant difference could be seen between them. The use of *Seeding* may have helped the algorithm explore more search space locations, slightly improving the diversity of the solutions, but it did not cause a significant improvement of the final result.

Figure 9 – Pareto frontier without the use of *Seeding*.

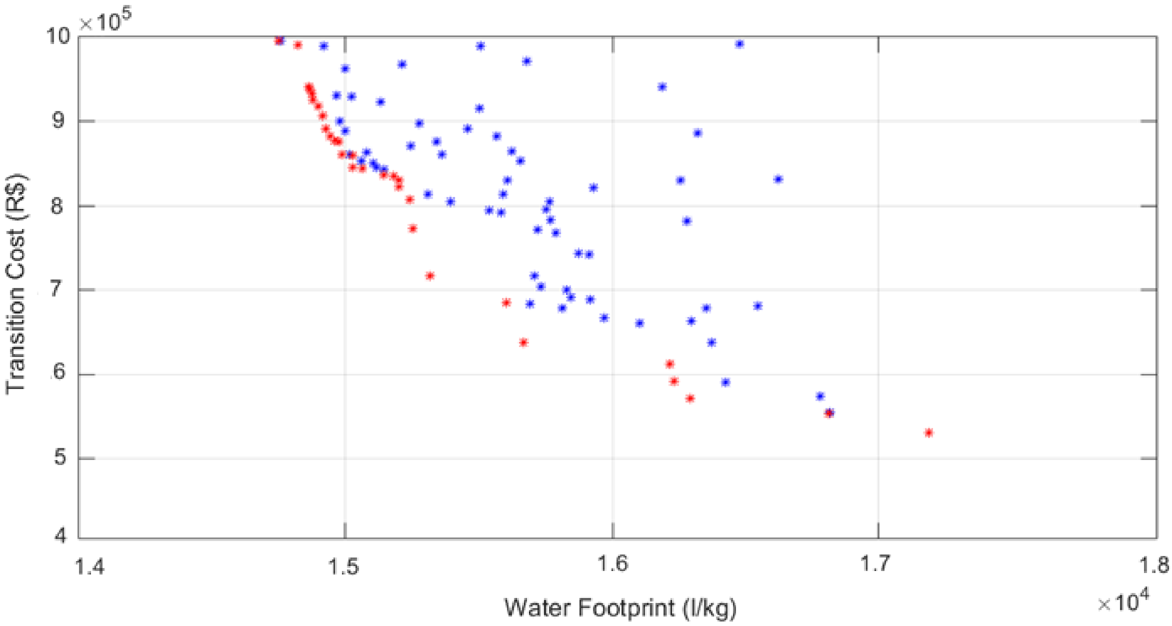
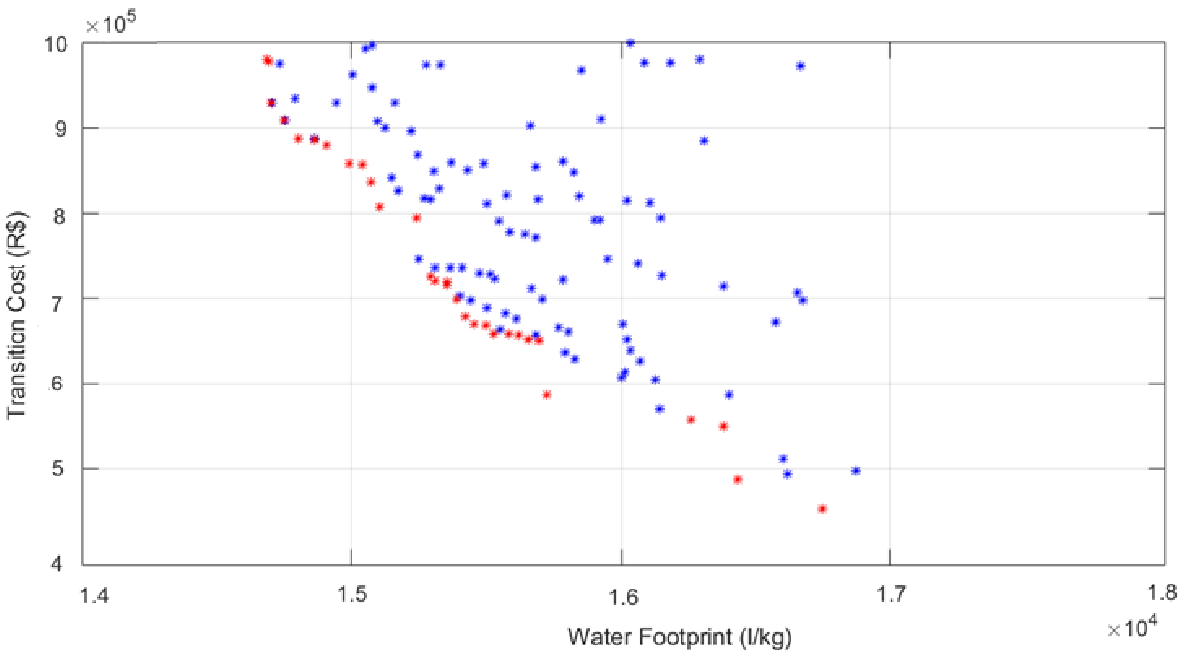


Figure 10 – Pareto frontier with the utilization of *Seeding*.



Given these results, it was decided not to use *Seeding* in the next simulations, since it was seen that in this case this technique does not make significant difference in the algorithm performance and in the final results.

4.2.14 Elitism

Similar to *Seeding*, Elitism is another technique widely used to improve the performance of genetic algorithms. Elitism, in its essence, consists of allocating the best individuals of the current population directly into the next generation (without they having to go through the genetic operator mechanisms). This technique is used to preserve the best solutions found so far (EIBEN; SMITH, 2015).

To test if the use of this technique would produce any significant difference in the algorithm performance, simulations were performed without and with the use of elitism. In those who used it, several numbers of individuals that pass directly to the next generation were tested (10, 50, 100, 150 and 200 individuals) in order to determine the optimal number of individuals.

Figure 11 shows that without the use of Elitism the Pareto frontier could not be formed, since the algorithm converged to a single solution. So to prevent the happening of this problem, it is necessary to allocate the best solutions directly to the next generation.

Figure 11 – Pareto frontier without the use of Elitism.

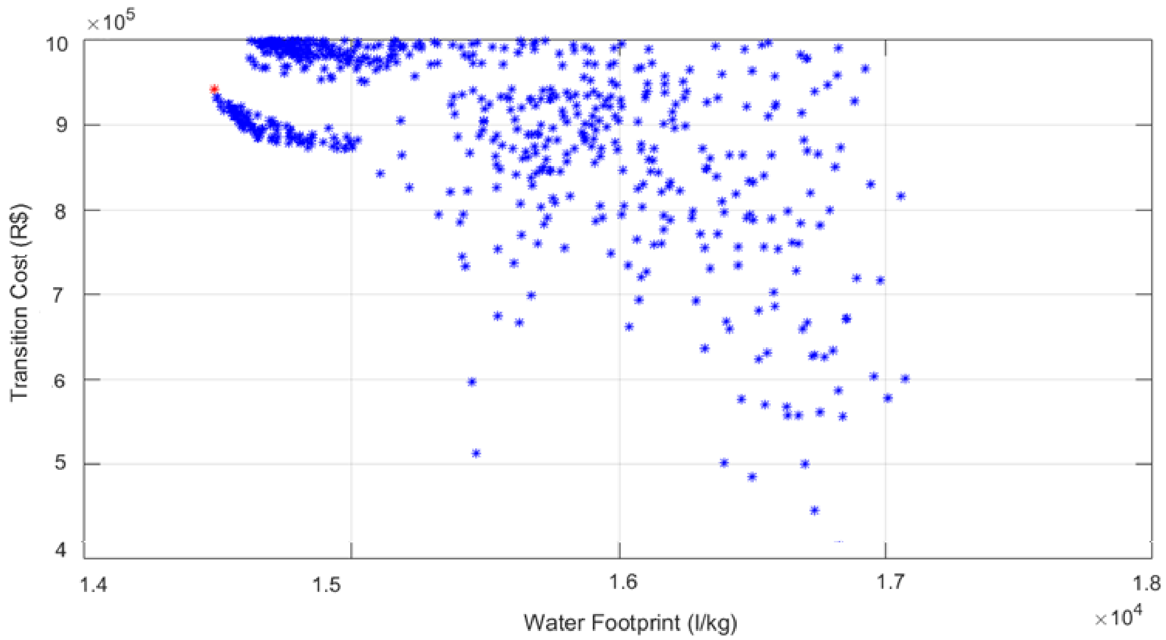
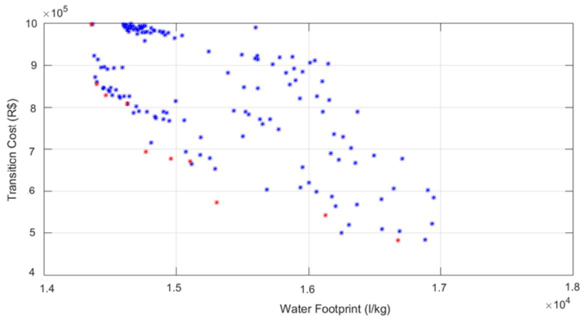


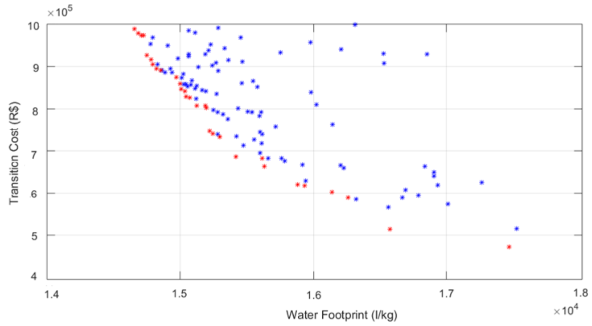
Figure 12 shows the Pareto frontiers for different numbers of individuals taken directly to the next generation by Elitism. Based on the analysis of these graphs, it is possible to conclude that the case 12b, where 50 individuals were used, was the one that presented the best result and, therefore, will be used from now on in the next simulations.

Figure 12 – Pareto frontiers for different numbers of individuals taken directly to the next generation by Elitism.

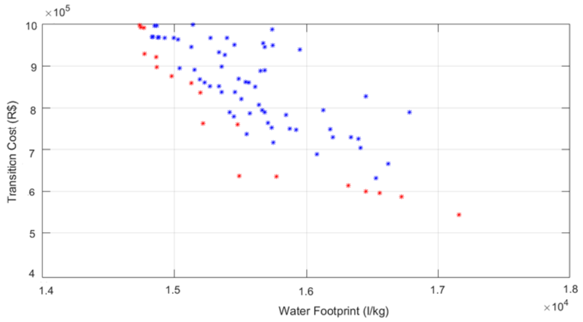
(a) 10 individuals



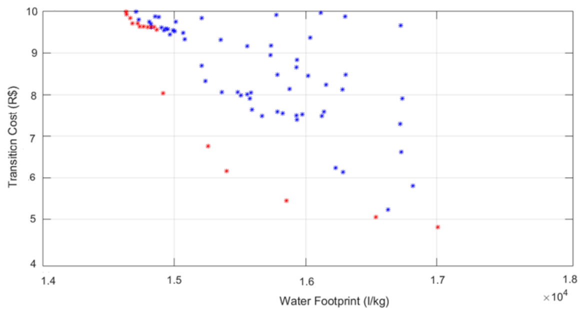
(b) 50 individuals



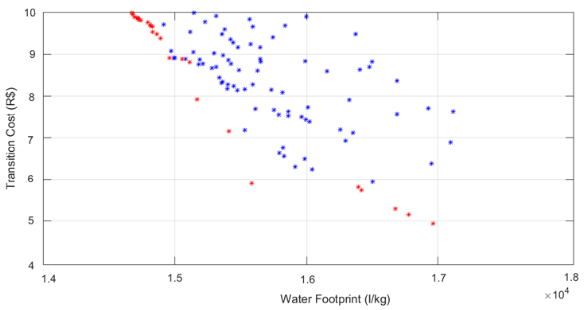
(c) 100 individuals



(d) 150 individuals



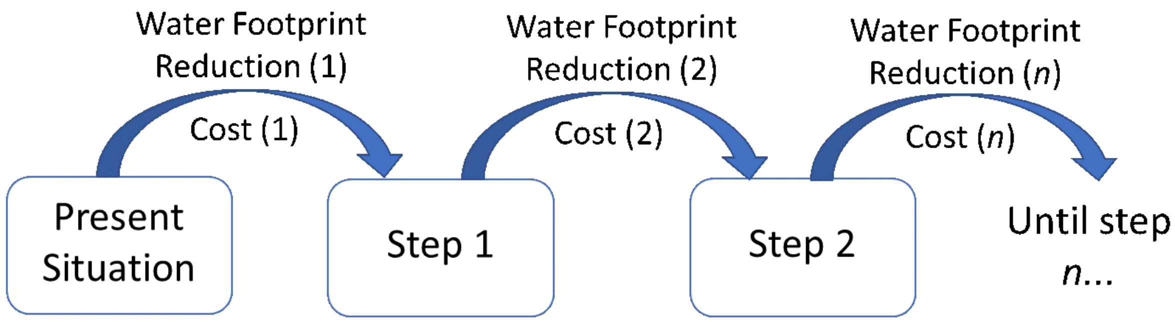
(e) 200 individuals



4.3 Optimization model

In the current research, an adaptation strategy in the agricultural sector is defined as all the potential changes or measures that a user can adopt in order to compensate the negative effects of climate change. The users can increase the water use efficiency/sustainability (changing to a more efficient irrigation method or adopting improved soil/crop management that requires less water) or reduce the crop area to consume less water, causing an undesirable effect of reduction in food production. Users will reduce crop area only if the strategy of the increase of water use efficiency/sustainability does not produce the expected results. The adaptation strategy is generated in several time steps. For the generation of each step, an optimization adaptation algorithm is executed once; in other words, the algorithm is designed to provide the answer for a single step and not for the complete adaptation strategy (set of all the steps) at once (Figure 13). The proposed method helps to determine the way that the users should evolve the water usage from the current situation to the ideal situation (step by step), considering their living environment.

Figure 13 – Structure of the adaptation strategy produced with the proposed methodology.

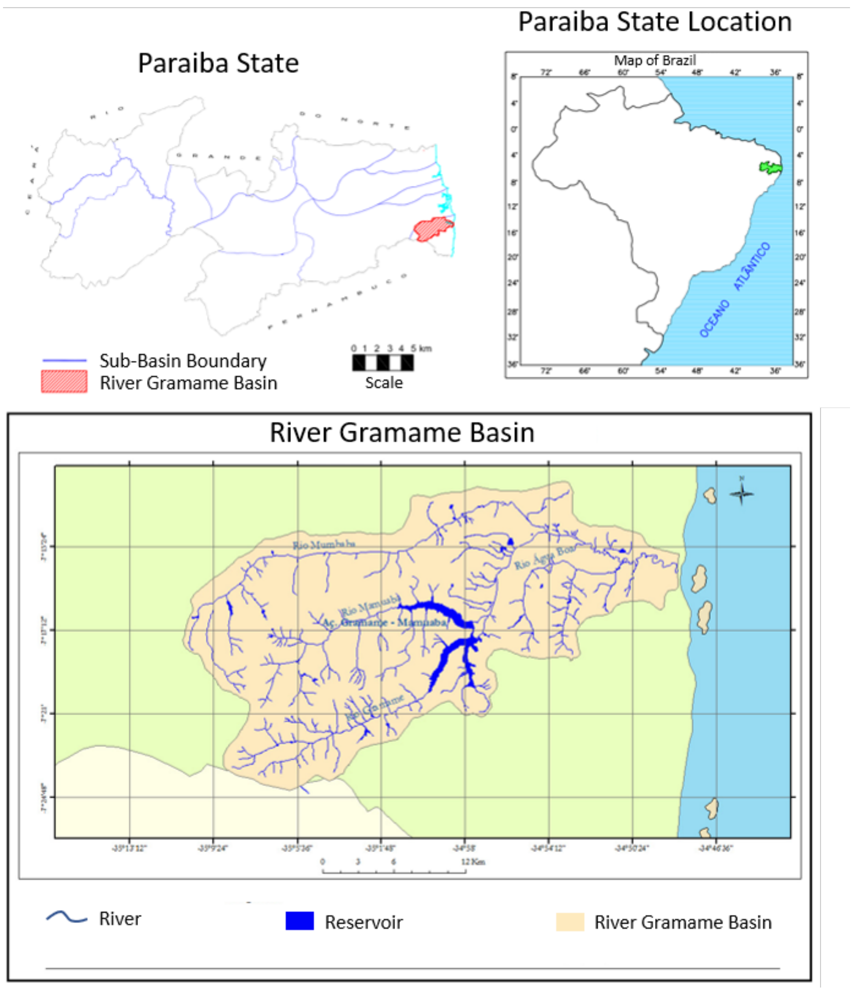


The size of the time interval considered in each step may be different (1, 2, 5, 10 years, etc.). Thus, the methodology users', e.g. the local water resources managers, can select the time period for achieving specific goals. Since each step is processed by a different optimization, these time ranges may also differ at each optimization step. It is also possible to consider additional changes, such as the climate, the users and the study area at each step, making the adaptation process much more flexible and dynamic. In the current research, the total time interval was defined from 2020 to 2070 and the time step was 10 years, hence the adaptation strategy was subdivided into 5 steps. Estimations about the last year of the decade were used to represent and product the results for the entire decade, since the strategies represents what should be done during the entire decade to reach its end adapted to the impacts of climate change that it is expected to occur within that same decade. After the completion of the first optimization set, one of the non-dominated solutions is selected as the starting point of the next optimization, which aims to determine the best strategies that are going to be used in the next step of the adaptation process, and so on. On the ground, this choice could be done by the farmers according to their interests. Since none solution is better than the other, one solution was picked randomly and was considered as if it was the farmer's choice, so the optimization process could be triggered.

5 Application

The Gramame river basin is located between latitudes 7°C11' e 7°C23' South and the longitudes 34°C86' e 35°C10' West on the southern coast of the state of Paraíba, Northeast of Brazil, as shown in Figure 14. This basin is considered strategic due to its importance to the region. In it is inserted the main reservoir from the coastal region of the state, Gramame-Mamuaba. This reservoir is responsible for supplying water for the capital of the state of Paraíba, the city of João Pessoa, which there are 720,954 inhabitants according to IBGE (2010). In addition, the Gramame reservoir serves as a water source for irrigation (SEMARH, 2000).

Figure 14 – River Gramame basin. Sources:(MACHADO et al., 2011; SEMARH, 2000)



Within the Gramame basin there are three sub-basins: river Mumbaba sub-basin, river Mamuaba sub-basin and river Água Boa sub-basin. Gramame basin area as well as the area of its sub-basins can be seen in Table 1.

Table 1 – River Gramame basin and its sub-basins areas. Source:(SEMARH, 2000)

Basin / Sub-basin	**Area**
Gramame Basin	589,1
Mumbaba Sub-basin	177,2
Mamuaba Sub-basin	128,0
Água Boa Sub-basin	65,4

Socio-economic characterization

The Gramame River basin is composed of the municipalities of Alhandra, Conde, Cruz do Espirito Santo, João Pessoa, Santa Rita, São Miguel de Taipu and Pedras de Fogo. The percentages of basin area participation by municipality are shown in Table 2 and the political map of the basin is shown in Figure 15.

Table 2 – Participation of each municipality on the basin. Source:(SEMARH, 2000)

Municipality	**Municipality Area** (km^2)	**Municipality Area on basin** (km^2)	**Participation (%)**
Alhandra	224,42	99,72	16,93
Conde	164,10	76,47	12,98
Cruz do Espírito Santo	189,32	3,50	0,59
João Pessoa	209,94	59,07	10,03
Santa Rita	762,33	155,59	26,41
São Miguel de Taipu	63,60	2,20	0,37
Pedras de Fogo	348,02	192,56	32,69

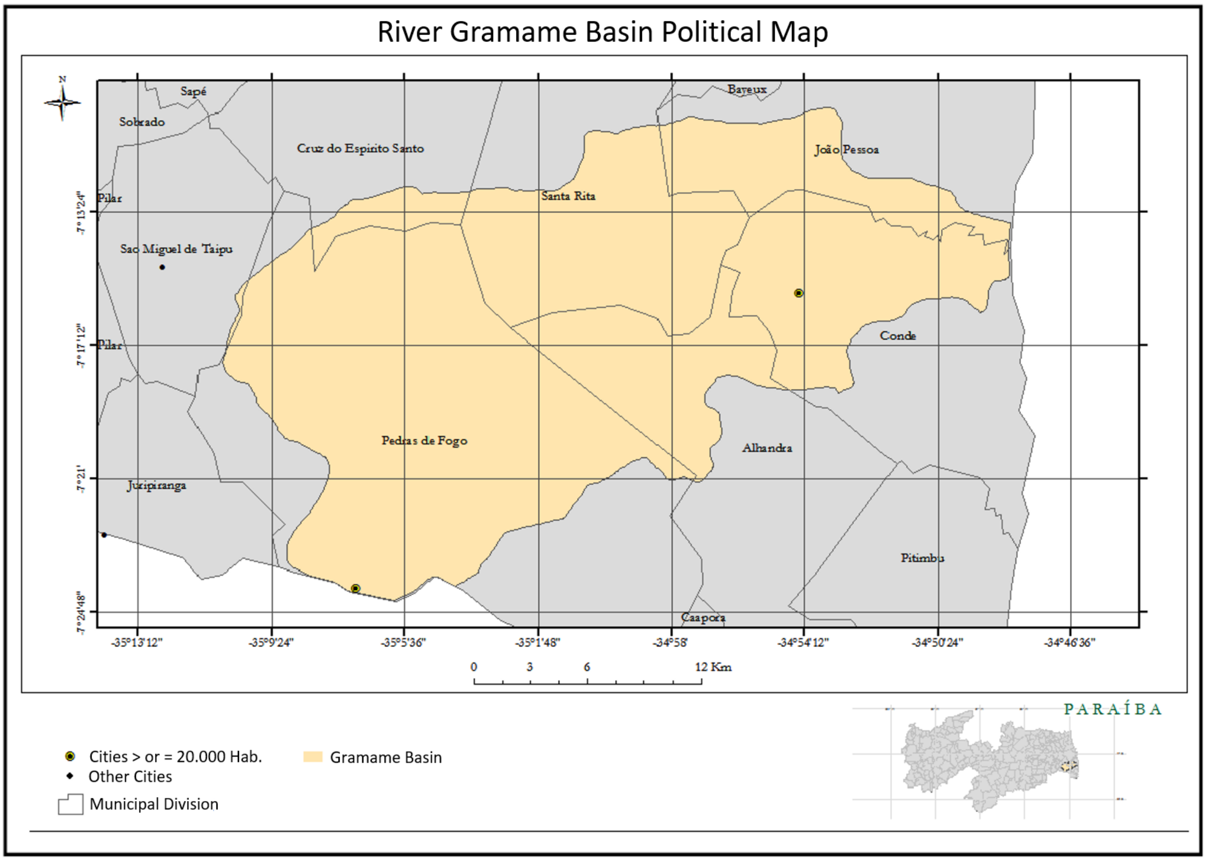
According to SEMARH (2000), the main economic activities of the basin are:

- **Agricultural Activities:** It is the main economic activity of the basin, besides being the largest consumer of water. There are more than 100 irrigation projects, from the most varied sizes. Sugar cane and pineapple are the crops with the largest irrigated areas.
- **Industrial Production:** Most industries are in the industrial district of João Pessoa.
- **Mining:** There is exploration of sand, clay, limestone and mineral water.
- **Tourism and Leisure:** They are concentrated in the lower part of the basin, near the coast.

Land use and cover

This region is historically marked by an intense process of deforestation, both by the logging industry and for intensive sugarcane planting (MACHADO, 2008). With regard

Figure 15 – Political map of river Gramame basin. Source:(MACHADO et al., 2011)



to land cover, only 12.9% of the basin area still contains native land cover, the remained area was anthropomorphized. It is possible to check it in the Table 3 which shows land use and land occupation in 1998.

Table 3 – Basin land use. Source: (SEMARH, 2000)

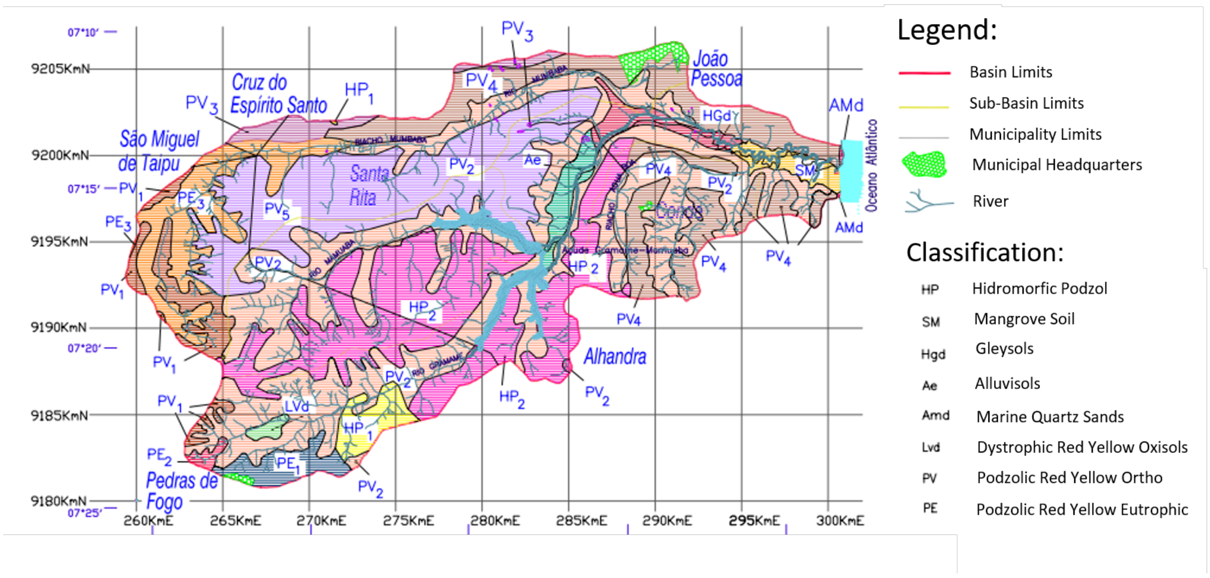
Land use and cover	Area (ha)	Percentage
Atlantic Forest	3.820	6,5
Cerrado	1.137	1,9
Lowland Vegetation	2.074	3,5
Mangrove Vegetation	613	1,0
Anthropism	51.266	87,1
Sum	58.910	100,0

Soil

The main rivers of the basin have their springs located in its southwestern part, which is characterized by the presence of a crystalline complex where there is occurrence of faults and fractures in the rocks. From this point on, rivers begin to develop in sloping valleys extending to the eastern part of the basin. Because of this characteristic, the springs are located in areas of low water availability. The perennialization of rivers only occurs from the moment they reach the high water potential sedimentary soil (PAIVA et al., 2001).

Looking at the soil map of the basin (Figure 16), it is possible to realize that the predominant soil in the Mamuaba River sub-basin is the Hydromorphic Podzol. This type of soil is sandy and deep, with a high infiltration rate and low water retention. In addition, it is known to be a soil with retarded runoff (PAIVA et al., 2001).

Figure 16 – Pedological map of the Gramame river basin. Source: (SEMARH, 2000)



Climate characteristics

The Northeast region is characterized by a strong intra and interannual variability of the rainfall, with alternations between dry and rainy periods (MOLION; BERNARDO, 2000). In the study area, the dry season usually starts in September and ends in February and the rainy season usually begins in late April and ends in the end of July, with the other months having intermediate characteristics. Figure 17 shows months of occurrence of dry, wet and rainy periods, as well as precipitation and average daily evapotranspirations for the study area.

According to SEMARH (2000), the average annual basin evapotranspiration is about 1312.5mm, while its average annual rainfall is around 1740mm. Using the FAO local climate estimator (New LocClim 1.10) (GRIESER; GOMMES; BERNARDI, 2006), it was possible to obtain the monthly averages of precipitation and potential evapotranspiration in the basin, which can be seen in Figure 18.

The geographical position of the state of Paraíba, close to the equator, the high incidence of solar radiation and the high number of hours of sunshine are determining factors for the occurrence of a warm climate, with an average annual temperature of 26.1 °C, according to SEMARH (2000).

Figure 17 – Dry, wet and rainy periods in the study area. Source: (GRIESER; GOMMES; BERNARDI, 2006)

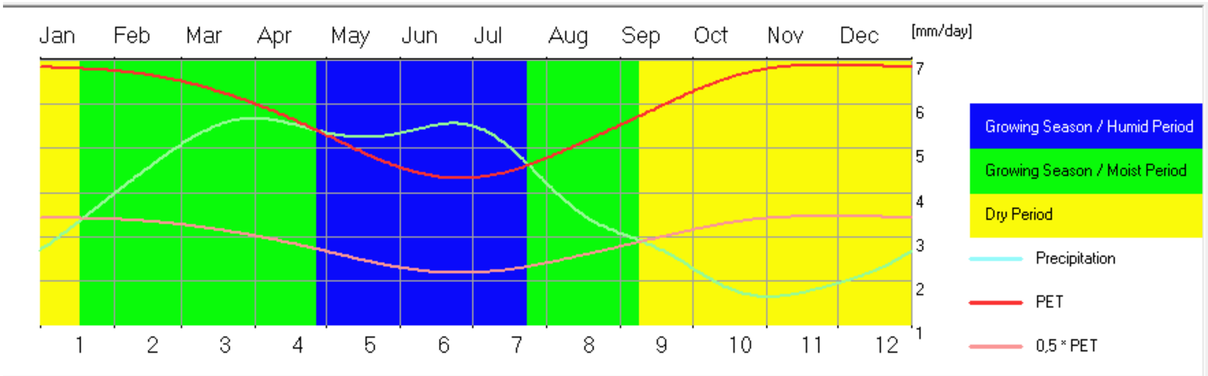
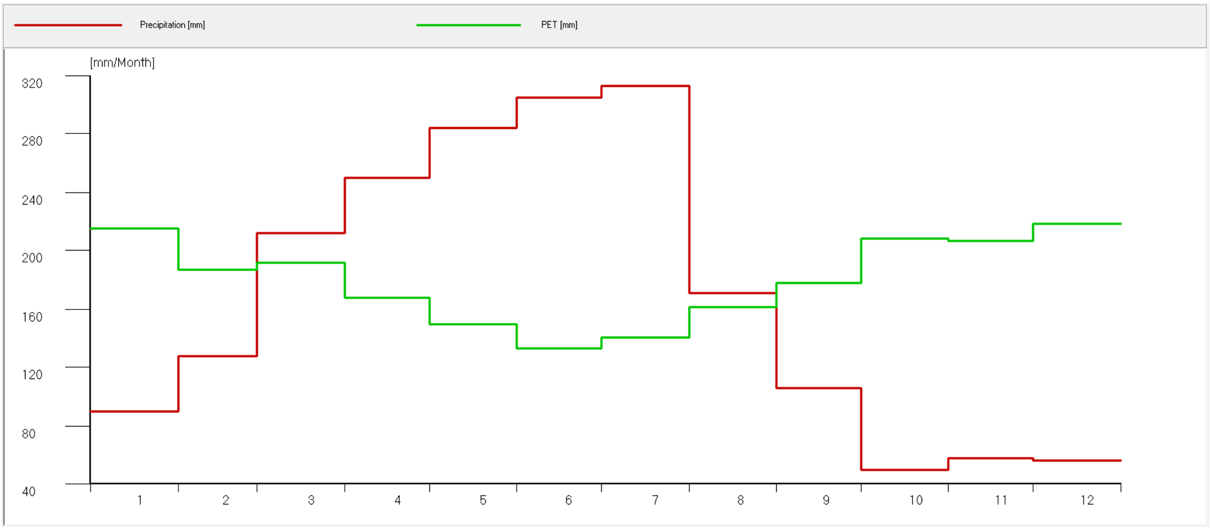


Figure 18 – : Monthly averages of precipitation and evapotranspiration for Gramame river basin. Source: (GRIESER; GOMMES; BERNARDI, 2006)



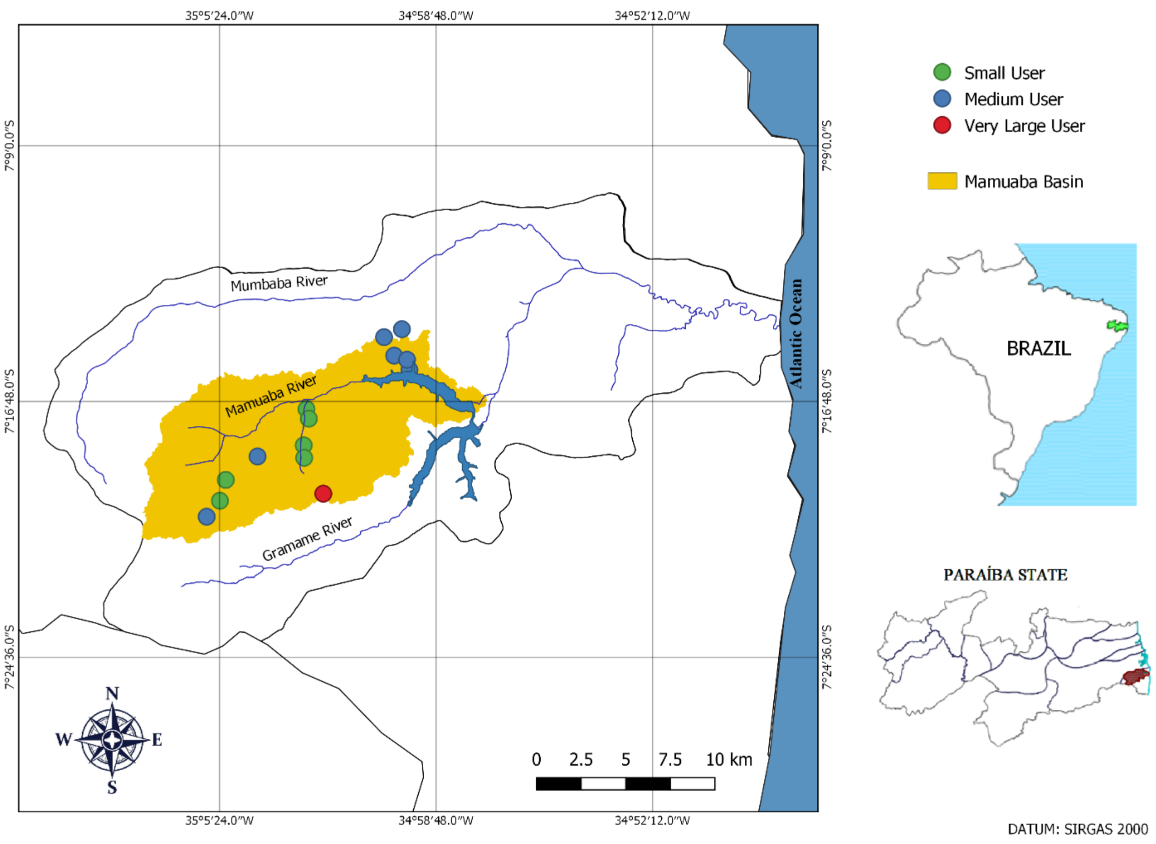
Climate data can be obtained from João Pessoa weather station, which is in a short distance from the Gramame river basin. This climatological station is managed by the National Institute of Meteorology of Brazil (INMET), which makes all data freely available on its site.

Daily data on sunshine, precipitation, radiation, minimum and maximum temperatures, humidity and wind speed (obtained both from FAO's local climate estimator and INMET), were treated and inserted in AquaCrop software to obtain a reference evapotranspiration estimation (essential data for the functioning of AquaCrop OS). Following this process, reference evapotranspiration, together with precipitation and maximum and minimum temperatures (all data on the daily scale), were used to feed the AquaCrop OS weather data input file. These data is presented on Annex A for each decade. Data for precipitation, temperature, and evapotranspiration changes from one decade to another to simulate the climate change effect (this topic will be better discussed forward in this chapter).

Water users

On this research, only the farmers present in the River Mamuaba basin were considered. Figure 19 shows the location of this basin , within the Gramame basin. In this same figure, we can still see the location of farmers within the basin according to the size of the area irrigated by them.

Figure 19 – Farmers location.



A register of farmers made by SEMARH (2000) (Table 4) was used as a basis for the characterization of the farmers, although these data are out of date and no longer represent the reality of the basin, it serves as a scenario to test the operation of the proposed method.

Despite the farmers names are present in the original source, these were omitted and replaced by numbers in this work. Depending on the size of the area irrigated by each user (A), these were classified as: Very small ($A < 5ha$), small ($5 < A < 10ha$), medium ($10 < A < 50ha$, large ($50 < A < 100ha$) or very large ($A > 100ha$). The intervals presented above are the same intervals used by SEMARH (2000) to classify the farmers based on the area irrigated by them.

In addition to this information, the Table 4 contains information about the crop, geographical coordinates, and the irrigation method used to irrigate each crop. None of the farmers utilizes any type of mulching or cover crop (at least we do not have any source informing about the utilization of this kind practice by the farmers in the study area), so all farmers are labeled with the "no mulching" status.

The water demands for each user were also reported by SEMARH (2000), but since AquaCrop OS could calculate them, it was preferred to use the demands obtained by AquaCrop OS, because them would have to be recalculated anyway at all stages of optimization in order to take into account the increases in demands caused by the impacts of climate change.

Although the user's data is outdated (the data is from approximately 20 years ago), we believed that this is not a problem for our research. That is because, it is not the intention of this work to produce an adaptation strategy for the area in question, but rather, to present an innovative methodology for the creation of this type of strategy, which can be used in various types of cases and locations. Therefore, the application in the Mamuaba basin has only an expository aspect of how the methodology works in practice. In addition, even if current data on the study area were used, we believe that the final result will not differ much from that obtained, since, although the absolute values vary over time, the relationships between different values remain more or less constant (dripping irrigation will always be more expensive than conventional sprinkler), so that the trends (which, in the end, are what guide the adoption of adaptation strategies) remained the same. In other words, it doesn't matter if the simulation starts with data from 2000 or 2020, it will tend to similar results when it arrives in 2070.

Besides irrigation, water is also used for other purposes in the basin. In Table 5 is possible to see all cities that use water from the basin to urban population supply, as well as the respective demand value in l/s. Table 6 shows, for each sub-basin, the demand for rural population and industry supply in m^3/s. Those values of demand, from both tables, are estimations made by SEMARH (2000) for the year of 2020.

Table 4 – Irrigators from the Mamuaba River Sub-basin. Source: (SEMARH, 2000)

Farmers	Crop	Area (ha)	Classification	Coordinates UTM (km)	Irrigation Method
1	Pineapple	30	MEDIUM	(279,9198)	Conventional Sprinkler
1	Pineapple	42	MEDIUM	(278,9198)	Center Pivot
2	Pineapple	4	SMALL	(274,9191)	Conventional Sprinkle
2	Yam	1,4	SMALL	(274,9191)	Conventional Sprinkle
3	Yam	1	SMALL	(274,9193)	Conventional Sprinkle
3	Pineapple	1	SMALL	(274,9193)	Conventional Sprinkle
3	Coconut	1	SMALL	(274,9193)	Conventional Sprinkle
3	Orange	1	SMALL	(274,9193)	Conventional Sprinkle
4	Pineapple	2,5	SMALL	(273,9192)	Conventional Sprinkle
4	Manioc Tree	2,5	SMALL	(273,9192)	Conventional Sprinkle
5	Beans	1	VERY SMALL	(274,9194)	Conventional Sprinkle
5	Corn	1	VERY SMALL	(274,9194)	Conventional Sprinkle
5	Yam	2	VERY SMALL	(274,9194)	Conventional Sprinkle
6	Beans	1	VERY SMALL	(269,9190)	Conventional Sprinkle
6	Yams	1	VERY SMALL	(269,9190)	Conventional Sprinkle
7	Pineapple	16	MEDIUM	(279,9197)	Center Pivot
7	Papaya	16	MEDIUM	(279,9197)	Center Pivot
8	Sugar Cane	600	VERY LARGE	(276,9186)	Giant Canon
9	Pineapple	15	MEDIUM	(279,9197)	Center Pivot
10	Pineapple	15	MEDIUM	(279,9196)	Conventional Sprinkle
10	Papaya	1	MEDIUM	(279,9196)	Conventional Sprinkle
11	Pineapple	1	SMALL	(269,9189)	Conventional Sprinkle
11	Yams	2	SMALL	(269,9189)	Conventional Sprinkle
11	Beans	2	SMALL	(269,9189)	Conventional Sprinkle
12	Pineapple	10	MEDIUM	(268,9188)	Conventional Sprinkle
13	Pineapple	10	MEDIUM	(271,9191)	Giant Canon
13	Sugar Cane	32	MEDIUM	(271,9191)	Giant Canon

Table 5 – Espected demand for urban population in 2020. Source: (SEMARH, 2000)

Municipalities	Urban Population Demand (l/s)
Bayeux	436,69
Cabedelo	292,16
João Pessoa	3.066,95
Conde	27,35
Pedras de Fogo	21,25
Várzea Nova	69,59

Table 6 – Espected demand for industries and rural population in 2020. Source: (SEMARH, 2000)

	Demand m^3/s	
Sub-basin	Rural Population	Industries
Água Boa	3.45	15
Gramame	7.90	244
Mamuaba	3.98	1
Mumbaba	5.74	629

Demand and Water Availability

The water availability of a basin represents the quantification of the water resources within that basin without human intervention, i.e. in its natural state. It is represented by the arithmetic mean of the natural flows historical series. Its value indicates the theoretically maximum average flow rate that could be withdrawn from that basin. However, according to SEMARH (2000), the maximum amount that can be made available for water use corresponds to a fraction of typically 60% of that maximum average flow rate. Table 7 shows the water availability of the Gramame basin and its sub-basins.

Table 7 – Water availability in River Gramame Basin. Source: (SEMARH, 2000)

Basin or Sub-basin	**Availability** m^3/s
Mamuaba Sub-basin	1,83
Mumbaba Sub-basin	2,38
Riacho da Salsa Sub-basin	0,51
Água Boa River Sub-basin	1,28
Gramame Basin	9,50

For Mamuaba sub-basin, where the farmers presented on Table 4 are, the availability is $1,83m^3/s$. If we multiply this value for the 60% fraction that is suggested by SEMARH (2000), we only stay with approximately $1,0m^3/s$ for human use. In this work, we had considered the last value as the sub-basin water availability.

IPCC-derived projections for Brazil (BRAZIL, 2015), considering scenario RCP 4.5 of Eta-HadGEM2ES model for the 2041-2070 period, were used to estimate future values of precipitation, air temperature, and water availability for each decade (step), considering the current conditions as the baseline (2020-2030). According to the projections, it is expected a:

- Reduction of 50 mm of surface flow until 2070;
- Increase of 6.7 °C (mean temperature) until 2100;
- Decrease of 22% on precipitation until 2100;

To estimate the reduction on water availability in the future decades, the reduction of the surface flow was considered to occur steadily on the 2020-2070 period. This can be considered a source of uncertainty and imprecision for the work, since, in practice, this dynamic occurs in a much more complex way. However, for the purposes of this research, the approximation that was made is considered satisfactory. To convert the reduction in surface flow into flow reduction (which is the parameter used to measure water avaliability), the water depth was multiplied by the area of the mamuaba basin and then divided by the simulation period.

Reductions in precipitation and increases in temperature were used to estimate the increase in demand, since both contribute to increasing the demand for water for irrigation. To make this estimation, the Aquacrop software was used, since it is able to calculate the demand for irrigation. All other parameters were kept constant, while temperature and precipitation were changed to reflect the expected changes. Other parameters considered in the AquaCrop modeling process, like duration of sunshine, net solar radiation, air humidity, and wind speed were considered constant during the whole process because we can not find any prediction about the behavior of those variables along this period. This simplification is another possible source of uncertainties for the work, as some of the variables considered constant may vary over time, however, for the same reasons already mentioned above, we believe that these uncertainties did not affect the quality of the final results of the work.

Adaptation Cost

A survey on various irrigation methods was preformed in order to collect the following data: percentage of wetted soil, irrigation method efficiency, and cost estimate for implementing the method per unit of area. This survey included both the methods that are already used in the study area, as well as methods that are more efficient than those that may replace the current ones in the adaptation process. Table 8 shows a summary of those information (RAES et al., 2018; SILVA; AZEVEDO; LIMA, 2002; COELHO; FILHO; OLIVEIRA, 2005; MAROUELLI; SILVA, 1998).

Table 8 – Information about the irrigation methods.

Irrigation Method	**% of wetted soil**	**Method Efficiency**	**Cost** $R\$/hc$
Conventional mobile sprinkler	100	70%	1500
Sprinkler with mini cannon	100	60%	2200
Sprinkler with giant cannon	100	50%	Not necessary
Center pivot	100	80%	3000
Micro sprinkler	40	90%	8000
Dripping	15	95%	8000

Similarly, information on soil management methods was collected in order to know the following data: reduction of water evaporation from the soil surface caused by the management practice, and estimated cost to implement the method per unit of area. Among the farmers considered, none used soil management practices, so all the surveyed methods are suggestions for future adoption during the adaptation process. Among all practices, only the mulching practices were considered, since they are the only ones that are simultaneously simulated by Aquacrop OS and are compatible with local crops. Table 9 shows a summary of those information (GUEDES et al., 2018; CARVALHO et al., 2017; RAES et al., 2018).

Table 9 – Information about the soil management methods.

Soil Management Methods	**% reduction on soil evaporation**	**Cost** $R\$/m^2$
Without Mulching	0	0
Organic Mulching	50	0.05
Plastic Mulching	100	0.1

Similarly to user's data, cost information is also out of date and has uncertainties in its estimation process (old production dates, sources from other parts of the country, produced for different cases at different time periods, uncertainties already present in the original sources), however, for the same reasons already exposed in the topic about user's data, it was considered that, despite all these uncertainties, the credibility of the results obtained was not impaired.

5.1 GA Parameters

In this work, we used the following parameters in the evolutionary algorithm:

- Population: 500 solutions
- External population: 200 solutions
- Probability of occurrence of *Crossover* : 80%
- Probability of occurrence of uniform mutation: 30%
- Probability of occurrence of directed mutation: 10%
- Number of simulated generations after the appearance of the first viable individual: 1000 generations

These parameters were kept constant during all simulations and were defined based on the usual values found on literature and tests performed on the algorithm itself (trial and error).

6 Results and Discussion

The algorithm was used to generate an adaptation strategy to climatic change to a group of farmers in the river Mamuaba sub-basin, that are already mentioned in the Study Case topic. The time interval considered was from 2020 to 2070 and the time step considered was 10 years hence the adaptation strategy was subdivided into 5 steps.

The results will be presented and discussed within five different sub-topics:

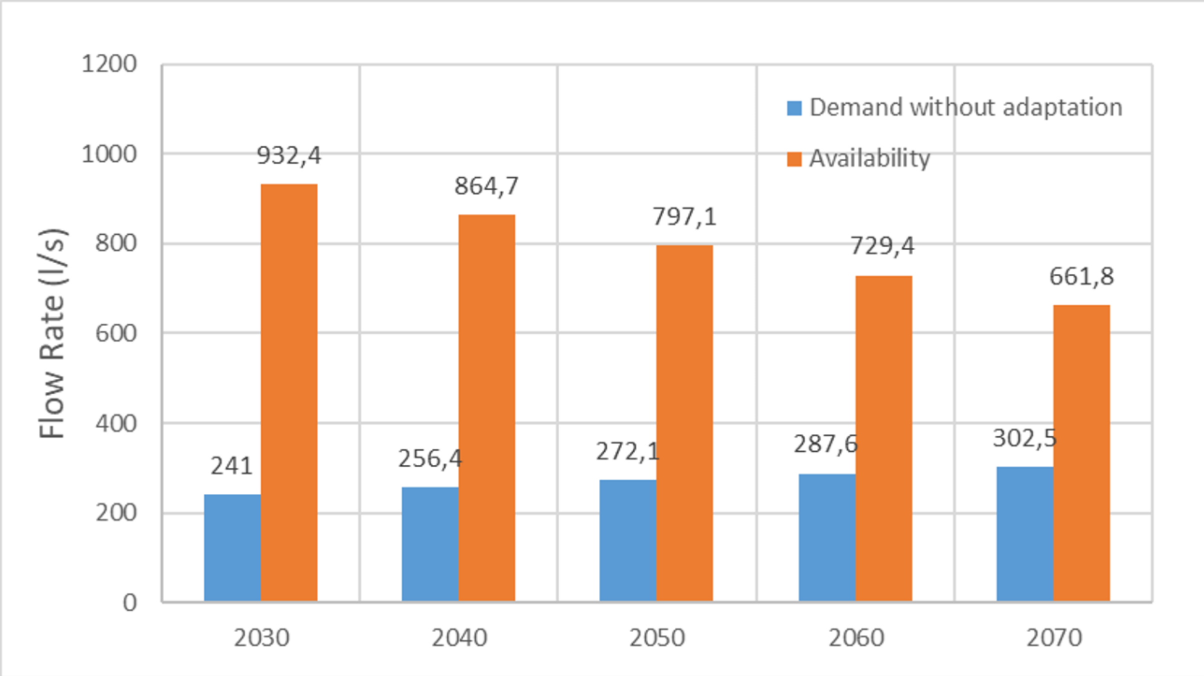
1. **Climate change impacts:** In this topic are going to be presented the predict impacts of climate change (that the adaptation strategy will need to compensate for).
2. **Adaptation strategy:** Here will be presented the main results of this work and the general recommendations for the farmer extracted from these results.
3. **Equity and adaptation:** Here we will show an analysis of the adaptation strategy from the water justice point of view
4. **Crops x irrigation methods x soil management:** Here we will present a general recommendation for adaptation, for this particular study case, with regards to the many adaptations options that are available.
5. **Setting water footprint benchmarks:** Here we will use some results extracted from the main results to recommend water footprint benchmarks to the time interval considered (2020 – 2070).

6.1 Climate Change Impacts

Using the projections from Brazil (2015) it was possible to make estimatives of the reference evapotranspiration for each time step. With this estimative, we could use Aquacrop to estimate how the demand for water for irrigation would increase. Figure 20 shows how water availability will decrease according to Brazil (2015) and how the demand for water for irrigation in the study area will increase according to the estimative obtained through AquaCrop.

From the results shown above, the increase in mean temperature caused by climate change will lead to an increase in evapotranspiration, as well as an increase in the agricultural demand for water. The decrease in precipitation also causes an increase in demand since more irrigation water will be necessary to supply the deficit between the amount of rainfall and the water demand for crop growth.

Figure 20 – Climate change impacts on water demand/availability



On the water availability side, the reduction in surface flow will culminate with a reduction in the river's streamflow, consequently reducing the availability of water. So we could see that the adaptation strategy will have to compensate not only for the reduction in availability but for the increase in water demand as well.

At Brazil, we have similar studies pointing out to analogous results. According to Krol and Bronstert (2007) climate change is concluded to have an enormous potential impact on the Semi-arid region of Brazil, with this phenomenon especially effecting river flow, water storage and irrigated production (even under plausible favorable changes in climate, these variables remain stressed). Perazzoli, Pinheiro and Kaufmann (2013) analyzed the impacts of climate changes on the flow and sediment production regimes in the Concórdia River drainage basin, in southern Brazil; the analysis shown a reduction in flow of 39.2% in the most favorable scenario and suggested that flood peaks could reach more extreme values in the future. Broad et al. (2007) discussed the influence of climate change and societal setting upon the value of forecasts of streamflows that replenish reservoirs in the semi-arid state of Ceará, Brazil, and they concluded that water demand for high-economic value activities are likely to increase in the future. According to Marengo and Bernasconi (2015), is expected an increase in the dryness of the Northeast Brazil region, with rainfall reductions, temperature increases, water deficits increases and longer dry spells, leading to drought and arid conditions expected to prevail by the second half of the 21th century. Rosenzweig et al. (2004) examined the implications of changes in crop water demand and water availability for the reliability of irrigation; the study takes place in several countries, including Brazil, and the conclusions were that even in the relatively water-rich areas changes in water demand will require appropriate improvements in crop cultivars, irrigation, drainage technology, and water management.

Seif-Ennasr et al. (2016) evaluated the effect of futures changes in precipitation and temperature distributions in the availability of water resources for agriculture in north-western Africa, region that, as the study area of this work, also have trends of decreasing precipitation and increasing temperatures; simulation results from this work also pointed out increasing demands and decreasing water availability that, in this particular case, will cause until 2050 the tripling of the basin water deficit.

6.2 Adaptation Strategy

Figure 21 shows the adaptation strategy generated by the genetic algorithm. That table alone says very little, but from it is possible to extract some valuable secondary data and conclusions, for instance: reduction on water footprint in each step, if small farmers were prioritized or not, and general recommendations for the farmers. All this secondary data will be presented and discussed in details on the next sections.

Figure 21 – Adaptation strategy.

INITIAL

FARMERS

	M	M	P		P				P		MP			MP		M		MG	M	M		P			M	M	
Crop	6	6	6	4	4	6	5	5	6	4	1	6	4	1	4	6	2	3	6	6	2	6	4	1	6	6	3
Irrigation Method	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	1	4	3	3	3	3	3	3	1	1
Soil manegement	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

2020 - 2030 (1)

FARMERS

	M	M	P		P				P		MP			MP		M		MG	M	M		P			M	M	
Crop	6	6	6	4	4	6	5	5	6	4	1	6	4	1	4	6	2	3	6	6	2	6	4	2	6	6	3
Irrigation Method	4	4	3	4	3	4	3	3	4	3	3	3	3	3	3	4	4	1	4	3	3	3	4	3	3	1	1
Soil manegement	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	2	1

2030 - 2040 (2)

FARMERS

	M	M	P		P				P		MP			MP		M		MG	M	M		P			M	M	
Crop	6	6	6	5	5	6	5	5	6	4	1	6	5	1	5	6	3	3	6	6	2	6	5	3	6	6	3
Irrigation Method	4	4	3	5	3	4	3	3	5	3	4	4	4	3	3	4	4	1	4	3	4	3	4	3	3	1	1
Soil manegement	1	1	2	1	1	1	2	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1	2	2	2	2	1

2040 - 2050 (2)

FARMERS

	M	M	P		P				P		MP			MP		M		MG	M	M		P			M	M	
Crop	6	6	6	5	5	6	5	5	6	4	1	6	5	1	5	6	3	3	6	6	2	6	5	3	6	6	3
Irrigation Method	4	4	4	5	3	4	3	3	5	3	4	5	4	3	4	4	4	1	4	3	4	3	5	4	3	1	1
Soil manegement	1	1	2	1	1	2	2	1	2	2	1	1	2	1	3	1	1	1	1	2	2	2	2	2	2	2	1

2050 - 2060

FARMERS

	M	M	P		P				P		MP			MP		M		MG	M	M		P			M	M	
Crop	6	6	6	5	5	6	5	5	6	5	1	6	6	1	5	6	4	4	6	6	2	6	5	3	6	6	3
Irrigation Method	4	4	4	5	3	5	4	4	5	4	4	5	4	3	5	4	4	1	4	3	4	4	5	4	3	1	1
Soil manegement	1	1	2	1	1	2	2	1	2	2	1	1	3	2	3	1	1	1	1	3	3	2	2	3	2	2	1

2060 - 2070

FARMERS

	M	M	P		P				P		MP			MP		M		MG	M	M		P			M	M	
Crop	6	6	6	5	5	6	5	5	6	5	1	6	6	1	5	6	4	4	6	6	2	6	5	3	6	6	3
Irrigation Method	4	4	4	5	4	5	4	4	5	4	4	5	4	3	5	4	4	1	4	3	4	4	5	4	3	1	1
Soil manegement	1	1	2	2	2	3	2	2	2	2	2	2	3	2	3	1	1	1	1	3	3	2	2	3	2	2	1

LEGEND

CROP			IRRIGATION METHOD			SOIL MANEGEMENT			USERS		
	1	CROP GROUP 1		1	ASPERSION WITH GIANT CANON		1	WITHOUT MULCHING		MP	VERY SMALL
	2	CROP GROUP 2		2	ASPERSION WITH MINI CANON		2	ORGANIC MULCHING		P	SMALL
	3	CROP GROUP 3		3	CONVENTIONAL ASPERSION		3	PLASTIC MULCHING		M	MEDIUM
	4	CROP GROUP 4		4	CENTRAL PIVOT					G	LARGE
	5	CROP GROUP 5		5	MICRO ASPERSION					MG	VERY LARGE
	6	CROP GROUP 6		6	DRIPPING						

6.3 Pareto Frontiers

Figures 22 to 26 presents the Pareto Frontiers of all optimizations, one for each period/decade. From these graphs, we can see that there is one adaptation strategy for each amount of money invested which produces the best final result in terms of a reduction in total water footprint. Other works have already done similar cost-effectiveness approaches, as Zou et al. (2013) that made a cost-effectiveness analysis of four water-saving irrigation techniques that are widely implemented in China, and concluded that water-saving irrigation is cost-effective in coping with climate change and has benefits for climate change mitigation and adaptation and for sustainable economic development. Whitehead et al. (2013) also performed a cost-benefit analyses finding the most effective strategies to cope with climate changes impacts in River Thames basin in southern England. Chukalla, Krol and Hoekstra (2017) made marginal cost curves (MCCs) to rank packages of water saving techniques (deficit irrigation, mulching, and changing irrigation methods) according to their cost effectiveness to reduce the water footprint need to support the decision making.

Figure 22 – Pareto Frontier for 2020 – 2030 period

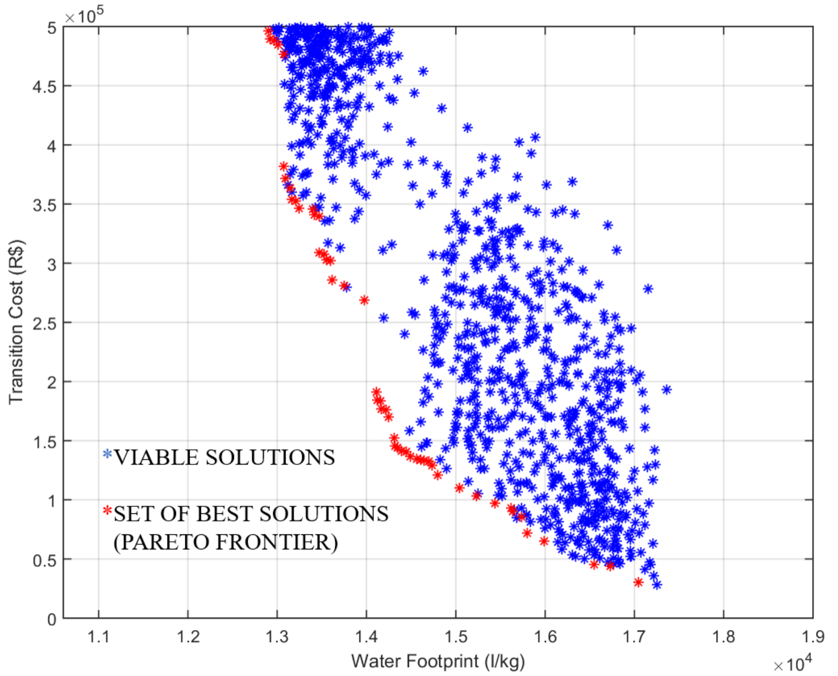


Figure 23 – Pareto Frontier for 2030 – 2040 period

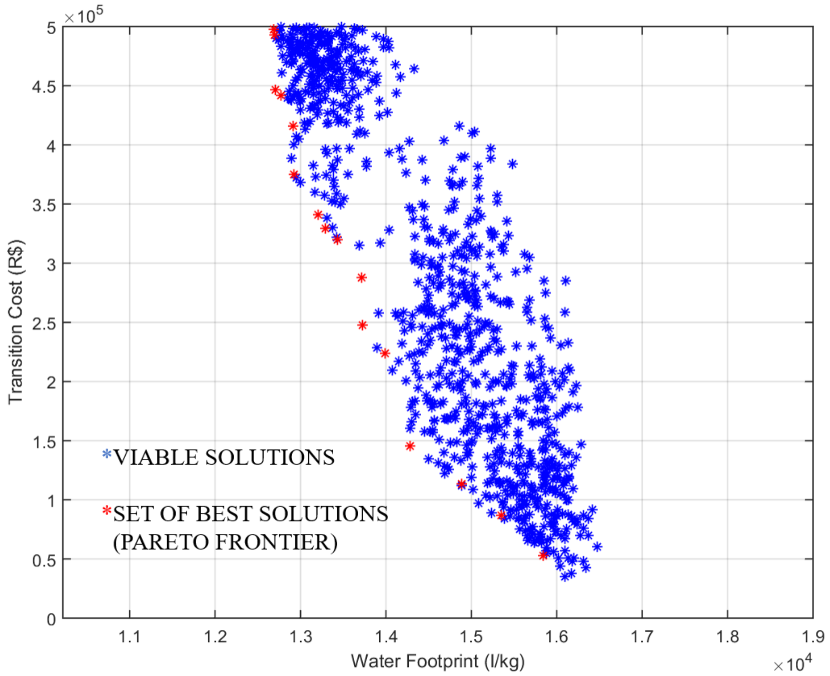


Figure 24 – Pareto Frontier for 2040 – 2050 period

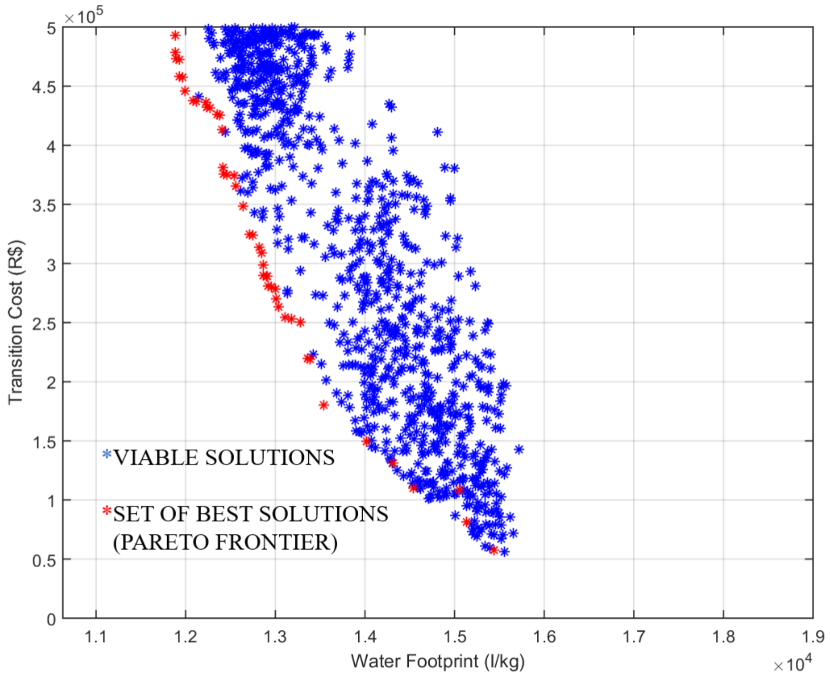


Figure 25 – Pareto Frontier for 2050 – 2060 period

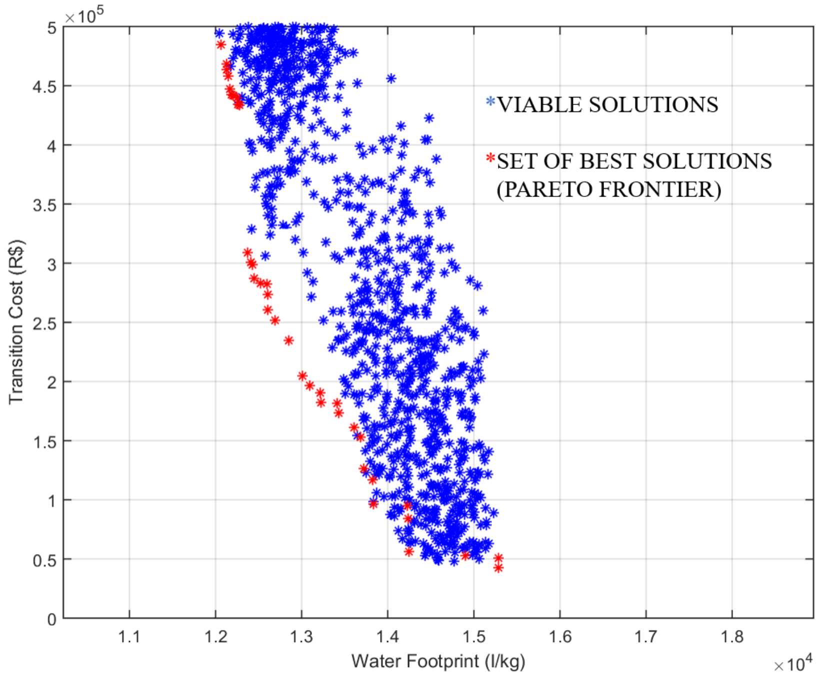


Figure 26 – Pareto Frontier for 2060 – 2070 period

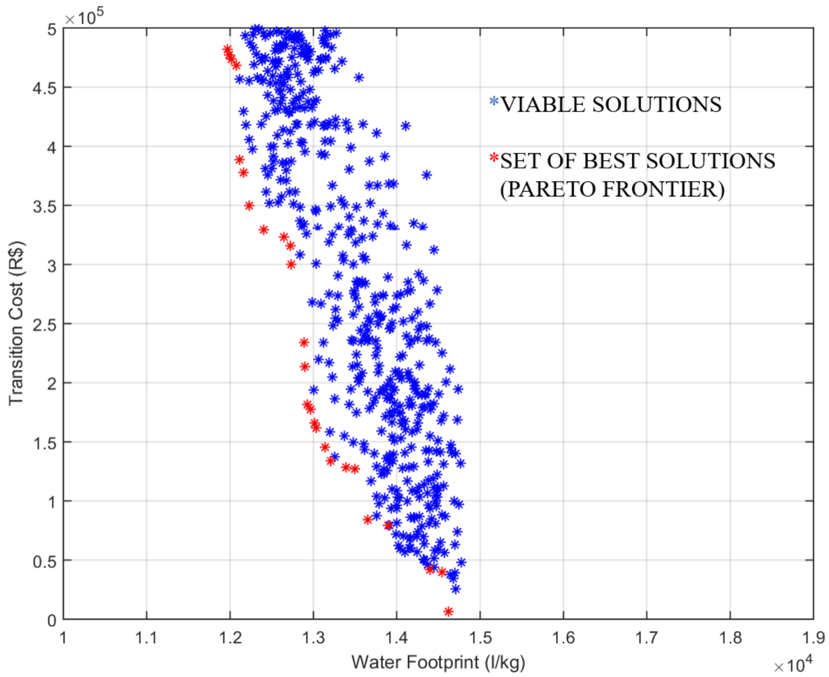
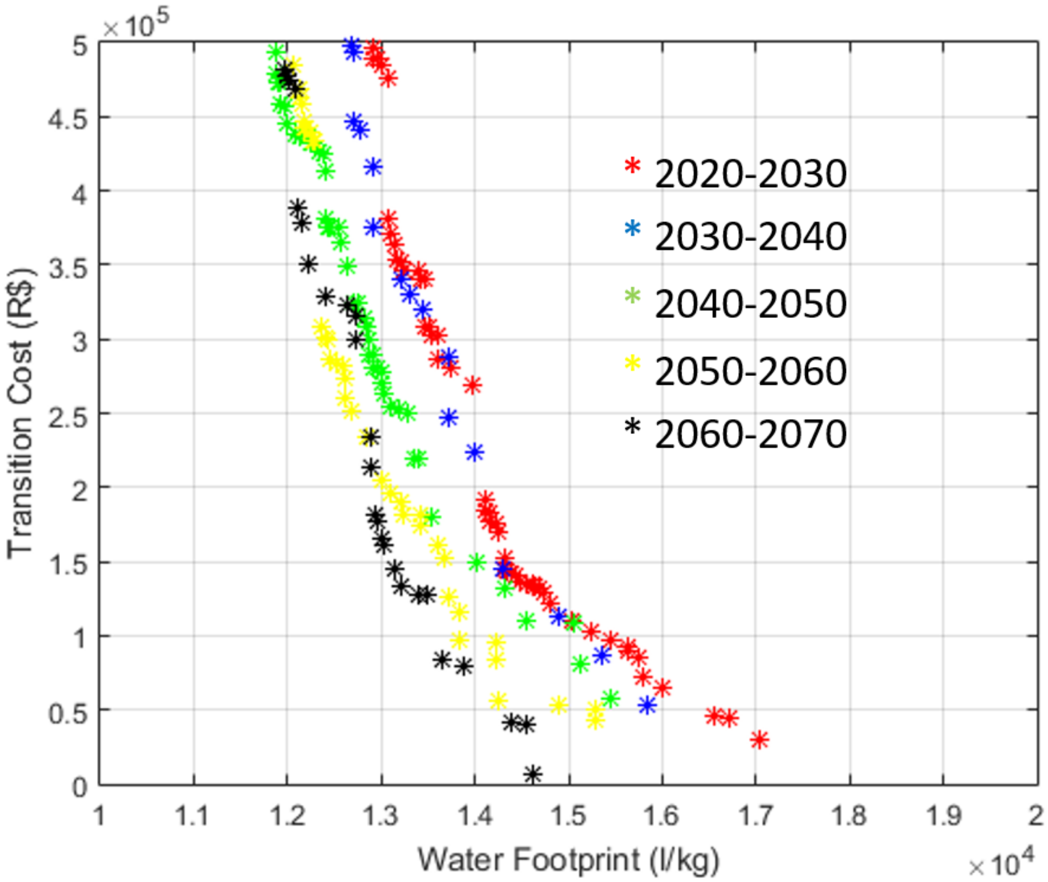


Figure 27 shows, in a single graph, the Pareto Frontiers of all periods, demonstrating that there is an evolution in sustainability/efficiency in water use across time because of the measures taken on the previous decades, showing that the process of adaptation occurs in an evolutionary way.

Figure 27 – Pareto frontiers of all periods.



Similar sequential multiobjective optimization were already done in several other works, mainly with the objective of saving processing time on complex problems with substantial number of decision making variables (RAHMANI; BEHZADIAN; ARDESHIR, 2015; ZHANG et al., 2017; HENG et al., 2017; XIE et al., 2017; LI et al., 2017). In these works, a complex optimization problem was subdivided into simpler ones, which, if solved in a sequential manner (with the result of the previous one serving as a starting point for the next optimization), it provided an approximate result for the more complex problem. Although the solution is being improved in each step, the goal remains in finding the final result. The method becomes attractive because it is faster.

In our case, the sequential optimization process was slightly different, firstly because the optimization problem was not simplified (as we were not interested in reducing the processing speed) and secondly because great importance was given to the intermediate stages (the evolution of the solution itself).This is a kind of solution that does not only care about the final result but, instead, gives to the transition process the same attention that is given to the final result. According to Pahl-Wostl (2007), more attention has to be devoted to understanding and managing the transition from current management regimes to more adaptive regimes that take into account environmental, technological, economic, institutional and cultural characteristics of river basins. It means that we have to move from a prediction and controlled water management to a more learning management, where more attention is given to local characteristics (GEORGAKAKOS et al., 2012; NOHARA; HORI, 2017).

The Pareto Frontier can be a powerful tool to assist in the decision making process for water and environmental problems, having already been used for this purpose in several works (KENNEDY et al., 2008) (DAS; MAZUMDER; GUPTA, 2012; BLASCO et al., 2008). Furthermore, all Pareto frontiers were analyzed in order to identify any potential pattern that could serve as a general recommendation to the farmers at each time period. Thus, for all the decades, except for the last one, it's obvious that the Pareto frontiers can be decomposed into two lines: one bottom line that is more horizontal, and an upper line that is more vertical (Figures 28 to 32). That behavior shows that, until a certain cost (the intersection of the lines), the reduction in water footprint per unit of money invested is more gainful than beyond that point. The intersection point can be a good, simplified and general recommendation for the users. For instance, in the first three decades, the intersection point lies approximately at the cost of R$ 150000, while in the fourth decade it lies on R$300000 and in the last decade we can see only the vertical line.

Figure 28 – Pareto Frontier general recommendation for 2020 – 2030 period

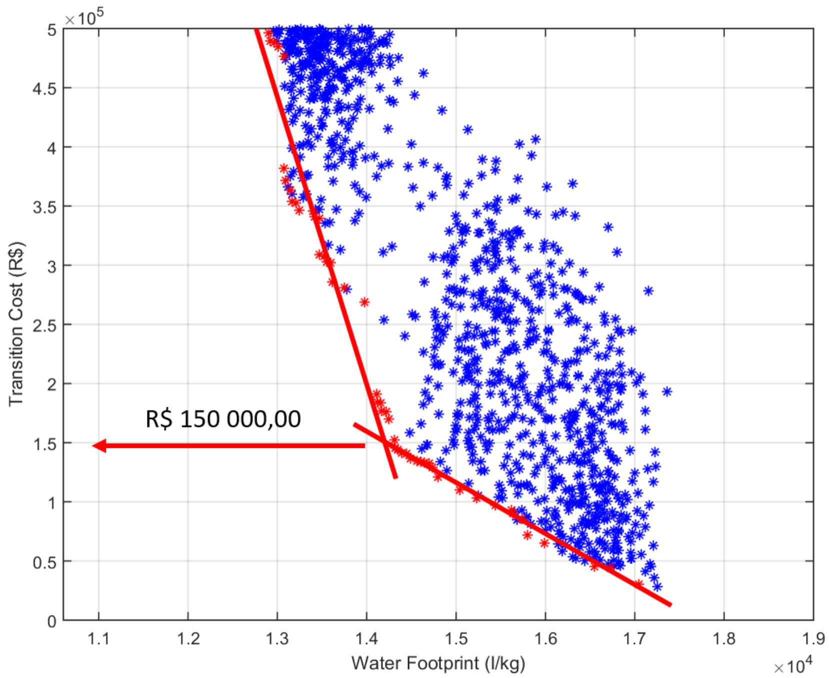


Figure 29 – Pareto Frontier general recommendation for 2030 – 2040 period

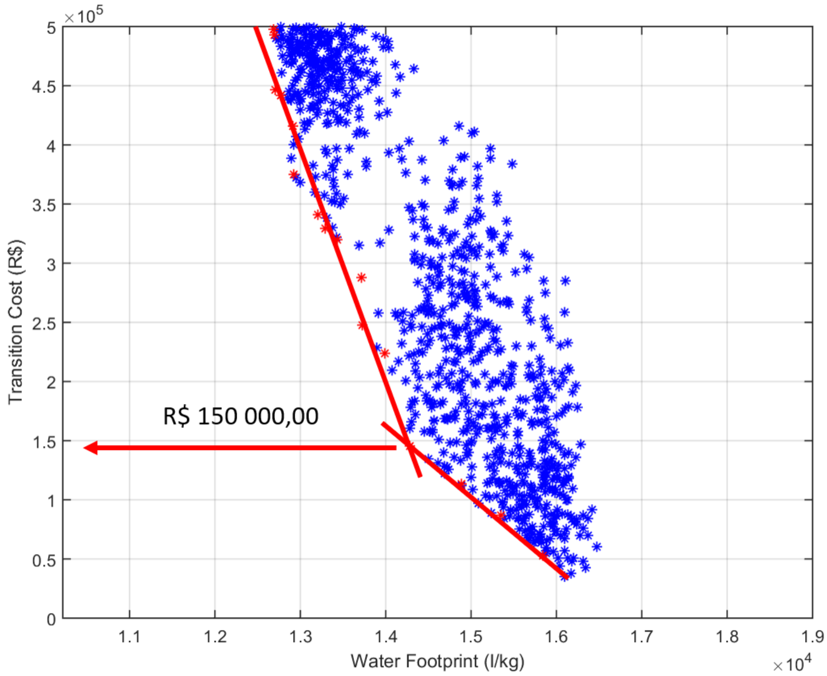


Figure 30 – Pareto Frontier general recommendation for 2040 – 2050 period

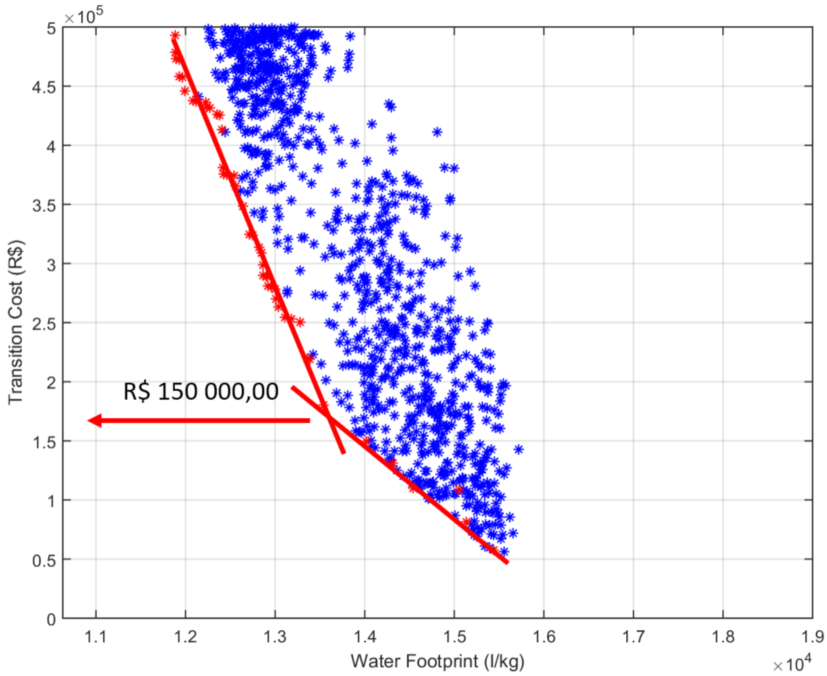


Figure 31 – Pareto Frontier general recommendation for 2050 – 2060 period

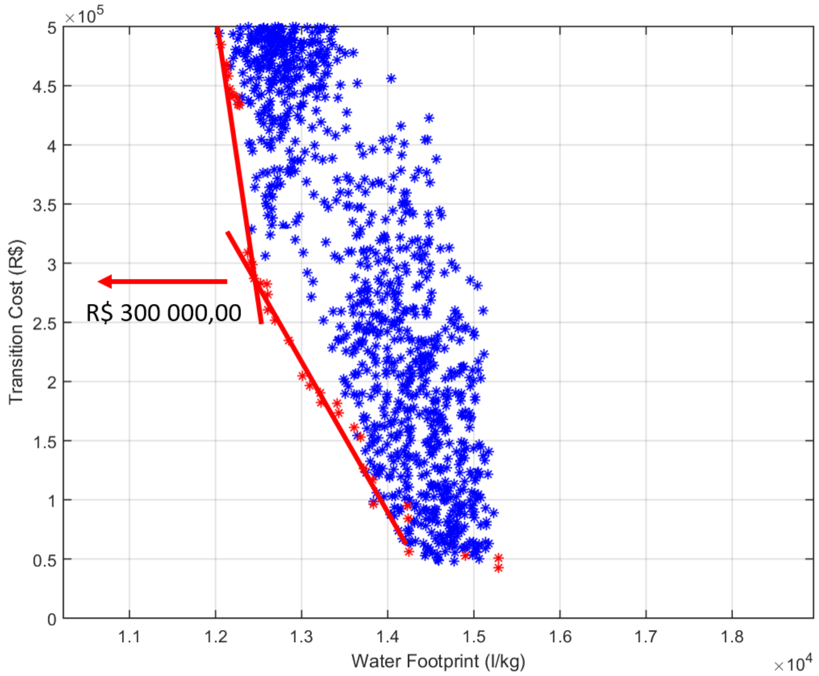
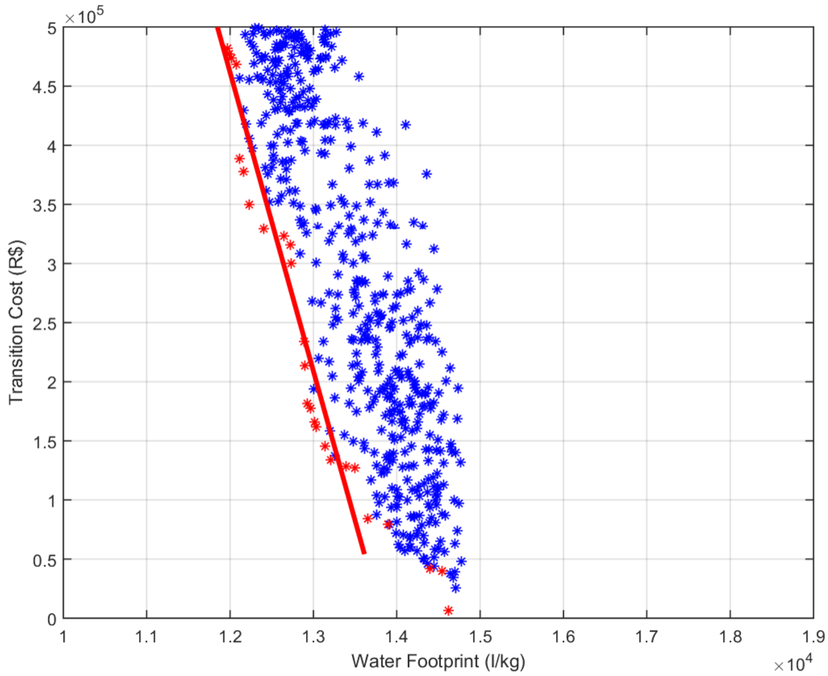


Figure 32 – Pareto Frontier general recommendation for 2060 – 2070 period

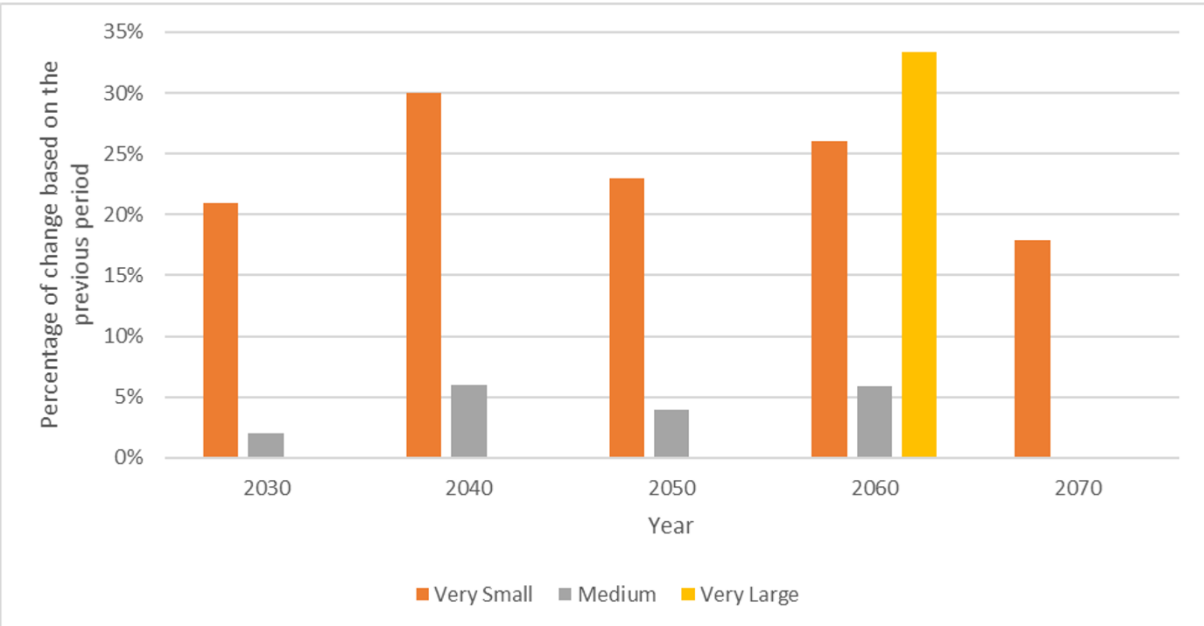


The intersection point could be a good, simplified and general recommendation for the farmers. For instance, in the first three decades, the intersection point lies approximately at the cost of R$ 150000, while in the fourth decade it lies on R$300000 and in the last decade we can see only the vertical line. That behavior on the Pareto frontier could be 'translated' to the farmer as: 'In the three first decades, we recommend investing R$150000 in adaptations measures. In the fourth decade, we recommend investing the double of this value. In the last decade, the best solution is probably adopting the cheaper strategy of the Pareto frontier.'

6.4 Equity and Adaptation

The classification of users based on the irrigated area was not inserted explicitly in the objective functions. Despite that, the final results showed that very small users were prioritized over medium and large ones, and received more adaptations measures, as shown in Figure 33.

Figure 33 – Percentage of change based on farmer's irrigated area size



The way that the first objective function was written was the reason for this result. Since the first objective function is the sum of all user's WF, a specific reduction in the WF of a small user has the same impact (in the fitness value) with the similar one in a large user's WF. Reducing the WF of a large user costs more than reducing the WF of a small user, thus it is more advantageous to adapt the smaller first.

Thomas and Twyman (2005) considers climate change as one of the factors that affects equity in natural-resource use, particularly in the developing world. So it is very important that the adaptation strategy is done in that way (prioritizing the implementation of the adaptation measures on the smaller farmers) because household farmers are much more vulnerable to climate change impacts and have much less power to respond to these impacts (KIMBALL, 2008).

In the present research, we were able to group together, in one single model, three important objectives (reducing water footprint, minimizing costs and seek for equity), with two of them explicitly and one implicitly included in the objective functions. This approach is of great importance, since little has been said about the joint resolution of issues adaptation and equity issues, being necessary more holistic approaches to build community resilience (MUKHEIBIR, 2010). According to Girard, Rinaudo and Pulido-Velazquez (2016), finding equitable strategies are as important as to select efficient, robust, and flexible adaptation strategies.

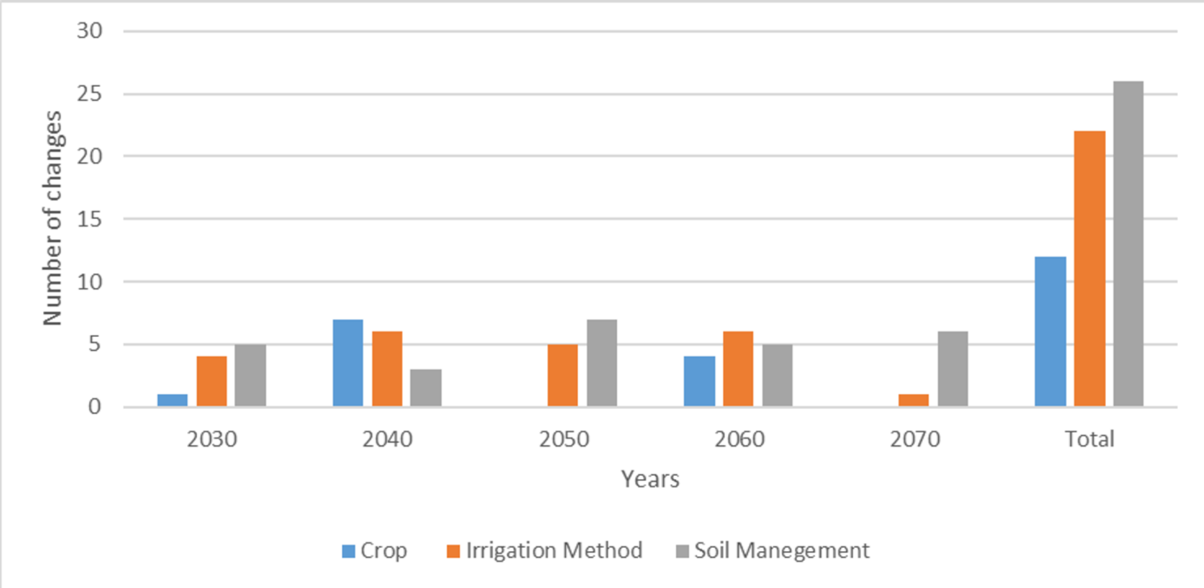
6.5 Crops x Irrigation Methods x Soil Management

Figure 34 shows the number of changes proposed by the adaptation strategy grouped into three categories: changes in crop type, changes in irrigation method, and changes in soil management methods. There is a clear preference for changes in irrigation methods and soil management methods rather than changes in crop types. These outputs could easily be transferred to the users, i.e. the farmers, in order to be replicated in the field. Practically this means that the farmers should prefer measures/changes that enhance the system's efficiency than solutions that propose the replacement of cultivations that consume more water with those that demand less water. Other works also have suggested the improvement of irrigation water use efficiency (including better irrigation techniques, mulching and cover crops) as a viable option for adaption to the impacts of climate change in agriculture (BIRD et al., 2016; KANBER et al., 2019; KAYE; QUEMADA, 2017; OGUNDEJI; JORDAAN; GROENEWALD, 2018)

This behavior can be explained by the concept of WF, which takes into consideration both water consumption and crop yield. It is possible to have a decrease in WF at the same time that is an increase in water demand. As water demand is a constraint of the algorithm, it is possible that the algorithm had given preference to changes in irrigation methods and soil management methods rather than changes in crop types to avoid increases in water demand.

This kind of pattern is useful for a series of other reasons too. For instance, changes of crop types are most difficult to be applied on the ground because of market reasons, e.g. the demand of products does not vary, certain kind of crop do not have demand on local market, and due to social/cultural reasons, e.g. farmers already have expertise on the cultivation a certain kind of crop, and they not want to change to a crop unknown to

Figure 34 – Number of changes in crop, irrigation method and soil management.



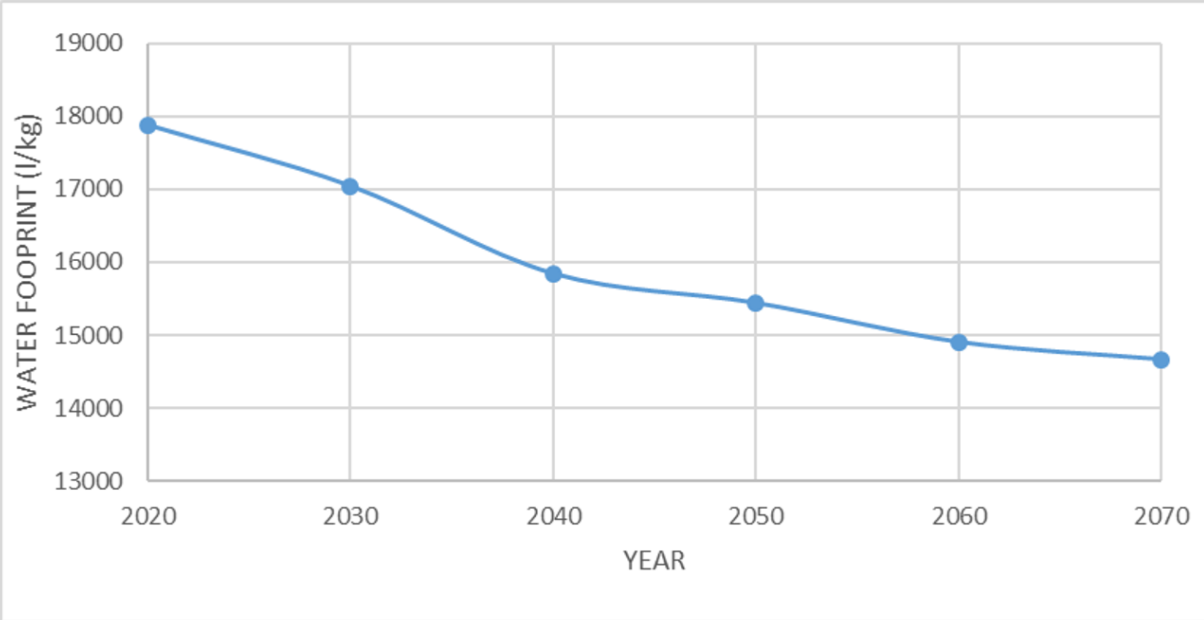
them (GREIG, 2009).

6.6 Setting Water Footprint Benchmarks

The evolution in time of the total WF of all users, as depicted in Figure 35, demonstrates a decreasing trend. In the first years, there were bigger reductions that in the last years. This is due to the fact that the more WF is reduced the more it costs to reduce it even more (the more efficient the irrigation method is, the more expensive it is). An additional argument is that in adaptation measures, there is an initial increased cost to apply the measure, with the benefits to be more obvious in the long term, i.e. after the year 2050.

The water footprint values can serve as benchmarks to monitor the adaptation strategy implementation process on the ground. According to Zhuo, Mekonnen and Hoekstra (2016b), benchmarks for the WF of crop production can serve as a reference and be helpful in setting WF reduction targets. Other authors have already set water footprint benchmarks to serve as targets in the process of reduction in water consumption (WANG et al., 2019; MEKONNEN; HOEKSTRA, 2014).

Figure 35 – Evolution of water footprint.



7 Conclusions

All the results obtained from this research take us to the following conclusions:

- The adaptation strategy should compensate not only for the reduction in availability but for the increase in water demand as well.
- Through the adaptation strategies, it was possible to identify general recommendations to be followed by the farmers, as:
  1. For the first decades, until a certain cost, the reduction in water footprint per unit of money invested is more effective than beyond that point in time. For the last decades, the best solution is probably adopting the cheaper strategy of the Pareto frontier.
  2. There is a clear recommendation for changes in irrigation and soil management methods rather than changes in crop types.
- There is an evolution in sustainability/efficiency in water use along time due to the measures taken in the first decades, showing that the process of adaptation occurs in an evolutionary way.
- The adaptation strategies have contributed positively to mitigate the power and opportunities differences that exists between householders and big farmers, as is possible to see that small farmers received more adaptations measures than large farmers.
- Based on local characteristics, we have set water footprint benchmarks to be used as sustainability goals in order to monitor and evaluate the adaptation strategy implementation process on the ground.
- We believe that the results and conclusions presented in this work will be especially important for stakeholders strategic decisions, in the form of supporting material to guide public policies and government investments.

Bibliography

ACSELRAD, H.; MELLO, C. C. A.; BEZERRA, G. d. N. O que é justiça ambiental? 2009. Cited on page 36.

ADGER, W. N.; ARNELL, N. W.; TOMPKINS, E. L. Successful adaptation to climate change across scales. *Global environmental change*, Elsevier, v. 15, n. 2, p. 77–86, 2005. Cited on page 37.

ADGER, W. N. et al. Adaptation to climate change in the developing world. *Progress in development studies*, Sage Publications Sage CA: Thousand Oaks, CA, v. 3, n. 3, p. 179–195, 2003. Cited on page 37.

ALDAYA, M. M.; HOEKSTRA, A. Y. The water needed for Italians to eat pasta and pizza. *Agricultural Systems*, 2010. ISSN 0308521X. Cited on page 41.

ALTIERI, M. A.; NICHOLLS, C. I. The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, v. 140, n. 1, p. 33–45, jan 2017. ISSN 0165-0009. Disponível em: <http://link.springer.com/10.1007/s10584-013-0909-y>. Cited on page 21.

ALTIERI, M. A. et al. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development*, v. 35, n. 3, p. 869–890, jul 2015. ISSN 1774-0746. Disponível em: <http://link.springer.com/10.1007/s13593-015-0285-2>. Cited on page 21.

ANDRADE, E. L. de. *Introdução à pesquisa operacional: métodos e modelos para a análise de decisão*. [S.l.]: Livros Técnicos e Científicos, 1998. Cited on page 42.

ARIF, C. et al. Genetic algorithms optimization for water management in irrigated paddy fields. In: IOP PUBLISHING. *IOP Conference Series: Earth and Environmental Science*. [S.l.], 2019. v. 335, n. 1, p. 012002. Cited on page 47.

ASHOFTEH, P.-S.; BOZORG-HADDAD, O.; LOÁICIGA, H. A. Development of adaptive strategies for irrigation water demand management under climate change. *Journal of Irrigation and Drainage Engineering*, American Society of Civil Engineers, v. 143, n. 2, p. 04016077, 2017. Cited on page 34.

BARÁN, B.; VILLAGRA, M. Multiobjective optimization in a quantum adiabatic computer. *Electronic Notes in Theoretical Computer Science*, Elsevier, v. 329, p. 27–38, 2016. Cited on page 47.

BARBOSA, E. M. *Introdução ao Direito Ambiental*. Campina Grande – PB: Editora da Universidade Federal de Campina Grande – EDUFCG, 2007. Cited on page 28.

BAZERMAN, M. *Processo decisório: para cursos de administração e economia*. [S.l.]: Elsevier Brasil, 2015. v. 8. Cited 2 times on pages 42 and 43.

BIRD, D. N. et al. Modelling climate change impacts on and adaptation strategies for agriculture in sardinia and tunisia using aquacrop and value-at-risk. *Science of the Total Environment*, Elsevier, v. 543, p. 1019–1027, 2016. Cited 2 times on pages 34 and 95.

BLASCO, X. et al. A new graphical visualization of n-dimensional pareto front for decision-making in multiobjective optimization. *Information Sciences*, Elsevier, v. 178, n. 20, p. 3908–3924, 2008. Cited on page 91.

BOSIRE, C. K. et al. Trends and spatial variation in water and land footprints of meat and milk production systems in Kenya. *Agriculture, Ecosystems and Environment*, 2015. ISSN 01678809. Cited on page 41.

BRAZIL, M. Terceira comunicação nacional do brasil à convenção-quadro das nações unidas sobre mudança do clima. *Setor Uso da Terra, Mudança do Uso da Terra e Florestas. MCT, Brasília, DF, Brazil*, 2015. Cited 2 times on pages 79 and 83.

BRINK, B. ten. *Contribution to Beyond GDP, Virtual Indicator Expo (The Natural Capital Index framework)*. 2010. Cited on page 38.

BROAD, K. et al. Climate, stream flow prediction and water management in northeast brazil: societal trends and forecast value. *Climatic Change*, Springer, v. 84, n. 2, p. 217–239, 2007. Cited on page 84.

BROWNLEE, J. *Clever Algorithms - Nature-Inspired Programming Recipes*. [S.l.: s.n.], 2011. ISSN 0269-2821. ISBN 9781446785065. Cited 2 times on pages 47 and 49.

BRUNDTLAND, r. Relatório brundtland “nosso futuro comum” – definição e princípios. *Proceedings of the National Academy of Sciences*, 1987. Cited on page 27.

BRÜSEKE, F. J. Parte 1: A Economia da Sustentabilidade: Princípios. O problema do desenvolvimento sustentável. In: *Desenvolvimento e natureza : estudos para uma sociedade sustentável*. [S.l.: s.n.], 1994. Cited on page 27.

CANTER, L. W. *Scientific uncertainty and water resources management*. [S.l.]: Blackwell Science Inc.: Cambridge, 1996. Cited on page 44.

CARVALHO, J. de et al. Manejo de coberturas vegetais para controle de plantas daninhas e proteção do solo na citricultura do amazonas. *Embrapa Mandioca e Fruticultura-Circular Técnica (INFOTECA-E)*, Cruz das Almas, BA: Embrapa Mandioca e Fruticultura, 2017., 2017. Cited on page 80.

CHALLINOR, A. J. et al. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change*, v. 4, n. 4, p. 287–291, apr 2014. ISSN 1758-678X. Disponível em: <http://www.nature.com/articles/nclimate2153>. Cited on page 21.

CHARCHOUSI, D.; TSOUKALA, V. K.; PAPADOPOULOU, M. P. How evapotranspiration process may affect the estimation of water footprint indicator in agriculture? *Desalination and Water Treatment*, 2015. ISSN 19443986. Cited on page 41.

CHAVES, H. M.; ALIPAZ, S. An integrated indicator based on basin hydrology, environment, life, and policy: the watershed sustainability index. *Water Resources Management*, Springer, v. 21, n. 5, p. 883–895, 2007. Cited on page 38.

CHEN, S.; CHEN, X.; XU, J. Impacts of climate change on agriculture: Evidence from China. *Journal of Environmental Economics and Management*, v. 76, p. 105–124, mar 2016. ISSN 00950696. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0095069615000066>. Cited on page 29.

CHUKALLA, A. D.; KROL, M. S.; HOEKSTRA, A. Y. Green and blue water footprint reduction in irrigated agriculture: effect of irrigation techniques, irrigation strategies and mulching. *Hydrology and Earth System Sciences*, v. 19, n. 12, p. 4877–4891, dec 2015. ISSN 1607-7938. Disponível em: <https://www.hydrol-earth-syst-sci.net/19/4877/2015/>. Cited on page 56.

CHUKALLA, A. D.; KROL, M. S.; HOEKSTRA, A. Y. Marginal cost curves for water footprint reduction in irrigated agriculture: guiding a cost-effective reduction of crop water consumption to a permit or benchmark level. *Hydrology and earth system sciences*, Copernicus GmbH, v. 21, n. 7, p. 3507–3524, 2017. Cited on page 87.

COELHO, E. F.; FILHO, M. A. C.; OLIVEIRA, S. d. Agricultura irrigada: eficiência de irrigação e de uso de água. *Bahia Agrícola*, v. 7, n. 1, p. 57–60, 2005. Cited on page 80.

COELLO, C. Evolutionary multi-objective optimization: a historical view of the field. *IEEE Computational Intelligence Magazine*, v. 1, n. 1, p. 28–36, feb 2006. ISSN 1556-603X. Disponível em: <http://ieeexplore.ieee.org/document/1597059/>. Cited on page 24.

COELLO, C.; VELDHUIZEN, D. V.; LAMONT, G. *Evolutionary Algorithms for Solving Multi-Objective Problems*. Kluwer Academic, 2002. (Genetic algorithms and evolutionary computation). ISBN 9780306467622. Disponível em: <https://books.google.com.br/books?id=sgX_Cst_yTsC>. Cited on page 24.

DAS, A.; MAZUMDER, T.; GUPTA, A. Pareto frontier analyses based decision making tool for transportation of hazardous waste. *Journal of hazardous materials*, Elsevier, v. 227, p. 341–352, 2012. Cited on page 91.

DAVIS, K. F.; GEPHART, J. A.; GUNDA, T. Sustaining food self-sufficiency of a nation: The case of Sri Lankan rice production and related water and fertilizer demands. *Ambio*, 2016. ISSN 16547209. Cited on page 41.

DEB, K. Multi-objective optimization. In: *Search methodologies*. [S.l.]: Springer, 2014. p. 403–449. Cited 4 times on pages 15, 45, 46, and 47.

DESSAI, S. et al. Do We Need Better Predictions to Adapt to a Changing Climate? *Eos, Transactions American Geophysical Union*, v. 90, n. 13, p. 111–112, mar 2009. ISSN 00963941. Disponível em: <http://doi.wiley.com/10.1029/2009EO130003>. Cited on page 21.

DOUXCHAMPS, S. et al. Linking agricultural adaptation strategies, food security and vulnerability: evidence from West Africa. *Regional Environmental Change*, v. 16, n. 5, p. 1305–1317, jun 2016. ISSN 1436-3798. Disponível em: <http://link.springer.com/10.1007/s10113-015-0838-6>. Cited 2 times on pages 21 and 22.

DUBEY, P. K.; SINGH, G. S.; ABHILASH, P. Agriculture in a changing climate. *Journal of Cleaner Production*, Elsevier, v. 113, p. 1046–1047, feb 2016. ISSN 09596526. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0959652615017333>. Cited on page 21.

EDIGER, V. Ş. et al. Fossil fuel sustainability index: An application of resource management. *Energy policy*, Elsevier, v. 35, n. 5, p. 2969–2977, 2007. Cited on page 38.

EIBEN, A. E.; SMITH, J. E. *Introduction to Evolutionary Computing*. 2. ed. New York: Springer International Publishing, 2015. 294 p. ISSN 1063-6560. ISBN 978-3-662-44873-1. Cited 2 times on pages 65 and 67.

ELLIOTT, J. et al. Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proceedings of the National Academy of Sciences*, v. 111, n. 9, p. 3239–3244, mar 2014. ISSN 0027-8424. Disponível em: <http://www.pnas.org/lookup/doi/10.1073/pnas.1222474110>. Cited on page 29.

ESTY, D. C. et al. Environmental sustainability index: Benchmarking national environmental stewardship. *New Haven: Yale Center for Environmental Law & Policy*, Yale University-Center for International Earth Science Information Network . . . , p. 47–60, 2005. Cited on page 38.

FADER, M. et al. Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrology and Earth System Sciences*, Copernicus GmbH, v. 20, n. 2, p. 953–973, 2016. Cited on page 34.

FANKHAUSER, S.; SMITH, J. B.; TOL, R. S. Weathering climate change: some simple rules to guide adaptation decisions. *Ecological Economics*, v. 30, n. 1, p. 67–78, jul 1999. ISSN 09218009. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0921800998001177>. Cited on page 32.

FILHO, F. S.; PORTO, R. Aprimoramento do processo de alocação de água de curto prazo no ceará através da utilização da informação climática. *XV Simpósio Brasileiro de Recursos Hídricos ABRH, Curitiva, Brasil*, 2003. Cited on page 45.

FISH, R. D.; IORIS, A. A. R.; WATSON, N. M. Water Governance and Agricultural Management: Collaboratively Dealing with Complex Policy Problems. In: *Agriculture, Environment and Development*. Cham: Springer International Publishing, 2016. p. 33–58. ISBN 9783319322551. Disponível em: <http://link.springer.com/10.1007/978-3-319-32255-1>. Cited on page 28.

FRANCE, P. B. et al. Understanding and Attributing Climate Change. *Change*, 2007. Cited on page 30.

FRANCKE, I. C.; CASTRO, J. F. Carbon and water footprint analysis of a soap bar produced in Brazil by Natura Cosmetics. *Water Resources and Industry*, 2013. ISSN 22123717. Cited on page 41.

FREITAS, M. A. d. S. Análise de risco e incerteza na tomada de decisão na gestão hidroambiental. *XV Simpósio Brasileiro de Recursos Hídricos*, 2003. Cited 2 times on pages 44 and 45.

FÜSSEL, H.-M. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science*, v. 2, n. 2, p. 265–275, sep 2007. ISSN 1862-4065. Disponível em: <http://link.springer.com/10.1007/s11625-007-0032-y>. Cited 2 times on pages 30 and 32.

FÜSSEL, H. M.; KLEIN, R. J. *Conceptual frameworks of adaptation to climate change and their applicability to human health*. [S.l.], 2004. Cited on page 31.

GALLOPIN, G. C. Indicators and their use: information for decision-making. *Scope-scientific committee on problems of the environment international council of scientific unions*, John Wiley & Sons, v. 58, p. 13–27, 1997. Cited on page 38.

GALVAO, C. et al. Considering Water Footprint in Reservoir Adaptation to Climate Change: an Evolutionary Approach. In: . HIC 2018. 13th International Conference on Hydroinformatics, 2018. p. 739–731. Disponível em: <https://easychair.org/publications/paper/Xc7l>. Cited on page 40.

GALVAO, C. de O. *Sistemas inteligentes: aplicações a recursos hídricos e ciências ambientais*. UFRGS: ABRH, 1999. (Colecao ABRH de Recursos Hidricos). ISBN 9788570255273. Disponível em: <https://books.google.com.br/books?id=qN7BAQAACAAJ>. Cited on page 64.

GEORGAKAKOS, A. et al. Value of adaptive water resources management in northern california under climatic variability and change: Reservoir management. *Journal of Hydrology*, Elsevier, v. 412, p. 34–46, 2012. Cited on page 91.

GIRARD, C.; RINAUDO, J.-D.; PULIDO-VELAZQUEZ, M. Sharing the cost of river basin adaptation portfolios to climate change: Insights from social justice and cooperative game theory. *Water Resources Research*, Wiley Online Library, v. 52, n. 10, p. 7945–7962, 2016. Cited on page 95.

GLEICK, P. H. Global Freshwater Resources: Soft-Path Solutions for the 21st Century. *Science*, v. 302, n. 5650, p. 1524–1528, nov 2003. ISSN 0036-8075. Disponível em: <http://www.sciencemag.org/cgi/doi/10.1126/science.1089967>. Cited on page 33.

GLEICK, P. H.; PALANIAPPAN, M. Peak water limits to freshwater withdrawal and use. *Proceedings of the National Academy of Sciences*, v. 107, n. 25, p. 11155–11162, jun 2010. ISSN 0027-8424. Disponível em: <http://www.pnas.org/cgi/doi/10.1073/pnas.1004812107>. Cited on page 33.

GOFF, M.; CROW, B. What is water equity? the unfortunate consequences of a global focus on 'drinking water'. *Water international*, Taylor & Francis, v. 39, n. 2, p. 159–171, 2014. Cited on page 36.

GOLDBERG, D. Genetic algorithms in search, optimization, and machine learning. *Choice Reviews Online*, v. 27, n. 02, p. 27–0936–27–0936, oct 1989. ISSN 0009-4978. Disponível em: <http://choicereviews.org/review/10.5860/CHOICE.27-0936>. Cited on page 49.

GOSLING, S. N.; ARNELL, N. W. A global assessment of the impact of climate change on water scarcity. *Climatic Change*, v. 134, n. 3, p. 371–385, feb 2016. ISSN 0165-0009. Disponível em: <http://link.springer.com/10.1007/s10584-013-0853-x>. Cited on page 29.

GREIG, L. An analysis of the key factors influencing farmer's choice of crop, kibamba ward, tanzania. *Journal of Agricultural Economics*, Wiley Online Library, v. 60, n. 3, p. 699–715, 2009. Cited on page 96.

GRIEGER, A. Only one earth: Stockholm and the beginning of modern environmental diplomacy. *Arcadia*, 2012. Cited on page 27.

GRIESER, J.; GOMMES, R.; BERNARDI, M. New LocClim - the Local Climate Estimator of FAO. *Geophysical Research Abstracts*, 2006. Cited 3 times on pages 15, 74, and 75.

GUEDES, A. J. L. et al. Importância e utilização do mulching em lavouras cafeeiras. *ESPAÇO ABERTO*, ., n. ., p. 1–5, 2018. Disponível em: <https://www.cafepoint.com.br/colunas/espaco-aberto/importancia-e-utilizacao-do-mulching-em-lavouras-cafeeiras-208250/>. Cited on page 80.

HENG, L. et al. Sequential multi-objective optimization of thin-walled aluminum alloy tube bending under various uncertainties. *Transactions of Nonferrous Metals Society of China*, Elsevier, v. 27, n. 3, p. 608–615, 2017. Cited on page 90.

HOEKSTRA, A. Virtual water trade. In: Proceedings of the International Expert Meeting on Virtual Water Trade. *International Expert Meeting on Virtual Water Trade*, 2003. ISSN 02731223. Cited 2 times on pages 39 and 40.

HOEKSTRA, A. et al. *The Water Footprint Assessment Manual: Setting the Global Standard*. [S.l.: s.n.], 2011. Cited 2 times on pages 40 and 41.

HOEKSTRA, A. Y. Sustainable, efficient, and equitable water use: the three pillars under wise freshwater allocation. *Wiley Interdisciplinary Reviews: Water*, v. 1, n. 1, p. 31–40, jan 2014. ISSN 20491948. Disponível em: <http://doi.wiley.com/10.1002/wat2.1000>. Cited on page 40.

HOEKSTRA, A. Y. Water Footprint Assessment: Evolvement of a New Research Field. *Water Resources Management*, 2017. ISSN 15731650. Cited on page 40.

HOLLAND, J. H. *Adaptation in natural and artificial systems : an introductory analysis with applications to biology, control, and artificial intelligence*. [S.l.: s.n.], 1975. ISBN 0472084607. Cited 2 times on pages 49 and 50.

HOWDEN, S. M. et al. Adapting agriculture to climate change. *Proceedings of the national academy of sciences*, National Acad Sciences, v. 104, n. 50, p. 19691–19696, 2007. Cited on page 33.

HURLBERT, M.; GUPTA, J. The split ladder of participation: A diagnostic, strategic, and evaluation tool to assess when participation is necessary. *Environmental Science & Policy*, v. 50, p. 100–113, jun 2015. ISSN 14629011. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S1462901115000131>. Cited on page 28.

IBGE. *Atlas do Censo Demográfico 2010*. [S.l.: s.n.], 2010. ISSN 1098-6596. ISBN 9788524042225. Cited on page 71.

IGLESIAS, A.; GARROTE, L. Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, v. 155, p. 113–124, jun 2015. ISSN 03783774. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S037837741500089X>. Cited 5 times on pages 15, 21, 33, 34, and 35.

IGLESIAS, A. et al. Re-thinking water policy priorities in the Mediterranean region in view of climate change. *Environmental Science and Policy*, 2011. ISSN 14629011. Cited on page 33.

INITIATIVE, P. R. et al. *Canadian Water Sustainability Index Retrieved 5 July 2007*. 2007. Cited on page 38.

IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: [s.n.], 2014. ISBN 9789291691432. Cited on page 21.

ITTERSUM, M. K. V. et al. Integrated assessment of agricultural systems–a component-based framework for the european union (seamless). *Agricultural systems*, Elsevier, v. 96, n. 1-3, p. 150–165, 2008. Cited on page 38.

JANSSEN, M.; VOORT, H. van der. Adaptive governance: Towards a stable, accountable and responsive government. *Government Information Quarterly*, v. 33, n. 1, p. 1–5, jan 2016. ISSN 0740624X. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0740624X16300156>. Cited on page 28.

JESINGHAUS, J. A european system of environmental pressure indices. *Environmental Pressure Indices Handbook*, v. 1, 1999. Cited on page 38.

JONES, J. et al. The DSSAT cropping system model. *European Journal of Agronomy*, v. 18, n. 3-4, p. 235–265, jan 2003. ISSN 11610301. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S1161030102001077>. Cited on page 55.

JUWANA, I.; MUTTIL, N.; PERERA, B. Indicator-based water sustainability assessment—a review. *Science of the Total Environment*, Elsevier, v. 438, p. 357–371, 2012. Cited 3 times on pages 37, 38, and 39.

JUWANA, I.; PERERA, B.; MUTTIL, N. A water sustainability index for west java–part 2: refining the conceptual framework using delphi technique. *Water Science and Technology*, IWA Publishing, v. 62, n. 7, p. 1641–1652, 2010. Cited on page 38.

KANBER, R. et al. Adaptation of contemporary irrigation systems to face the challenges of future climate changes in the mediterranean region: A case study of the lower seyhan irrigation system. In: *Climate Change Impacts on Basin Agro-ecosystems*. [S.l.]: Springer, 2019. p. 125–161. Cited 2 times on pages 34 and 95.

KATES, R. W. Cautionary tales: adaptation and the global poor. *Climatic change*, Springer, v. 45, n. 1, p. 5–17, 2000. Cited on page 37.

KAYE, J. P.; QUEMADA, M. Using cover crops to mitigate and adapt to climate change. a review. *Agronomy for sustainable development*, Springer, v. 37, n. 1, p. 4, 2017. Cited 2 times on pages 34 and 95.

KENNEDY, M. C. et al. Informed multi-objective decision-making in environmental management using pareto optimality. *Journal of Applied Ecology*, Wiley Online Library, v. 45, n. 1, p. 181–192, 2008. Cited on page 91.

KIMBALL, B. A. Climate Variability and the Global Harvest: Impacts of El Niño and Other Oscillations on Agroecosystems. *Crop Science*, v. 48, n. 5, p. 2049, 2008. ISSN 1435-0653. Disponível em: <https://www.crops.org/publications/cs/abstracts/48/5/2049>. Cited 2 times on pages 21 and 95.

KOLOKYTHA, E. Agricultural Development in Lake Koronia . The Role of the Water Footprint of Major Crops in Combating Climate Change. In: *3rd IAHR Europe Congress, Book of Proceedings*. Porto - Portugal: [s.n.], 2014. p. 237–250. ISBN 9789899647923. Cited 2 times on pages 34 and 40.

KROL, M. S.; BRONSTERT, A. Regional integrated modelling of climate change impacts on natural resources and resource usage in semi-arid northeast brazil. *Environmental Modelling & Software*, Elsevier, v. 22, n. 2, p. 259–268, 2007. Cited on page 84.

KURKA, T.; BLACKWOOD, D. Participatory selection of sustainability criteria and indicators for bioenergy developments. *Renewable and Sustainable Energy Reviews*, Elsevier, v. 24, p. 92–102, 2013. Cited on page 37.

LANNA, A. E. Análise de sistemas e engenharia de recursos hídricos. *Técnicas Quantitativas para o Gerenciamento de Recursos Hídricos*, UFRGS/ABRH Porto Alegre, p. 15–41, 1997. Cited on page 44.

LAST, J. *Public Health and Human Ecology*. Appleton & Lange, 1998. ISBN 9780838580806. Disponível em: <https://books.google.com.br/books?id=VSMUmHJX2GEC>. Cited on page 31.

LAWRENCE, P. R. et al. *The water poverty index: an international comparison*. [S.l.]: Citeseer, 2002. Cited on page 38.

LI, J. S.; CHEN, G. Q. Water footprint assessment for service sector: A case study of gaming industry in water scarce Macao. *Ecological Indicators*, 2014. ISSN 1470160X. Cited on page 41.

LI, Y. et al. Sequential multi-objective optimization method for electromagnetic inverse problems. In: IEEE. *2017 20th International Conference on Electrical Machines and Systems (ICEMS)*. [S.l.], 2017. p. 1–4. Cited on page 90.

LIVERMAN, D. M. et al. Global sustainability: toward measurement. *Environmental management*, Springer, v. 12, n. 2, p. 133–143, 1988. Cited on page 38.

LU, Y. et al. Changes in water use efficiency and water footprint in grain production over the past 35 years: a case study in the North China Plain. *Journal of Cleaner Production*, v. 116, p. 71–79, mar 2016. ISSN 09596526. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0959652616000147>. Cited on page 24.

LUCA, A. I. D. et al. Multidisciplinary and innovative methodologies for sustainable management in agricultural systems. *Environmental Engineering & Management Journal (EEMJ)*, v. 14, n. 7, 2015. Cited on page 28.

MACHADO, É. C. M. N. *Operação de redes de escoamento de petróleo utilizando algoritmo genético multi-objetivo*. 161 p. Tese (Dissertação de Mestrado) — Universidade Federal de Campina Grande, 2006. Disponível em: <http://rigeo.cprm.gov.br/xmlui/bitstream/handle/doc/280/diss{__}erica{__}machado.pdf?sequence=1{&}is>. Cited 2 times on pages 15 and 63.

MACHADO, É. C. M. N. et al. Metodologia multi-objetivo para alocação da vazão excedente em bacias hidrográficas. Universidade Federal de Campina Grande, 2011. Cited 4 times on pages 15, 53, 71, and 73.

MACHADO, M. R. O processo histórico do desmatamento do nordeste brasileiro: impactos ambientais e atividades econômicas. *Revista de Geografia (Recife)*, v. 23, n. 2, p. 123–134, 2008. Cited on page 72.

MALEK, Ž.; VERBURG, P. H. Adaptation of land management in the mediterranean under scenarios of irrigation water use and availability. *Mitigation and adaptation strategies for global change*, Springer, v. 23, n. 6, p. 821–837, 2018. Cited on page 34.

MAO-GUO, G. et al. Evolutionary multi-objective optimization algorithms. Citeseer, 2009. Cited on page 47.

MARENGO, J. A.; BERNASCONI, M. Regional differences in aridity/drought conditions over northeast brazil: present state and future projections. *Climatic Change*, Springer, v. 129, n. 1-2, p. 103–115, 2015. Cited on page 84.

MARLER, R. T.; ARORA, J. S. Survey of multi-objective optimization methods for engineering. *Structural and multidisciplinary optimization*, Springer, v. 26, n. 6, p. 369–395, 2004. Cited on page 46.

MARLER, R. T.; ARORA, J. S. The weighted sum method for multi-objective optimization: new insights. *Structural and multidisciplinary optimization*, Springer, v. 41, n. 6, p. 853–862, 2010. Cited on page 47.

MAROUELLI, W.; SILVA, W. Seleção de sistemas de irrigação para hortaliças. *Embrapa Hortaliças-Circular Técnica (INFOTECA-E)*, Brasilia: EMBRAPA-CNPH, 1998., 1998. Cited on page 80.

MCCARTHY, J. J. et al. Working Group II: Impacts, Adaptation, and Vulnerability. In: *IPCC Third Assessment Report: Climate Change 2001*. [S.l.: s.n.], 2001. Cited on page 30.

MCCOOL, S. F.; STANKEY, G. H. Indicators of sustainability: challenges and opportunities at the interface of science and policy. *Environmental management*, Springer, v. 33, n. 3, p. 294–305, 2004. Cited on page 39.

MEEHL, G. A. et al. Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [S.l.: s.n.], 2007. Cited on page 30.

MEKONNEN, M. M.; HOEKSTRA, A. Y. The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, v. 15, n. 5, p. 1577–1600, may 2011. ISSN 1607-7938. Disponível em: <https://www.hydrol-earth-syst-sci.net/15/1577/2011/>. Cited on page 41.

MEKONNEN, M. M.; HOEKSTRA, A. Y. Water footprint benchmarks for crop production: A first global assessment. *Ecological indicators*, Elsevier, v. 46, p. 214–223, 2014. Cited on page 96.

MILLY, P. C. D.; DUNNE, K. A.; VECCHIA, A. V. Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, v. 438, n. 7066, p. 347–350, nov 2005. ISSN 0028-0836. Disponível em: <http://www.nature.com/articles/nature04312>. Cited on page 29.

MIRZABAEV, A.; NKONYA, E.; BRAUN, J. von. Economics of sustainable land management. *Current Opinion in Environmental Sustainability*, v. 15, p. 9–19, aug 2015. ISSN 18773435. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S1877343515000688>. Cited on page 21.

MOLDAN, B.; JANOUŠKOVÁ, S.; HÁK, T. How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators*, Elsevier, v. 17, p. 4–13, 2012. Cited on page 38.

MOLION, L. C. B.; BERNARDO, S. d. O. Dinâmica das chuvas no nordeste brasileiro. In: *Congresso Brasileiro de Meteorologia, Anais... (CD-ROM). Rio de Janeiro*. [S.l.: s.n.], 2000. Cited on page 74.

MORTON, J. F. The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences*, v. 104, n. 50, p. 19680–19685, dec 2007. ISSN 0027-8424. Disponível em: <http://www.pnas.org/cgi/doi/10.1073/pnas.0701855104>. Cited on page 21.

MUKHEIBIR, P. Water access, water scarcity, and climate change. *Environmental management*, Springer, v. 45, n. 5, p. 1027–1039, 2010. Cited 3 times on pages 36, 37, and 95.

MUKHEIBIR, P. et al. The potential economic impact of climate change on equitable water access in small towns: a south african case study. *International journal of water*, v. 5, n. 3, p. 223, 2010. Cited on page 37.

NICHOLSON, E. et al. Making robust policy decisions using global biodiversity indicators. *PloS one*, Public Library of Science, v. 7, n. 7, p. e41128, 2012. Cited on page 38.

NICKLOW, J. et al. State of the art for genetic algorithms and beyond in water resources planning and management. *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, v. 136, n. 4, p. 412–432, 2009. Cited on page 47.

NOHARA, D.; HORI, T. Integrated reservoir operation considering real-time hydrological prediction for adaptive water resources management. In: *Sustainable Water Resources Planning and Management Under Climate Change*. [S.l.]: Springer, 2017. p. 101–132. Cited on page 91.

NOURI, H. et al. Water scarcity alleviation through water footprint reduction in agriculture: The effect of soil mulching and drip irrigation. *Science of The Total Environment*, v. 653, p. 241–252, feb 2019. ISSN 00489697. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0048969718342074>. Cited on page 56.

OGUNDEJI, A. A.; JORDAAN, H.; GROENEWALD, J. Economics of climate change adaptation: a case study of ceres–south africa. *Climate and Development*, Taylor & Francis, v. 10, n. 4, p. 377–384, 2018. Cited on page 95.

PAAVOLA, J.; ADGER, W. N. Justice and adaptation to climate change. *Tyndall Centre Working Pap*, v. 23, 2002. Cited on page 37.

PAHL-WOSTL, C. Transitions towards adaptive management of water facing climate and global change. *Water resources management*, Springer, v. 21, n. 1, p. 49–62, 2007. Cited on page 91.

PAHLOW, M.; SNOWBALL, J.; FRASER, G. Water footprint assessment to inform water management and policy making in South Africa. *Water SA*, v. 41, n. 3, p. 300, apr 2015. ISSN 0378-4738. Disponível em: <http://www.ajol.info/index.php/wsa/article/view/116148>. Cited on page 24.

PAIVA, A. E. D. B. et al. *Simulações hidrológicas na bacia do Rio Gramame como subsídio ao processo de outorga*. Tese (Doutorado), 2001. Cited on page 74.

PARETO, V. *Manuale di economia politica*. [S.l.]: Societa Editrice, 1906. v. 13. Cited on page 46.

PARKER, P. et al. Simulating regional climate-adaptive field cropping with fuzzy logic management rules and genetic advance. *The Journal of Agricultural Science*, v. 154, n. 2, p. 207–222, mar 2016. ISSN 0021-8596. Disponível em: <https://www.cambridge.org/core/product/identifier/S0021859615000490/type/journal{_}arti>. Cited on page 21.

PELLICER-MARTÍNEZ, F.; MARTÍNEZ-PAZ, J. M. The water footprint as an indicator of environmental sustainability in water use at the river basin level. *Science of the Total Environment*, Elsevier, v. 571, p. 561–574, 2016. Cited on page 39.

PERAZZOLI, M.; PINHEIRO, A.; KAUFMANN, V. Assessing the impact of climate change scenarios on water resources in southern brazil. *Hydrological Sciences Journal*, Taylor & Francis, v. 58, n. 1, p. 77–87, 2013. Cited on page 84.

PHANSALKAR, S. J. Water, equity and development. *International Journal of Rural Management*, Sage Publications India Pvt. Ltd, B-42, Panchsheel Enclave, New Delhi, v. 3, n. 1, p. 1–25, 2007. Cited on page 36.

PIRES, A. et al. Sustainability assessment of indicators for integrated water resources management. *Science of the total environment*, Elsevier, v. 578, p. 139–147, 2017. Cited 2 times on pages 38 and 39.

POLASKY, S. et al. Decision-making under great uncertainty: environmental management in an era of global change. *Trends in Ecology & Evolution*, v. 26, n. 8, p. 398–404, aug 2011. ISSN 01695347. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0169534711001157>. Cited on page 28.

PORTNEY, K. *Taking sustainability seriously*. [S.l.]: MIT Press, Cambridge, MA, 2003. Cited on page 38.

PRESCOTT-ALLEN, R. *Barometer of Sustainability: Measuring and communicating wellbeing and sustainable development*. [S.l.]: IUCN, Gland, CH, 1997. Cited on page 38.

QUEVAUVILLER, P. et al. Science-policy integration needs in support of the implementation of the EU Water Framework Directive. *Environmental Science & Policy*, v. 8, n. 3, p. 203–211, jun 2005. ISSN 14629011. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S1462901105000353>. Cited 2 times on pages 33 and 34.

RAES, D. et al. *AquaCrop (Version 6.0-6.1) - Reference Manual*. Rome, Italy: [s.n.], 2018. Cited 4 times on pages 15, 56, 58, and 80.

RAHMANI, F.; BEHZADIAN, K.; ARDESHIR, A. Rehabilitation of a water distribution system using sequential multiobjective optimization models. *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, v. 142, n. 5, p. C4015003, 2015. Cited on page 90.

REED, P. et al. Evolutionary multiobjective optimization in water resources: The past, present, and future. *Advances in Water Resources*, v. 51, p. 438 – 456, 2013. ISSN 0309-1708. 35th Year Anniversary Issue. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0309170812000073>. Cited on page 47.

REILLY, J.; SCHIMMELPFENNIG, D. Irreversibility, uncertainty, and learning: Portraits of adaptation to long-term climate change. *Climatic Change*, 2000. ISSN 01650009. Cited on page 32.

RIPPKE, U. et al. Timescales of transformational climate change adaptation in sub-Saharan African agriculture. *Nature Climate Change*, v. 6, n. 6, p. 605–609, jun 2016. ISSN 1758-678X. Disponível em: <http://www.nature.com/articles/nclimate2947>. Cited on page 22.

ROMAGUERA, M. et al. Potential of Using Remote Sensing Techniques for Global Assessment of Water Footprint of Crops. *Remote Sensing*, v. 2, n. 4, p. 1177–1196, apr 2010. ISSN 2072-4292. Disponível em: <http://www.mdpi.com/2072-4292/2/4/1177>. Cited on page 41.

ROSENZWEIG, C. et al. Water resources for agriculture in a changing climate: international case studies. *Global Environmental Change*, Elsevier, v. 14, n. 4, p. 345–360, 2004. Cited on page 84.

SEIF-ENNASR, M. et al. Climate change and adaptive water management measures in chtouka aït baha region (morocco). *Science of the Total Environment*, Elsevier, v. 573, p. 862–875, 2016. Cited on page 85.

SEMARH. *Plano diretor de recursos hídricos da Bacia do rio Gramame*. Governo do Estado da Paraíba, 2000. Cited 11 times on pages 15, 17, 71, 72, 73, 74, 75, 76, 77, 78, and 79.

SERAFINI, P. Simulated annealing for multi objective optimization problems. In: *Multiple criteria decision making*. [S.l.]: Springer, 1994. p. 283–292. Cited on page 47.

SILVA, E. M. da; AZEVEDO, J. A. de; LIMA, J. E. F. W. *Análise de Desempenho da Irrigação*. 1. ed. Planaltina - DF: Embrapa Cerrados, 2002. 84 p. ISBN 1517-5111. Disponível em: <https://ainfo.cnptia.embrapa.br/digital/bitstream/CPAC-2009/24826/1/doc{_}70.> Cited on page 80.

SILVA, V. d. P. R. da et al. Medições e modelagem da pegada hídrica da cana-de-açúcar cultivada no Estado da Paraíba. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 19, n. 6, p. 521–526, jun 2015. ISSN 1415-4366. Disponível em: <http://www.scielo.br/scielo.php?script=sci{_}arttext{&}pid=S1415-43662015000600521{&}lng=p>. Cited on page 41.

SMIT, B. et al. The science of adaptation: A framework for assessment. *Mitigation and Adaptation Strategies for Global Change*, 1999. ISSN 13812386. Cited on page 30.

SMITH, J.; LENHART, S. Climate change adaptation policy options. *Climate Research*, v. 6, p. 193–201, 1996. ISSN 0936-577X. Disponível em: <http://www.int-res.com/abstracts/cr/v06/n2/p193-201/>. Cited on page 32.

SMITH, J. B. Setting priorities for adapting to climate change. *Global Environmental Change*, v. 7, n. 3, p. 251–264, oct 1997. ISSN 09593780. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0959378097000010>. Cited on page 32.

SOUZA, F. d. A. F. *Alocação de água sazonal e anual: modelos matemáticos, experimentação comportamental e justiça alocativa. 2005. 439 f.* Tese (Doutorado) — Tese (Doutorado), Escola Politécnica da Universidade de São Paulo . . . , 2005. Cited on page 45.

SPANGENBERG, J. H. Reconciling sustainability and growth: criteria, indicators, policies. *Sustainable development*, Wiley Online Library, v. 12, n. 2, p. 74–86, 2004. Cited on page 37.

SPANGENBERG, J. H. Second order governance: learning processes to identify indicators. *Corporate Social Responsibility and Environmental Management*, Wiley Online Library, v. 15, n. 3, p. 125–139, 2008. Cited on page 39.

SPANGENBERG, J. H.; BONNIOT, O. *Sustainability indicators: a compass on the road towards sustainability.* [S.l.], 1998. Cited on page 38.

STÖCKLE, C. O.; DONATELLI, M.; NELSON, R. CropSyst, a cropping systems simulation model. *European Journal of Agronomy*, v. 18, n. 3-4, p. 289–307, jan 2003. ISSN 11610301. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S1161030102001090>. Cited on page 55.

SWART, R. et al. Agreeing to disagree: uncertainty management in assessing climate change, impacts and responses by the IPCC. *Climatic Change*, v. 92, n. 1-2, p. 1–29, jan 2009. ISSN 0165-0009. Disponível em: <http://link.springer.com/10.1007/s10584-008-9444-7>. Cited on page 21.

TANG, Y.; REED, P.; KOLLAT, J. Parallelization strategies for rapid and robust evolutionary multiobjective optimization in water resources applications. *Advances in Water Resources*, Elsevier, v. 30, n. 3, p. 335–353, 2007. Cited on page 47.

THOMAS, D. S.; TWYMAN, C. Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Global environmental change*, Elsevier, v. 15, n. 2, p. 115–124, 2005. Cited 2 times on pages 37 and 94.

TSAKMAKIS, I. D. et al. Impact of Irrigation Technologies and Strategies on Cotton Water Footprint Using AquaCrop and CROPWAT Models. *Environmental Processes*, v. 5, n. S1, p. 181–199, nov 2018. ISSN 2198-7491. Disponível em: <http://link.springer.com/10.1007/s40710-018-0289-4>. Cited 2 times on pages 34 and 56.

TYAGI, G. et al. Applications of genetic algorithm in water resources management and optimization. *Applications of Genetic Algorithm in Water Resources Management and Optimization (March 9, 2019)*, 2019. Cited on page 47.

VANUYTRECHT, E. et al. AquaCrop: FAO's crop water productivity and yield response model. *Environmental Modelling & Software*, v. 62, p. 351–360, dec 2014. ISSN 13648152. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S136481521400228X>. Cited on page 56.

VARELA-ORTEGA, C. et al. How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain. *Regional Environmental Change*, v. 16, n. 1, p. 59–70, jan 2016. ISSN 1436-3798. Disponível em: <http://link.springer.com/10.1007/s10113-014-0720-y>. Cited on page 21.

VICENS, G.; RODRIGUEZ-ITURBE, I.; SCHAAKE, J. C. A bayesian framework for the use of regional information in hydrology. *Water Resources Research*, Wiley Online Library, v. 11, n. 3, p. 405–414, 1975. Cited on page 43.

VIEIRA, V. Análise de risco. *CAMPOS, N.; STUDART, TM de C (org.). Gestão de águas: princípios e práticas. Porto Alegre: ABRH*, p. 129–138, 2001. Cited on page 44.

VOROSMARTY, C. J. Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science*, v. 289, n. 5477, p. 284–288, jul 2000. ISSN 00368075. Disponível em: <http://www.sciencemag.org/cgi/doi/10.1126/science.289.5477.284>. Cited on page 29.

WACHERNAGEL, M.; REES, W. *Our Ecological Footprint: Reducing Human Impact on the Earth*. [S.l.: s.n.], 1996. ISBN 1-55092-251-3. Cited on page 40.

WALGENBACH, W.; PARENTONI, R.; BARBOSA, F. A. R. Modos operativos de integracao disciplinar nas ciencias ambientais. *Interdisciplinaridade em Ciências Ambientais. PNUMA/ORPALC: Rede de Formação Ambiental*, v. 5, p. 211–245, 2000. Cited on page 43.

WANG, W. et al. The effect of development in water-saving irrigation techniques on spatial-temporal variations in crop water footprint and benchmarking. *Journal of Hydrology*, Elsevier, v. 577, p. 123916, 2019. Cited 2 times on pages 34 and 96.

WANG, X.-j. et al. Adaptation to climate change impacts on water demand. *Mitigation and Adaptation Strategies for Global Change*, v. 21, n. 1, p. 81–99, jan 2016. ISSN 1381-2386. Disponível em: <http://link.springer.com/10.1007/s11027-014-9571-6>. Cited on page 29.

WATKINS, K. Human development report 2006-beyond scarcity: Power, poverty and the global water crisis. *UNDP Human Development Reports (2006)*, 2006. Cited on page 36.

WHEELER, T.; BRAUN, J. von. Climate Change Impacts on Global Food Security. *Science*, v. 341, n. 6145, p. 508–513, aug 2013. ISSN 0036-8075. Disponível em: <http://www.sciencemag.org/cgi/doi/10.1126/science.1239402>. Cited on page 21.

WHITEHEAD, P. et al. A cost-effectiveness analysis of water security and water quality: impacts of climate and land-use change on the river thames system. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, The Royal Society Publishing, v. 371, n. 2002, p. 20120413, 2013. Cited on page 87.

WWAP, U. *World Water Assessment Programme: The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. [S.l.]: Paris: UNESCO, 2012. Cited on page 39.

XIE, T. et al. A sequential multi-objective robust optimization approach under interval uncertainty based on support vector machines. In: IEEE. *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*. [S.l.], 2017. p. 2088–2092. Cited on page 90.

YANG, H. et al. Hybrid-maize—a maize simulation model that combines two crop modeling approaches. *Field Crops Research*, v. 87, n. 2-3, p. 131–154, may 2004. ISSN 03784290. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0378429003002272>. Cited on page 55.

YOON, E. J. et al. Modeling spatial climate change landuse adaptation with multi-objective genetic algorithms to improve resilience for rice yield and species richness and to mitigate disaster risk. *Environmental Research Letters*, v. 14, n. 2, p. 024001, jan 2019. ISSN 1748-9326. Disponível em: <http://stacks.iop.org/1748-9326/14/i=2/a=024001?key=crossref.c35ecc95b4d9c09f1acc18573dbd3539>. Cited on page 22.

ZHANG, J. et al. Sequential multi-objective optimization for lubrication system of gasoline engines with bilevel optimization structure. *Journal of Mechanical Design*, American Society of Mechanical Engineers, v. 139, n. 2, p. 021405, 2017. Cited on page 90.

ZHUO, L.; MEKONNEN, M. M.; HOEKSTRA, A. Y. Benchmark levels for the consumptive water footprint of crop production for different environmental conditions: a case study for winter wheat in China. *Hydrology and Earth System Sciences*, v. 20, n. 11, p. 4547–4559, nov 2016. ISSN 1607-7938. Disponível em: <https://www.hydrol-earth-syst-sci.net/20/4547/2016/>. Cited on page 56.

ZHUO, L.; MEKONNEN, M. M.; HOEKSTRA, A. Y. Benchmark levels for the consumptive water footprint of crop production for different environmental conditions: a case study for winter wheat in china. *Hydrology and earth system sciences*, Copernicus GmbH, v. 20, n. 11, p. 4547–4559, 2016. Cited on page 96.

ZOU, X. et al. Cost-effectiveness analysis of water-saving irrigation technologies based on climate change response: A case study of china. *Agricultural water management*, Elsevier, v. 129, p. 9–20, 2013. Cited on page 87.

Appendix

APPENDIX A – Source Code

```
format long
%Number of generations
n_ger=10;
%number of individuals into initial population
n_popu=500;
%number of individuals into external population
n_popu_ext=200;
%probability of crossover occurring
p_cross=0.8;
%probability of mutation occurring
p_mut=0.3;
%probability of occurrence of targeted mutation
p_mut_dir=0.1;
%number of users
n_usuarios=27;
%Avaliability (l/s)
q_100=147.9;
q_100=q_100/1000; %m3/s
%Number of crops
n_crop=6;
%Number of irrigation methods
n_irrig=6;
%Number of soil management methods
n_mane=3;
%Cultivation time of each crop (days)
t_days=[90 120 364 90 90 120];
t_sec=t_days*24*60*60;
%number of objective functions
n_funcoes=2;
%budget
custo_limite=500000;

%Cost (R$/m2)
cost=[0 0 0 0 0 0
     0 0.22 0.15 0.3 0.8 0.8 %cost to change irrigation method
     0 0.05 0.1 Inf Inf Inf]; %cost to change mulching practice

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Initial Configuration

%Users configuration at the beginning of the period
IniConfig= [6 6 6 5 5 6 5 5 6 5 1 6 6 1 5 6 4 4 6 6 2 6 5 3 6 6 3
4 4 4 5 3 5 4 4 5 4 4 5 4 3 5 4 4 1 4 3 4 4 5 4 3 1 1
1 1 2 1 1 2 2 1 2 2 1 1 3 2 3 1 1 1 1 3 3 2 2 3 2 2 1];

%Maximum values that the solution can assume (used in reproduction,
    ↪ to avoid the birth of unviable children)
MaxConfig=[ 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
            6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
            3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3];

%Maximum area per user (m2)
A_max=[300000 420000 40000 14000 10000 10000 10000 10000 25000 25000 10000
    ↪ 10000 20000 10000 10000 160000 160000 6000000 150000 150000 10000 10000
    ↪ 20000 20000 100000 100000 320000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 %generating initial population
 popu_inicial=zeros(3,n_usuarios,n_popu);
for k=1:n_popu
    for j=1:n_usuarios
        for i=1:3
            if i==1
            popu_inicial(i,j,k)=IniConfig(i,j)+round((n_crop-IniConfig(i,j))*
                ↪ rand(1));
            elseif i==2
            popu_inicial(i,j,k)=IniConfig(i,j)+round((n_irrig-IniConfig(i,j))*
                ↪ rand(1));
            else
            popu_inicial(i,j,k)=IniConfig(i,j)+round((n_mane-IniConfig(i,j))*
                ↪ rand(1));
            end
        end
    end
end

for k=1:n_popu
    popu_inicial(1,:,k)=IniConfig(1,:);
```

```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Water footprint estimation

matriz_PH=zeros(n_crop,n_irrig,n_mane);
matriz_TotIrr=zeros(n_crop,n_irrig,n_mane);
for cropt=1:n_crop
for irrig=1:n_irrig
for mane=1:n_mane

if cropt==1
%Dry Bean
crop={'Maize'};
for i=1:1
fid2 = fopen('Crop.txt','wt');

fprintf(fid2,'%%%% ---------- Crop parameters for AquaCropOS ---------- %%\n');
fprintf(fid2,'%%%% Crop Type (1: Leafy vegetable, 2: Root/tuber, 3: Fruit/grain ) %%\n');
fprintf(fid2,'CropType : %f\n', 3);%
fprintf(fid2,'%%%% Calendar Type (1: Calendar days, 2: Growing degree days)\n');
fprintf(fid2,'CalendarType : %f \n', 2);%
fprintf(fid2,'%%%% Convert calendar to GDD mode if inputs are given in calendar days (0: No; 1: Yes) %%\n');
fprintf(fid2,'SwitchGDD : %f \n', 1);%
fprintf(fid2,'%%%% Planting Date (dd/mm) %%\n');
fprintf(fid2,'PlantingDate : %s \n','01/09');%
fprintf(fid2,'%%%% Latest Harvest Date (dd/mm) %%\n');
fprintf(fid2,'HarvestDate : %s \n','30/11');%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to emergenc \n');
fprintf(fid2,'Emergence : %f \n', 59);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to \n');
fprintf(fid2,'MaxRooting : %f \n', 888);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to senescence %%\n');
fprintf(fid2,'Senescence : %f \n', 903);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to maturity %% \n');
fprintf(fid2,'Maturity : %f \n', 1298);%
```

```
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to start of yield formation %% \n');
fprintf(fid2,'HIstart : %f \n', 650);%
fprintf(fid2,'%%%% Duration of flowering in growing degree/calendar days (-999 for non-fruit/grain crops) %% \n');
fprintf(fid2,'Flowering : %f \n', 233);%
fprintf(fid2,'%%%% Duration of yield formation in growing degree/calendar days %% \n');
fprintf(fid2,'YldForm : %f \n', 668);%
fprintf(fid2,'%%%% Growing degree day calculation method %% \n');
fprintf(fid2,'GDDmethod : %f \n', 2);%
fprintf(fid2,'%%%% Base temperature (degC) below which growth does not progress  %% \n');
fprintf(fid2,'Tbase : %f \n', 9);%
fprintf(fid2,'%%%% Upper temperature (degC) above which crop development no longer increases %% \n');
fprintf(fid2,'Tupp : %f \n', 30); %
fprintf(fid2,'%%%% Pollination affected by heat stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolHeatStress : %f \n', 0);%
fprintf(fid2,'%%%% Maximum air temperature (degC) above which pollination begins to fail %% \n');
fprintf(fid2,'Tmax_up : %f \n', 45);%
fprintf(fid2,'%%%% Maximum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmax_lo : %f \n', 50);%
fprintf(fid2,'%%%% Pollination affected by cold stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolColdStress : %f \n', 0);%
fprintf(fid2,'%%%% Minimum air temperature (degC) below which pollination begins to fail %% \n');
fprintf(fid2,'Tmin_up : %f \n', 5);%
fprintf(fid2,'%%%% Minimum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmin_lo : %f \n', 0);%
fprintf(fid2,'%%%% Biomass production affected by temperature stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'BioTempStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum growing degree days (degC/day) required for full biomass production %% \n');
fprintf(fid2,'GDD_up : %f \n', 14);%
fprintf(fid2,'%%%% Growing degree days (degC/day) at which no biomass production occurs %% \n');
fprintf(fid2,'GDD_lo : %f \n', 0);%
```

```matlab
fprintf(fid2,'%%%% Shape factor describing the reduction in biomass productig degree days %% \n');
fprintf(fid2,'fshape_b : %f \n', 13.8135);%
fprintf(fid2,'%%%% Initial percentage of minimum effective rooting depth %% \n');
fprintf(fid2,'PctZmin : %f \n', 70);%
fprintf(fid2,'%%%% Minimum effective rooting depth (m) %% \n');
fprintf(fid2,'Zmin : %f \n', 0.30);%
fprintf(fid2,'%%%% Maximum rooting depth (m) %% \n');
fprintf(fid2,'Zmax : %f \n', 1.70);%
fprintf(fid2,'%%%% Shape factor describing root expansion %% \n');
fprintf(fid2,'fshape_r : %f \n', 1.5);%
fprintf(fid2,'%%%% Shape factor describing the effects of water stress on root expansion %% \n');
fprintf(fid2,'fshape_ex : %f \n', -6);%
fprintf(fid2,'%%%% Maximum root water extraction at top of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxTopQ : %f \n', 0.019);%
fprintf(fid2,'%%%% Maximum root water extraction at the bottom of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxBotQ : %f \n', 0.006);%
fprintf(fid2,'%%%% Exponent parameter for adjustment of Kcx once senescence is triggered %% \n');
fprintf(fid2,'a_Tr : %f \n', 1);%
fprintf(fid2,'%%%% Soil surface area (cm2) covered by an individual seedling %% \n');
fprintf(fid2,'SeedSize : %f \n', 10); %
fprintf(fid2,'%%%% Number of plants per hectare %% \n');
fprintf(fid2,'PlantPop : %f \n', 250000);%
fprintf(fid2,'%%%% Minimum canopy size below which yield formation cannot occur %% \n');
fprintf(fid2,'CCmin : %f \n', 0.0225);%
fprintf(fid2,'%%%% Maximum canopy cover (fraction of soil cover) %% \n');
fprintf(fid2,'CCx : %f \n', 0.99);%
fprintf(fid2,'%%%% Canopy decline coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CDC : %f \n', 0.00881);%
fprintf(fid2,'%%%% Canopy growth coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CGC : %f \n', 0.118);%
fprintf(fid2,'%%%% Crop coefficient when canopy growth is complete but prior to senescence %% \n');
fprintf(fid2,'Kcb : %f \n', 1.10);%
fprintf(fid2,'%%%% Decline of crop coefficient due to ageing (day) %% \n');
```

```
fprintf(fid2,'fage : %f \n', 0.15);%
fprintf(fid2,'%%%% Water productivity normalized for ET0 and CO2 (g/m2) %% \n');
fprintf(fid2,'WP : %f \n', 15);%
fprintf(fid2,'%%%% Adjustment of water productivity in yield formation stage (of WP) %% \n');
fprintf(fid2,'WPy : %f \n', 90);%
fprintf(fid2,'%%%% Crop co2 sink strength coefficient %% \n');
fprintf(fid2,'fsink : %f \n', 0.5);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by Steduto et al. 2007 %% \n');
fprintf(fid2,'bsted : %f \n', 0.000138);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by FACE experiments %% \n');
fprintf(fid2,'bface : %f \n', 0.001165);%
fprintf(fid2,'%%%% Reference harvest index %% \n');
fprintf(fid2,'HI0 : %f \n', 0.40);%
fprintf(fid2,'%%%% Initial harvest index %% \n');
fprintf(fid2,'HIini : %f \n', 0.01);%
fprintf(fid2,'%%%% Possible increase of harvest index due to water stress before flowering %% \n');
fprintf(fid2,'dHI_pre : %f \n', 5);%
fprintf(fid2,'%%%% Coefficient describing positive ed vegetative formation %% \n');
fprintf(fid2,'a_HI : %f \n', 10);%
fprintf(fid2,'%%%% Coefficient describing negative impact on harves %% \n');
fprintf(fid2,'b_HI : %f \n', 5);%
fprintf(fid2,'%%%% Maximum allowable increase of harvest index above reference %% \n');
fprintf(fid2,'dHI0 : %f \n', 10);%
fprintf(fid2,'%%%% Crop Determinancy (0: Indeterminant, 1: Determinant) %% \n');
fprintf(fid2,'Determinant : %f \n', 1);%
fprintf(fid2,'%%%% Excess of potential fruits %% \n');
fprintf(fid2,'exc : %f \n', 100);%
fprintf(fid2,'%%%% Percentage of total flowering at which peak flowering occurs %% \n');
fprintf(fid2,'MaxFlowPct : %f \n', 33.33);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on affect canopy expansion %% \n');
fprintf(fid2,'p_up1 : %f \n', 0.15);%
```

```
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy stomatal control %% \n');
fprintf(fid2,'p_up2 : %f \n', 0.15);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy senescence %% \n');
fprintf(fid2,'p_up3 : %f \n', 0.15);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy pollination %% \n');
fprintf(fid2,'p_up4 : %f \n', 0.15);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress
    ↪ effects on canopy expansion %% \n');
fprintf(fid2,'p_lo1 : %f \n', 0.65);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress
    ↪ effects on canopy stomatal control %% \n');
fprintf(fid2,'p_lo2 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress
    ↪ effects on canopy senescence %% \n');
fprintf(fid2,'p_lo3 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress
    ↪ effects on canopy pollination %% \n');
fprintf(fid2,'p_lo4 : %f \n', 1);%
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy
    ↪ expansion %% \n');
fprintf(fid2,'fshape_w1 : %f \n', 2.5);
fprintf(fid2,'%%%% Shape factor describing water stress effects on stomatal
    ↪ control %% \n');
fprintf(fid2,'fshape_w2 : %f \n', 2.5);
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy
    ↪ senescence %% \n');
fprintf(fid2,'fshape_w3 : %f \n', 2.5);
fprintf(fid2,'%%%% Shape factor describing water stress effects on pollination
    ↪ %% \n');
fprintf(fid2,'fshape_w4 : %f \n', 1);
fprintf(fid2,'%%%% Adjustment to water stress thresholds depending on daily ET0
    ↪  (0: No, 1: Yes) %% \n');
fprintf(fid2,'ETadj : %f \n', 1);
fprintf(fid2,'%%%% Vol below saturation at which stress begins to occur due to
    ↪ deficient aeration %% \n');
fprintf(fid2,'Aer : %f \n', 5);
fprintf(fid2,'%%%% Number of days lag before aeration stress affects crop
    ↪ growth %% \n');
fprintf(fid2,'LagAer : %f \n', 3);
```

```
fprintf(fid2,'%%%% Reduction to p_lo3 when early canopy senescence is triggered
    ↪  %% \n');
fprintf(fid2,'beta : %f \n', 12);
fprintf(fid2,'%%%% Proportion of total water storage needed for crop to
    ↪ germinate %% \n');
fprintf(fid2,'GermThr : %f \n', 0.2);

fclose(fid2);
end

elseif cropt==2
%Tomato
crop={'Tomato'};
for i=1:1
fid2 = fopen('Crop.txt','wt');

fprintf(fid2,'%%%% ---------- Crop parameters for AquaCropOS ---------- %%\n');
fprintf(fid2,'%%%% Crop Type (1: Leafy vegetable, 2: Root/tuber, 3: Fruit/grain
    ↪ ) %%\n');
fprintf(fid2,'CropType : %f\n', 3);%
fprintf(fid2,'%%%% Calendar Type (1: Calendar days, 2: Growing degree days)\n')
    ↪ ;
fprintf(fid2,'CalendarType : %f \n', 2);%
fprintf(fid2,'%%%% Convert calendar to GDD mode if inputs are given in calendar
    ↪  days (0: No; 1: Yes) %%\n');
fprintf(fid2,'SwitchGDD : %f \n', 1);%
fprintf(fid2,'%%%% Planting Date (dd/mm) %%\n');
fprintf(fid2,'PlantingDate : %s \n','01/09');%
fprintf(fid2,'%%%% Latest Harvest Date (dd/mm) %%\n');
fprintf(fid2,'HarvestDate : %s \n','30/12');%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to emergenc \n');
fprintf(fid2,'Emergence : %f \n', 43);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to \n');
fprintf(fid2,'MaxRooting : %f \n', 891);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to senescence %%\n'
    ↪ );
fprintf(fid2,'Senescence : %f \n', 1533);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to maturity %% \n')
    ↪ ;
fprintf(fid2,'Maturity : %f \n', 1933);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to start of yield
    ↪ formation %% \n');
```

```
fprintf(fid2,'HIstart : %f \n', 525);%
fprintf(fid2,'%%%% Duration of flowering in growing degree/calendar days (-999 for non-fruit/grain crops) %% \n');
fprintf(fid2,'Flowering : %f \n', 750);%
fprintf(fid2,'%%%% Duration of yield formation in growing degree/calendar days %% \n');
fprintf(fid2,'YldForm : %f \n', 1050);%
fprintf(fid2,'%%%% Growing degree day calculation method %% \n');
fprintf(fid2,'GDDmethod : %f \n', 2);%
fprintf(fid2,'%%%% Base temperature (degC) below which growth does not progress  %% \n');
fprintf(fid2,'Tbase : %f \n', 7);%
fprintf(fid2,'%%%% Upper temperature (degC) above which crop development no longer increases %% \n');
fprintf(fid2,'Tupp : %f \n', 28); %
fprintf(fid2,'%%%% Pollination affected by heat stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolHeatStress : %f \n', 1);%
fprintf(fid2,'%%%% Maximum air temperature (degC) above which pollination begins to fail %% \n');
fprintf(fid2,'Tmax_up : %f \n', 40);%
fprintf(fid2,'%%%% Maximum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmax_lo : %f \n', 45);%
fprintf(fid2,'%%%% Pollination affected by cold stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolColdStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum air temperature (degC) below which pollination begins to fail %% \n');
fprintf(fid2,'Tmin_up : %f \n', 10);%
fprintf(fid2,'%%%% Minimum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmin_lo : %f \n', 5);%
fprintf(fid2,'%%%% Biomass production affected by temperature stress (0: No; 1:  Yes) %% \n');
fprintf(fid2,'BioTempStress : %f \n', 0);%
fprintf(fid2,'%%%% Minimum growing degree days (degC/day) required for full biomass production %% \n');
fprintf(fid2,'GDD_up : %f \n', -999);%
fprintf(fid2,'%%%% Growing degree days (degC/day) at which no biomass production occurs %% \n');
fprintf(fid2,'GDD_lo : %f \n', -999);%
fprintf(fid2,'%%%% Shape factor describing the reduction in biomass productig degree days %% \n');
```

```
fprintf(fid2,'fshape_b : %f \n', 13.8135);%
fprintf(fid2,'%%%% Initial percentage of minimum effective rooting depth %% \n');
fprintf(fid2,'PctZmin : %f \n', 70);%
fprintf(fid2,'%%%% Minimum effective rooting depth (m) %% \n');
fprintf(fid2,'Zmin : %f \n', 0.30);%
fprintf(fid2,'%%%% Maximum rooting depth (m) %% \n');
fprintf(fid2,'Zmax : %f \n', 1);%
fprintf(fid2,'%%%% Shape factor describing root expansion %% \n');
fprintf(fid2,'fshape_r : %f \n', 1.5);%
fprintf(fid2,'%%%% Shape factor describing the effects of water stress on root expansion %% \n');
fprintf(fid2,'fshape_ex : %f \n', -6);%
fprintf(fid2,'%%%% Maximum root water extraction at top of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxTopQ : %f \n', 0.024);%
fprintf(fid2,'%%%% Maximum root water extraction at the bottom of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxBotQ : %f \n', 0.006);%
fprintf(fid2,'%%%% Exponent parameter for adjustment of Kcx once senescence is triggered %% \n');
fprintf(fid2,'a_Tr : %f \n', 1);%
fprintf(fid2,'%%%% Soil surface area (cm2) covered by an individual seedling %% \n');
fprintf(fid2,'SeedSize : %f \n', 20); %
fprintf(fid2,'%%%% Number of plants per hectare %% \n');
fprintf(fid2,'PlantPop : %f \n', 33333);%
fprintf(fid2,'%%%% Minimum canopy size below which yield formation cannot occur %% \n');
fprintf(fid2,'CCmin : %f \n', 0.0067);%
fprintf(fid2,'%%%% Maximum canopy cover (fraction of soil cover) %% \n');
fprintf(fid2,'CCx : %f \n', 0.75);%
fprintf(fid2,'%%%% Canopy decline coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CDC : %f \n', 0.004);%
fprintf(fid2,'%%%% Canopy growth coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CGC : %f \n', 0.007504);%
fprintf(fid2,'%%%% Crop coefficient when canopy growth is complete but prior to senescence %% \n');
fprintf(fid2,'Kcb : %f \n', 1.1);%
fprintf(fid2,'%%%% Decline of crop coefficient due to ageing (day) %% \n');
fprintf(fid2,'fage : %f \n', 0.15);%
```

```
fprintf(fid2,'%%%% Water productivity normalized for ETO and CO2 (g/m2) %% \n')
    ↪ ;
fprintf(fid2,'WP : %f \n', 18);%
fprintf(fid2,'%%%% Adjustment of water productivity in yield formation stage (
    ↪ of WP) %% \n');
fprintf(fid2,'WPy : %f \n', 100);%
fprintf(fid2,'%%%% Crop co2 sink strength coefficient %% \n');
fprintf(fid2,'fsink : %f \n', 0.5);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by Steduto et al. 2007 %%
    ↪ \n');
fprintf(fid2,'bsted : %f \n', 0.000138);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by FACE experiments %% \n'
    ↪ );
fprintf(fid2,'bface : %f \n', 0.001165);%
fprintf(fid2,'%%%% Reference harvest index %% \n');
fprintf(fid2,'HI0 : %f \n', 0.63);%
fprintf(fid2,'%%%% Initial harvest index %% \n');
fprintf(fid2,'HIini : %f \n', 0.01);%
fprintf(fid2,'%%%% Possible increase of harvest index due to water stress
    ↪ before flowering %% \n');
fprintf(fid2,'dHI_pre : %f \n', 0);%
fprintf(fid2,'%%%% Coefficient describing positive ed vegetative formation %% \
    ↪ n');
fprintf(fid2,'a_HI : %f \n', -9);%
fprintf(fid2,'%%%% Coefficient describing negative impact on harves %% \n');
fprintf(fid2,'b_HI : %f \n', 3);%
fprintf(fid2,'%%%% Maximum allowable increase of harvest index above reference
    ↪ %% \n');
fprintf(fid2,'dHI0 : %f \n', 15);%
fprintf(fid2,'%%%% Crop Determinancy (0: Indeterminant, 1: Determinant) %% \n')
    ↪ ;
fprintf(fid2,'Determinant : %f \n', 1);%
fprintf(fid2,'%%%% Excess of potential fruits %% \n');
fprintf(fid2,'exc : %f \n', 100);%
fprintf(fid2,'%%%% Percentage of total flowering at which peak flowering occurs
    ↪  %% \n');
fprintf(fid2,'MaxFlowPct : %f \n', 33.33);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on affect canopy expansion %% \n');
fprintf(fid2,'p_up1 : %f \n', 0.15);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy stomatal control %% \n');
```

```
fprintf(fid2,'p_up2 : %f \n', 0.5);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_up3 : %f \n', 0.7);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_up4 : %f \n', 0.92);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy expansion %% \n');
fprintf(fid2,'p_lo1 : %f \n', 0.55);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_lo2 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_lo3 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_lo4 : %f \n', 1);%
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy expansion %% \n');
fprintf(fid2,'fshape_w1 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on stomatal control %% \n');
fprintf(fid2,'fshape_w2 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy senescence %% \n');
fprintf(fid2,'fshape_w3 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on pollination %% \n');
fprintf(fid2,'fshape_w4 : %f \n', 1);
fprintf(fid2,'%%%% Adjustment to water stress thresholds depending on daily ET0  (0: No, 1: Yes) %% \n');
fprintf(fid2,'ETadj : %f \n', 1);
fprintf(fid2,'%%%% Vol below saturation at which stress begins to occur due to deficient aeration %% \n');
fprintf(fid2,'Aer : %f \n', 5);
fprintf(fid2,'%%%% Number of days lag before aeration stress affects crop growth %% \n');
fprintf(fid2,'LagAer : %f \n', 3);
fprintf(fid2,'%%%% Reduction to p_lo3 when early canopy senescence is triggered  %% \n');
```

```
fprintf(fid2,'beta : %f \n', 12);
fprintf(fid2,'%%%% Proportion of total water storage needed for crop to germinate %% \n');
fprintf(fid2,'GermThr : %f \n', 0.2);

fclose(fid2);
end

elseif cropt==3
%Sugar Cane
crop={'Maize'};
for i=1:1
fid2 = fopen('Crop.txt','wt');

fprintf(fid2,'%%%% ---------- Crop parameters for AquaCropOS ---------- %%\n');
fprintf(fid2,'%%%% Crop Type (1: Leafy vegetable, 2: Root/tuber, 3: Fruit/grain) %%\n');
fprintf(fid2,'CropType : %f\n', 1);%
fprintf(fid2,'%%%% Calendar Type (1: Calendar days, 2: Growing degree days)\n');
fprintf(fid2,'CalendarType : %f \n', 1);%
fprintf(fid2,'%%%% Convert calendar to GDD mode if inputs are given in calendar days (0: No; 1: Yes) %%\n');
fprintf(fid2,'SwitchGDD : %f \n', 0);%
fprintf(fid2,'%%%% Planting Date (dd/mm) %%\n');
fprintf(fid2,'PlantingDate : %s \n','01/09');%
fprintf(fid2,'%%%% Latest Harvest Date (dd/mm) %%\n');
fprintf(fid2,'HarvestDate : %s \n','30/08');%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to emergenc \n');
fprintf(fid2,'Emergence : %f \n', 7);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to \n');
fprintf(fid2,'MaxRooting : %f \n', 60);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to senescence %%\n');
fprintf(fid2,'Senescence : %f \n', 330);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to maturity %% \n');
fprintf(fid2,'Maturity : %f \n', 365);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to start of yield formation %% \n');
fprintf(fid2,'HIstart : %f \n', 0);%
```

```
fprintf(fid2,'%%%% Duration of flowering in growing degree/calendar days (-999 for non-fruit/grain crops) %% \n');
fprintf(fid2,'Flowering : %f \n', -999);%
fprintf(fid2,'%%%% Duration of yield formation in growing degree/calendar days %% \n');
fprintf(fid2,'YldForm : %f \n', 73);%
fprintf(fid2,'%%%% Growing degree day calculation method %% \n');
fprintf(fid2,'GDDmethod : %f \n', 2);%
fprintf(fid2,'%%%% Base temperature (degC) below which growth does not progress  %% \n');
fprintf(fid2,'Tbase : %f \n', 9);%
fprintf(fid2,'%%%% Upper temperature (degC) above which crop development no longer increases %% \n');
fprintf(fid2,'Tupp : %f \n', 40); %
fprintf(fid2,'%%%% Pollination affected by heat stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolHeatStress : %f \n', 0);%
fprintf(fid2,'%%%% Maximum air temperature (degC) above which pollination begins to fail %% \n');
fprintf(fid2,'Tmax_up : %f \n', -999);%
fprintf(fid2,'%%%% Maximum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmax_lo : %f \n', -999);%
fprintf(fid2,'%%%% Pollination affected by cold stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolColdStress : %f \n', 0);%
fprintf(fid2,'%%%% Minimum air temperature (degC) below which pollination begins to fail %% \n');
fprintf(fid2,'Tmin_up : %f \n', -999);%
fprintf(fid2,'%%%% Minimum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmin_lo : %f \n', -999);%
fprintf(fid2,'%%%% Biomass production affected by temperature stress (0: No; 1:  Yes) %% \n');
fprintf(fid2,'BioTempStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum growing degree days (degC/day) required for full biomass production %% \n');
fprintf(fid2,'GDD_up : %f \n', 12);%
fprintf(fid2,'%%%% Growing degree days (degC/day) at which no biomass production occurs %% \n');
fprintf(fid2,'GDD_lo : %f \n', 0);%
fprintf(fid2,'%%%% Shape factor describing the reduction in biomass productig degree days %% \n');
fprintf(fid2,'fshape_b : %f \n', 13.8135);%
```

```
fprintf(fid2,'%%%% Initial percentage of minimum effective rooting depth %% \n');
fprintf(fid2,'PctZmin : %f \n', 70);%
fprintf(fid2,'%%%% Minimum effective rooting depth (m) %% \n');
fprintf(fid2,'Zmin : %f \n', 0.30);%
fprintf(fid2,'%%%% Maximum rooting depth (m) %% \n');
fprintf(fid2,'Zmax : %f \n', 1.80);%
fprintf(fid2,'%%%% Shape factor describing root expansion %% \n');
fprintf(fid2,'fshape_r : %f \n', 1.3);%
fprintf(fid2,'%%%% Shape factor describing the effects of water stress on root expansion %% \n');
fprintf(fid2,'fshape_ex : %f \n', -6);%
fprintf(fid2,'%%%% Maximum root water extraction at top of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxTopQ : %f \n', 0.013);%
fprintf(fid2,'%%%% Maximum root water extraction at the bottom of the root zone  (m3/m3/day) %% \n');
fprintf(fid2,'SxBotQ : %f \n', 0.003);%
fprintf(fid2,'%%%% Exponent parameter for adjustment of Kcx once senescence is triggered %% \n');
fprintf(fid2,'a_Tr : %f \n', 1);%
fprintf(fid2,'%%%% Soil surface area (cm2) covered by an individual seedling %%  \n');
fprintf(fid2,'SeedSize : %f \n', 6.5); %
fprintf(fid2,'%%%% Number of plants per hectare %% \n');
fprintf(fid2,'PlantPop : %f \n', 140000);%
fprintf(fid2,'%%%% Minimum canopy size below which yield formation cannot occur  %% \n');
fprintf(fid2,'CCmin : %f \n', 0.0091);%
fprintf(fid2,'%%%% Maximum canopy cover (fraction of soil cover) %% \n');
fprintf(fid2,'CCx : %f \n', 0.95);%
fprintf(fid2,'%%%% Canopy decline coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CDC : %f \n', 0.076);%
fprintf(fid2,'%%%% Canopy growth coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CGC : %f \n', 0.125);%
fprintf(fid2,'%%%% Crop coefficient when canopy growth is complete but prior to  senescence %% \n');
fprintf(fid2,'Kcb : %f \n', 1.10);%
fprintf(fid2,'%%%% Decline of crop coefficient due to ageing (day) %% \n');
fprintf(fid2,'fage : %f \n', 0.15);%
fprintf(fid2,'%%%% Water productivity normalized for ET0 and C02 (g/m2) %% \n');
```

```
fprintf(fid2,'WP : %f \n', 30);%
fprintf(fid2,'%%%% Adjustment of water productivity in yield formation stage (
    ↪ of WP) %% \n');
fprintf(fid2,'WPy : %f \n', 100);%
fprintf(fid2,'%%%% Crop co2 sink strength coefficient %% \n');
fprintf(fid2,'fsink : %f \n', 0.5);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by Steduto et al. 2007 %%
    ↪ \n');
fprintf(fid2,'bsted : %f \n', 0.000138);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by FACE experiments %% \n'
    ↪ );
fprintf(fid2,'bface : %f \n', 0.001165);%
fprintf(fid2,'%%%% Reference harvest index %% \n');
fprintf(fid2,'HI0 : %f \n', 0.35);%
fprintf(fid2,'%%%% Initial harvest index %% \n');
fprintf(fid2,'HIini : %f \n', 0.01);%
fprintf(fid2,'%%%% Possible increase of harvest index due to water stress
    ↪ before flowering %% \n');
fprintf(fid2,'dHI_pre : %f \n', 0);%
fprintf(fid2,'%%%% Coefficient describing positive ed vegetative formation %% \
    ↪ n');
fprintf(fid2,'a_HI : %f \n', -999);%
fprintf(fid2,'%%%% Coefficient describing negative impact on harves %% \n');
fprintf(fid2,'b_HI : %f \n', -999);%
fprintf(fid2,'%%%% Maximum allowable increase of harvest index above reference
    ↪ %% \n');
fprintf(fid2,'dHI0 : %f \n', -999);%
fprintf(fid2,'%%%% Crop Determinancy (0: Indeterminant, 1: Determinant) %% \n')
    ↪ ;
fprintf(fid2,'Determinant : %f \n', 0);%
fprintf(fid2,'%%%% Excess of potential fruits %% \n');
fprintf(fid2,'exc : %f \n', 0);%
fprintf(fid2,'%%%% Percentage of total flowering at which peak flowering occurs
    ↪  %% \n');
fprintf(fid2,'MaxFlowPct : %f \n', 33.33);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on affect canopy expansion %% \n');
fprintf(fid2,'p_up1 : %f \n', 0.25);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy stomatal control %% \n');
fprintf(fid2,'p_up2 : %f \n', 0.5);%
```

```
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_up3 : %f \n', 0.6);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_up4 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy expansion %% \n');
fprintf(fid2,'p_lo1 : %f \n', 0.55);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_lo2 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_lo3 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_lo4 : %f \n', 1);%
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy expansion %% \n');
fprintf(fid2,'fshape_w1 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on stomatal control %% \n');
fprintf(fid2,'fshape_w2 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy senescence %% \n');
fprintf(fid2,'fshape_w3 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on pollination %% \n');
fprintf(fid2,'fshape_w4 : %f \n', 1);
fprintf(fid2,'%%%% Adjustment to water stress thresholds depending on daily ET0 (0: No, 1: Yes) %% \n');
fprintf(fid2,'ETadj : %f \n', 1);
fprintf(fid2,'%%%% Vol below saturation at which stress begins to occur due to deficient aeration %% \n');
fprintf(fid2,'Aer : %f \n', 5);
fprintf(fid2,'%%%% Number of days lag before aeration stress affects crop growth %% \n');
fprintf(fid2,'LagAer : %f \n', 3);
fprintf(fid2,'%%%% Reduction to p_lo3 when early canopy senescence is triggered %% \n');
fprintf(fid2,'beta : %f \n', 12);
```

```
fprintf(fid2,'%%%% Proportion of total water storage needed for crop to germinate %% \n');
fprintf(fid2,'GermThr : %f \n', 0.2);

fclose(fid2);
end

elseif cropt==4
%Potato
crop={'Potato'};
for i=1:1
fid2 = fopen('Crop.txt','wt');

fprintf(fid2,'%%%% ---------- Crop parameters for AquaCropOS ---------- %%\n');
fprintf(fid2,'%%%% Crop Type (1: Leafy vegetable, 2: Root/tuber, 3: Fruit/grain ) %%\n');
fprintf(fid2,'CropType : %f\n', 2);%
fprintf(fid2,'%%%% Calendar Type (1: Calendar days, 2: Growing degree days)\n');
fprintf(fid2,'CalendarType : %f \n', 2);%
fprintf(fid2,'%%%% Convert calendar to GDD mode if inputs are given in calendar days (0: No; 1: Yes) %%\n');
fprintf(fid2,'SwitchGDD : %f \n', 1);%
fprintf(fid2,'%%%% Planting Date (dd/mm) %%\n');
fprintf(fid2,'PlantingDate : %s \n','01/09');%
fprintf(fid2,'%%%% Latest Harvest Date (dd/mm) %%\n');
fprintf(fid2,'HarvestDate : %s \n','30/11');%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to emergenc \n');
fprintf(fid2,'Emergence : %f \n', 200);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to \n');
fprintf(fid2,'MaxRooting : %f \n', 1079);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to senescence %%\n');
fprintf(fid2,'Senescence : %f \n', 984);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to maturity %% \n');
fprintf(fid2,'Maturity : %f \n', 1276);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to start of yield formation %% \n');
fprintf(fid2,'HIstart : %f \n', 550);%
fprintf(fid2,'%%%% Duration of flowering in growing degree/calendar days (-999 for non-fruit/grain crops) %% \n');
```

```
fprintf(fid2,'Flowering : %f \n', 0);%
fprintf(fid2,'%%%% Duration of yield formation in growing degree/calendar days %% \n');
fprintf(fid2,'YldForm : %f \n', 700);%
fprintf(fid2,'%%%% Growing degree day calculation method %% \n');
fprintf(fid2,'GDDmethod : %f \n', 2);%
fprintf(fid2,'%%%% Base temperature (degC) below which growth does not progress  %% \n');
fprintf(fid2,'Tbase : %f \n', 2);%
fprintf(fid2,'%%%% Upper temperature (degC) above which crop development no longer increases %% \n');
fprintf(fid2,'Tupp : %f \n', 40); %
fprintf(fid2,'%%%% Pollination affected by heat stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolHeatStress : %f \n', 0);%
fprintf(fid2,'%%%% Maximum air temperature (degC) above which pollination begins to fail %% \n');
fprintf(fid2,'Tmax_up : %f \n', -999);%
fprintf(fid2,'%%%% Maximum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmax_lo : %f \n', -999);%
fprintf(fid2,'%%%% Pollination affected by cold stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolColdStress : %f \n', 0);%
fprintf(fid2,'%%%% Minimum air temperature (degC) below which pollination begins to fail %% \n');
fprintf(fid2,'Tmin_up : %f \n', -999);%
fprintf(fid2,'%%%% Minimum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmin_lo : %f \n', -999);%
fprintf(fid2,'%%%% Biomass production affected by temperature stress (0: No; 1:  Yes) %% \n');
fprintf(fid2,'BioTempStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum growing degree days (degC/day) required for full biomass production %% \n');
fprintf(fid2,'GDD_up : %f \n', 7);%
fprintf(fid2,'%%%% Growing degree days (degC/day) at which no biomass production occurs %% \n');
fprintf(fid2,'GDD_lo : %f \n', 0);%
fprintf(fid2,'%%%% Shape factor describing the reduction in biomass productig degree days %% \n');
fprintf(fid2,'fshape_b : %f \n', 13.8135);%
fprintf(fid2,'%%%% Initial percentage of minimum effective rooting depth %% \n');
```

```
fprintf(fid2,'PctZmin : %f \n', 70);%
fprintf(fid2,'%%%% Minimum effective rooting depth (m) %% \n');
fprintf(fid2,'Zmin : %f \n', 0.30);%
fprintf(fid2,'%%%% Maximum rooting depth (m) %% \n');
fprintf(fid2,'Zmax : %f \n', 1.5);%
fprintf(fid2,'%%%% Shape factor describing root expansion %% \n');
fprintf(fid2,'fshape_r : %f \n', 1.5);%
fprintf(fid2,'%%%% Shape factor describing the effects of water stress on root expansion %% \n');
fprintf(fid2,'fshape_ex : %f \n', -6);%
fprintf(fid2,'%%%% Maximum root water extraction at top of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxTopQ : %f \n', 0.016);%
fprintf(fid2,'%%%% Maximum root water extraction at the bottom of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxBotQ : %f \n', 0.004);%
fprintf(fid2,'%%%% Exponent parameter for adjustment of Kcx once senescence is triggered %% \n');
fprintf(fid2,'a_Tr : %f \n', 1);%
fprintf(fid2,'%%%% Soil surface area (cm2) covered by an individual seedling %% \n');
fprintf(fid2,'SeedSize : %f \n', 15); %
fprintf(fid2,'%%%% Number of plants per hectare %% \n');
fprintf(fid2,'PlantPop : %f \n', 40000);%
fprintf(fid2,'%%%% Minimum canopy size below which yield formation cannot occur %% \n');
fprintf(fid2,'CCmin : %f \n', 0.006);%
fprintf(fid2,'%%%% Maximum canopy cover (fraction of soil cover) %% \n');
fprintf(fid2,'CCx : %f \n', 0.92);%
fprintf(fid2,'%%%% Canopy decline coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CDC : %f \n', 0.002);%
fprintf(fid2,'%%%% Canopy growth coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CGC : %f \n', 0.01615);%
fprintf(fid2,'%%%% Crop coefficient when canopy growth is complete but prior to senescence %% \n');
fprintf(fid2,'Kcb : %f \n', 1.1);%
fprintf(fid2,'%%%% Decline of crop coefficient due to ageing (day) %% \n');
fprintf(fid2,'fage : %f \n', 0.15);%
fprintf(fid2,'%%%% Water productivity normalized for ET0 and C02 (g/m2) %% \n');
fprintf(fid2,'WP : %f \n', 18);%
```

```
fprintf(fid2,'%%%% Adjustment of water productivity in yield formation stage (of WP) %% \n');
fprintf(fid2,'WPy : %f \n', 100);%
fprintf(fid2,'%%%% Crop co2 sink strength coefficient %% \n');
fprintf(fid2,'fsink : %f \n', 0.5);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by Steduto et al. 2007 %% \n');
fprintf(fid2,'bsted : %f \n', 0.000138);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by FACE experiments %% \n');
fprintf(fid2,'bface : %f \n', 0.001165);%
fprintf(fid2,'%%%% Reference harvest index %% \n');
fprintf(fid2,'HI0 : %f \n', 0.75);%
fprintf(fid2,'%%%% Initial harvest index %% \n');
fprintf(fid2,'HIini : %f \n', 0.01);%
fprintf(fid2,'%%%% Possible increase of harvest index due to water stress before flowering %% \n');
fprintf(fid2,'dHI_pre : %f \n', 2);%
fprintf(fid2,'%%%% Coefficient describing positive ed vegetative formation %% \n');
fprintf(fid2,'a_HI : %f \n', -999);%
fprintf(fid2,'%%%% Coefficient describing negative impact on harves %% \n');
fprintf(fid2,'b_HI : %f \n', 10);%
fprintf(fid2,'%%%% Maximum allowable increase of harvest index above reference %% \n');
fprintf(fid2,'dHI0 : %f \n', 5);%
fprintf(fid2,'%%%% Crop Determinancy (0: Indeterminant, 1: Determinant) %% \n');
fprintf(fid2,'Determinant : %f \n', 0);%
fprintf(fid2,'%%%% Excess of potential fruits %% \n');
fprintf(fid2,'exc : %f \n', -999);%
fprintf(fid2,'%%%% Percentage of total flowering at which peak flowering occurs  %% \n');
fprintf(fid2,'MaxFlowPct : %f \n', 33.33);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on affect canopy expansion %% \n');
fprintf(fid2,'p_up1 : %f \n', 0.2);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_up2 : %f \n', 0.55);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy senescence %% \n');
```

```
fprintf(fid2,'p_up3 : %f \n', 0.7);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_up4 : %f \n', -999);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy expansion %% \n');
fprintf(fid2,'p_lo1 : %f \n', 0.7);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_lo2 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_lo3 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_lo4 : %f \n', -999);%
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy expansion %% \n');
fprintf(fid2,'fshape_w1 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on stomatal control %% \n');
fprintf(fid2,'fshape_w2 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy senescence %% \n');
fprintf(fid2,'fshape_w3 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on pollination %% \n');
fprintf(fid2,'fshape_w4 : %f \n', -999);
fprintf(fid2,'%%%% Adjustment to water stress thresholds depending on daily ET0 (0: No, 1: Yes) %% \n');
fprintf(fid2,'ETadj : %f \n', 1);
fprintf(fid2,'%%%% Vol below saturation at which stress begins to occur due to deficient aeration %% \n');
fprintf(fid2,'Aer : %f \n', 5);
fprintf(fid2,'%%%% Number of days lag before aeration stress affects crop growth %% \n');
fprintf(fid2,'LagAer : %f \n', 3);
fprintf(fid2,'%%%% Reduction to p_lo3 when early canopy senescence is triggered %% \n');
fprintf(fid2,'beta : %f \n', 12);
fprintf(fid2,'%%%% Proportion of total water storage needed for crop to germinate %% \n');
```

```
fprintf(fid2,'GermThr : %f \n', 0.2);

fclose(fid2);
end

elseif cropt==5
%Sorghum
crop={'Sorghum'};
for i=1:1
fid2 = fopen('Crop.txt','wt');

fprintf(fid2,'%%%% ---------- Crop parameters for AquaCropOS ---------- %%\n');
fprintf(fid2,'%%%% Crop Type (1: Leafy vegetable, 2: Root/tuber, 3: Fruit/grain ) %%\n');
fprintf(fid2,'CropType : %f\n', 3);%
fprintf(fid2,'%%%% Calendar Type (1: Calendar days, 2: Growing degree days)\n');
fprintf(fid2,'CalendarType : %f \n', 2);%
fprintf(fid2,'%%%% Convert calendar to GDD mode if inputs are given in calendar  days (0: No; 1: Yes) %%\n');
fprintf(fid2,'SwitchGDD : %f \n', 1);%
fprintf(fid2,'%%%% Planting Date (dd/mm) %%\n');
fprintf(fid2,'PlantingDate : %s \n','01/09');%
fprintf(fid2,'%%%% Latest Harvest Date (dd/mm) %%\n');
fprintf(fid2,'HarvestDate : %s \n','30/12');%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to emergenc \n');
fprintf(fid2,'Emergence : %f \n', 136);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to \n');
fprintf(fid2,'MaxRooting : %f \n', 1583);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to senescence %%\n');
fprintf(fid2,'Senescence : %f \n', 1579);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to maturity %% \n');
fprintf(fid2,'Maturity : %f \n', 1760);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to start of yield formation %% \n');
fprintf(fid2,'HIstart : %f \n', 1041);%
fprintf(fid2,'%%%% Duration of flowering in growing degree/calendar days (-999 for non-fruit/grain crops) %% \n');
fprintf(fid2,'Flowering : %f \n', 306);%
```

```
fprintf(fid2,'%%%% Duration of yield formation in growing degree/calendar days %% \n');
fprintf(fid2,'YldForm : %f \n', 719);%
fprintf(fid2,'%%%% Growing degree day calculation method %% \n');
fprintf(fid2,'GDDmethod : %f \n', 2);%
fprintf(fid2,'%%%% Base temperature (degC) below which growth does not progress  %% \n');
fprintf(fid2,'Tbase : %f \n', 8);%
fprintf(fid2,'%%%% Upper temperature (degC) above which crop development no longer increases %% \n');
fprintf(fid2,'Tupp : %f \n', 30); %
fprintf(fid2,'%%%% Pollination affected by heat stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolHeatStress : %f \n', 1);%
fprintf(fid2,'%%%% Maximum air temperature (degC) above which pollination begins to fail %% \n');
fprintf(fid2,'Tmax_up : %f \n', 40);%
fprintf(fid2,'%%%% Maximum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmax_lo : %f \n', 45);%
fprintf(fid2,'%%%% Pollination affected by cold stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolColdStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum air temperature (degC) below which pollination begins to fail %% \n');
fprintf(fid2,'Tmin_up : %f \n', 10);%
fprintf(fid2,'%%%% Minimum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmin_lo : %f \n', 5);%
fprintf(fid2,'%%%% Biomass production affected by temperature stress (0: No; 1:  Yes) %% \n');
fprintf(fid2,'BioTempStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum growing degree days (degC/day) required for full biomass production %% \n');
fprintf(fid2,'GDD_up : %f \n', 12);%
fprintf(fid2,'%%%% Growing degree days (degC/day) at which no biomass production occurs %% \n');
fprintf(fid2,'GDD_lo : %f \n', 0);%
fprintf(fid2,'%%%% Shape factor describing the reduction in biomass productig degree days %% \n');
fprintf(fid2,'fshape_b : %f \n', 13.8135);%
fprintf(fid2,'%%%% Initial percentage of minimum effective rooting depth %% \n');
fprintf(fid2,'PctZmin : %f \n', 70);%
```

```
fprintf(fid2,'%%%% Minimum effective rooting depth (m) %% \n');
fprintf(fid2,'Zmin : %f \n', 0.30);%
fprintf(fid2,'%%%% Maximum rooting depth (m) %% \n');
fprintf(fid2,'Zmax : %f \n', 1.8);%
fprintf(fid2,'%%%% Shape factor describing root expansion %% \n');
fprintf(fid2,'fshape_r : %f \n', 1.3);%
fprintf(fid2,'%%%% Shape factor describing the effects of water stress on root expansion %% \n');
fprintf(fid2,'fshape_ex : %f \n', -6);%
fprintf(fid2,'%%%% Maximum root water extraction at top of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxTopQ : %f \n', 0.016);%
fprintf(fid2,'%%%% Maximum root water extraction at the bottom of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxBotQ : %f \n', 0.004);%
fprintf(fid2,'%%%% Exponent parameter for adjustment of Kcx once senescence is triggered %% \n');
fprintf(fid2,'a_Tr : %f \n', 1);%
fprintf(fid2,'%%%% Soil surface area (cm2) covered by an individual seedling %% \n');
fprintf(fid2,'SeedSize : %f \n', 3); %
fprintf(fid2,'%%%% Number of plants per hectare %% \n');
fprintf(fid2,'PlantPop : %f \n', 200000);%
fprintf(fid2,'%%%% Minimum canopy size below which yield formation cannot occur %% \n');
fprintf(fid2,'CCmin : %f \n', 0.006);%
fprintf(fid2,'%%%% Maximum canopy cover (fraction of soil cover) %% \n');
fprintf(fid2,'CCx : %f \n', 0.9);%
fprintf(fid2,'%%%% Canopy decline coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CDC : %f \n', 0.009862);%
fprintf(fid2,'%%%% Canopy growth coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CGC : %f \n', 0.012);%
fprintf(fid2,'%%%% Crop coefficient when canopy growth is complete but prior to senescence %% \n');
fprintf(fid2,'Kcb : %f \n', 1.07);%
fprintf(fid2,'%%%% Decline of crop coefficient due to ageing (day) %% \n');
fprintf(fid2,'fage : %f \n', 0.3);%
fprintf(fid2,'%%%% Water productivity normalized for ET0 and C02 (g/m2) %% \n');
fprintf(fid2,'WP : %f \n', 33.7);%
fprintf(fid2,'%%%% Adjustment of water productivity in yield formation stage ( of WP) %% \n');
```

```
fprintf(fid2,'WPy : %f \n', 100);%
fprintf(fid2,'%%%% Crop co2 sink strength coefficient %% \n');
fprintf(fid2,'fsink : %f \n', 0.5);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by Steduto et al. 2007 %%
    ↪ \n');
fprintf(fid2,'bsted : %f \n', 0.000138);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by FACE experiments %% \n'
    ↪ );
fprintf(fid2,'bface : %f \n', 0.001165);%
fprintf(fid2,'%%%% Reference harvest index %% \n');
fprintf(fid2,'HI0 : %f \n', 0.45);%
fprintf(fid2,'%%%% Initial harvest index %% \n');
fprintf(fid2,'HIini : %f \n', 0.01);%
fprintf(fid2,'%%%% Possible increase of harvest index due to water stress
    ↪ before flowering %% \n');
fprintf(fid2,'dHI_pre : %f \n', 4);%
fprintf(fid2,'%%%% Coefficient describing positive ed vegetative formation %% \
    ↪ n');
fprintf(fid2,'a_HI : %f \n', 1);%
fprintf(fid2,'%%%% Coefficient describing negative impact on harves %% \n');
fprintf(fid2,'b_HI : %f \n', 3);%
fprintf(fid2,'%%%% Maximum allowable increase of harvest index above reference
    ↪ %% \n');
fprintf(fid2,'dHI0 : %f \n', 25);%
fprintf(fid2,'%%%% Crop Determinancy (0: Indeterminant, 1: Determinant) %% \n')
    ↪ ;
fprintf(fid2,'Determinant : %f \n', 1);%
fprintf(fid2,'%%%% Excess of potential fruits %% \n');
fprintf(fid2,'exc : %f \n', 100);%
fprintf(fid2,'%%%% Percentage of total flowering at which peak flowering occurs
    ↪  %% \n');
fprintf(fid2,'MaxFlowPct : %f \n', 33.33);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on affect canopy expansion %% \n');
fprintf(fid2,'p_up1 : %f \n', 0.15);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy stomatal control %% \n');
fprintf(fid2,'p_up2 : %f \n', 0.7);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress
    ↪ effects on canopy senescence %% \n');
fprintf(fid2,'p_up3 : %f \n', 0.7);%
```

```
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_up4 : %f \n', 0.8);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy expansion %% \n');
fprintf(fid2,'p_lo1 : %f \n', 0.7);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_lo2 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_lo3 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_lo4 : %f \n', 1);%
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy expansion %% \n');
fprintf(fid2,'fshape_w1 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on stomatal control %% \n');
fprintf(fid2,'fshape_w2 : %f \n', 6);
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy senescence %% \n');
fprintf(fid2,'fshape_w3 : %f \n', 3);
fprintf(fid2,'%%%% Shape factor describing water stress effects on pollination %% \n');
fprintf(fid2,'fshape_w4 : %f \n', 1);
fprintf(fid2,'%%%% Adjustment to water stress thresholds depending on daily ET0 (0: No, 1: Yes) %% \n');
fprintf(fid2,'ETadj : %f \n', 1);
fprintf(fid2,'%%%% Vol below saturation at which stress begins to occur due to deficient aeration %% \n');
fprintf(fid2,'Aer : %f \n', 5);
fprintf(fid2,'%%%% Number of days lag before aeration stress affects crop growth %% \n');
fprintf(fid2,'LagAer : %f \n', 3);
fprintf(fid2,'%%%% Reduction to p_lo3 when early canopy senescence is triggered %% \n');
fprintf(fid2,'beta : %f \n', 12);
fprintf(fid2,'%%%% Proportion of total water storage needed for crop to germinate %% \n');
fprintf(fid2,'GermThr : %f \n', 0.2);
```

```
fclose(fid2);
end

else
%Maize
crop={'Maize'};
for i=1:1
fid2 = fopen('Crop.txt','wt');

fprintf(fid2,'%%%% ---------- Crop parameters for AquaCropOS ---------- %%\n');
fprintf(fid2,'%%%% Crop Type (1: Leafy vegetable, 2: Root/tuber, 3: Fruit/grain ) %%\n');
fprintf(fid2,'CropType : %f\n', 3);%
fprintf(fid2,'%%%% Calendar Type (1: Calendar days, 2: Growing degree days)\n');
fprintf(fid2,'CalendarType : %f \n', 2);%
fprintf(fid2,'%%%% Convert calendar to GDD mode if inputs are given in calendar days (0: No; 1: Yes) %%\n');
fprintf(fid2,'SwitchGDD : %f \n', 1);%
fprintf(fid2,'%%%% Planting Date (dd/mm) %%\n');
fprintf(fid2,'PlantingDate : %s \n','01/09');%
fprintf(fid2,'%%%% Latest Harvest Date (dd/mm) %%\n');
fprintf(fid2,'HarvestDate : %s \n','30/12');%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to emergenc \n');
fprintf(fid2,'Emergence : %f \n', 80);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to \n');
fprintf(fid2,'MaxRooting : %f \n', 1400);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to senescence %%\n');
fprintf(fid2,'Senescence : %f \n', 1400);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to maturity %% \n');
fprintf(fid2,'Maturity : %f \n', 1700);%
fprintf(fid2,'%%%% Growing degree/Calendar days from sowing to start of yield formation %% \n');
fprintf(fid2,'HIstart : %f \n', 880);%
fprintf(fid2,'%%%% Duration of flowering in growing degree/calendar days (-999 for non-fruit/grain crops) %% \n');
fprintf(fid2,'Flowering : %f \n', 180);%
fprintf(fid2,'%%%% Duration of yield formation in growing degree/calendar days %% \n');
```

```
fprintf(fid2,'YldForm : %f \n', 750);%
fprintf(fid2,'%%%% Growing degree day calculation method %% \n');
fprintf(fid2,'GDDmethod : %f \n', 2);%
fprintf(fid2,'%%%% Base temperature (degC) below which growth does not progress %% \n');
fprintf(fid2,'Tbase : %f \n', 8);%
fprintf(fid2,'%%%% Upper temperature (degC) above which crop development no longer increases %% \n');
fprintf(fid2,'Tupp : %f \n', 30); %
fprintf(fid2,'%%%% Pollination affected by heat stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolHeatStress : %f \n', 1);%
fprintf(fid2,'%%%% Maximum air temperature (degC) above which pollination begins to fail %% \n');
fprintf(fid2,'Tmax_up : %f \n', 40);%
fprintf(fid2,'%%%% Maximum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmax_lo : %f \n', 45);%
fprintf(fid2,'%%%% Pollination affected by cold stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'PolColdStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum air temperature (degC) below which pollination begins to fail %% \n');
fprintf(fid2,'Tmin_up : %f \n', 10);%
fprintf(fid2,'%%%% Minimum air temperature (degC) at which pollination completely fails %% \n');
fprintf(fid2,'Tmin_lo : %f \n', 5);%
fprintf(fid2,'%%%% Biomass production affected by temperature stress (0: No; 1: Yes) %% \n');
fprintf(fid2,'BioTempStress : %f \n', 1);%
fprintf(fid2,'%%%% Minimum growing degree days (degC/day) required for full biomass production %% \n');
fprintf(fid2,'GDD_up : %f \n', 12);%
fprintf(fid2,'%%%% Growing degree days (degC/day) at which no biomass production occurs %% \n');
fprintf(fid2,'GDD_lo : %f \n', 0);%
fprintf(fid2,'%%%% Shape factor describing the reduction in biomass productig degree days %% \n');
fprintf(fid2,'fshape_b : %f \n', 13.8135);%
fprintf(fid2,'%%%% Initial percentage of minimum effective rooting depth %% \n');
fprintf(fid2,'PctZmin : %f \n', 70);%
fprintf(fid2,'%%%% Minimum effective rooting depth (m) %% \n');
fprintf(fid2,'Zmin : %f \n', 0.30);%
```

```
fprintf(fid2,'%%%% Maximum rooting depth (m) %% \n');
fprintf(fid2,'Zmax : %f \n', 2);%
fprintf(fid2,'%%%% Shape factor describing root expansion %% \n');
fprintf(fid2,'fshape_r : %f \n', 1.3);%
fprintf(fid2,'%%%% Shape factor describing the effects of water stress on root expansion %% \n');
fprintf(fid2,'fshape_ex : %f \n', -6);%
fprintf(fid2,'%%%% Maximum root water extraction at top of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxTopQ : %f \n', 0.0104);%
fprintf(fid2,'%%%% Maximum root water extraction at the bottom of the root zone (m3/m3/day) %% \n');
fprintf(fid2,'SxBotQ : %f \n', 0.0026);%
fprintf(fid2,'%%%% Exponent parameter for adjustment of Kcx once senescence is triggered %% \n');
fprintf(fid2,'a_Tr : %f \n', 1);%
fprintf(fid2,'%%%% Soil surface area (cm2) covered by an individual seedling %% \n');
fprintf(fid2,'SeedSize : %f \n', 6.5); %
fprintf(fid2,'%%%% Number of plants per hectare %% \n');
fprintf(fid2,'PlantPop : %f \n', 75000);%
fprintf(fid2,'%%%% Minimum canopy size below which yield formation cannot occur %% \n');
fprintf(fid2,'CCmin : %f \n', 0.049);%
fprintf(fid2,'%%%% Maximum canopy cover (fraction of soil cover) %% \n');
fprintf(fid2,'CCx : %f \n', 0.96);%
fprintf(fid2,'%%%% Canopy decline coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CDC : %f \n', 0.01);%
fprintf(fid2,'%%%% Canopy growth coefficient (fraction per day/GDD) %% \n');
fprintf(fid2,'CGC : %f \n', 0.0125);%
fprintf(fid2,'%%%% Crop coefficient when canopy growth is complete but prior to senescence %% \n');
fprintf(fid2,'Kcb : %f \n', 1.05);%
fprintf(fid2,'%%%% Decline of crop coefficient due to ageing (day) %% \n');
fprintf(fid2,'fage : %f \n', 0.3);%
fprintf(fid2,'%%%% Water productivity normalized for ET0 and CO2 (g/m2) %% \n');
fprintf(fid2,'WP : %f \n', 33.7);%
fprintf(fid2,'%%%% Adjustment of water productivity in yield formation stage (of WP) %% \n');
fprintf(fid2,'WPy : %f \n', 100);%
fprintf(fid2,'%%%% Crop co2 sink strength coefficient %% \n');
```

```matlab
fprintf(fid2,'fsink : %f \n', 0.5);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by Steduto et al. 2007 %% \n');
fprintf(fid2,'bsted : %f \n', 0.000138);%
fprintf(fid2,'%%%% WP co2 adjustment parameter given by FACE experiments %% \n');
fprintf(fid2,'bface : %f \n', 0.001165);%
fprintf(fid2,'%%%% Reference harvest index %% \n');
fprintf(fid2,'HI0 : %f \n', 0.48);%
fprintf(fid2,'%%%% Initial harvest index %% \n');
fprintf(fid2,'HIini : %f \n', 0.01);%
fprintf(fid2,'%%%% Possible increase of harvest index due to water stress before flowering %% \n');
fprintf(fid2,'dHI_pre : %f \n', 0);%
fprintf(fid2,'%%%% Coefficient describing positive ed vegetative formation %% \n');
fprintf(fid2,'a_HI : %f \n', 7);%
fprintf(fid2,'%%%% Coefficient describing negative impact on harves %% \n');
fprintf(fid2,'b_HI : %f \n', 3);%
fprintf(fid2,'%%%% Maximum allowable increase of harvest index above reference %% \n');
fprintf(fid2,'dHI0 : %f \n', 15);%
fprintf(fid2,'%%%% Crop Determinancy (0: Indeterminant, 1: Determinant) %% \n');
fprintf(fid2,'Determinant : %f \n', 1);%
fprintf(fid2,'%%%% Excess of potential fruits %% \n');
fprintf(fid2,'exc : %f \n', 50);%
fprintf(fid2,'%%%% Percentage of total flowering at which peak flowering occurs %% \n');
fprintf(fid2,'MaxFlowPct : %f \n', 33.33);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on affect canopy expansion %% \n');
fprintf(fid2,'p_up1 : %f \n', 0.14);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_up2 : %f \n', 0.69);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_up3 : %f \n', 0.69);%
fprintf(fid2,'%%%% Upper soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_up4 : %f \n', 0.8);%
```

```
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy expansion %% \n');
fprintf(fid2,'p_lo1 : %f \n', 0.72);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy stomatal control %% \n');
fprintf(fid2,'p_lo2 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy senescence %% \n');
fprintf(fid2,'p_lo3 : %f \n', 1);%
fprintf(fid2,'%%%% Lower soil water depletion threshold for water stress effects on canopy pollination %% \n');
fprintf(fid2,'p_lo4 : %f \n', 1);%
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy expansion %% \n');
fprintf(fid2,'fshape_w1 : %f \n', 2.9);
fprintf(fid2,'%%%% Shape factor describing water stress effects on stomatal control %% \n');
fprintf(fid2,'fshape_w2 : %f \n', 6);
fprintf(fid2,'%%%% Shape factor describing water stress effects on canopy senescence %% \n');
fprintf(fid2,'fshape_w3 : %f \n', 2.7);
fprintf(fid2,'%%%% Shape factor describing water stress effects on pollination %% \n');
fprintf(fid2,'fshape_w4 : %f \n', 1);
fprintf(fid2,'%%%% Adjustment to water stress thresholds depending on daily ET0 (0: No, 1: Yes) %% \n');
fprintf(fid2,'ETadj : %f \n', 1);
fprintf(fid2,'%%%% Vol below saturation at which stress begins to occur due to deficient aeration %% \n');
fprintf(fid2,'Aer : %f \n', 5);
fprintf(fid2,'%%%% Number of days lag before aeration stress affects crop growth %% \n');
fprintf(fid2,'LagAer : %f \n', 3);
fprintf(fid2,'%%%% Reduction to p_lo3 when early canopy senescence is triggered %% \n');
fprintf(fid2,'beta : %f \n', 12);
fprintf(fid2,'%%%% Proportion of total water storage needed for crop to germinate %% \n');
fprintf(fid2,'GermThr : %f \n', 0.2);

fclose(fid2);
end
```

```
end

%Crop mix file
for i=1
fid2 = fopen('CropMix.txt','wt');
fprintf(fid2,'%%%% ---------- Crop mix options for AquaCropOS ---------- %% \n');
fprintf(fid2,'%%%% Number of crop options %% \n');
fprintf(fid2,'%f \n',1);
fprintf(fid2,'%%%% Specified planting calendar %% \n');
fprintf(fid2,'N \n');
fprintf(fid2,'%%%% Crop rotation filename %% \n');
fprintf(fid2,'CropRotation.txt \n');
fprintf(fid2,'%%%% Information about each crop type %% \n');
fprintf(fid2,'%%%% CropType, CropFilename, IrrigationFilename %% \n');
fprintf(fid2,'%s, Crop.txt, IrrigationManagement.txt \n',crop{:});

fclose(fid2);
end

%Crop Rotation file
for i=1:1
fid2 = fopen('CropRotation.txt','wt');
fprintf(fid2,'%%%% --------- Crop rotation time-series for AquaCropOS --------- %% \n');
fprintf(fid2,'%%%% PlantDate HarvestDate Crop %% \n');
fprintf(fid2,'01/05/2019 30/09/2019 %s \n',crop{:});
fclose(fid2);
end

%FieldManagement.txt
if mane==1
    Mulches=0;
    fMulch=0.5;
elseif mane==2
    Mulches=1;
    fMulch=0.5;
else
    Mulches=1;
    fMulch=1;
end
```

```
for i=1:1
fid2 = fopen('FieldManagement.txt','wt');

fprintf(fid2,'%%%% -- Soil parameter inputs for AquaCropOS %%%%\n');
fprintf(fid2,'%%%% Soil surface covered by mulches (0: No; 1: Yes) %%%%\n');
fprintf(fid2,'Mulches : %f \n', Mulches);
fprintf(fid2,'%%%% Area of soil surface covered by mulches during growing \n');
fprintf(fid2,'MulchPctGS : %f \n', 50);
fprintf(fid2,'%%%% Area of soil surface covered by mulches outside growing \n')
    ↪ ;
fprintf(fid2,'MulchPctOS : %f \n', 50);
fprintf(fid2,'%%%% Soil evaporation adjustment factor due to effect of mulches
    ↪ %%\n');
fprintf(fid2,'fMulch : %f \n', fMulch);
fprintf(fid2,'%%%% Surface bunds present (0: No; 1: Yes) %%\n');
fprintf(fid2,'Bunds : %f \n', 0);
fprintf(fid2,'%%%% Bund height (m) %%\n');
fprintf(fid2,'zBund : %f \n', 0);
fprintf(fid2,'%%%% Initial water height in surface bunds (mm) %%\n');
fprintf(fid2,'BundWater : %f \n', 0);

fclose(fid2);

end

%Running AquaCrop Model
AquaCropOS_RUN

%reading Aquacrop output data
temp=importdata('Sample_WaterFluxes.txt');
WaterFluxes=temp.data;
clear temp;

Es=sum(WaterFluxes(:,15)); %(mm) Evaporation from soil surface

Tr=sum(WaterFluxes(:,17)); %(mm) Crop transpiration

if irrig==1
    Es=Es/0.5;
elseif irrig==2
    Es=Es/0.6;
elseif irrig==3
```

```
    Es=Es/0.7;
elseif irrig==4
    Es=Es/0.8;
elseif irrig==5
    Es=Es/0.9;
else
    Es=Es/0.95;
end


temp=importdata('Sample_FinalOutput.txt');
FinalOutput=temp.data;
clear temp;

Yield=sum(FinalOutput(:,2)); %(ton/ha) Crop Yield

if cropt==3
    if irrig==1
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/0.5;% (mm) Total Irrigation
    elseif irrig==2
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/0.6;
    elseif irrig==3
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/0.7;
    elseif irrig==4
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/0.8;
    elseif irrig==5
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/0.9;
    else
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/0.95;
    end

else
    if irrig==1
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/(2*0.5); % (mm) Total Irrigation
    elseif irrig==2
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/(2*0.6);
    elseif irrig==3
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/(2*0.7);
    elseif irrig==4
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/(2*0.8);
```

```
    elseif irrig==5
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/(2*0.9);
    else
        matriz_TotIrr(cropt,irrig,mane)=sum(FinalOutput(:,3))/(2*0.95);
    end
end

matriz_PH(cropt,irrig,mane)=10*(Es+Tr)/Yield; %(l/kg)

end
end
end

cont_interacao=0;
cont_parada=0;
parar=0;
while parar==0

for ger=1:n_ger

PH=zeros(1,n_usuarios,n_popu);
Q_total=zeros(n_popu);
TotIrr=zeros(1,n_usuarios,n_popu);
for creature=1:n_popu
for user=1:n_usuarios
    TotIrr(1,user,creature)=matriz_TotIrr(popu_inicial(1,user,creature), popu_inicial(2,user,creature),popu_inicial(3,user,creature));
    PH(1,user,creature)=matriz_PH(popu_inicial(1,user,creature),popu_inicial(2,user,creature),popu_inicial(3,user,creature));
end
for u=1:n_usuarios
    %flow to irrigate total area
    Q_total(creature)=Q_total(creature)+TotIrr(1,u,creature)*A_max(u)/(1000*t_sec(popu_inicial(1,user,creature)));
end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Feasibility of solutions
inviaveis=zeros(n_popu);

%Calculates the cost of each individual
```

```
custo=zeros(1,1,n_popu);
for k=1:n_popu
    for j=1:n_usuarios
        for i=2:3
            if popu_inicial(i,j,k)>IniConfig(i,j)
                custo(1,1,k)=custo(1,1,k)+cost(i,popu_inicial(i,j,k))*A_max(j);
            end
        end
    end
    if custo(1,1,k)>custo_limite
        inviaveis(k)=1;
    end
end

%Unviability by demand greater than availability
for u=1:n_popu
    if Q_total(u)>q_100
        inviaveis(u)=1;
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Objective functions

%calculation of objective functions
aptidao=zeros(1,n_funcoes,n_popu);%creating matrix to store the value of
    ↪ fitness

%calculation of the first objective function
for k=1:n_popu
     aptidao(1,1,k)= sum(PH(1,:,k));
end

%calculation of the second objective function
aptidao(1,2,:)= custo(1,1,:);

%standardization of fitness values
maior_aptidao=max(aptidao,[],3);
menor_aptidao=min(aptidao,[],3);

aptidao_norm=zeros(1,n_funcoes,n_popu);
for k=1:n_popu
```

```
    aptidao_norm(:,:,k)=100*(aptidao(:,:,k)-menor_aptidao)./(maior_aptidao-menor_aptidao);
end

%Strength of individuals
strength=zeros(n_popu);
for i=1:n_popu
    if inviaveis(i)==0
        for j=1:n_popu
            if inviaveis(j)==0
                if and(and(aptidao_norm(:,1,i)<=aptidao_norm(:,1,j),aptidao_norm(:,2,i)<=aptidao_norm(:,2,j)),or(aptidao_norm(:,1,i)<aptidao_norm(:,1,j),aptidao_norm(:,2,i)<aptidao_norm(:,2,j)))
                    strength(i)=strength(i)+1;
                end
            end
        end
    else
        for j=1:n_popu
            if inviaveis(j)==1
                if and(and(aptidao_norm(:,1,i)<=aptidao_norm(:,1,j),aptidao_norm(:,2,i)<=aptidao_norm(:,2,j)),or(aptidao_norm(:,1,i)<aptidao_norm(:,1,j),aptidao_norm(:,2,i)<aptidao_norm(:,2,j)))
                    strength(i)=strength(i)+1;
                end
            end
        end
    end
end

%Raw Fitness of individuals
raw_fitness=zeros(n_popu);
for i=1:n_popu
    if inviaveis(i)==0
        for j=1:n_popu
            if inviaveis(j)==0
                if and(and(aptidao_norm(:,1,i)<=aptidao_norm(:,1,j),aptidao_norm(:,2,i)<=aptidao_norm(:,2,j)),or(aptidao_norm(:,1,i)<aptidao_norm(:,1,j),aptidao_norm(:,2,i)<aptidao_norm(:,2,j)))
```

```
                raw_fitness(j)=raw_fitness(j)+strength(i);
            end
        end
    end
else
    for j=1:n_popu
        if inviaveis(j)==1
            if and(and(aptidao_norm(:,1,i)<=aptidao_norm(:,1,j),aptidao_norm
                ↪ (:,2,i)<=aptidao_norm(:,2,j)),or(aptidao_norm(:,1,i)<
                ↪ aptidao_norm(:,1,j),aptidao_norm(:,2,i)<aptidao_norm(:,2,j
                ↪ )))
                raw_fitness(j)=raw_fitness(j)+strength(i);
            end
        end
    end
end
end

%Calculation of neighborhood density of individuals
distancia_euclidiana=NaN(n_popu,n_popu);
for i=1:n_popu
    restante=i+1;
    for j=restante:n_popu
        distancia_euclidiana(i,j)=sqrt((aptidao_norm(1,1,j)-aptidao_norm(1,1,i))
            ↪ ^2+(aptidao_norm(1,2,j)-aptidao_norm(1,2,i))^2);
        distancia_euclidiana(j,i)=distancia_euclidiana(i,j);
    end
end
densidade_vizinhanca=1./(2+distancia_euclidiana);

%Fitness calculation
fitness=zeros(n_popu);
for i=1:n_popu
    temp=densidade_vizinhanca(i,:);
    fitness(i)=max(temp)+raw_fitness(i);
end

%filling the external population
aptidao_ext=zeros(1,n_funcoes,n_popu_ext);
viabilidade_ext=zeros(n_popu_ext);
q_ext=zeros(n_popu_ext);
custo_ext=zeros(n_popu_ext);
```

```
popu_ext=zeros(3,n_usuarios,n_popu_ext); %creating the matrix to store the individuals of the external population
for i=1:n_popu_ext
    %making, initially, the first individual of the population to be the best individual. After that, it will be compared with each other individual of the population. If a individual is found to be better than the best so far, this will be the new best.
    n_melhor=1;
    viabilidade_melhor=inviaveis(1);
    raw_fitness_melhor=raw_fitness(1);
    aptidao_melhor=fitness(1);
    for j=2:n_popu
        if viabilidade_melhor==0 %if the best individual is viable
            if inviaveis(j)==0 %if the individual in comparison is viable
                if raw_fitness_melhor==0 %if the best individual is viable and not dominated
                    if raw_fitness(j)==0 %if the individual in comparison is viable and not dominated
                        if fitness(j)<aptidao_melhor
                            n_melhor=j;
                            viabilidade_melhor=inviaveis(j);
                            raw_fitness_melhor=raw_fitness(j);
                            aptidao_melhor=fitness(j);
                        end
                    end
                else %if the best individual is viable and dominated
                   if raw_fitness(j)==0 %if the individual in comparison is viable and not dominated
                       n_melhor=j;
                       viabilidade_melhor=inviaveis(j);
                       raw_fitness_melhor=raw_fitness(j);
                       aptidao_melhor=fitness(j);
                   else %if the individual in comparison is viable and dominated
                       if fitness(j)<aptidao_melhor
                           n_melhor=j;
                           viabilidade_melhor=inviaveis(j);
                           raw_fitness_melhor=raw_fitness(j);
                           aptidao_melhor=fitness(j);
                        end
                   end
```

```
                end
            end
        else %if the best individual is not viable
            if inviaveis(j)==0 %if the individual in comparison is viable
                n_melhor=j;
                viabilidade_melhor=inviaveis(j);
                raw_fitness_melhor=raw_fitness(j);
                aptidao_melhor=fitness(j);
            else %if the individual in comparison is not viable
                if raw_fitness_melhor==0 %if the best individual is unviable and not dominated
                    if raw_fitness(j)==0 %if the individual in comparison is unviable and not dominated
                        if fitness(j)<aptidao_melhor
                            n_melhor=j;
                            viabilidade_melhor=inviaveis(j);
                            raw_fitness_melhor=raw_fitness(j);
                            aptidao_melhor=fitness(j);
                        end
                    end
                else %if the best individual is unviable and dominated
                   if raw_fitness(j)==0 %if the individual in comparison is unviable and not dominated
                       n_melhor=j;
                       viabilidade_melhor=inviaveis(j);
                       raw_fitness_melhor=raw_fitness(j);
                       aptidao_melhor=fitness(j);
                   else %if the individual in comparison is unviable and dominated
                        if fitness(j)<aptidao_melhor
                            n_melhor=j;
                            viabilidade_melhor=inviaveis(j);
                            raw_fitness_melhor=raw_fitness(j);
                            aptidao_melhor=fitness(j);
                        end
                   end
                end
            end
        end
    end
```

```
    popu_ext(:,:,i)=popu_inicial(:,:,n_melhor); %storing the best
        ↪ individual in the external population
    custo_ext(i)=custo(1,1,n_melhor);
    viabilidade_ext(i)=inviaveis(n_melhor);
    q_ext(i)=Q_total(n_melhor);
    aptidao_ext(:,:,i)=aptidao(:,:,n_melhor);

    %removing the best individual (who was transferred to the external
        ↪ population) from the selection process, so that in the next
        ↪ cycle the second best will be selected as the best.
    inviaveis(n_melhor)=1;
    raw_fitness(n_melhor)=Inf;
    fitness(n_melhor)=Inf;
end

%Transferring the 50 best individuals of this generation directly to
    ↪ the next generation (Elitism), so as not to lose the best
    ↪ solutions found so far.

for ini=1:50
    popu_inicial(:,:,ini)=popu_ext(:,:,ini);
end

for ini=1:10
    if viabilidade_ext(ini)==0
        x=aptidao_ext(1,1,ini);
        y=aptidao_ext(1,2,ini);
        plot(x,y,'b*')
        xlim([10000,19000]);
        ylim([0,custo_limite]);
        xlabel('Water Footprint (l/kg)')
        ylabel('Transition Cost (R$)')
        grid on
        hold on
    end
end

filho=IniConfig;

for i=51:n_popu

%Selection of individuals for reproduction
```

```

%draws two random individuals
colocacao1=round(rand(1)*n_popu_ext);%saves the individual's classification (1 is the fittest)
if colocacao1==0
    colocacao1=1;
end
colocacao2=round(rand(1)*n_popu_ext);
if colocacao2==0
    colocacao2=1;
end
%selects the best of both and sends it to reproduction
if colocacao1<colocacao2
    pai=popu_ext(:,:,colocacao1);
    colocacao_pai=colocacao1;
else
    pai=popu_ext(:,:,colocacao2);
    colocacao_pai=colocacao2;
end

%repeats the draw for mother's selection
colocacao3=round(rand(1)*n_popu_ext);
if colocacao3==0
    colocacao3=1;
end
colocacao4=round(rand(1)*n_popu_ext);
if colocacao4==0
    colocacao4=1;
end
if colocacao3>colocacao4
    mae=popu_ext(:,:,colocacao3);
    colocacao_mae=colocacao3;
else
    mae=popu_ext(:,:,colocacao4);
    colocacao_mae=colocacao4;
end

%Performs targeted mutation
if custo_ext(colocacao_pai)>custo_limite
    for col=1:n_usuarios
        for lin=1:3
```

```
            pai(lin,col)=pai(lin,col)-round((pai(lin,col)-IniConfig(lin,col))*
                ↪ rand(1));
        end
    end
end
if custo_ext(colocacao_mae)>custo_limite
    for col=1:n_usuarios
        for lin=1:3
            mae(lin,col)=mae(lin,col)-round((mae(lin,col)-IniConfig(lin,col))*
                ↪ rand(1));
        end
    end
end

% crossover
sorteado=rand(1);
if sorteado<=p_cross
    for col=1:n_usuarios
        for lin=1:3
            filho(lin,col)=round((pai(lin,col)+mae(lin,col))/2);
        end
    end
else
    if colocacao_pai>colocacao_mae
        filho=pai;
    else
        filho=mae;
    end
end

%performs uniform mutation
sorteado=rand(1);
if sorteado<=p_mut
    for col=1:n_usuarios
        for lin=1:3
            if lin==1
                filho(lin,col)=IniConfig(lin,col)+round((n_crop-IniConfig(lin,
                    ↪ col))*rand(1));
            elseif lin==2
                filho(lin,col)=IniConfig(lin,col)+round((n_irrig-IniConfig(lin,
                    ↪ col))*rand(1));
            else
```

```
                filho(lin,col)=IniConfig(lin,col)+round((n_mane-IniConfig(lin,
                    ↪ col))*rand(1));
            end
        end
    end
end

popu_inicial(:,:,i)=filho;

end

cont_interacao=cont_interacao+1;
fprintf('I'm in genaration %i \n',cont_interacao)
if viabilidade_ext(1)==0
    fprintf('The best individual is viable \n')
    cont_parada=cont_parada+1;
end

end

if cont_parada>1000
    parar=1;
    x=zeros(30);
    y=zeros(30);
    for ponto=1:30
        x(ponto)=aptidao_ext(1,1,ponto);
        y(ponto)=aptidao_ext(1,2,ponto);
    end
    plot(x,y,'r*')
    xlim([10000,19000]);
    ylim([0,custo_limite]);
    xlabel('Water Footprint (l/kg)')
    ylabel('Transition Cost (R$)')
    grid on
    hold on
    saveas(gcf,'pareto.png')
end
end
```

Annex

ANNEX A – Climatic Data

ATUAL							
Horas de Sol	Precipitação	Radiação	Temperatura		Umidade	Velocidade do Vento	Evapotranspiração de Referência
horas/dia	mm	MJ/m2.dia	Min °C	Max °C	%	m/s	mm
9.52	2.31	16.74	20.54	31.17	70.58	1.66	5.7
9.5	2.34	20.54	20.54	31.18	71.29	1.66	6.7
9.47	2.37	20.11	20.55	31.18	79.71	1.67	6.3
9.45	2.4	19.22	20.55	31.18	79.75	1.68	6.0
9.43	2.43	9.25	20.55	31.19	90.38	1.68	3.0
9.42	2.47	19.25	20.56	31.19	74.17	1.68	6.2
9.38	2.5	18.41	20.56	31.19	74.58	1.69	6.0
9.37	2.54	16.08	20.57	31.19	83.83	1.69	5.0
9.33	2.58	19.01	20.57	31.2	77	1.7	6.1
9.32	2.62	14.11	20.57	31.2	83.92	1.71	4.5
9.28	2.66	15.26	20.58	31.2	72.54	1.71	5.3
9.25	2.7	18.79	20.58	31.2	72.79	1.72	6.2
9.23	2.74	20.08	20.59	31.21	77.46	1.72	6.4
9.2	2.79	20.26	20.6	31.21	76.75	1.73	6.4
9.17	2.83	19.65	20.6	31.21	76.96	1.73	6.3
9.13	2.88	20.77	20.61	31.21	72.33	1.74	6.7
9.1	2.92	19.25	20.61	31.21	79.67	1.74	6.1
9.07	2.97	7.88	20.62	31.21	88.46	1.75	2.7
9.03	3.02	20.91	20.63	31.21	81.29	1.76	6.4
9	3.07	20.74	20.63	31.21	77.67	1.76	6.5
8.97	3.12	17.33	20.64	31.21	82.63	1.76	5.4
8.93	3.17	21.38	20.64	31.22	76.13	1.77	6.8
8.9	3.22	20.65	20.65	31.22	73.79	1.78	6.7
8.87	3.28	20.48	20.66	31.22	72.17	1.78	6.7
8.83	3.33	18.52	20.67	31.21	74.58	1.79	6.1
8.8	3.38	20.51	20.67	31.21	71.25	1.79	6.7
8.77	3.44	18.46	20.68	31.21	73.67	1.79	6.1
8.73	3.49	18.16	20.69	31.21	68.92	1.8	6.2
8.7	3.55	21.72	20.69	31.21	70.21	1.81	7.1
8.67	3.61	19.02	20.7	31.21	74.33	1.81	6.2
8.63	3.66	18.48	20.71	31.21	70.58	1.81	6.2
8.58	3.72	19.3	20.72	31.2	71.21	1.82	6.4
8.55	3.78	20.38	20.72	31.2	75.83	1.82	6.5
8.52	3.84	18.94	20.73	31.2	81.92	1.83	5.9
8.48	3.9	20.01	20.74	31.2	76.71	1.83	6.4
8.45	3.96	20.91	20.74	31.19	71.96	1.84	6.8
8.42	4.02	21.85	20.75	31.19	74.04	1.84	7.0
8.38	4.09	21.68	20.76	31.18	73.42	1.84	7.0
8.35	4.15	19.34	20.76	31.18	78.13	1.85	6.1
8.32	4.21	23.84	20.77	31.17	66.67	1.85	7.8
8.28	4.28	21.31	20.78	31.17	77.08	1.86	6.7
8.25	4.34	17.04	20.78	31.16	83.13	1.86	5.3
8.22	4.41	21.49	20.79	31.16	73.17	1.86	6.9
8.18	4.47	22.38	20.79	31.15	73.04	1.86	7.2
8.15	4.54	22.64	20.8	31.14	71.92	1.87	7.3
8.12	4.6	20.58	20.81	31.14	74.17	1.87	6.6

8.08	4.67	21.86	20.81	31.13	71.21	1.88	7.1
8.05	4.74	20.83	20.82	31.12	72	1.88	6.8
8.02	4.81	21.88	20.82	31.11	76.79	1.88	6.9
7.98	4.87	17.03	20.82	31.1	83.38	1.88	5.3
7.95	4.94	12.35	20.83	31.09	76.08	1.88	4.4
7.92	5.01	22.64	20.83	31.08	69.17	1.89	7.4
7.88	5.08	23.55	20.84	31.07	67.75	1.89	7.7
7.87	5.15	23.24	20.84	31.06	73.21	1.89	7.4
7.83	5.22	22.16	20.84	31.05	72.04	1.89	7.1
7.8	5.29	15.93	20.84	31.04	81.17	1.89	5.1
7.77	5.37	22.57	20.85	31.03	76.13	1.9	7.1
7.75	5.44	21.34	20.85	31.02	75.21	1.9	6.8
7.72	5.51	15.36	20.85	31	73.58	1.9	5.3
7.68	5.58	21.67	20.85	30.99	73.08	1.9	7.0
7.67	5.65	19	20.85	30.98	75.38	1.9	6.2
7.63	5.72	23.81	20.86	30.96	69.08	1.91	7.7
7.62	5.79	19.59	20.86	30.95	76.54	1.91	6.3
7.58	5.87	20.13	20.86	30.93	74.79	1.91	6.5
7.57	5.94	20.29	20.86	30.92	74.13	1.91	6.6
7.53	6.01	20.05	20.86	30.9	71.63	1.91	6.6
7.52	6.08	20.13	20.86	30.89	73.17	1.91	6.5
7.48	6.15	24.96	20.86	30.87	72.71	1.91	7.8
7.47	6.22	21.16	20.86	30.85	79.58	1.91	6.5
7.45	6.29	23.91	20.86	30.83	70.75	1.91	7.6
7.42	6.36	24.5	20.86	30.82	65.04	1.91	8.0
7.4	6.43	25.31	20.86	30.8	70.17	1.91	8.0
7.38	6.5	23.9	20.85	30.78	75.67	1.91	7.4
7.35	6.57	18.44	20.85	30.76	74.38	1.92	6.0
7.33	6.64	23	20.85	30.74	70.04	1.92	7.4
7.32	6.71	24.39	20.85	30.72	69	1.92	7.8
7.3	6.77	22.71	20.85	30.7	73	1.92	7.2
7.28	6.84	24.84	20.85	30.68	68	1.92	8.0
7.27	6.91	21.92	20.85	30.66	69.08	1.92	7.2
7.23	6.97	18.89	20.84	30.64	70.83	1.92	6.3
7.22	7.04	24.61	20.84	30.62	67.88	1.92	7.9
7.2	7.1	24.68	20.84	30.6	66.96	1.92	8.0
7.18	7.16	19.29	20.84	30.58	70.08	1.92	6.4
7.17	7.23	20.53	20.84	30.56	69.67	1.92	6.8
7.15	7.29	17.91	20.83	30.53	73.42	1.92	5.9
7.13	7.35	22.57	20.83	30.51	71.13	1.92	7.2
7.12	7.41	21.78	20.83	30.49	72.04	1.92	7.0
7.1	7.46	24.69	20.83	30.47	69.54	1.92	7.8
7.08	7.52	26.08	20.82	30.44	67.04	1.92	8.3
7.07	7.58	23.77	20.82	30.42	69.58	1.93	7.6
7.05	7.63	23.59	20.82	30.4	72.08	1.93	7.4
7.03	7.69	24.74	20.81	30.37	70.96	1.93	7.8
7.02	7.74	24.7	20.81	30.35	68.29	1.93	7.9
7	7.79	22.63	20.81	30.32	70.92	1.93	7.2
6.98	7.84	23.76	20.8	30.3	70.46	1.93	7.5
6.97	7.9	23.65	20.8	30.27	72.13	1.93	7.4

6.95	7.94	24.54	20.79	30.25	65.88	1.93	7.9
6.93	7.99	25.66	20.79	30.22	67.63	1.93	8.2
6.92	8.04	24.57	20.78	30.2	72.33	1.93	7.7
6.9	8.09	22.81	20.78	30.17	71.71	1.94	7.2
6.88	8.13	24.48	20.77	30.15	68.83	1.94	7.8
6.87	8.18	25.45	20.76	30.12	68	1.94	8.1
6.85	8.22	25.15	20.76	30.09	69.54	1.94	7.9
6.83	8.26	23.58	20.75	30.07	70.83	1.94	7.5
6.82	8.3	24.62	20.74	30.04	66.42	1.94	7.9
6.8	8.34	24.58	20.73	30.01	66.71	1.95	7.9
6.77	8.38	25.08	20.73	29.98	67.33	1.95	8.0
6.75	8.42	20.61	20.72	29.96	71.33	1.95	6.7
6.73	8.46	25.04	20.71	29.93	66.33	1.95	8.0
6.72	8.49	23.66	20.7	29.9	69.58	1.96	7.5
6.7	8.53	25.43	20.69	29.87	66.63	1.96	8.1
6.68	8.57	22.6	20.67	29.84	68.38	1.96	7.3
6.67	8.6	24.59	20.66	29.81	65.54	1.97	7.9
6.65	8.63	21.65	20.65	29.79	69.63	1.97	7.0
6.63	8.67	24.69	20.64	29.76	69.21	1.97	7.8
6.62	8.7	25.82	20.62	29.73	65.63	1.98	8.2
6.6	8.73	23.69	20.61	29.7	68.83	1.98	7.5
6.57	8.76	25.93	20.59	29.67	67.88	1.98	8.1
6.55	8.79	25.59	20.57	29.64	65.17	1.99	8.2
6.53	8.83	20.6	20.56	29.61	68.38	1.99	6.8
6.52	8.86	23.7	20.54	29.58	70.04	2	7.5
6.5	8.89	23.08	20.52	29.55	70.5	2	7.3
6.48	8.92	22.32	20.5	29.52	70.88	2.01	7.1
6.47	8.94	24.03	20.48	29.48	71.42	2.01	7.5
6.45	8.97	21.37	20.46	29.45	75.38	2.02	6.6
6.43	9	15.29	20.44	29.42	76.25	2.02	5.0
6.42	9.03	16.18	20.41	29.39	78.38	2.03	5.2
6.4	9.06	17.04	20.39	29.36	78.96	2.03	5.4
6.38	9.09	17.55	20.37	29.33	72.5	2.04	5.8
6.37	9.12	23.69	20.34	29.29	69.54	2.04	7.5
6.37	9.15	25.7	20.32	29.26	70.08	2.05	7.9
6.35	9.18	23.27	20.29	29.23	71.58	2.06	7.3
6.33	9.21	22.63	20.26	29.2	75.46	2.06	6.9
6.32	9.24	23.68	20.23	29.17	72.25	2.07	7.3
6.32	9.27	22.81	20.2	29.13	71.67	2.08	7.1
6.3	9.3	24.47	20.17	29.1	72.96	2.08	7.5
6.28	9.34	23.45	20.14	29.07	75.21	2.09	7.1
6.28	9.37	24.28	20.11	29.04	69.88	2.1	7.6
6.27	9.4	25.26	20.08	29	70.71	2.11	7.8
6.25	9.43	22.59	20.05	28.97	73.83	2.11	7.0
6.25	9.47	22.93	20.02	28.94	76.46	2.12	6.9
6.23	9.5	23.76	19.98	28.9	69.33	2.13	7.4
6.23	9.54	16.38	19.95	28.87	71.5	2.14	5.5
6.23	9.57	23.29	19.92	28.84	70.88	2.14	7.2
6.22	9.61	25.07	19.88	28.81	66.13	2.15	7.9
6.22	9.64	27.13	19.85	28.77	62.33	2.16	8.6

6.22	9.68	23.72	19.81	28.74	65.58	2.17	7.6
6.2	9.72	19.18	19.78	28.71	80.83	2.18	5.8
6.2	9.76	16.17	19.74	28.68	73.33	2.19	5.4
6.2	9.79	25.81	19.71	28.65	64.58	2.19	8.1
6.2	9.83	23.72	19.67	28.61	68.5	2.2	7.4
6.2	9.87	23.86	19.63	28.58	68.42	2.21	7.5
6.2	9.91	23.69	19.6	28.55	70.83	2.22	7.3
6.2	9.95	23.7	19.56	28.52	70.08	2.23	7.3
6.2	9.99	14.71	19.52	28.49	70.25	2.24	5.1
6.2	10.03	24.97	19.49	28.46	66.29	2.25	7.8
6.2	10.07	25.62	19.45	28.43	62.96	2.26	8.1
6.2	10.1	23.59	19.41	28.4	68.25	2.27	7.4
6.2	10.14	25.16	19.38	28.37	70.92	2.28	7.6
6.2	10.18	26.32	19.34	28.34	65.96	2.29	8.2
6.2	10.22	27.13	19.3	28.31	64.75	2.29	8.4
6.22	10.25	26.19	19.27	28.28	73.33	2.31	7.8
6.22	10.29	20.07	19.23	28.26	75.63	2.31	6.2
6.22	10.32	23	19.19	28.23	72	2.32	7.0
6.22	10.35	24.48	19.16	28.2	67.21	2.33	7.6
6.23	10.38	22.3	19.12	28.17	70.25	2.34	6.9
6.23	10.41	16.24	19.09	28.15	72.21	2.35	5.4
6.23	10.44	19.1	19.05	28.12	69.38	2.36	6.2
6.25	10.46	21.28	19.02	28.1	73.96	2.37	6.5
6.25	10.48	19.61	18.98	28.07	69	2.38	6.3
6.27	10.5	22.14	18.95	28.05	67.04	2.39	7.0
6.27	10.52	25.24	18.92	28.03	65.88	2.4	7.8
6.28	10.53	23.75	18.89	28.01	72.83	2.41	7.2
6.28	10.55	6.21	18.85	27.98	84.58	2.42	2.4
6.3	10.55	23.53	18.82	27.96	79.67	2.43	6.8
6.3	10.56	23.61	18.79	27.94	74.54	2.43	7.0
6.32	10.56	24.21	18.76	27.92	70.29	2.44	7.4
6.33	10.56	25.56	18.73	27.9	73.17	2.45	7.6
6.33	10.55	24.02	18.7	27.88	73.46	2.46	7.2
6.35	10.54	25.85	18.67	27.87	69.38	2.47	7.8
6.37	10.53	25.41	18.64	27.85	72.33	2.48	7.5
6.37	10.51	24	18.61	27.83	72.96	2.48	7.2
6.38	10.48	23.85	18.59	27.82	67.38	2.49	7.4
6.4	10.46	20.3	18.56	27.8	70.29	2.5	6.4
6.42	10.43	26.94	18.53	27.79	65.46	2.51	8.2
6.42	10.39	25.77	18.51	27.78	66.67	2.51	7.9
6.43	10.35	26.98	18.48	27.77	65.67	2.52	8.2
6.45	10.3	9.96	18.46	27.75	80.83	2.53	3.5
6.47	10.25	25.05	18.44	27.74	73.54	2.54	7.4
6.48	10.2	13.08	18.41	27.73	82.46	2.54	4.1
6.5	10.14	24.28	18.39	27.72	73.83	2.55	7.2
6.52	10.07	23.93	18.37	27.72	70.29	2.55	7.3
6.53	10.01	27.92	18.35	27.71	72.96	2.56	8.1
6.55	9.93	24.79	18.33	27.7	69.54	2.57	7.5
6.57	9.86	29.04	18.31	27.7	71.92	2.57	8.4
6.58	9.77	9.74	18.29	27.69	86.17	2.58	3.2

6.6	9.69	21.06	18.28	27.69	85.33	2.58	5.8
6.62	9.6	9.49	18.26	27.69	87.42	2.59	3.0
6.63	9.5	7.21	18.25	27.68	85.71	2.59	2.6
6.65	9.4	28.05	18.23	27.68	71.75	2.59	8.2
6.67	9.3	22.01	18.22	27.68	73.67	2.6	6.6
6.68	9.2	21.86	18.2	27.68	70.71	2.6	6.8
6.72	9.09	30	18.19	27.69	69.83	2.61	8.7
6.73	8.98	9.95	18.18	27.69	74.13	2.61	3.8
6.75	8.86	11.86	18.17	27.69	78.08	2.61	4.1
6.77	8.75	10.39	18.16	27.69	89.29	2.61	3.1
6.8	8.63	25.25	18.16	27.7	79.5	2.61	7.1
6.82	8.5	15	18.15	27.71	79.17	2.62	4.7
6.83	8.38	18.89	18.14	27.71	81.71	2.62	5.5
6.85	8.25	15.54	18.14	27.72	85.33	2.62	4.6
6.88	8.13	24.94	18.14	27.73	78.83	2.62	7.1
6.9	8	21.02	18.13	27.74	76.33	2.62	6.3
6.92	7.87	17.97	18.13	27.75	75.04	2.62	5.6
6.95	7.74	29	18.13	27.76	70.04	2.62	8.5
6.97	7.61	19.54	18.13	27.77	73.67	2.62	6.1
6.98	7.48	20.05	18.13	27.78	74.58	2.62	6.2
7.02	7.34	13.92	18.14	27.8	76.29	2.62	4.6
7.03	7.21	30	18.14	27.81	75.04	2.62	8.5
7.07	7.08	10.79	18.15	27.83	77.33	2.61	3.9
7.08	6.95	15.56	18.15	27.84	71.92	2.61	5.2
7.1	6.82	18.86	18.16	27.86	70.25	2.61	6.1
7.13	6.69	12.8	18.17	27.88	76.46	2.61	4.4
7.15	6.56	11.38	18.18	27.9	81.54	2.61	3.8
7.18	6.44	8.64	18.19	27.92	86	2.6	2.9
7.2	6.31	11.2	18.2	27.94	82.25	2.6	3.7
7.23	6.19	25.58	18.21	27.96	70.75	2.59	7.7
7.25	6.07	27.62	18.23	27.98	68.63	2.59	8.3
7.28	5.95	20.11	18.24	28	73.63	2.58	6.2
7.3	5.83	26.96	18.26	28.02	72.29	2.58	7.9
7.33	5.72	20.04	18.28	28.05	71.88	2.57	6.3
7.35	5.6	22.22	18.3	28.07	70.63	2.57	6.9
7.38	5.49	7.73	18.31	28.1	78.38	2.56	3.1
7.4	5.38	12.49	18.33	28.13	80.83	2.56	4.1
7.43	5.27	18.37	18.35	28.15	81.17	2.55	5.5
7.45	5.17	19.24	18.38	28.18	79	2.54	5.8
7.48	5.07	18.24	18.4	28.21	71.21	2.53	5.9
7.5	4.97	21.9	18.42	28.24	76	2.53	6.6
7.53	4.87	10.15	18.45	28.27	85.08	2.52	3.3
7.57	4.77	12.18	18.47	28.3	86.75	2.51	3.7
7.58	4.68	30	18.5	28.33	76.13	2.5	8.5
7.62	4.59	15.72	18.52	28.36	80.71	2.49	4.9
7.65	4.5	22.96	18.55	28.4	78.42	2.48	6.7
7.67	4.41	23.42	18.57	28.43	76.79	2.48	6.9
7.7	4.33	23.38	18.6	28.46	78.42	2.46	6.8
7.73	4.24	27.19	18.63	28.5	74.21	2.46	8.0
7.77	4.16	19.92	18.66	28.53	80.67	2.44	5.9

7.78	4.08	12.74	18.69	28.57	84.83	2.44	4.0
7.82	4.01	8.99	18.71	28.6	87.75	2.43	2.9
7.85	3.93	10.07	18.74	28.64	87.96	2.41	3.2
7.88	3.86	10.63	18.77	28.68	88.13	2.4	3.3
7.92	3.78	11.63	18.8	28.72	87.38	2.39	3.6
7.95	3.71	6.34	18.83	28.75	90.42	2.38	2.2
7.98	3.64	13.24	18.86	28.79	87.5	2.37	4.0
8.02	3.57	23.4	18.89	28.83	79.17	2.36	6.9
8.03	3.5	20.24	18.92	28.87	82.46	2.34	5.9
8.07	3.44	21.81	18.95	28.91	80.96	2.33	6.4
8.1	3.37	21.47	18.98	28.95	75.96	2.32	6.6
8.13	3.31	18.02	19.01	28.99	79.38	2.31	5.6
8.17	3.24	18.16	19.04	29.03	76.17	2.29	5.7
8.2	3.18	22.19	19.06	29.07	74.38	2.28	6.8
8.23	3.12	23.72	19.09	29.11	73.42	2.27	7.2
8.27	3.05	20.88	19.12	29.15	73.21	2.26	6.6
8.3	2.99	9.04	19.15	29.19	84.79	2.24	3.1
8.33	2.93	10.14	19.18	29.23	91.04	2.23	3.1
8.37	2.87	17.46	19.2	29.27	77.79	2.22	5.5
8.4	2.82	22.22	19.23	29.31	78.5	2.21	6.7
8.43	2.76	22.07	19.26	29.36	80	2.19	6.6
8.47	2.7	20.65	19.28	29.4	76.92	2.18	6.4
8.5	2.64	22.21	19.31	29.44	78.92	2.16	6.7
8.53	2.59	20.83	19.33	29.48	77.38	2.15	6.4
8.57	2.53	13.02	19.36	29.52	82.54	2.14	4.2
8.6	2.48	9.97	19.38	29.56	88.04	2.13	3.2
8.63	2.43	19.07	19.41	29.6	76.88	2.11	6.0
8.67	2.38	18.03	19.43	29.64	80.54	2.1	5.6
8.7	2.33	19.54	19.45	29.67	81.5	2.08	5.9
8.72	2.28	18.52	19.48	29.71	78.63	2.07	5.8
8.75	2.23	17.18	19.5	29.75	79.92	2.06	5.4
8.78	2.18	17.44	19.52	29.79	78.08	2.04	5.5
8.8	2.14	17.81	19.54	29.83	75.33	2.03	5.7
8.83	2.09	18.18	19.57	29.86	81.38	2.02	5.6
8.87	2.05	16.09	19.59	29.9	83.67	2	5.0
8.88	2.01	23.27	19.61	29.94	76.5	1.99	7.1
8.92	1.97	15.41	19.63	29.97	72.38	1.98	5.3
8.93	1.93	21.68	19.65	30.01	68.92	1.96	7.0
8.97	1.89	13.62	19.67	30.04	70.13	1.95	4.9
8.98	1.85	30	19.69	30.08	70.58	1.94	9.1
9	1.82	8.54	19.71	30.11	77.67	1.93	3.3
9.02	1.79	6.58	19.72	30.14	84.42	1.91	2.5
9.05	1.76	9.88	19.74	30.18	88.13	1.9	3.2
9.07	1.73	17.37	19.76	30.21	85.38	1.89	5.2
9.08	1.71	18.55	19.78	30.24	77.13	1.88	5.9
9.1	1.68	15.55	19.8	30.27	75.75	1.86	5.2
9.12	1.66	13.16	19.81	30.3	75.96	1.85	4.5
9.13	1.64	14.42	19.83	30.33	81.13	1.84	4.7
9.15	1.62	17.46	19.85	30.35	80.08	1.83	5.5
9.15	1.6	19.52	19.87	30.38	78.13	1.82	6.1

9.17	1.59	18.81	19.88	30.41	78.17	1.81	5.9
9.18	1.58	17.08	19.9	30.43	74.25	1.8	5.6
9.2	1.57	19.14	19.92	30.46	72.58	1.79	6.2
9.2	1.56	24.17	19.93	30.48	75.92	1.78	7.4
9.22	1.55	13.69	19.95	30.51	84.17	1.76	4.4
9.23	1.54	13.91	19.97	30.53	82.88	1.76	4.5
9.23	1.54	19.65	19.98	30.55	78.46	1.74	6.1
9.25	1.54	16.94	20	30.58	76.54	1.74	5.5
9.27	1.54	12.72	20.02	30.6	80.67	1.73	4.2
9.27	1.54	16.98	20.03	30.62	73.46	1.72	5.6
9.28	1.54	18.87	20.05	30.64	80.88	1.71	5.8
9.28	1.54	15.93	20.06	30.66	83.25	1.7	5.0
9.3	1.54	12.86	20.08	30.68	81.79	1.69	4.2
9.3	1.55	26.03	20.09	30.69	76.08	1.68	7.9
9.32	1.56	17.11	20.11	30.71	80.17	1.68	5.4
9.32	1.56	16.81	20.12	30.73	82.46	1.67	5.2
9.33	1.57	5.38	20.14	30.75	83.33	1.66	2.2
9.33	1.58	17.81	20.15	30.76	74	1.66	5.8
9.35	1.59	18.24	20.17	30.78	71.21	1.65	6.0
9.35	1.6	25.02	20.18	30.79	69.5	1.64	7.9
9.37	1.61	18.06	20.19	30.81	76.13	1.64	5.8
9.37	1.62	21.19	20.21	30.82	73.96	1.63	6.7
9.38	1.63	12.3	20.22	30.83	77.29	1.63	4.2
9.38	1.64	14.75	20.24	30.85	74	1.62	5.0
9.4	1.65	21.51	20.25	30.86	74.83	1.62	6.8
9.4	1.67	14.58	20.26	30.87	80.13	1.61	4.7
9.42	1.68	9.32	20.27	30.88	80.96	1.61	3.3
9.43	1.69	12.21	20.29	30.9	81.42	1.6	4.1
9.43	1.7	5.89	20.3	30.91	91.79	1.6	2.0
9.45	1.71	7.48	20.31	30.92	88.17	1.6	2.6
9.45	1.72	12.65	20.32	30.93	81.71	1.59	4.2
9.47	1.74	6.43	20.33	30.94	90.88	1.59	2.2
9.48	1.75	3.13	20.34	30.95	93.75	1.59	1.2
9.48	1.76	7.78	20.35	30.96	91.38	1.59	2.5
9.5	1.77	11.68	20.36	30.97	85.17	1.58	3.8
9.52	1.78	12.38	20.37	30.98	83.33	1.58	4.0
9.52	1.79	18.83	20.38	30.99	76.13	1.58	6.0
9.53	1.8	24.41	20.39	30.99	71.88	1.58	7.7
9.53	1.81	8.9	20.4	31	74.04	1.58	3.4
9.55	1.82	15.96	20.41	31.01	77.75	1.58	5.2
9.57	1.83	14.5	20.41	31.02	81.38	1.58	4.7
9.57	1.84	15.32	20.42	31.03	84.17	1.58	4.8
9.58	1.85	12.07	20.43	31.03	82.92	1.58	4.0
9.58	1.86	14.51	20.43	31.04	75.46	1.58	4.9
9.6	1.87	19.35	20.44	31.05	76.21	1.58	6.2
9.6	1.88	19.22	20.45	31.05	74.88	1.58	6.2
9.62	1.89	15.81	20.45	31.06	77.13	1.58	5.2
9.62	1.9	22.1	20.46	31.07	79.58	1.58	6.8
9.62	1.91	4	20.46	31.07	87.58	1.58	1.7
9.63	1.92	22.31	20.47	31.08	86.21	1.59	6.6

9.63	1.93	18.05	20.47	31.08	78.96	1.59	5.7
9.63	1.95	17.78	20.48	31.09	74.83	1.59	5.8
9.63	1.96	17.76	20.48	31.1	76.54	1.59	5.7
9.63	1.97	17.55	20.49	31.1	79.42	1.59	5.6
9.63	1.99	8.26	20.49	31.11	87.04	1.6	2.8
9.63	2	27.03	20.49	31.11	76.71	1.6	8.2
9.63	2.02	0.37	20.5	31.12	84.38	1.6	0.8
9.63	2.03	30	20.5	31.12	69.04	1.61	9.3
9.63	2.05	17.84	20.5	31.13	80.42	1.61	5.6
9.63	2.07	14.02	20.51	31.13	85.58	1.61	4.4
9.62	2.09	18.9	20.51	31.14	79.17	1.62	6.0
9.62	2.11	14.5	20.51	31.14	79.71	1.62	4.8
9.6	2.13	11.76	20.52	31.15	79.83	1.63	4.0
9.6	2.15	22.86	20.52	31.15	77.04	1.63	7.1
9.58	2.17	11.93	20.52	31.15	80.71	1.64	4.0
9.57	2.2	10.41	20.53	31.16	82.88	1.64	3.6
9.55	2.22	16.09	20.53	31.16	80.83	1.64	5.2
9.55	2.25	11.87	20.53	31.17	86.08	1.65	3.8
9.53	2.28	11.87	20.53	31.17	86.08	1.65	3.8

2020 - 2030							
Horas de Sol	Precipitação	Radiação	Temperatura		Umidade	Velocidade do Vento	Evapotranspiração de Referência
horas/dia	mm	MJ/m2.dia	Min °C	Max °C	%	m/s	mm
9.52	2.175	16.74	21.28	31.91	70.58	1.66	5.8
9.5	2.205	20.54	21.28	31.92	71.29	1.66	6.8
9.47	2.235	20.11	21.29	31.92	79.71	1.67	6.4
9.45	2.265	19.22	21.29	31.92	79.75	1.68	6.1
9.43	2.295	9.25	21.29	31.93	90.38	1.68	3.0
9.42	2.335	19.25	21.3	31.93	74.17	1.68	6.3
9.38	2.365	18.41	21.3	31.93	74.58	1.69	6.1
9.37	2.405	16.08	21.31	31.93	83.83	1.69	5.1
9.33	2.445	19.01	21.31	31.94	77	1.7	6.2
9.32	2.485	14.11	21.31	31.94	83.92	1.71	4.6
9.28	2.525	15.26	21.32	31.94	72.54	1.71	5.3
9.25	2.565	18.79	21.32	31.94	72.79	1.72	6.3
9.23	2.605	20.08	21.33	31.95	77.46	1.72	6.4
9.2	2.655	20.26	21.34	31.95	76.75	1.73	6.5
9.17	2.695	19.65	21.34	31.95	76.96	1.73	6.3
9.13	2.745	20.77	21.35	31.95	72.33	1.74	6.8
9.1	2.785	19.25	21.35	31.95	79.67	1.74	6.1
9.07	2.835	7.88	21.36	31.95	88.46	1.75	2.7
9.03	2.885	20.91	21.37	31.95	81.29	1.76	6.5
9	2.935	20.74	21.37	31.95	77.67	1.76	6.6
8.97	2.985	17.33	21.38	31.95	82.63	1.76	5.5
8.93	3.035	21.38	21.38	31.96	76.13	1.77	6.8
8.9	3.085	20.65	21.39	31.96	73.79	1.78	6.7
8.87	3.145	20.48	21.4	31.96	72.17	1.78	6.8
8.83	3.195	18.52	21.41	31.95	74.58	1.79	6.1
8.8	3.245	20.51	21.41	31.95	71.25	1.79	6.8
8.77	3.305	18.46	21.42	31.95	73.67	1.79	6.2
8.73	3.355	18.16	21.43	31.95	68.92	1.8	6.3
8.7	3.415	21.72	21.43	31.95	70.21	1.81	7.2
8.67	3.475	19.02	21.44	31.95	74.33	1.81	6.3
8.63	3.525	18.48	21.45	31.95	70.58	1.81	6.3
8.58	3.585	19.3	21.46	31.94	71.21	1.82	6.5
8.55	3.645	20.38	21.46	31.94	75.83	1.82	6.6
8.52	3.705	18.94	21.47	31.94	81.92	1.83	6.0
8.48	3.765	20.01	21.48	31.94	76.71	1.83	6.5
8.45	3.825	20.91	21.48	31.93	71.96	1.84	6.9
8.42	3.885	21.85	21.49	31.93	74.04	1.84	7.1
8.38	3.955	21.68	21.5	31.92	73.42	1.84	7.1
8.35	4.015	19.34	21.5	31.92	78.13	1.85	6.2
8.32	4.075	23.84	21.51	31.91	66.67	1.85	7.9
8.28	4.145	21.31	21.52	31.91	77.08	1.86	6.8
8.25	4.205	17.04	21.52	31.9	83.13	1.86	5.4
8.22	4.275	21.49	21.53	31.9	73.17	1.86	7.0
8.18	4.335	22.38	21.53	31.89	73.04	1.86	7.3
8.15	4.405	22.64	21.54	31.88	71.92	1.87	7.4
8.12	4.465	20.58	21.55	31.88	74.17	1.87	6.7

8.08	4.535	21.86	21.55	31.87	71.21	1.88	7.2
8.05	4.605	20.83	21.56	31.86	72	1.88	6.9
8.02	4.675	21.88	21.56	31.85	76.79	1.88	7.0
7.98	4.735	17.03	21.56	31.84	83.38	1.88	5.4
7.95	4.805	12.35	21.57	31.83	76.08	1.88	4.5
7.92	4.875	22.64	21.57	31.82	69.17	1.89	7.5
7.88	4.945	23.55	21.58	31.81	67.75	1.89	7.8
7.87	5.015	23.24	21.58	31.8	73.21	1.89	7.5
7.83	5.085	22.16	21.58	31.79	72.04	1.89	7.2
7.8	5.155	15.93	21.58	31.78	81.17	1.89	5.2
7.77	5.235	22.57	21.59	31.77	76.13	1.9	7.2
7.75	5.305	21.34	21.59	31.76	75.21	1.9	6.9
7.72	5.375	15.36	21.59	31.74	73.58	1.9	5.4
7.68	5.445	21.67	21.59	31.73	73.08	1.9	7.1
7.67	5.515	19	21.59	31.72	75.38	1.9	6.2
7.63	5.585	23.81	21.6	31.7	69.08	1.91	7.8
7.62	5.655	19.59	21.6	31.69	76.54	1.91	6.4
7.58	5.735	20.13	21.6	31.67	74.79	1.91	6.6
7.57	5.805	20.29	21.6	31.66	74.13	1.91	6.6
7.53	5.875	20.05	21.6	31.64	71.63	1.91	6.7
7.52	5.945	20.13	21.6	31.63	73.17	1.91	6.6
7.48	6.015	24.96	21.6	31.61	72.71	1.91	7.9
7.47	6.085	21.16	21.6	31.59	79.58	1.91	6.6
7.45	6.155	23.91	21.6	31.57	70.75	1.91	7.7
7.42	6.225	24.5	21.6	31.56	65.04	1.91	8.1
7.4	6.295	25.31	21.6	31.54	70.17	1.91	8.1
7.38	6.365	23.9	21.59	31.52	75.67	1.91	7.5
7.35	6.435	18.44	21.59	31.5	74.38	1.92	6.1
7.33	6.505	23	21.59	31.48	70.04	1.92	7.5
7.32	6.575	24.39	21.59	31.46	69	1.92	7.9
7.3	6.635	22.71	21.59	31.44	73	1.92	7.3
7.28	6.705	24.84	21.59	31.42	68	1.92	8.1
7.27	6.775	21.92	21.59	31.4	69.08	1.92	7.3
7.23	6.835	18.89	21.58	31.38	70.83	1.92	6.4
7.22	6.905	24.61	21.58	31.36	67.88	1.92	8.0
7.2	6.965	24.68	21.58	31.34	66.96	1.92	8.1
7.18	7.025	19.29	21.58	31.32	70.08	1.92	6.5
7.17	7.095	20.53	21.58	31.3	69.67	1.92	6.9
7.15	7.155	17.91	21.57	31.27	73.42	1.92	6.0
7.13	7.215	22.57	21.57	31.25	71.13	1.92	7.3
7.12	7.275	21.78	21.57	31.23	72.04	1.92	7.1
7.1	7.325	24.69	21.57	31.21	69.54	1.92	8.0
7.08	7.385	26.08	21.56	31.18	67.04	1.92	8.4
7.07	7.445	23.77	21.56	31.16	69.58	1.93	7.7
7.05	7.495	23.59	21.56	31.14	72.08	1.93	7.6
7.03	7.555	24.74	21.55	31.11	70.96	1.93	7.9
7.02	7.605	24.7	21.55	31.09	68.29	1.93	8.0
7	7.655	22.63	21.55	31.06	70.92	1.93	7.3
6.98	7.705	23.76	21.54	31.04	70.46	1.93	7.7
6.97	7.765	23.65	21.54	31.01	72.13	1.93	7.6

6.95	7.805	24.54	21.53	30.99	65.88	1.93	8.0
6.93	7.855	25.66	21.53	30.96	67.63	1.93	8.3
6.92	7.905	24.57	21.52	30.94	72.33	1.93	7.8
6.9	7.955	22.81	21.52	30.91	71.71	1.94	7.3
6.88	7.995	24.48	21.51	30.89	68.83	1.94	7.9
6.87	8.045	25.45	21.5	30.86	68	1.94	8.2
6.85	8.085	25.15	21.5	30.83	69.54	1.94	8.0
6.83	8.125	23.58	21.49	30.81	70.83	1.94	7.6
6.82	8.165	24.62	21.48	30.78	66.42	1.94	8.0
6.8	8.205	24.58	21.47	30.75	66.71	1.95	8.0
6.77	8.245	25.08	21.47	30.72	67.33	1.95	8.1
6.75	8.285	20.61	21.46	30.7	71.33	1.95	6.8
6.73	8.325	25.04	21.45	30.67	66.33	1.95	8.1
6.72	8.355	23.66	21.44	30.64	69.58	1.96	7.6
6.7	8.395	25.43	21.43	30.61	66.63	1.96	8.2
6.68	8.435	22.6	21.41	30.58	68.38	1.96	7.4
6.67	8.465	24.59	21.4	30.55	65.54	1.97	8.0
6.65	8.495	21.65	21.39	30.53	69.63	1.97	7.1
6.63	8.535	24.69	21.38	30.5	69.21	1.97	7.9
6.62	8.565	25.82	21.36	30.47	65.63	1.98	8.3
6.6	8.595	23.69	21.35	30.44	68.83	1.98	7.6
6.57	8.625	25.93	21.33	30.41	67.88	1.98	8.3
6.55	8.655	25.59	21.31	30.38	65.17	1.99	8.3
6.53	8.695	20.6	21.3	30.35	68.38	1.99	6.9
6.52	8.725	23.7	21.28	30.32	70.04	2	7.6
6.5	8.755	23.08	21.26	30.29	70.5	2	7.4
6.48	8.785	22.32	21.24	30.26	70.88	2.01	7.2
6.47	8.805	24.03	21.22	30.22	71.42	2.01	7.6
6.45	8.835	21.37	21.2	30.19	75.38	2.02	6.7
6.43	8.865	15.29	21.18	30.16	76.25	2.02	5.1
6.42	8.895	16.18	21.15	30.13	78.38	2.03	5.3
6.4	8.925	17.04	21.13	30.1	78.96	2.03	5.5
6.38	8.955	17.55	21.11	30.07	72.5	2.04	5.9
6.37	8.985	23.69	21.08	30.03	69.54	2.04	7.6
6.37	9.015	25.7	21.06	30	70.08	2.05	8.1
6.35	9.045	23.27	21.03	29.97	71.58	2.06	7.4
6.33	9.075	22.63	21	29.94	75.46	2.06	7.0
6.32	9.105	23.68	20.97	29.91	72.25	2.07	7.4
6.32	9.135	22.81	20.94	29.87	71.67	2.08	7.2
6.3	9.165	24.47	20.91	29.84	72.96	2.08	7.6
6.28	9.205	23.45	20.88	29.81	75.21	2.09	7.2
6.28	9.235	24.28	20.85	29.78	69.88	2.1	7.7
6.27	9.265	25.26	20.82	29.74	70.71	2.11	7.9
6.25	9.295	22.59	20.79	29.71	73.83	2.11	7.1
6.25	9.335	22.93	20.76	29.68	76.46	2.12	7.0
6.23	9.365	23.76	20.72	29.64	69.33	2.13	7.6
6.23	9.405	16.38	20.69	29.61	71.5	2.14	5.6
6.23	9.435	23.29	20.66	29.58	70.88	2.14	7.4
6.22	9.475	25.07	20.62	29.55	66.13	2.15	8.0
6.22	9.505	27.13	20.59	29.51	62.33	2.16	8.7

6.22	9.545	23.72	20.55	29.48	65.58	2.17	7.7
6.2	9.585	19.18	20.52	29.45	80.83	2.18	5.9
6.2	9.625	16.17	20.48	29.42	73.33	2.19	5.4
6.2	9.655	25.81	20.45	29.39	64.58	2.19	8.3
6.2	9.695	23.72	20.41	29.35	68.5	2.2	7.5
6.2	9.735	23.86	20.37	29.32	68.42	2.21	7.6
6.2	9.775	23.69	20.34	29.29	70.83	2.22	7.4
6.2	9.815	23.7	20.3	29.26	70.08	2.23	7.5
6.2	9.855	14.71	20.26	29.23	70.25	2.24	5.2
6.2	9.895	24.97	20.23	29.2	66.29	2.25	7.9
6.2	9.935	25.62	20.19	29.17	62.96	2.26	8.3
6.2	9.965	23.59	20.15	29.14	68.25	2.27	7.5
6.2	10.005	25.16	20.12	29.11	70.92	2.28	7.8
6.2	10.045	26.32	20.08	29.08	65.96	2.29	8.3
6.2	10.085	27.13	20.04	29.05	64.75	2.29	8.5
6.22	10.115	26.19	20.01	29.02	73.33	2.31	7.9
6.22	10.155	20.07	19.97	29	75.63	2.31	6.3
6.22	10.185	23	19.93	28.97	72	2.32	7.2
6.22	10.215	24.48	19.9	28.94	67.21	2.33	7.7
6.23	10.245	22.3	19.86	28.91	70.25	2.34	7.1
6.23	10.275	16.24	19.83	28.89	72.21	2.35	5.5
6.23	10.305	19.1	19.79	28.86	69.38	2.36	6.3
6.25	10.325	21.28	19.76	28.84	73.96	2.37	6.6
6.25	10.345	19.61	19.72	28.81	69	2.38	6.5
6.27	10.365	22.14	19.69	28.79	67.04	2.39	7.2
6.27	10.385	25.24	19.66	28.77	65.88	2.4	8.0
6.28	10.395	23.75	19.63	28.75	72.83	2.41	7.3
6.28	10.415	6.21	19.59	28.72	84.58	2.42	2.4
6.3	10.415	23.53	19.56	28.7	79.67	2.43	6.9
6.3	10.425	23.61	19.53	28.68	74.54	2.43	7.1
6.32	10.425	24.21	19.5	28.66	70.29	2.44	7.5
6.33	10.425	25.56	19.47	28.64	73.17	2.45	7.7
6.33	10.415	24.02	19.44	28.62	73.46	2.46	7.3
6.35	10.405	25.85	19.41	28.61	69.38	2.47	7.9
6.37	10.395	25.41	19.38	28.59	72.33	2.48	7.7
6.37	10.375	24	19.35	28.57	72.96	2.48	7.3
6.38	10.345	23.85	19.33	28.56	67.38	2.49	7.5
6.4	10.325	20.3	19.3	28.54	70.29	2.5	6.5
6.42	10.295	26.94	19.27	28.53	65.46	2.51	8.4
6.42	10.255	25.77	19.25	28.52	66.67	2.51	8.0
6.43	10.215	26.98	19.22	28.51	65.67	2.52	8.4
6.45	10.165	9.96	19.2	28.49	80.83	2.53	3.5
6.47	10.115	25.05	19.18	28.48	73.54	2.54	7.5
6.48	10.065	13.08	19.15	28.47	82.46	2.54	4.2
6.5	10.005	24.28	19.13	28.46	73.83	2.55	7.3
6.52	9.935	23.93	19.11	28.46	70.29	2.55	7.4
6.53	9.875	27.92	19.09	28.45	72.96	2.56	8.2
6.55	9.795	24.79	19.07	28.44	69.54	2.57	7.6
6.57	9.725	29.04	19.05	28.44	71.92	2.57	8.5
6.58	9.635	9.74	19.03	28.43	86.17	2.58	3.2

6.6	9.555	21.06	19.02	28.43	85.33	2.58	5.9
6.62	9.465	9.49	19	28.43	87.42	2.59	3.1
6.63	9.365	7.21	18.99	28.42	85.71	2.59	2.6
6.65	9.265	28.05	18.97	28.42	71.75	2.59	8.3
6.67	9.165	22.01	18.96	28.42	73.67	2.6	6.8
6.68	9.065	21.86	18.94	28.42	70.71	2.6	6.9
6.72	8.955	30	18.93	28.43	69.83	2.61	8.9
6.73	8.845	9.95	18.92	28.43	74.13	2.61	3.9
6.75	8.725	11.86	18.91	28.43	78.08	2.61	4.1
6.77	8.615	10.39	18.9	28.43	89.29	2.61	3.2
6.8	8.495	25.25	18.9	28.44	79.5	2.61	7.2
6.82	8.365	15	18.89	28.45	79.17	2.62	4.8
6.83	8.245	18.89	18.88	28.45	81.71	2.62	5.6
6.85	8.115	15.54	18.88	28.46	85.33	2.62	4.6
6.88	7.995	24.94	18.88	28.47	78.83	2.62	7.2
6.9	7.865	21.02	18.87	28.48	76.33	2.62	6.4
6.92	7.735	17.97	18.87	28.49	75.04	2.62	5.7
6.95	7.605	29	18.87	28.5	70.04	2.62	8.6
6.97	7.475	19.54	18.87	28.51	73.67	2.62	6.2
6.98	7.345	20.05	18.87	28.52	74.58	2.62	6.3
7.02	7.205	13.92	18.88	28.54	76.29	2.62	4.7
7.03	7.075	30	18.88	28.55	75.04	2.62	8.6
7.07	6.945	10.79	18.89	28.57	77.33	2.61	3.9
7.08	6.815	15.56	18.89	28.58	71.92	2.61	5.3
7.1	6.685	18.86	18.9	28.6	70.25	2.61	6.2
7.13	6.555	12.8	18.91	28.62	76.46	2.61	4.4
7.15	6.425	11.38	18.92	28.64	81.54	2.61	3.9
7.18	6.305	8.64	18.93	28.66	86	2.6	3.0
7.2	6.175	11.2	18.94	28.68	82.25	2.6	3.8
7.23	6.055	25.58	18.95	28.7	70.75	2.59	7.8
7.25	5.935	27.62	18.97	28.72	68.63	2.59	8.4
7.28	5.815	20.11	18.98	28.74	73.63	2.58	6.3
7.3	5.695	26.96	19	28.76	72.29	2.58	8.1
7.33	5.585	20.04	19.02	28.79	71.88	2.57	6.4
7.35	5.465	22.22	19.04	28.81	70.63	2.57	7.0
7.38	5.355	7.73	19.05	28.84	78.38	2.56	3.1
7.4	5.245	12.49	19.07	28.87	80.83	2.56	4.2
7.43	5.135	18.37	19.09	28.89	81.17	2.55	5.6
7.45	5.035	19.24	19.12	28.92	79	2.54	5.9
7.48	4.935	18.24	19.14	28.95	71.21	2.53	6.0
7.5	4.835	21.9	19.16	28.98	76	2.53	6.7
7.53	4.735	10.15	19.19	29.01	85.08	2.52	3.4
7.57	4.635	12.18	19.21	29.04	86.75	2.51	3.8
7.58	4.545	30	19.24	29.07	76.13	2.5	8.6
7.62	4.455	15.72	19.26	29.1	80.71	2.49	5.0
7.65	4.365	22.96	19.29	29.14	78.42	2.48	6.8
7.67	4.275	23.42	19.31	29.17	76.79	2.48	7.0
7.7	4.195	23.38	19.34	29.2	78.42	2.46	6.9
7.73	4.105	27.19	19.37	29.24	74.21	2.46	8.1
7.77	4.025	19.92	19.4	29.27	80.67	2.44	6.0

7.78	3.945	12.74	19.43	29.31	84.83	2.44	4.0
7.82	3.875	8.99	19.45	29.34	87.75	2.43	3.0
7.85	3.795	10.07	19.48	29.38	87.96	2.41	3.2
7.88	3.725	10.63	19.51	29.42	88.13	2.4	3.4
7.92	3.645	11.63	19.54	29.46	87.38	2.39	3.7
7.95	3.575	6.34	19.57	29.49	90.42	2.38	2.2
7.98	3.505	13.24	19.6	29.53	87.5	2.37	4.1
8.02	3.435	23.4	19.63	29.57	79.17	2.36	7.0
8.03	3.365	20.24	19.66	29.61	82.46	2.34	6.0
8.07	3.305	21.81	19.69	29.65	80.96	2.33	6.5
8.1	3.235	21.47	19.72	29.69	75.96	2.32	6.7
8.13	3.175	18.02	19.75	29.73	79.38	2.31	5.6
8.17	3.105	18.16	19.78	29.77	76.17	2.29	5.8
8.2	3.045	22.19	19.8	29.81	74.38	2.28	6.9
8.23	2.985	23.72	19.83	29.85	73.42	2.27	7.4
8.27	2.915	20.88	19.86	29.89	73.21	2.26	6.7
8.3	2.855	9.04	19.89	29.93	84.79	2.24	3.2
8.33	2.795	10.14	19.92	29.97	91.04	2.23	3.1
8.37	2.735	17.46	19.94	30.01	77.79	2.22	5.6
8.4	2.685	22.22	19.97	30.05	78.5	2.21	6.8
8.43	2.625	22.07	20	30.1	80	2.19	6.7
8.47	2.565	20.65	20.02	30.14	76.92	2.18	6.5
8.5	2.505	22.21	20.05	30.18	78.92	2.16	6.8
8.53	2.455	20.83	20.07	30.22	77.38	2.15	6.5
8.57	2.395	13.02	20.1	30.26	82.54	2.14	4.3
8.6	2.345	9.97	20.12	30.3	88.04	2.13	3.3
8.63	2.295	19.07	20.15	30.34	76.88	2.11	6.1
8.67	2.245	18.03	20.17	30.38	80.54	2.1	5.6
8.7	2.195	19.54	20.19	30.41	81.5	2.08	6.0
8.72	2.145	18.52	20.22	30.45	78.63	2.07	5.9
8.75	2.095	17.18	20.24	30.49	79.92	2.06	5.5
8.78	2.045	17.44	20.26	30.53	78.08	2.04	5.6
8.8	2.005	17.81	20.28	30.57	75.33	2.03	5.8
8.83	1.955	18.18	20.31	30.6	81.38	2.02	5.7
8.87	1.915	16.09	20.33	30.64	83.67	2	5.0
8.88	1.875	23.27	20.35	30.68	76.5	1.99	7.2
8.92	1.835	15.41	20.37	30.71	72.38	1.98	5.3
8.93	1.795	21.68	20.39	30.75	68.92	1.96	7.1
8.97	1.755	13.62	20.41	30.78	70.13	1.95	5.0
8.98	1.715	30	20.43	30.82	70.58	1.94	9.2
9	1.685	8.54	20.45	30.85	77.67	1.93	3.3
9.02	1.655	6.58	20.46	30.88	84.42	1.91	2.5
9.05	1.625	9.88	20.48	30.92	88.13	1.9	3.2
9.07	1.595	17.37	20.5	30.95	85.38	1.89	5.3
9.08	1.575	18.55	20.52	30.98	77.13	1.88	6.0
9.1	1.545	15.55	20.54	31.01	75.75	1.86	5.2
9.12	1.525	13.16	20.55	31.04	75.96	1.85	4.6
9.13	1.505	14.42	20.57	31.07	81.13	1.84	4.7
9.15	1.485	17.46	20.59	31.09	80.08	1.83	5.6
9.15	1.465	19.52	20.61	31.12	78.13	1.82	6.2

9.17	1.455	18.81	20.62	31.15	78.17	1.81	6.0
9.18	1.445	17.08	20.64	31.17	74.25	1.8	5.7
9.2	1.435	19.14	20.66	31.2	72.58	1.79	6.3
9.2	1.425	24.17	20.67	31.22	75.92	1.78	7.5
9.22	1.415	13.69	20.69	31.25	84.17	1.76	4.4
9.23	1.405	13.91	20.71	31.27	82.88	1.76	4.5
9.23	1.405	19.65	20.72	31.29	78.46	1.74	6.2
9.25	1.405	16.94	20.74	31.32	76.54	1.74	5.6
9.27	1.405	12.72	20.76	31.34	80.67	1.73	4.3
9.27	1.405	16.98	20.77	31.36	73.46	1.72	5.7
9.28	1.405	18.87	20.79	31.38	80.88	1.71	5.9
9.28	1.405	15.93	20.8	31.4	83.25	1.7	5.0
9.3	1.405	12.86	20.82	31.42	81.79	1.69	4.3
9.3	1.415	26.03	20.83	31.43	76.08	1.68	8.0
9.32	1.425	17.11	20.85	31.45	80.17	1.68	5.5
9.32	1.425	16.81	20.86	31.47	82.46	1.67	5.3
9.33	1.435	5.38	20.88	31.49	83.33	1.66	2.2
9.33	1.445	17.81	20.89	31.5	74	1.66	5.9
9.35	1.455	18.24	20.91	31.52	71.21	1.65	6.1
9.35	1.465	25.02	20.92	31.53	69.5	1.64	8.0
9.37	1.475	18.06	20.93	31.55	76.13	1.64	5.9
9.37	1.485	21.19	20.95	31.56	73.96	1.63	6.8
9.38	1.495	12.3	20.96	31.57	77.29	1.63	4.3
9.38	1.505	14.75	20.98	31.59	74	1.62	5.1
9.4	1.515	21.51	20.99	31.6	74.83	1.62	6.9
9.4	1.535	14.58	21	31.61	80.13	1.61	4.8
9.42	1.545	9.32	21.01	31.62	80.96	1.61	3.4
9.43	1.555	12.21	21.03	31.64	81.42	1.6	4.1
9.43	1.565	5.89	21.04	31.65	91.79	1.6	2.0
9.45	1.575	7.48	21.05	31.66	88.17	1.6	2.6
9.45	1.585	12.65	21.06	31.67	81.71	1.59	4.2
9.47	1.605	6.43	21.07	31.68	90.88	1.59	2.2
9.48	1.615	3.13	21.08	31.69	93.75	1.59	1.2
9.48	1.625	7.78	21.09	31.7	91.38	1.59	2.6
9.5	1.635	11.68	21.1	31.71	85.17	1.58	3.8
9.52	1.645	12.38	21.11	31.72	83.33	1.58	4.1
9.52	1.655	18.83	21.12	31.73	76.13	1.58	6.1
9.53	1.665	24.41	21.13	31.73	71.88	1.58	7.8
9.53	1.675	8.9	21.14	31.74	74.04	1.58	3.5
9.55	1.685	15.96	21.15	31.75	77.75	1.58	5.3
9.57	1.695	14.5	21.15	31.76	81.38	1.58	4.7
9.57	1.705	15.32	21.16	31.77	84.17	1.58	4.9
9.58	1.715	12.07	21.17	31.77	82.92	1.58	4.0
9.58	1.725	14.51	21.17	31.78	75.46	1.58	5.0
9.6	1.735	19.35	21.18	31.79	76.21	1.58	6.3
9.6	1.745	19.22	21.19	31.79	74.88	1.58	6.3
9.62	1.755	15.81	21.19	31.8	77.13	1.58	5.3
9.62	1.765	22.1	21.2	31.81	79.58	1.58	6.9
9.62	1.775	4	21.2	31.81	87.58	1.58	1.7
9.63	1.785	22.31	21.21	31.82	86.21	1.59	6.7

9.63	1.795	18.05	21.21	31.82	78.96	1.59	5.8
9.63	1.815	17.78	21.22	31.83	74.83	1.59	5.9
9.63	1.825	17.76	21.22	31.84	76.54	1.59	5.8
9.63	1.835	17.55	21.23	31.84	79.42	1.59	5.7
9.63	1.855	8.26	21.23	31.85	87.04	1.6	2.9
9.63	1.865	27.03	21.23	31.85	76.71	1.6	8.3
9.63	1.885	0.37	21.24	31.86	84.38	1.6	0.8
9.63	1.895	30	21.24	31.86	69.04	1.61	9.4
9.63	1.915	17.84	21.24	31.87	80.42	1.61	5.7
9.63	1.935	14.02	21.25	31.87	85.58	1.61	4.5
9.62	1.955	18.9	21.25	31.88	79.17	1.62	6.0
9.62	1.975	14.5	21.25	31.88	79.71	1.62	4.8
9.6	1.995	11.76	21.26	31.89	79.83	1.63	4.1
9.6	2.015	22.86	21.26	31.89	77.04	1.63	7.2
9.58	2.035	11.93	21.26	31.89	80.71	1.64	4.1
9.57	2.065	10.41	21.27	31.9	82.88	1.64	3.6
9.55	2.085	16.09	21.27	31.9	80.83	1.64	5.2
9.55	2.115	11.87	21.27	31.91	86.08	1.65	3.9
9.53	2.145	11.87	21.27	31.91	86.08	1.65	3.9

2030 - 2040							
Horas de Sol	Precipitação	Radiação	Temperatura		Umidade	Velocidade do Vento	Evapotranspiração de Referência
horas/dia	mm	MJ/m2.dia	Min °C	Max °C	%	m/s	mm
9.52	2.04	16.74	22.02	32.65	70.58	1.66	5.9
9.5	2.07	20.54	22.02	32.66	71.29	1.66	6.9
9.47	2.1	20.11	22.03	32.66	79.71	1.67	6.4
9.45	2.13	19.22	22.03	32.66	79.75	1.68	6.2
9.43	2.16	9.25	22.03	32.67	90.38	1.68	3.1
9.42	2.2	19.25	22.04	32.67	74.17	1.68	6.4
9.38	2.23	18.41	22.04	32.67	74.58	1.69	6.2
9.37	2.27	16.08	22.05	32.67	83.83	1.69	5.2
9.33	2.31	19.01	22.05	32.68	77	1.7	6.2
9.32	2.35	14.11	22.05	32.68	83.92	1.71	4.6
9.28	2.39	15.26	22.06	32.68	72.54	1.71	5.4
9.25	2.43	18.79	22.06	32.68	72.79	1.72	6.4
9.23	2.47	20.08	22.07	32.69	77.46	1.72	6.5
9.2	2.52	20.26	22.08	32.69	76.75	1.73	6.6
9.17	2.56	19.65	22.08	32.69	76.96	1.73	6.4
9.13	2.61	20.77	22.09	32.69	72.33	1.74	6.9
9.1	2.65	19.25	22.09	32.69	79.67	1.74	6.2
9.07	2.7	7.88	22.1	32.69	88.46	1.75	2.8
9.03	2.75	20.91	22.11	32.69	81.29	1.76	6.6
9	2.8	20.74	22.11	32.69	77.67	1.76	6.7
8.97	2.85	17.33	22.12	32.69	82.63	1.76	5.6
8.93	2.9	21.38	22.12	32.7	76.13	1.77	6.9
8.9	2.95	20.65	22.13	32.7	73.79	1.78	6.8
8.87	3.01	20.48	22.14	32.7	72.17	1.78	6.9
8.83	3.06	18.52	22.15	32.69	74.58	1.79	6.2
8.8	3.11	20.51	22.15	32.69	71.25	1.79	6.9
8.77	3.17	18.46	22.16	32.69	73.67	1.79	6.3
8.73	3.22	18.16	22.17	32.69	68.92	1.8	6.4
8.7	3.28	21.72	22.17	32.69	70.21	1.81	7.3
8.67	3.34	19.02	22.18	32.69	74.33	1.81	6.4
8.63	3.39	18.48	22.19	32.69	70.58	1.81	6.4
8.58	3.45	19.3	22.2	32.68	71.21	1.82	6.6
8.55	3.51	20.38	22.2	32.68	75.83	1.82	6.7
8.52	3.57	18.94	22.21	32.68	81.92	1.83	6.0
8.48	3.63	20.01	22.22	32.68	76.71	1.83	6.6
8.45	3.69	20.91	22.22	32.67	71.96	1.84	7.0
8.42	3.75	21.85	22.23	32.67	74.04	1.84	7.2
8.38	3.82	21.68	22.24	32.66	73.42	1.84	7.1
8.35	3.88	19.34	22.24	32.66	78.13	1.85	6.3
8.32	3.94	23.84	22.25	32.65	66.67	1.85	8.0
8.28	4.01	21.31	22.26	32.65	77.08	1.86	6.9
8.25	4.07	17.04	22.26	32.64	83.13	1.86	5.5
8.22	4.14	21.49	22.27	32.64	73.17	1.86	7.1
8.18	4.2	22.38	22.27	32.63	73.04	1.86	7.4
8.15	4.27	22.64	22.28	32.62	71.92	1.87	7.5
8.12	4.33	20.58	22.29	32.62	74.17	1.87	6.8

8.08	4.4	21.86	22.29	32.61	71.21	1.88	7.3
8.05	4.47	20.83	22.3	32.6	72	1.88	7.0
8.02	4.54	21.88	22.3	32.59	76.79	1.88	7.1
7.98	4.6	17.03	22.3	32.58	83.38	1.88	5.5
7.95	4.67	12.35	22.31	32.57	76.08	1.88	4.5
7.92	4.74	22.64	22.31	32.56	69.17	1.89	7.6
7.88	4.81	23.55	22.32	32.55	67.75	1.89	7.9
7.87	4.88	23.24	22.32	32.54	73.21	1.89	7.6
7.83	4.95	22.16	22.32	32.53	72.04	1.89	7.3
7.8	5.02	15.93	22.32	32.52	81.17	1.89	5.3
7.77	5.1	22.57	22.33	32.51	76.13	1.9	7.3
7.75	5.17	21.34	22.33	32.5	75.21	1.9	7.0
7.72	5.24	15.36	22.33	32.48	73.58	1.9	5.4
7.68	5.31	21.67	22.33	32.47	73.08	1.9	7.2
7.67	5.38	19	22.33	32.46	75.38	1.9	6.3
7.63	5.45	23.81	22.34	32.44	69.08	1.91	7.9
7.62	5.52	19.59	22.34	32.43	76.54	1.91	6.4
7.58	5.6	20.13	22.34	32.41	74.79	1.91	6.7
7.57	5.67	20.29	22.34	32.4	74.13	1.91	6.7
7.53	5.74	20.05	22.34	32.38	71.63	1.91	6.8
7.52	5.81	20.13	22.34	32.37	73.17	1.91	6.7
7.48	5.88	24.96	22.34	32.35	72.71	1.91	8.0
7.47	5.95	21.16	22.34	32.33	79.58	1.91	6.7
7.45	6.02	23.91	22.34	32.31	70.75	1.91	7.8
7.42	6.09	24.5	22.34	32.3	65.04	1.91	8.2
7.4	6.16	25.31	22.34	32.28	70.17	1.91	8.2
7.38	6.23	23.9	22.33	32.26	75.67	1.91	7.6
7.35	6.3	18.44	22.33	32.24	74.38	1.92	6.2
7.33	6.37	23	22.33	32.22	70.04	1.92	7.6
7.32	6.44	24.39	22.33	32.2	69	1.92	8.0
7.3	6.5	22.71	22.33	32.18	73	1.92	7.4
7.28	6.57	24.84	22.33	32.16	68	1.92	8.2
7.27	6.64	21.92	22.33	32.14	69.08	1.92	7.4
7.23	6.7	18.89	22.32	32.12	70.83	1.92	6.5
7.22	6.77	24.61	22.32	32.1	67.88	1.92	8.1
7.2	6.83	24.68	22.32	32.08	66.96	1.92	8.2
7.18	6.89	19.29	22.32	32.06	70.08	1.92	6.6
7.17	6.96	20.53	22.32	32.04	69.67	1.92	7.0
7.15	7.02	17.91	22.31	32.01	73.42	1.92	6.1
7.13	7.08	22.57	22.31	31.99	71.13	1.92	7.4
7.12	7.14	21.78	22.31	31.97	72.04	1.92	7.2
7.1	7.19	24.69	22.31	31.95	69.54	1.92	8.1
7.08	7.25	26.08	22.3	31.92	67.04	1.92	8.5
7.07	7.31	23.77	22.3	31.9	69.58	1.93	7.8
7.05	7.36	23.59	22.3	31.88	72.08	1.93	7.7
7.03	7.42	24.74	22.29	31.85	70.96	1.93	8.0
7.02	7.47	24.7	22.29	31.83	68.29	1.93	8.1
7	7.52	22.63	22.29	31.8	70.92	1.93	7.4
6.98	7.57	23.76	22.28	31.78	70.46	1.93	7.8
6.97	7.63	23.65	22.28	31.75	72.13	1.93	7.7

6.95	7.67	24.54	22.27	31.73	65.88	1.93	8.2
6.93	7.72	25.66	22.27	31.7	67.63	1.93	8.4
6.92	7.77	24.57	22.26	31.68	72.33	1.93	7.9
6.9	7.82	22.81	22.26	31.65	71.71	1.94	7.4
6.88	7.86	24.48	22.25	31.63	68.83	1.94	8.0
6.87	7.91	25.45	22.24	31.6	68	1.94	8.3
6.85	7.95	25.15	22.24	31.57	69.54	1.94	8.1
6.83	7.99	23.58	22.23	31.55	70.83	1.94	7.7
6.82	8.03	24.62	22.22	31.52	66.42	1.94	8.1
6.8	8.07	24.58	22.21	31.49	66.71	1.95	8.1
6.77	8.11	25.08	22.21	31.46	67.33	1.95	8.2
6.75	8.15	20.61	22.2	31.44	71.33	1.95	6.9
6.73	8.19	25.04	22.19	31.41	66.33	1.95	8.2
6.72	8.22	23.66	22.18	31.38	69.58	1.96	7.7
6.7	8.26	25.43	22.17	31.35	66.63	1.96	8.3
6.68	8.3	22.6	22.15	31.32	68.38	1.96	7.5
6.67	8.33	24.59	22.14	31.29	65.54	1.97	8.1
6.65	8.36	21.65	22.13	31.27	69.63	1.97	7.2
6.63	8.4	24.69	22.12	31.24	69.21	1.97	8.0
6.62	8.43	25.82	22.1	31.21	65.63	1.98	8.5
6.6	8.46	23.69	22.09	31.18	68.83	1.98	7.8
6.57	8.49	25.93	22.07	31.15	67.88	1.98	8.4
6.55	8.52	25.59	22.05	31.12	65.17	1.99	8.4
6.53	8.56	20.6	22.04	31.09	68.38	1.99	7.0
6.52	8.59	23.7	22.02	31.06	70.04	2	7.7
6.5	8.62	23.08	22	31.03	70.5	2	7.5
6.48	8.65	22.32	21.98	31	70.88	2.01	7.3
6.47	8.67	24.03	21.96	30.96	71.42	2.01	7.7
6.45	8.7	21.37	21.94	30.93	75.38	2.02	6.8
6.43	8.73	15.29	21.92	30.9	76.25	2.02	5.2
6.42	8.76	16.18	21.89	30.87	78.38	2.03	5.3
6.4	8.79	17.04	21.87	30.84	78.96	2.03	5.5
6.38	8.82	17.55	21.85	30.81	72.5	2.04	5.9
6.37	8.85	23.69	21.82	30.77	69.54	2.04	7.7
6.37	8.88	25.7	21.8	30.74	70.08	2.05	8.2
6.35	8.91	23.27	21.77	30.71	71.58	2.06	7.5
6.33	8.94	22.63	21.74	30.68	75.46	2.06	7.1
6.32	8.97	23.68	21.71	30.65	72.25	2.07	7.5
6.32	9	22.81	21.68	30.61	71.67	2.08	7.3
6.3	9.03	24.47	21.65	30.58	72.96	2.08	7.7
6.28	9.07	23.45	21.62	30.55	75.21	2.09	7.3
6.28	9.1	24.28	21.59	30.52	69.88	2.1	7.8
6.27	9.13	25.26	21.56	30.48	70.71	2.11	8.0
6.25	9.16	22.59	21.53	30.45	73.83	2.11	7.2
6.25	9.2	22.93	21.5	30.42	76.46	2.12	7.1
6.23	9.23	23.76	21.46	30.38	69.33	2.13	7.7
6.23	9.27	16.38	21.43	30.35	71.5	2.14	5.7
6.23	9.3	23.29	21.4	30.32	70.88	2.14	7.5
6.22	9.34	25.07	21.36	30.29	66.13	2.15	8.1
6.22	9.37	27.13	21.33	30.25	62.33	2.16	8.8

6.22	9.41	23.72	21.29	30.22	65.58	2.17	7.8
6.2	9.45	19.18	21.26	30.19	80.83	2.18	5.9
6.2	9.49	16.17	21.22	30.16	73.33	2.19	5.5
6.2	9.52	25.81	21.19	30.13	64.58	2.19	8.4
6.2	9.56	23.72	21.15	30.09	68.5	2.2	7.7
6.2	9.6	23.86	21.11	30.06	68.42	2.21	7.7
6.2	9.64	23.69	21.08	30.03	70.83	2.22	7.5
6.2	9.68	23.7	21.04	30	70.08	2.23	7.6
6.2	9.72	14.71	21	29.97	70.25	2.24	5.3
6.2	9.76	24.97	20.97	29.94	66.29	2.25	8.1
6.2	9.8	25.62	20.93	29.91	62.96	2.26	8.4
6.2	9.83	23.59	20.89	29.88	68.25	2.27	7.6
6.2	9.87	25.16	20.86	29.85	70.92	2.28	7.9
6.2	9.91	26.32	20.82	29.82	65.96	2.29	8.4
6.2	9.95	27.13	20.78	29.79	64.75	2.29	8.7
6.22	9.98	26.19	20.75	29.76	73.33	2.31	8.0
6.22	10.02	20.07	20.71	29.74	75.63	2.31	6.4
6.22	10.05	23	20.67	29.71	72	2.32	7.3
6.22	10.08	24.48	20.64	29.68	67.21	2.33	7.9
6.23	10.11	22.3	20.6	29.65	70.25	2.34	7.2
6.23	10.14	16.24	20.57	29.63	72.21	2.35	5.6
6.23	10.17	19.1	20.53	29.6	69.38	2.36	6.4
6.25	10.19	21.28	20.5	29.58	73.96	2.37	6.7
6.25	10.21	19.61	20.46	29.55	69	2.38	6.6
6.27	10.23	22.14	20.43	29.53	67.04	2.39	7.3
6.27	10.25	25.24	20.4	29.51	65.88	2.4	8.1
6.28	10.26	23.75	20.37	29.49	72.83	2.41	7.4
6.28	10.28	6.21	20.33	29.46	84.58	2.42	2.5
6.3	10.28	23.53	20.3	29.44	79.67	2.43	7.0
6.3	10.29	23.61	20.27	29.42	74.54	2.43	7.3
6.32	10.29	24.21	20.24	29.4	70.29	2.44	7.6
6.33	10.29	25.56	20.21	29.38	73.17	2.45	7.8
6.33	10.28	24.02	20.18	29.36	73.46	2.46	7.4
6.35	10.27	25.85	20.15	29.35	69.38	2.47	8.1
6.37	10.26	25.41	20.12	29.33	72.33	2.48	7.8
6.37	10.24	24	20.09	29.31	72.96	2.48	7.4
6.38	10.21	23.85	20.07	29.3	67.38	2.49	7.7
6.4	10.19	20.3	20.04	29.28	70.29	2.5	6.6
6.42	10.16	26.94	20.01	29.27	65.46	2.51	8.5
6.42	10.12	25.77	19.99	29.26	66.67	2.51	8.2
6.43	10.08	26.98	19.96	29.25	65.67	2.52	8.5
6.45	10.03	9.96	19.94	29.23	80.83	2.53	3.6
6.47	9.98	25.05	19.92	29.22	73.54	2.54	7.6
6.48	9.93	13.08	19.89	29.21	82.46	2.54	4.3
6.5	9.87	24.28	19.87	29.2	73.83	2.55	7.4
6.52	9.8	23.93	19.85	29.2	70.29	2.55	7.5
6.53	9.74	27.92	19.83	29.19	72.96	2.56	8.3
6.55	9.66	24.79	19.81	29.18	69.54	2.57	7.8
6.57	9.59	29.04	19.79	29.18	71.92	2.57	8.7
6.58	9.5	9.74	19.77	29.17	86.17	2.58	3.3

6.6	9.42	21.06	19.76	29.17	85.33	2.58	6.0
6.62	9.33	9.49	19.74	29.17	87.42	2.59	3.1
6.63	9.23	7.21	19.73	29.16	85.71	2.59	2.7
6.65	9.13	28.05	19.71	29.16	71.75	2.59	8.4
6.67	9.03	22.01	19.7	29.16	73.67	2.6	6.9
6.68	8.93	21.86	19.68	29.16	70.71	2.6	7.0
6.72	8.82	30	19.67	29.17	69.83	2.61	9.0
6.73	8.71	9.95	19.66	29.17	74.13	2.61	3.9
6.75	8.59	11.86	19.65	29.17	78.08	2.61	4.2
6.77	8.48	10.39	19.64	29.17	89.29	2.61	3.3
6.8	8.36	25.25	19.64	29.18	79.5	2.61	7.3
6.82	8.23	15	19.63	29.19	79.17	2.62	4.9
6.83	8.11	18.89	19.62	29.19	81.71	2.62	5.7
6.85	7.98	15.54	19.62	29.2	85.33	2.62	4.7
6.88	7.86	24.94	19.62	29.21	78.83	2.62	7.3
6.9	7.73	21.02	19.61	29.22	76.33	2.62	6.5
6.92	7.6	17.97	19.61	29.23	75.04	2.62	5.8
6.95	7.47	29	19.61	29.24	70.04	2.62	8.8
6.97	7.34	19.54	19.61	29.25	73.67	2.62	6.3
6.98	7.21	20.05	19.61	29.26	74.58	2.62	6.4
7.02	7.07	13.92	19.62	29.28	76.29	2.62	4.8
7.03	6.94	30	19.62	29.29	75.04	2.62	8.7
7.07	6.81	10.79	19.63	29.31	77.33	2.61	4.0
7.08	6.68	15.56	19.63	29.32	71.92	2.61	5.4
7.1	6.55	18.86	19.64	29.34	70.25	2.61	6.3
7.13	6.42	12.8	19.65	29.36	76.46	2.61	4.5
7.15	6.29	11.38	19.66	29.38	81.54	2.61	3.9
7.18	6.17	8.64	19.67	29.4	86	2.6	3.0
7.2	6.04	11.2	19.68	29.42	82.25	2.6	3.8
7.23	5.92	25.58	19.69	29.44	70.75	2.59	7.9
7.25	5.8	27.62	19.71	29.46	68.63	2.59	8.5
7.28	5.68	20.11	19.72	29.48	73.63	2.58	6.4
7.3	5.56	26.96	19.74	29.5	72.29	2.58	8.2
7.33	5.45	20.04	19.76	29.53	71.88	2.57	6.5
7.35	5.33	22.22	19.78	29.55	70.63	2.57	7.1
7.38	5.22	7.73	19.79	29.58	78.38	2.56	3.2
7.4	5.11	12.49	19.81	29.61	80.83	2.56	4.2
7.43	5	18.37	19.83	29.63	81.17	2.55	5.6
7.45	4.9	19.24	19.86	29.66	79	2.54	6.0
7.48	4.8	18.24	19.88	29.69	71.21	2.53	6.1
7.5	4.7	21.9	19.9	29.72	76	2.53	6.8
7.53	4.6	10.15	19.93	29.75	85.08	2.52	3.4
7.57	4.5	12.18	19.95	29.78	86.75	2.51	3.9
7.58	4.41	30	19.98	29.81	76.13	2.5	8.8
7.62	4.32	15.72	20	29.84	80.71	2.49	5.0
7.65	4.23	22.96	20.03	29.88	78.42	2.48	6.9
7.67	4.14	23.42	20.05	29.91	76.79	2.48	7.1
7.7	4.06	23.38	20.08	29.94	78.42	2.46	7.1
7.73	3.97	27.19	20.11	29.98	74.21	2.46	8.2
7.77	3.89	19.92	20.14	30.01	80.67	2.44	6.1

7.78	3.81	12.74	20.17	30.05	84.83	2.44	4.1
7.82	3.74	8.99	20.19	30.08	87.75	2.43	3.0
7.85	3.66	10.07	20.22	30.12	87.96	2.41	3.3
7.88	3.59	10.63	20.25	30.16	88.13	2.4	3.4
7.92	3.51	11.63	20.28	30.2	87.38	2.39	3.7
7.95	3.44	6.34	20.31	30.23	90.42	2.38	2.2
7.98	3.37	13.24	20.34	30.27	87.5	2.37	4.1
8.02	3.3	23.4	20.37	30.31	79.17	2.36	7.1
8.03	3.23	20.24	20.4	30.35	82.46	2.34	6.1
8.07	3.17	21.81	20.43	30.39	80.96	2.33	6.6
8.1	3.1	21.47	20.46	30.43	75.96	2.32	6.8
8.13	3.04	18.02	20.49	30.47	79.38	2.31	5.7
8.17	2.97	18.16	20.52	30.51	76.17	2.29	5.9
8.2	2.91	22.19	20.54	30.55	74.38	2.28	7.0
8.23	2.85	23.72	20.57	30.59	73.42	2.27	7.5
8.27	2.78	20.88	20.6	30.63	73.21	2.26	6.8
8.3	2.72	9.04	20.63	30.67	84.79	2.24	3.2
8.33	2.66	10.14	20.66	30.71	91.04	2.23	3.2
8.37	2.6	17.46	20.68	30.75	77.79	2.22	5.7
8.4	2.55	22.22	20.71	30.79	78.5	2.21	6.9
8.43	2.49	22.07	20.74	30.84	80	2.19	6.8
8.47	2.43	20.65	20.76	30.88	76.92	2.18	6.5
8.5	2.37	22.21	20.79	30.92	78.92	2.16	6.9
8.53	2.32	20.83	20.81	30.96	77.38	2.15	6.6
8.57	2.26	13.02	20.84	31	82.54	2.14	4.3
8.6	2.21	9.97	20.86	31.04	88.04	2.13	3.3
8.63	2.16	19.07	20.89	31.08	76.88	2.11	6.2
8.67	2.11	18.03	20.91	31.12	80.54	2.1	5.7
8.7	2.06	19.54	20.93	31.15	81.5	2.08	6.1
8.72	2.01	18.52	20.96	31.19	78.63	2.07	5.9
8.75	1.96	17.18	20.98	31.23	79.92	2.06	5.5
8.78	1.91	17.44	21	31.27	78.08	2.04	5.7
8.8	1.87	17.81	21.02	31.31	75.33	2.03	5.9
8.83	1.82	18.18	21.05	31.34	81.38	2.02	5.7
8.87	1.78	16.09	21.07	31.38	83.67	2	5.1
8.88	1.74	23.27	21.09	31.42	76.5	1.99	7.3
8.92	1.7	15.41	21.11	31.45	72.38	1.98	5.4
8.93	1.66	21.68	21.13	31.49	68.92	1.96	7.2
8.97	1.62	13.62	21.15	31.52	70.13	1.95	5.0
8.98	1.58	30	21.17	31.56	70.58	1.94	9.3
9	1.55	8.54	21.19	31.59	77.67	1.93	3.4
9.02	1.52	6.58	21.2	31.62	84.42	1.91	2.6
9.05	1.49	9.88	21.22	31.66	88.13	1.9	3.3
9.07	1.46	17.37	21.24	31.69	85.38	1.89	5.4
9.08	1.44	18.55	21.26	31.72	77.13	1.88	6.0
9.1	1.41	15.55	21.28	31.75	75.75	1.86	5.3
9.12	1.39	13.16	21.29	31.78	75.96	1.85	4.7
9.13	1.37	14.42	21.31	31.81	81.13	1.84	4.8
9.15	1.35	17.46	21.33	31.83	80.08	1.83	5.6
9.15	1.33	19.52	21.35	31.86	78.13	1.82	6.3

9.17	1.32	18.81	21.36	31.89	78.17	1.81	6.1
9.18	1.31	17.08	21.38	31.91	74.25	1.8	5.8
9.2	1.3	19.14	21.4	31.94	72.58	1.79	6.4
9.2	1.29	24.17	21.41	31.96	75.92	1.78	7.6
9.22	1.28	13.69	21.43	31.99	84.17	1.76	4.5
9.23	1.27	13.91	21.45	32.01	82.88	1.76	4.6
9.23	1.27	19.65	21.46	32.03	78.46	1.74	6.3
9.25	1.27	16.94	21.48	32.06	76.54	1.74	5.6
9.27	1.27	12.72	21.5	32.08	80.67	1.73	4.3
9.27	1.27	16.98	21.51	32.1	73.46	1.72	5.8
9.28	1.27	18.87	21.53	32.12	80.88	1.71	6.0
9.28	1.27	15.93	21.54	32.14	83.25	1.7	5.1
9.3	1.27	12.86	21.56	32.16	81.79	1.69	4.3
9.3	1.28	26.03	21.57	32.17	76.08	1.68	8.1
9.32	1.29	17.11	21.59	32.19	80.17	1.68	5.6
9.32	1.29	16.81	21.6	32.21	82.46	1.67	5.4
9.33	1.3	5.38	21.62	32.23	83.33	1.66	2.3
9.33	1.31	17.81	21.63	32.24	74	1.66	6.0
9.35	1.32	18.24	21.65	32.26	71.21	1.65	6.2
9.35	1.33	25.02	21.66	32.27	69.5	1.64	8.1
9.37	1.34	18.06	21.67	32.29	76.13	1.64	6.0
9.37	1.35	21.19	21.69	32.3	73.96	1.63	6.9
9.38	1.36	12.3	21.7	32.31	77.29	1.63	4.4
9.38	1.37	14.75	21.72	32.33	74	1.62	5.1
9.4	1.38	21.51	21.73	32.34	74.83	1.62	7.0
9.4	1.4	14.58	21.74	32.35	80.13	1.61	4.9
9.42	1.41	9.32	21.75	32.36	80.96	1.61	3.4
9.43	1.42	12.21	21.77	32.38	81.42	1.6	4.2
9.43	1.43	5.89	21.78	32.39	91.79	1.6	2.1
9.45	1.44	7.48	21.79	32.4	88.17	1.6	2.6
9.45	1.45	12.65	21.8	32.41	81.71	1.59	4.3
9.47	1.47	6.43	21.81	32.42	90.88	1.59	2.2
9.48	1.48	3.13	21.82	32.43	93.75	1.59	1.2
9.48	1.49	7.78	21.83	32.44	91.38	1.59	2.6
9.5	1.5	11.68	21.84	32.45	85.17	1.58	3.9
9.52	1.51	12.38	21.85	32.46	83.33	1.58	4.2
9.52	1.52	18.83	21.86	32.47	76.13	1.58	6.2
9.53	1.53	24.41	21.87	32.47	71.88	1.58	7.9
9.53	1.54	8.9	21.88	32.48	74.04	1.58	3.5
9.55	1.55	15.96	21.89	32.49	77.75	1.58	5.3
9.57	1.56	14.5	21.89	32.5	81.38	1.58	4.8
9.57	1.57	15.32	21.9	32.51	84.17	1.58	4.9
9.58	1.58	12.07	21.91	32.51	82.92	1.58	4.1
9.58	1.59	14.51	21.91	32.52	75.46	1.58	5.0
9.6	1.6	19.35	21.92	32.53	76.21	1.58	6.3
9.6	1.61	19.22	21.93	32.53	74.88	1.58	6.3
9.62	1.62	15.81	21.93	32.54	77.13	1.58	5.3
9.62	1.63	22.1	21.94	32.55	79.58	1.58	7.0
9.62	1.64	4	21.94	32.55	87.58	1.58	1.7
9.63	1.65	22.31	21.95	32.56	86.21	1.59	6.8

9.63	1.66	18.05	21.95	32.56	78.96	1.59	5.9
9.63	1.68	17.78	21.96	32.57	74.83	1.59	6.0
9.63	1.69	17.76	21.96	32.58	76.54	1.59	5.9
9.63	1.7	17.55	21.97	32.58	79.42	1.59	5.7
9.63	1.72	8.26	21.97	32.59	87.04	1.6	2.9
9.63	1.73	27.03	21.97	32.59	76.71	1.6	8.4
9.63	1.75	0.37	21.98	32.6	84.38	1.6	0.8
9.63	1.76	30	21.98	32.6	69.04	1.61	9.5
9.63	1.78	17.84	21.98	32.61	80.42	1.61	5.8
9.63	1.8	14.02	21.99	32.61	85.58	1.61	4.5
9.62	1.82	18.9	21.99	32.62	79.17	1.62	6.1
9.62	1.84	14.5	21.99	32.62	79.71	1.62	4.9
9.6	1.86	11.76	22	32.63	79.83	1.63	4.1
9.6	1.88	22.86	22	32.63	77.04	1.63	7.3
9.58	1.9	11.93	22	32.63	80.71	1.64	4.2
9.57	1.93	10.41	22.01	32.64	82.88	1.64	3.7
9.55	1.95	16.09	22.01	32.64	80.83	1.64	5.3
9.55	1.98	11.87	22.01	32.65	86.08	1.65	3.9
9.53	2.01	11.87	22.01	32.65	86.08	1.65	3.9

2040 - 2050							
Horas de Sol	Precipitação	Radiação	Temperatura		Umidade	Velocidade do Vento	Evapotranspiração de Referência
horas/dia	mm	MJ/m2.dia	Min °C	Max °C	%	m/s	mm
9.52	1.905	16.74	22.76	33.39	70.58	1.66	5.9
9.5	1.935	20.54	22.76	33.4	71.29	1.66	7.0
9.47	1.965	20.11	22.77	33.4	79.71	1.67	6.5
9.45	1.995	19.22	22.77	33.4	79.75	1.68	6.3
9.43	2.025	9.25	22.77	33.41	90.38	1.68	3.1
9.42	2.065	19.25	22.78	33.41	74.17	1.68	6.5
9.38	2.095	18.41	22.78	33.41	74.58	1.69	6.3
9.37	2.135	16.08	22.79	33.41	83.83	1.69	5.2
9.33	2.175	19.01	22.79	33.42	77	1.7	6.3
9.32	2.215	14.11	22.79	33.42	83.92	1.71	4.7
9.28	2.255	15.26	22.8	33.42	72.54	1.71	5.5
9.25	2.295	18.79	22.8	33.42	72.79	1.72	6.4
9.23	2.335	20.08	22.81	33.43	77.46	1.72	6.6
9.2	2.385	20.26	22.82	33.43	76.75	1.73	6.7
9.17	2.425	19.65	22.82	33.43	76.96	1.73	6.5
9.13	2.475	20.77	22.83	33.43	72.33	1.74	7.0
9.1	2.515	19.25	22.83	33.43	79.67	1.74	6.3
9.07	2.565	7.88	22.84	33.43	88.46	1.75	2.8
9.03	2.615	20.91	22.85	33.43	81.29	1.76	6.7
9	2.665	20.74	22.85	33.43	77.67	1.76	6.8
8.97	2.715	17.33	22.86	33.43	82.63	1.76	5.6
8.93	2.765	21.38	22.86	33.44	76.13	1.77	7.0
8.9	2.815	20.65	22.87	33.44	73.79	1.78	6.9
8.87	2.875	20.48	22.88	33.44	72.17	1.78	6.9
8.83	2.925	18.52	22.89	33.43	74.58	1.79	6.3
8.8	2.975	20.51	22.89	33.43	71.25	1.79	7.0
8.77	3.035	18.46	22.9	33.43	73.67	1.79	6.3
8.73	3.085	18.16	22.91	33.43	68.92	1.8	6.5
8.7	3.145	21.72	22.91	33.43	70.21	1.81	7.4
8.67	3.205	19.02	22.92	33.43	74.33	1.81	6.5
8.63	3.255	18.48	22.93	33.43	70.58	1.81	6.5
8.58	3.315	19.3	22.94	33.42	71.21	1.82	6.7
8.55	3.375	20.38	22.94	33.42	75.83	1.82	6.8
8.52	3.435	18.94	22.95	33.42	81.92	1.83	6.1
8.48	3.495	20.01	22.96	33.42	76.71	1.83	6.6
8.45	3.555	20.91	22.96	33.41	71.96	1.84	7.1
8.42	3.615	21.85	22.97	33.41	74.04	1.84	7.3
8.38	3.685	21.68	22.98	33.4	73.42	1.84	7.2
8.35	3.745	19.34	22.98	33.4	78.13	1.85	6.4
8.32	3.805	23.84	22.99	33.39	66.67	1.85	8.1
8.28	3.875	21.31	23	33.39	77.08	1.86	7.0
8.25	3.935	17.04	23	33.38	83.13	1.86	5.6
8.22	4.005	21.49	23.01	33.38	73.17	1.86	7.2
8.18	4.065	22.38	23.01	33.37	73.04	1.86	7.4
8.15	4.135	22.64	23.02	33.36	71.92	1.87	7.6
8.12	4.195	20.58	23.03	33.36	74.17	1.87	6.9

8.08	4.265	21.86	23.03	33.35	71.21	1.88	7.4
8.05	4.335	20.83	23.04	33.34	72	1.88	7.1
8.02	4.405	21.88	23.04	33.33	76.79	1.88	7.1
7.98	4.465	17.03	23.04	33.32	83.38	1.88	5.5
7.95	4.535	12.35	23.05	33.31	76.08	1.88	4.6
7.92	4.605	22.64	23.05	33.3	69.17	1.89	7.7
7.88	4.675	23.55	23.06	33.29	67.75	1.89	8.0
7.87	4.745	23.24	23.06	33.28	73.21	1.89	7.7
7.83	4.815	22.16	23.06	33.27	72.04	1.89	7.4
7.8	4.885	15.93	23.06	33.26	81.17	1.89	5.3
7.77	4.965	22.57	23.07	33.25	76.13	1.9	7.4
7.75	5.035	21.34	23.07	33.24	75.21	1.9	7.1
7.72	5.105	15.36	23.07	33.22	73.58	1.9	5.5
7.68	5.175	21.67	23.07	33.21	73.08	1.9	7.2
7.67	5.245	19	23.07	33.2	75.38	1.9	6.4
7.63	5.315	23.81	23.08	33.18	69.08	1.91	8.0
7.62	5.385	19.59	23.08	33.17	76.54	1.91	6.5
7.58	5.465	20.13	23.08	33.15	74.79	1.91	6.7
7.57	5.535	20.29	23.08	33.14	74.13	1.91	6.8
7.53	5.605	20.05	23.08	33.12	71.63	1.91	6.9
7.52	5.675	20.13	23.08	33.11	73.17	1.91	6.8
7.48	5.745	24.96	23.08	33.09	72.71	1.91	8.1
7.47	5.815	21.16	23.08	33.07	79.58	1.91	6.8
7.45	5.885	23.91	23.08	33.05	70.75	1.91	7.9
7.42	5.955	24.5	23.08	33.04	65.04	1.91	8.4
7.4	6.025	25.31	23.08	33.02	70.17	1.91	8.3
7.38	6.095	23.9	23.07	33	75.67	1.91	7.7
7.35	6.165	18.44	23.07	32.98	74.38	1.92	6.3
7.33	6.235	23	23.07	32.96	70.04	1.92	7.7
7.32	6.305	24.39	23.07	32.94	69	1.92	8.1
7.3	6.365	22.71	23.07	32.92	73	1.92	7.5
7.28	6.435	24.84	23.07	32.9	68	1.92	8.3
7.27	6.505	21.92	23.07	32.88	69.08	1.92	7.5
7.23	6.565	18.89	23.06	32.86	70.83	1.92	6.6
7.22	6.635	24.61	23.06	32.84	67.88	1.92	8.2
7.2	6.695	24.68	23.06	32.82	66.96	1.92	8.3
7.18	6.755	19.29	23.06	32.8	70.08	1.92	6.7
7.17	6.825	20.53	23.06	32.78	69.67	1.92	7.0
7.15	6.885	17.91	23.05	32.75	73.42	1.92	6.2
7.13	6.945	22.57	23.05	32.73	71.13	1.92	7.5
7.12	7.005	21.78	23.05	32.71	72.04	1.92	7.3
7.1	7.055	24.69	23.05	32.69	69.54	1.92	8.2
7.08	7.115	26.08	23.04	32.66	67.04	1.92	8.7
7.07	7.175	23.77	23.04	32.64	69.58	1.93	7.9
7.05	7.225	23.59	23.04	32.62	72.08	1.93	7.8
7.03	7.285	24.74	23.03	32.59	70.96	1.93	8.1
7.02	7.335	24.7	23.03	32.57	68.29	1.93	8.2
7	7.385	22.63	23.03	32.54	70.92	1.93	7.5
6.98	7.435	23.76	23.02	32.52	70.46	1.93	7.9
6.97	7.495	23.65	23.02	32.49	72.13	1.93	7.8

6.95	7.535	24.54	23.01	32.47	65.88	1.93	8.3
6.93	7.585	25.66	23.01	32.44	67.63	1.93	8.5
6.92	7.635	24.57	23	32.42	72.33	1.93	8.0
6.9	7.685	22.81	23	32.39	71.71	1.94	7.5
6.88	7.725	24.48	22.99	32.37	68.83	1.94	8.1
6.87	7.775	25.45	22.98	32.34	68	1.94	8.4
6.85	7.815	25.15	22.98	32.31	69.54	1.94	8.3
6.83	7.855	23.58	22.97	32.29	70.83	1.94	7.8
6.82	7.895	24.62	22.96	32.26	66.42	1.94	8.2
6.8	7.935	24.58	22.95	32.23	66.71	1.95	8.2
6.77	7.975	25.08	22.95	32.2	67.33	1.95	8.3
6.75	8.015	20.61	22.94	32.18	71.33	1.95	6.9
6.73	8.055	25.04	22.93	32.15	66.33	1.95	8.4
6.72	8.085	23.66	22.92	32.12	69.58	1.96	7.8
6.7	8.125	25.43	22.91	32.09	66.63	1.96	8.4
6.68	8.165	22.6	22.89	32.06	68.38	1.96	7.6
6.67	8.195	24.59	22.88	32.03	65.54	1.97	8.3
6.65	8.225	21.65	22.87	32.01	69.63	1.97	7.3
6.63	8.265	24.69	22.86	31.98	69.21	1.97	8.1
6.62	8.295	25.82	22.84	31.95	65.63	1.98	8.6
6.6	8.325	23.69	22.83	31.92	68.83	1.98	7.9
6.57	8.355	25.93	22.81	31.89	67.88	1.98	8.5
6.55	8.385	25.59	22.79	31.86	65.17	1.99	8.5
6.53	8.425	20.6	22.78	31.83	68.38	1.99	7.0
6.52	8.455	23.7	22.76	31.8	70.04	2	7.8
6.5	8.485	23.08	22.74	31.77	70.5	2	7.6
6.48	8.515	22.32	22.72	31.74	70.88	2.01	7.4
6.47	8.535	24.03	22.7	31.7	71.42	2.01	7.8
6.45	8.565	21.37	22.68	31.67	75.38	2.02	6.9
6.43	8.595	15.29	22.66	31.64	76.25	2.02	5.3
6.42	8.625	16.18	22.63	31.61	78.38	2.03	5.4
6.4	8.655	17.04	22.61	31.58	78.96	2.03	5.6
6.38	8.685	17.55	22.59	31.55	72.5	2.04	6.0
6.37	8.715	23.69	22.56	31.51	69.54	2.04	7.8
6.37	8.745	25.7	22.54	31.48	70.08	2.05	8.3
6.35	8.775	23.27	22.51	31.45	71.58	2.06	7.6
6.33	8.805	22.63	22.48	31.42	75.46	2.06	7.2
6.32	8.835	23.68	22.45	31.39	72.25	2.07	7.6
6.32	8.865	22.81	22.42	31.35	71.67	2.08	7.4
6.3	8.895	24.47	22.39	31.32	72.96	2.08	7.8
6.28	8.935	23.45	22.36	31.29	75.21	2.09	7.4
6.28	8.965	24.28	22.33	31.26	69.88	2.1	7.9
6.27	8.995	25.26	22.3	31.22	70.71	2.11	8.1
6.25	9.025	22.59	22.27	31.19	73.83	2.11	7.3
6.25	9.065	22.93	22.24	31.16	76.46	2.12	7.2
6.23	9.095	23.76	22.2	31.12	69.33	2.13	7.8
6.23	9.135	16.38	22.17	31.09	71.5	2.14	5.7
6.23	9.165	23.29	22.14	31.06	70.88	2.14	7.6
6.22	9.205	25.07	22.1	31.03	66.13	2.15	8.3
6.22	9.235	27.13	22.07	30.99	62.33	2.16	9.0

6.22	9.275	23.72	22.03	30.96	65.58	2.17	7.9
6.2	9.315	19.18	22	30.93	80.83	2.18	6.0
6.2	9.355	16.17	21.96	30.9	73.33	2.19	5.6
6.2	9.385	25.81	21.93	30.87	64.58	2.19	8.5
6.2	9.425	23.72	21.89	30.83	68.5	2.2	7.8
6.2	9.465	23.86	21.85	30.8	68.42	2.21	7.8
6.2	9.505	23.69	21.82	30.77	70.83	2.22	7.6
6.2	9.545	23.7	21.78	30.74	70.08	2.23	7.7
6.2	9.585	14.71	21.74	30.71	70.25	2.24	5.4
6.2	9.625	24.97	21.71	30.68	66.29	2.25	8.2
6.2	9.665	25.62	21.67	30.65	62.96	2.26	8.5
6.2	9.695	23.59	21.63	30.62	68.25	2.27	7.7
6.2	9.735	25.16	21.6	30.59	70.92	2.28	8.0
6.2	9.775	26.32	21.56	30.56	65.96	2.29	8.5
6.2	9.815	27.13	21.52	30.53	64.75	2.29	8.8
6.22	9.845	26.19	21.49	30.5	73.33	2.31	8.1
6.22	9.885	20.07	21.45	30.48	75.63	2.31	6.5
6.22	9.915	23	21.41	30.45	72	2.32	7.4
6.22	9.945	24.48	21.38	30.42	67.21	2.33	8.0
6.23	9.975	22.3	21.34	30.39	70.25	2.34	7.3
6.23	10.005	16.24	21.31	30.37	72.21	2.35	5.6
6.23	10.035	19.1	21.27	30.34	69.38	2.36	6.5
6.25	10.055	21.28	21.24	30.32	73.96	2.37	6.8
6.25	10.075	19.61	21.2	30.29	69	2.38	6.7
6.27	10.095	22.14	21.17	30.27	67.04	2.39	7.4
6.27	10.115	25.24	21.14	30.25	65.88	2.4	8.2
6.28	10.125	23.75	21.11	30.23	72.83	2.41	7.5
6.28	10.145	6.21	21.07	30.2	84.58	2.42	2.5
6.3	10.145	23.53	21.04	30.18	79.67	2.43	7.1
6.3	10.155	23.61	21.01	30.16	74.54	2.43	7.4
6.32	10.155	24.21	20.98	30.14	70.29	2.44	7.7
6.33	10.155	25.56	20.95	30.12	73.17	2.45	7.9
6.33	10.145	24.02	20.92	30.1	73.46	2.46	7.5
6.35	10.135	25.85	20.89	30.09	69.38	2.47	8.2
6.37	10.125	25.41	20.86	30.07	72.33	2.48	7.9
6.37	10.105	24	20.83	30.05	72.96	2.48	7.5
6.38	10.075	23.85	20.81	30.04	67.38	2.49	7.8
6.4	10.055	20.3	20.78	30.02	70.29	2.5	6.7
6.42	10.025	26.94	20.75	30.01	65.46	2.51	8.6
6.42	9.985	25.77	20.73	30	66.67	2.51	8.3
6.43	9.945	26.98	20.7	29.99	65.67	2.52	8.6
6.45	9.895	9.96	20.68	29.97	80.83	2.53	3.6
6.47	9.845	25.05	20.66	29.96	73.54	2.54	7.7
6.48	9.795	13.08	20.63	29.95	82.46	2.54	4.3
6.5	9.735	24.28	20.61	29.94	73.83	2.55	7.5
6.52	9.665	23.93	20.59	29.94	70.29	2.55	7.6
6.53	9.605	27.92	20.57	29.93	72.96	2.56	8.5
6.55	9.525	24.79	20.55	29.92	69.54	2.57	7.9
6.57	9.455	29.04	20.53	29.92	71.92	2.57	8.8
6.58	9.365	9.74	20.51	29.91	86.17	2.58	3.3

6.6	9.285	21.06	20.5	29.91	85.33	2.58	6.1
6.62	9.195	9.49	20.48	29.91	87.42	2.59	3.2
6.63	9.095	7.21	20.47	29.9	85.71	2.59	2.7
6.65	8.995	28.05	20.45	29.9	71.75	2.59	8.6
6.67	8.895	22.01	20.44	29.9	73.67	2.6	7.0
6.68	8.795	21.86	20.42	29.9	70.71	2.6	7.1
6.72	8.685	30	20.41	29.91	69.83	2.61	9.1
6.73	8.575	9.95	20.4	29.91	74.13	2.61	4.0
6.75	8.455	11.86	20.39	29.91	78.08	2.61	4.3
6.77	8.345	10.39	20.38	29.91	89.29	2.61	3.3
6.8	8.225	25.25	20.38	29.92	79.5	2.61	7.5
6.82	8.095	15	20.37	29.93	79.17	2.62	5.0
6.83	7.975	18.89	20.36	29.93	81.71	2.62	5.8
6.85	7.845	15.54	20.36	29.94	85.33	2.62	4.8
6.88	7.725	24.94	20.36	29.95	78.83	2.62	7.4
6.9	7.595	21.02	20.35	29.96	76.33	2.62	6.6
6.92	7.465	17.97	20.35	29.97	75.04	2.62	5.9
6.95	7.335	29	20.35	29.98	70.04	2.62	8.9
6.97	7.205	19.54	20.35	29.99	73.67	2.62	6.4
6.98	7.075	20.05	20.35	30	74.58	2.62	6.5
7.02	6.935	13.92	20.36	30.02	76.29	2.62	4.9
7.03	6.805	30	20.36	30.03	75.04	2.62	8.9
7.07	6.675	10.79	20.37	30.05	77.33	2.61	4.1
7.08	6.545	15.56	20.37	30.06	71.92	2.61	5.5
7.1	6.415	18.86	20.38	30.08	70.25	2.61	6.4
7.13	6.285	12.8	20.39	30.1	76.46	2.61	4.6
7.15	6.155	11.38	20.4	30.12	81.54	2.61	4.0
7.18	6.035	8.64	20.41	30.14	86	2.6	3.1
7.2	5.905	11.2	20.42	30.16	82.25	2.6	3.9
7.23	5.785	25.58	20.43	30.18	70.75	2.59	8.0
7.25	5.665	27.62	20.45	30.2	68.63	2.59	8.7
7.28	5.545	20.11	20.46	30.22	73.63	2.58	6.6
7.3	5.425	26.96	20.48	30.24	72.29	2.58	8.3
7.33	5.315	20.04	20.5	30.27	71.88	2.57	6.6
7.35	5.195	22.22	20.52	30.29	70.63	2.57	7.2
7.38	5.085	7.73	20.53	30.32	78.38	2.56	3.2
7.4	4.975	12.49	20.55	30.35	80.83	2.56	4.3
7.43	4.865	18.37	20.57	30.37	81.17	2.55	5.7
7.45	4.765	19.24	20.6	30.4	79	2.54	6.1
7.48	4.665	18.24	20.62	30.43	71.21	2.53	6.2
7.5	4.565	21.9	20.64	30.46	76	2.53	6.9
7.53	4.465	10.15	20.67	30.49	85.08	2.52	3.5
7.57	4.365	12.18	20.69	30.52	86.75	2.51	3.9
7.58	4.275	30	20.72	30.55	76.13	2.5	8.9
7.62	4.185	15.72	20.74	30.58	80.71	2.49	5.1
7.65	4.095	22.96	20.77	30.62	78.42	2.48	7.1
7.67	4.005	23.42	20.79	30.65	76.79	2.48	7.3
7.7	3.925	23.38	20.82	30.68	78.42	2.46	7.2
7.73	3.835	27.19	20.85	30.72	74.21	2.46	8.3
7.77	3.755	19.92	20.88	30.75	80.67	2.44	6.2

7.78	3.675	12.74	20.91	30.79	84.83	2.44	4.2
7.82	3.605	8.99	20.93	30.82	87.75	2.43	3.1
7.85	3.525	10.07	20.96	30.86	87.96	2.41	3.3
7.88	3.455	10.63	20.99	30.9	88.13	2.4	3.5
7.92	3.375	11.63	21.02	30.94	87.38	2.39	3.8
7.95	3.305	6.34	21.05	30.97	90.42	2.38	2.3
7.98	3.235	13.24	21.08	31.01	87.5	2.37	4.2
8.02	3.165	23.4	21.11	31.05	79.17	2.36	7.2
8.03	3.095	20.24	21.14	31.09	82.46	2.34	6.2
8.07	3.035	21.81	21.17	31.13	80.96	2.33	6.7
8.1	2.965	21.47	21.2	31.17	75.96	2.32	6.9
8.13	2.905	18.02	21.23	31.21	79.38	2.31	5.8
8.17	2.835	18.16	21.26	31.25	76.17	2.29	6.0
8.2	2.775	22.19	21.28	31.29	74.38	2.28	7.1
8.23	2.715	23.72	21.31	31.33	73.42	2.27	7.6
8.27	2.645	20.88	21.34	31.37	73.21	2.26	6.9
8.3	2.585	9.04	21.37	31.41	84.79	2.24	3.3
8.33	2.525	10.14	21.4	31.45	91.04	2.23	3.2
8.37	2.465	17.46	21.42	31.49	77.79	2.22	5.8
8.4	2.415	22.22	21.45	31.53	78.5	2.21	7.0
8.43	2.355	22.07	21.48	31.58	80	2.19	6.9
8.47	2.295	20.65	21.5	31.62	76.92	2.18	6.6
8.5	2.235	22.21	21.53	31.66	78.92	2.16	7.0
8.53	2.185	20.83	21.55	31.7	77.38	2.15	6.7
8.57	2.125	13.02	21.58	31.74	82.54	2.14	4.4
8.6	2.075	9.97	21.6	31.78	88.04	2.13	3.3
8.63	2.025	19.07	21.63	31.82	76.88	2.11	6.2
8.67	1.975	18.03	21.65	31.86	80.54	2.1	5.8
8.7	1.925	19.54	21.67	31.89	81.5	2.08	6.2
8.72	1.875	18.52	21.7	31.93	78.63	2.07	6.0
8.75	1.825	17.18	21.72	31.97	79.92	2.06	5.6
8.78	1.775	17.44	21.74	32.01	78.08	2.04	5.8
8.8	1.735	17.81	21.76	32.05	75.33	2.03	6.0
8.83	1.685	18.18	21.79	32.08	81.38	2.02	5.8
8.87	1.645	16.09	21.81	32.12	83.67	2	5.2
8.88	1.605	23.27	21.83	32.16	76.5	1.99	7.4
8.92	1.565	15.41	21.85	32.19	72.38	1.98	5.5
8.93	1.525	21.68	21.87	32.23	68.92	1.96	7.3
8.97	1.485	13.62	21.89	32.26	70.13	1.95	5.1
8.98	1.445	30	21.91	32.3	70.58	1.94	9.5
9	1.415	8.54	21.93	32.33	77.67	1.93	3.4
9.02	1.385	6.58	21.94	32.36	84.42	1.91	2.6
9.05	1.355	9.88	21.96	32.4	88.13	1.9	3.3
9.07	1.325	17.37	21.98	32.43	85.38	1.89	5.5
9.08	1.305	18.55	22	32.46	77.13	1.88	6.1
9.1	1.275	15.55	22.02	32.49	75.75	1.86	5.4
9.12	1.255	13.16	22.03	32.52	75.96	1.85	4.7
9.13	1.235	14.42	22.05	32.55	81.13	1.84	4.8
9.15	1.215	17.46	22.07	32.57	80.08	1.83	5.7
9.15	1.195	19.52	22.09	32.6	78.13	1.82	6.4

9.17	1.185	18.81	22.1	32.63	78.17	1.81	6.2
9.18	1.175	17.08	22.12	32.65	74.25	1.8	5.9
9.2	1.165	19.14	22.14	32.68	72.58	1.79	6.5
9.2	1.155	24.17	22.15	32.7	75.92	1.78	7.7
9.22	1.145	13.69	22.17	32.73	84.17	1.76	4.5
9.23	1.135	13.91	22.19	32.75	82.88	1.76	4.6
9.23	1.135	19.65	22.2	32.77	78.46	1.74	6.4
9.25	1.135	16.94	22.22	32.8	76.54	1.74	5.7
9.27	1.135	12.72	22.24	32.82	80.67	1.73	4.4
9.27	1.135	16.98	22.25	32.84	73.46	1.72	5.9
9.28	1.135	18.87	22.27	32.86	80.88	1.71	6.1
9.28	1.135	15.93	22.28	32.88	83.25	1.7	5.2
9.3	1.135	12.86	22.3	32.9	81.79	1.69	4.4
9.3	1.145	26.03	22.31	32.91	76.08	1.68	8.2
9.32	1.155	17.11	22.33	32.93	80.17	1.68	5.6
9.32	1.155	16.81	22.34	32.95	82.46	1.67	5.5
9.33	1.165	5.38	22.36	32.97	83.33	1.66	2.3
9.33	1.175	17.81	22.37	32.98	74	1.66	6.1
9.35	1.185	18.24	22.39	33	71.21	1.65	6.3
9.35	1.195	25.02	22.4	33.01	69.5	1.64	8.2
9.37	1.205	18.06	22.41	33.03	76.13	1.64	6.0
9.37	1.215	21.19	22.43	33.04	73.96	1.63	7.0
9.38	1.225	12.3	22.44	33.05	77.29	1.63	4.4
9.38	1.235	14.75	22.46	33.07	74	1.62	5.2
9.4	1.245	21.51	22.47	33.08	74.83	1.62	7.0
9.4	1.265	14.58	22.48	33.09	80.13	1.61	4.9
9.42	1.275	9.32	22.49	33.1	80.96	1.61	3.4
9.43	1.285	12.21	22.51	33.12	81.42	1.6	4.2
9.43	1.295	5.89	22.52	33.13	91.79	1.6	2.1
9.45	1.305	7.48	22.53	33.14	88.17	1.6	2.7
9.45	1.315	12.65	22.54	33.15	81.71	1.59	4.3
9.47	1.335	6.43	22.55	33.16	90.88	1.59	2.3
9.48	1.345	3.13	22.56	33.17	93.75	1.59	1.3
9.48	1.355	7.78	22.57	33.18	91.38	1.59	2.6
9.5	1.365	11.68	22.58	33.19	85.17	1.58	3.9
9.52	1.375	12.38	22.59	33.2	83.33	1.58	4.2
9.52	1.385	18.83	22.6	33.21	76.13	1.58	6.3
9.53	1.395	24.41	22.61	33.21	71.88	1.58	8.0
9.53	1.405	8.9	22.62	33.22	74.04	1.58	3.6
9.55	1.415	15.96	22.63	33.23	77.75	1.58	5.4
9.57	1.425	14.5	22.63	33.24	81.38	1.58	4.9
9.57	1.435	15.32	22.64	33.25	84.17	1.58	5.0
9.58	1.445	12.07	22.65	33.25	82.92	1.58	4.1
9.58	1.455	14.51	22.65	33.26	75.46	1.58	5.1
9.6	1.465	19.35	22.66	33.27	76.21	1.58	6.4
9.6	1.475	19.22	22.67	33.27	74.88	1.58	6.4
9.62	1.485	15.81	22.67	33.28	77.13	1.58	5.4
9.62	1.495	22.1	22.68	33.29	79.58	1.58	7.1
9.62	1.505	4	22.68	33.29	87.58	1.58	1.7
9.63	1.515	22.31	22.69	33.3	86.21	1.59	6.9

9.63	1.525	18.05	22.69	33.3	78.96	1.59	6.0
9.63	1.545	17.78	22.7	33.31	74.83	1.59	6.0
9.63	1.555	17.76	22.7	33.32	76.54	1.59	6.0
9.63	1.565	17.55	22.71	33.32	79.42	1.59	5.8
9.63	1.585	8.26	22.71	33.33	87.04	1.6	2.9
9.63	1.595	27.03	22.71	33.33	76.71	1.6	8.5
9.63	1.615	0.37	22.72	33.34	84.38	1.6	0.8
9.63	1.625	30	22.72	33.34	69.04	1.61	9.6
9.63	1.645	17.84	22.72	33.35	80.42	1.61	5.8
9.63	1.665	14.02	22.73	33.35	85.58	1.61	4.6
9.62	1.685	18.9	22.73	33.36	79.17	1.62	6.2
9.62	1.705	14.5	22.73	33.36	79.71	1.62	4.9
9.6	1.725	11.76	22.74	33.37	79.83	1.63	4.2
9.6	1.745	22.86	22.74	33.37	77.04	1.63	7.4
9.58	1.765	11.93	22.74	33.37	80.71	1.64	4.2
9.57	1.795	10.41	22.75	33.38	82.88	1.64	3.7
9.55	1.815	16.09	22.75	33.38	80.83	1.64	5.4
9.55	1.845	11.87	22.75	33.39	86.08	1.65	4.0
9.53	1.875	11.87	22.75	33.39	86.08	1.65	4.0

2050 - 2060							
Horas de Sol	Precipitação	Radiação	Temperatura		Umidade	Velocidade do Vento	Evapotranspiração de Referência
horas/dia	mm	MJ/m2.dia	Min °C	Max °C	%	m/s	mm
9.52	1.77	16.74	23.5	34.13	70.58	1.66	6.0
9.5	1.8	20.54	23.5	34.14	71.29	1.66	7.0
9.47	1.83	20.11	23.51	34.14	79.71	1.67	6.6
9.45	1.86	19.22	23.51	34.14	79.75	1.68	6.3
9.43	1.89	9.25	23.51	34.15	90.38	1.68	3.1
9.42	1.93	19.25	23.52	34.15	74.17	1.68	6.6
9.38	1.96	18.41	23.52	34.15	74.58	1.69	6.3
9.37	2	16.08	23.53	34.15	83.83	1.69	5.3
9.33	2.04	19.01	23.53	34.16	77	1.7	6.4
9.32	2.08	14.11	23.53	34.16	83.92	1.71	4.8
9.28	2.12	15.26	23.54	34.16	72.54	1.71	5.5
9.25	2.16	18.79	23.54	34.16	72.79	1.72	6.5
9.23	2.2	20.08	23.55	34.17	77.46	1.72	6.7
9.2	2.25	20.26	23.56	34.17	76.75	1.73	6.8
9.17	2.29	19.65	23.56	34.17	76.96	1.73	6.6
9.13	2.34	20.77	23.57	34.17	72.33	1.74	7.1
9.1	2.38	19.25	23.57	34.17	79.67	1.74	6.4
9.07	2.43	7.88	23.58	34.17	88.46	1.75	2.8
9.03	2.48	20.91	23.59	34.17	81.29	1.76	6.8
9	2.53	20.74	23.59	34.17	77.67	1.76	6.9
8.97	2.58	17.33	23.6	34.17	82.63	1.76	5.7
8.93	2.63	21.38	23.6	34.18	76.13	1.77	7.1
8.9	2.68	20.65	23.61	34.18	73.79	1.78	7.0
8.87	2.74	20.48	23.62	34.18	72.17	1.78	7.0
8.83	2.79	18.52	23.63	34.17	74.58	1.79	6.4
8.8	2.84	20.51	23.63	34.17	71.25	1.79	7.1
8.77	2.9	18.46	23.64	34.17	73.67	1.79	6.4
8.73	2.95	18.16	23.65	34.17	68.92	1.8	6.5
8.7	3.01	21.72	23.65	34.17	70.21	1.81	7.5
8.67	3.07	19.02	23.66	34.17	74.33	1.81	6.5
8.63	3.12	18.48	23.67	34.17	70.58	1.81	6.6
8.58	3.18	19.3	23.68	34.16	71.21	1.82	6.8
8.55	3.24	20.38	23.68	34.16	75.83	1.82	6.9
8.52	3.3	18.94	23.69	34.16	81.92	1.83	6.2
8.48	3.36	20.01	23.7	34.16	76.71	1.83	6.7
8.45	3.42	20.91	23.7	34.15	71.96	1.84	7.2
8.42	3.48	21.85	23.71	34.15	74.04	1.84	7.3
8.38	3.55	21.68	23.72	34.14	73.42	1.84	7.3
8.35	3.61	19.34	23.72	34.14	78.13	1.85	6.5
8.32	3.67	23.84	23.73	34.13	66.67	1.85	8.2
8.28	3.74	21.31	23.74	34.13	77.08	1.86	7.1
8.25	3.8	17.04	23.74	34.12	83.13	1.86	5.6
8.22	3.87	21.49	23.75	34.12	73.17	1.86	7.3
8.18	3.93	22.38	23.75	34.11	73.04	1.86	7.5
8.15	4	22.64	23.76	34.1	71.92	1.87	7.7
8.12	4.06	20.58	23.77	34.1	74.17	1.87	7.0

8.08	4.13	21.86	23.77	34.09	71.21	1.88	7.5
8.05	4.2	20.83	23.78	34.08	72	1.88	7.2
8.02	4.27	21.88	23.78	34.07	76.79	1.88	7.2
7.98	4.33	17.03	23.78	34.06	83.38	1.88	5.6
7.95	4.4	12.35	23.79	34.05	76.08	1.88	4.6
7.92	4.47	22.64	23.79	34.04	69.17	1.89	7.8
7.88	4.54	23.55	23.8	34.03	67.75	1.89	8.1
7.87	4.61	23.24	23.8	34.02	73.21	1.89	7.8
7.83	4.68	22.16	23.8	34.01	72.04	1.89	7.5
7.8	4.75	15.93	23.8	34	81.17	1.89	5.4
7.77	4.83	22.57	23.81	33.99	76.13	1.9	7.5
7.75	4.9	21.34	23.81	33.98	75.21	1.9	7.2
7.72	4.97	15.36	23.81	33.96	73.58	1.9	5.6
7.68	5.04	21.67	23.81	33.95	73.08	1.9	7.3
7.67	5.11	19	23.81	33.94	75.38	1.9	6.5
7.63	5.18	23.81	23.82	33.92	69.08	1.91	8.1
7.62	5.25	19.59	23.82	33.91	76.54	1.91	6.6
7.58	5.33	20.13	23.82	33.89	74.79	1.91	6.8
7.57	5.4	20.29	23.82	33.88	74.13	1.91	6.9
7.53	5.47	20.05	23.82	33.86	71.63	1.91	6.9
7.52	5.54	20.13	23.82	33.85	73.17	1.91	6.9
7.48	5.61	24.96	23.82	33.83	72.71	1.91	8.3
7.47	5.68	21.16	23.82	33.81	79.58	1.91	6.9
7.45	5.75	23.91	23.82	33.79	70.75	1.91	8.0
7.42	5.82	24.5	23.82	33.78	65.04	1.91	8.5
7.4	5.89	25.31	23.82	33.76	70.17	1.91	8.5
7.38	5.96	23.9	23.81	33.74	75.67	1.91	7.8
7.35	6.03	18.44	23.81	33.72	74.38	1.92	6.4
7.33	6.1	23	23.81	33.7	70.04	1.92	7.8
7.32	6.17	24.39	23.81	33.68	69	1.92	8.2
7.3	6.23	22.71	23.81	33.66	73	1.92	7.6
7.28	6.3	24.84	23.81	33.64	68	1.92	8.4
7.27	6.37	21.92	23.81	33.62	69.08	1.92	7.6
7.23	6.43	18.89	23.8	33.6	70.83	1.92	6.6
7.22	6.5	24.61	23.8	33.58	67.88	1.92	8.3
7.2	6.56	24.68	23.8	33.56	66.96	1.92	8.4
7.18	6.62	19.29	23.8	33.54	70.08	1.92	6.8
7.17	6.69	20.53	23.8	33.52	69.67	1.92	7.1
7.15	6.75	17.91	23.79	33.49	73.42	1.92	6.3
7.13	6.81	22.57	23.79	33.47	71.13	1.92	7.6
7.12	6.87	21.78	23.79	33.45	72.04	1.92	7.4
7.1	6.92	24.69	23.79	33.43	69.54	1.92	8.3
7.08	6.98	26.08	23.78	33.4	67.04	1.92	8.8
7.07	7.04	23.77	23.78	33.38	69.58	1.93	8.0
7.05	7.09	23.59	23.78	33.36	72.08	1.93	7.9
7.03	7.15	24.74	23.77	33.33	70.96	1.93	8.2
7.02	7.2	24.7	23.77	33.31	68.29	1.93	8.3
7	7.25	22.63	23.77	33.28	70.92	1.93	7.6
6.98	7.3	23.76	23.76	33.26	70.46	1.93	8.0
6.97	7.36	23.65	23.76	33.23	72.13	1.93	7.9

6.95	7.4	24.54	23.75	33.21	65.88	1.93	8.4
6.93	7.45	25.66	23.75	33.18	67.63	1.93	8.6
6.92	7.5	24.57	23.74	33.16	72.33	1.93	8.1
6.9	7.55	22.81	23.74	33.13	71.71	1.94	7.6
6.88	7.59	24.48	23.73	33.11	68.83	1.94	8.2
6.87	7.64	25.45	23.72	33.08	68	1.94	8.5
6.85	7.68	25.15	23.72	33.05	69.54	1.94	8.4
6.83	7.72	23.58	23.71	33.03	70.83	1.94	7.9
6.82	7.76	24.62	23.7	33	66.42	1.94	8.4
6.8	7.8	24.58	23.69	32.97	66.71	1.95	8.3
6.77	7.84	25.08	23.69	32.94	67.33	1.95	8.4
6.75	7.88	20.61	23.68	32.92	71.33	1.95	7.0
6.73	7.92	25.04	23.67	32.89	66.33	1.95	8.5
6.72	7.95	23.66	23.66	32.86	69.58	1.96	7.9
6.7	7.99	25.43	23.65	32.83	66.63	1.96	8.6
6.68	8.03	22.6	23.63	32.8	68.38	1.96	7.7
6.67	8.06	24.59	23.62	32.77	65.54	1.97	8.4
6.65	8.09	21.65	23.61	32.75	69.63	1.97	7.4
6.63	8.13	24.69	23.6	32.72	69.21	1.97	8.2
6.62	8.16	25.82	23.58	32.69	65.63	1.98	8.7
6.6	8.19	23.69	23.57	32.66	68.83	1.98	8.0
6.57	8.22	25.93	23.55	32.63	67.88	1.98	8.6
6.55	8.25	25.59	23.53	32.6	65.17	1.99	8.6
6.53	8.29	20.6	23.52	32.57	68.38	1.99	7.1
6.52	8.32	23.7	23.5	32.54	70.04	2	7.9
6.5	8.35	23.08	23.48	32.51	70.5	2	7.7
6.48	8.38	22.32	23.46	32.48	70.88	2.01	7.5
6.47	8.4	24.03	23.44	32.44	71.42	2.01	7.9
6.45	8.43	21.37	23.42	32.41	75.38	2.02	7.0
6.43	8.46	15.29	23.4	32.38	76.25	2.02	5.3
6.42	8.49	16.18	23.37	32.35	78.38	2.03	5.5
6.4	8.52	17.04	23.35	32.32	78.96	2.03	5.7
6.38	8.55	17.55	23.33	32.29	72.5	2.04	6.1
6.37	8.58	23.69	23.3	32.25	69.54	2.04	7.9
6.37	8.61	25.7	23.28	32.22	70.08	2.05	8.4
6.35	8.64	23.27	23.25	32.19	71.58	2.06	7.7
6.33	8.67	22.63	23.22	32.16	75.46	2.06	7.3
6.32	8.7	23.68	23.19	32.13	72.25	2.07	7.8
6.32	8.73	22.81	23.16	32.09	71.67	2.08	7.5
6.3	8.76	24.47	23.13	32.06	72.96	2.08	7.9
6.28	8.8	23.45	23.1	32.03	75.21	2.09	7.5
6.28	8.83	24.28	23.07	32	69.88	2.1	8.0
6.27	8.86	25.26	23.04	31.96	70.71	2.11	8.2
6.25	8.89	22.59	23.01	31.93	73.83	2.11	7.4
6.25	8.93	22.93	22.98	31.9	76.46	2.12	7.3
6.23	8.96	23.76	22.94	31.86	69.33	2.13	7.9
6.23	9	16.38	22.91	31.83	71.5	2.14	5.8
6.23	9.03	23.29	22.88	31.8	70.88	2.14	7.7
6.22	9.07	25.07	22.84	31.77	66.13	2.15	8.4
6.22	9.1	27.13	22.81	31.73	62.33	2.16	9.1

6.22	9.14	23.72	22.77	31.7	65.58	2.17	8.0
6.2	9.18	19.18	22.74	31.67	80.83	2.18	6.1
6.2	9.22	16.17	22.7	31.64	73.33	2.19	5.7
6.2	9.25	25.81	22.67	31.61	64.58	2.19	8.6
6.2	9.29	23.72	22.63	31.57	68.5	2.2	7.9
6.2	9.33	23.86	22.59	31.54	68.42	2.21	7.9
6.2	9.37	23.69	22.56	31.51	70.83	2.22	7.8
6.2	9.41	23.7	22.52	31.48	70.08	2.23	7.8
6.2	9.45	14.71	22.48	31.45	70.25	2.24	5.4
6.2	9.49	24.97	22.45	31.42	66.29	2.25	8.3
6.2	9.53	25.62	22.41	31.39	62.96	2.26	8.6
6.2	9.56	23.59	22.37	31.36	68.25	2.27	7.8
6.2	9.6	25.16	22.34	31.33	70.92	2.28	8.1
6.2	9.64	26.32	22.3	31.3	65.96	2.29	8.7
6.2	9.68	27.13	22.26	31.27	64.75	2.29	8.9
6.22	9.71	26.19	22.23	31.24	73.33	2.31	8.3
6.22	9.75	20.07	22.19	31.22	75.63	2.31	6.6
6.22	9.78	23	22.15	31.19	72	2.32	7.5
6.22	9.81	24.48	22.12	31.16	67.21	2.33	8.1
6.23	9.84	22.3	22.08	31.13	70.25	2.34	7.4
6.23	9.87	16.24	22.05	31.11	72.21	2.35	5.7
6.23	9.9	19.1	22.01	31.08	69.38	2.36	6.6
6.25	9.92	21.28	21.98	31.06	73.96	2.37	6.9
6.25	9.94	19.61	21.94	31.03	69	2.38	6.8
6.27	9.96	22.14	21.91	31.01	67.04	2.39	7.5
6.27	9.98	25.24	21.88	30.99	65.88	2.4	8.4
6.28	9.99	23.75	21.85	30.97	72.83	2.41	7.6
6.28	10.01	6.21	21.81	30.94	84.58	2.42	2.5
6.3	10.01	23.53	21.78	30.92	79.67	2.43	7.2
6.3	10.02	23.61	21.75	30.9	74.54	2.43	7.5
6.32	10.02	24.21	21.72	30.88	70.29	2.44	7.9
6.33	10.02	25.56	21.69	30.86	73.17	2.45	8.0
6.33	10.01	24.02	21.66	30.84	73.46	2.46	7.6
6.35	10	25.85	21.63	30.83	69.38	2.47	8.3
6.37	9.99	25.41	21.6	30.81	72.33	2.48	8.0
6.37	9.97	24	21.57	30.79	72.96	2.48	7.6
6.38	9.94	23.85	21.55	30.78	67.38	2.49	7.9
6.4	9.92	20.3	21.52	30.76	70.29	2.5	6.9
6.42	9.89	26.94	21.49	30.75	65.46	2.51	8.8
6.42	9.85	25.77	21.47	30.74	66.67	2.51	8.4
6.43	9.81	26.98	21.44	30.73	65.67	2.52	8.8
6.45	9.76	9.96	21.42	30.71	80.83	2.53	3.7
6.47	9.71	25.05	21.4	30.7	73.54	2.54	7.9
6.48	9.66	13.08	21.37	30.69	82.46	2.54	4.4
6.5	9.6	24.28	21.35	30.68	73.83	2.55	7.7
6.52	9.53	23.93	21.33	30.68	70.29	2.55	7.8
6.53	9.47	27.92	21.31	30.67	72.96	2.56	8.6
6.55	9.39	24.79	21.29	30.66	69.54	2.57	8.0
6.57	9.32	29.04	21.27	30.66	71.92	2.57	8.9
6.58	9.23	9.74	21.25	30.65	86.17	2.58	3.4

6.6	9.15	21.06	21.24	30.65	85.33	2.58	6.2
6.62	9.06	9.49	21.22	30.65	87.42	2.59	3.2
6.63	8.96	7.21	21.21	30.64	85.71	2.59	2.8
6.65	8.86	28.05	21.19	30.64	71.75	2.59	8.7
6.67	8.76	22.01	21.18	30.64	73.67	2.6	7.1
6.68	8.66	21.86	21.16	30.64	70.71	2.6	7.2
6.72	8.55	30	21.15	30.65	69.83	2.61	9.3
6.73	8.44	9.95	21.14	30.65	74.13	2.61	4.1
6.75	8.32	11.86	21.13	30.65	78.08	2.61	4.3
6.77	8.21	10.39	21.12	30.65	89.29	2.61	3.4
6.8	8.09	25.25	21.12	30.66	79.5	2.61	7.6
6.82	7.96	15	21.11	30.67	79.17	2.62	5.1
6.83	7.84	18.89	21.1	30.67	81.71	2.62	5.9
6.85	7.71	15.54	21.1	30.68	85.33	2.62	4.9
6.88	7.59	24.94	21.1	30.69	78.83	2.62	7.5
6.9	7.46	21.02	21.09	30.7	76.33	2.62	6.7
6.92	7.33	17.97	21.09	30.71	75.04	2.62	6.0
6.95	7.2	29	21.09	30.72	70.04	2.62	9.0
6.97	7.07	19.54	21.09	30.73	73.67	2.62	6.5
6.98	6.94	20.05	21.09	30.74	74.58	2.62	6.6
7.02	6.8	13.92	21.1	30.76	76.29	2.62	4.9
7.03	6.67	30	21.1	30.77	75.04	2.62	9.0
7.07	6.54	10.79	21.11	30.79	77.33	2.61	4.1
7.08	6.41	15.56	21.11	30.8	71.92	2.61	5.6
7.1	6.28	18.86	21.12	30.82	70.25	2.61	6.5
7.13	6.15	12.8	21.13	30.84	76.46	2.61	4.7
7.15	6.02	11.38	21.14	30.86	81.54	2.61	4.0
7.18	5.9	8.64	21.15	30.88	86	2.6	3.1
7.2	5.77	11.2	21.16	30.9	82.25	2.6	4.0
7.23	5.65	25.58	21.17	30.92	70.75	2.59	8.2
7.25	5.53	27.62	21.19	30.94	68.63	2.59	8.8
7.28	5.41	20.11	21.2	30.96	73.63	2.58	6.7
7.3	5.29	26.96	21.22	30.98	72.29	2.58	8.4
7.33	5.18	20.04	21.24	31.01	71.88	2.57	6.7
7.35	5.06	22.22	21.26	31.03	70.63	2.57	7.4
7.38	4.95	7.73	21.27	31.06	78.38	2.56	3.3
7.4	4.84	12.49	21.29	31.09	80.83	2.56	4.4
7.43	4.73	18.37	21.31	31.11	81.17	2.55	5.8
7.45	4.63	19.24	21.34	31.14	79	2.54	6.2
7.48	4.53	18.24	21.36	31.17	71.21	2.53	6.3
7.5	4.43	21.9	21.38	31.2	76	2.53	7.0
7.53	4.33	10.15	21.41	31.23	85.08	2.52	3.6
7.57	4.23	12.18	21.43	31.26	86.75	2.51	4.0
7.58	4.14	30	21.46	31.29	76.13	2.5	9.1
7.62	4.05	15.72	21.48	31.32	80.71	2.49	5.2
7.65	3.96	22.96	21.51	31.36	78.42	2.48	7.2
7.67	3.87	23.42	21.53	31.39	76.79	2.48	7.4
7.7	3.79	23.38	21.56	31.42	78.42	2.46	7.3
7.73	3.7	27.19	21.59	31.46	74.21	2.46	8.5
7.77	3.62	19.92	21.62	31.49	80.67	2.44	6.3

7.78	3.54	12.74	21.65	31.53	84.83	2.44	4.2
7.82	3.47	8.99	21.67	31.56	87.75	2.43	3.1
7.85	3.39	10.07	21.7	31.6	87.96	2.41	3.4
7.88	3.32	10.63	21.73	31.64	88.13	2.4	3.5
7.92	3.24	11.63	21.76	31.68	87.38	2.39	3.8
7.95	3.17	6.34	21.79	31.71	90.42	2.38	2.3
7.98	3.1	13.24	21.82	31.75	87.5	2.37	4.2
8.02	3.03	23.4	21.85	31.79	79.17	2.36	7.3
8.03	2.96	20.24	21.88	31.83	82.46	2.34	6.3
8.07	2.9	21.81	21.91	31.87	80.96	2.33	6.8
8.1	2.83	21.47	21.94	31.91	75.96	2.32	7.0
8.13	2.77	18.02	21.97	31.95	79.38	2.31	5.9
8.17	2.7	18.16	22	31.99	76.17	2.29	6.1
8.2	2.64	22.19	22.02	32.03	74.38	2.28	7.2
8.23	2.58	23.72	22.05	32.07	73.42	2.27	7.7
8.27	2.51	20.88	22.08	32.11	73.21	2.26	7.0
8.3	2.45	9.04	22.11	32.15	84.79	2.24	3.3
8.33	2.39	10.14	22.14	32.19	91.04	2.23	3.3
8.37	2.33	17.46	22.16	32.23	77.79	2.22	5.8
8.4	2.28	22.22	22.19	32.27	78.5	2.21	7.1
8.43	2.22	22.07	22.22	32.32	80	2.19	7.0
8.47	2.16	20.65	22.24	32.36	76.92	2.18	6.7
8.5	2.1	22.21	22.27	32.4	78.92	2.16	7.1
8.53	2.05	20.83	22.29	32.44	77.38	2.15	6.8
8.57	1.99	13.02	22.32	32.48	82.54	2.14	4.5
8.6	1.94	9.97	22.34	32.52	88.04	2.13	3.4
8.63	1.89	19.07	22.37	32.56	76.88	2.11	6.3
8.67	1.84	18.03	22.39	32.6	80.54	2.1	5.9
8.7	1.79	19.54	22.41	32.63	81.5	2.08	6.2
8.72	1.74	18.52	22.44	32.67	78.63	2.07	6.1
8.75	1.69	17.18	22.46	32.71	79.92	2.06	5.7
8.78	1.64	17.44	22.48	32.75	78.08	2.04	5.9
8.8	1.6	17.81	22.5	32.79	75.33	2.03	6.1
8.83	1.55	18.18	22.53	32.82	81.38	2.02	5.9
8.87	1.51	16.09	22.55	32.86	83.67	2	5.2
8.88	1.47	23.27	22.57	32.9	76.5	1.99	7.5
8.92	1.43	15.41	22.59	32.93	72.38	1.98	5.6
8.93	1.39	21.68	22.61	32.97	68.92	1.96	7.4
8.97	1.35	13.62	22.63	33	70.13	1.95	5.2
8.98	1.31	30	22.65	33.04	70.58	1.94	9.6
9	1.28	8.54	22.67	33.07	77.67	1.93	3.5
9.02	1.25	6.58	22.68	33.1	84.42	1.91	2.6
9.05	1.22	9.88	22.7	33.14	88.13	1.9	3.4
9.07	1.19	17.37	22.72	33.17	85.38	1.89	5.5
9.08	1.17	18.55	22.74	33.2	77.13	1.88	6.2
9.1	1.14	15.55	22.76	33.23	75.75	1.86	5.4
9.12	1.12	13.16	22.77	33.26	75.96	1.85	4.8
9.13	1.1	14.42	22.79	33.29	81.13	1.84	4.9
9.15	1.08	17.46	22.81	33.31	80.08	1.83	5.8
9.15	1.06	19.52	22.83	33.34	78.13	1.82	6.4

9.17	1.05	18.81	22.84	33.37	78.17	1.81	6.2
9.18	1.04	17.08	22.86	33.39	74.25	1.8	5.9
9.2	1.03	19.14	22.88	33.42	72.58	1.79	6.6
9.2	1.02	24.17	22.89	33.44	75.92	1.78	7.8
9.22	1.01	13.69	22.91	33.47	84.17	1.76	4.6
9.23	1	13.91	22.93	33.49	82.88	1.76	4.7
9.23	1	19.65	22.94	33.51	78.46	1.74	6.5
9.25	1	16.94	22.96	33.54	76.54	1.74	5.8
9.27	1	12.72	22.98	33.56	80.67	1.73	4.5
9.27	1	16.98	22.99	33.58	73.46	1.72	5.9
9.28	1	18.87	23.01	33.6	80.88	1.71	6.2
9.28	1	15.93	23.02	33.62	83.25	1.7	5.2
9.3	1	12.86	23.04	33.64	81.79	1.69	4.5
9.3	1.01	26.03	23.05	33.65	76.08	1.68	8.3
9.32	1.02	17.11	23.07	33.67	80.17	1.68	5.7
9.32	1.02	16.81	23.08	33.69	82.46	1.67	5.5
9.33	1.03	5.38	23.1	33.71	83.33	1.66	2.3
9.33	1.04	17.81	23.11	33.72	74	1.66	6.1
9.35	1.05	18.24	23.13	33.74	71.21	1.65	6.4
9.35	1.06	25.02	23.14	33.75	69.5	1.64	8.3
9.37	1.07	18.06	23.15	33.77	76.13	1.64	6.1
9.37	1.08	21.19	23.17	33.78	73.96	1.63	7.1
9.38	1.09	12.3	23.18	33.79	77.29	1.63	4.5
9.38	1.1	14.75	23.2	33.81	74	1.62	5.3
9.4	1.11	21.51	23.21	33.82	74.83	1.62	7.1
9.4	1.13	14.58	23.22	33.83	80.13	1.61	5.0
9.42	1.14	9.32	23.23	33.84	80.96	1.61	3.5
9.43	1.15	12.21	23.25	33.86	81.42	1.6	4.3
9.43	1.16	5.89	23.26	33.87	91.79	1.6	2.1
9.45	1.17	7.48	23.27	33.88	88.17	1.6	2.7
9.45	1.18	12.65	23.28	33.89	81.71	1.59	4.4
9.47	1.2	6.43	23.29	33.9	90.88	1.59	2.3
9.48	1.21	3.13	23.3	33.91	93.75	1.59	1.3
9.48	1.22	7.78	23.31	33.92	91.38	1.59	2.7
9.5	1.23	11.68	23.32	33.93	85.17	1.58	4.0
9.52	1.24	12.38	23.33	33.94	83.33	1.58	4.3
9.52	1.25	18.83	23.34	33.95	76.13	1.58	6.3
9.53	1.26	24.41	23.35	33.95	71.88	1.58	8.1
9.53	1.27	8.9	23.36	33.96	74.04	1.58	3.6
9.55	1.28	15.96	23.37	33.97	77.75	1.58	5.5
9.57	1.29	14.5	23.37	33.98	81.38	1.58	4.9
9.57	1.3	15.32	23.38	33.99	84.17	1.58	5.1
9.58	1.31	12.07	23.39	33.99	82.92	1.58	4.2
9.58	1.32	14.51	23.39	34	75.46	1.58	5.2
9.6	1.33	19.35	23.4	34.01	76.21	1.58	6.5
9.6	1.34	19.22	23.41	34.01	74.88	1.58	6.5
9.62	1.35	15.81	23.41	34.02	77.13	1.58	5.5
9.62	1.36	22.1	23.42	34.03	79.58	1.58	7.1
9.62	1.37	4	23.42	34.03	87.58	1.58	1.7
9.63	1.38	22.31	23.43	34.04	86.21	1.59	6.9

9.63	1.39	18.05	23.43	34.04	78.96	1.59	6.0
9.63	1.41	17.78	23.44	34.05	74.83	1.59	6.1
9.63	1.42	17.76	23.44	34.06	76.54	1.59	6.0
9.63	1.43	17.55	23.45	34.06	79.42	1.59	5.9
9.63	1.45	8.26	23.45	34.07	87.04	1.6	3.0
9.63	1.46	27.03	23.45	34.07	76.71	1.6	8.6
9.63	1.48	0.37	23.46	34.08	84.38	1.6	0.9
9.63	1.49	30	23.46	34.08	69.04	1.61	9.8
9.63	1.51	17.84	23.46	34.09	80.42	1.61	5.9
9.63	1.53	14.02	23.47	34.09	85.58	1.61	4.6
9.62	1.55	18.9	23.47	34.1	79.17	1.62	6.3
9.62	1.57	14.5	23.47	34.1	79.71	1.62	5.0
9.6	1.59	11.76	23.48	34.11	79.83	1.63	4.2
9.6	1.61	22.86	23.48	34.11	77.04	1.63	7.5
9.58	1.63	11.93	23.48	34.11	80.71	1.64	4.3
9.57	1.66	10.41	23.49	34.12	82.88	1.64	3.7
9.55	1.68	16.09	23.49	34.12	80.83	1.64	5.4
9.55	1.71	11.87	23.49	34.13	86.08	1.65	4.0
9.53	1.74	11.87	23.49	34.13	86.08	1.65	4.0

2060 - 2070							
Horas de Sol	**Precipitação**	**Radiação**	**Temperatura**		**Umidade**	**Velocidade do Vento**	**Evapotranspiração de Referência**
horas/dia	**mm**	**MJ/m2.dia**	**Min °C**	**Max °C**	**%**	**m/s**	**mm**
9.52	1.635	16.74	24.24	34.87	70.58	1.66	6.1
9.5	1.665	20.54	24.24	34.88	71.29	1.66	7.1
9.47	1.695	20.11	24.25	34.88	79.71	1.67	6.7
9.45	1.725	19.22	24.25	34.88	79.75	1.68	6.4
9.43	1.755	9.25	24.25	34.89	90.38	1.68	3.2
9.42	1.795	19.25	24.26	34.89	74.17	1.68	6.7
9.38	1.825	18.41	24.26	34.89	74.58	1.69	6.4
9.37	1.865	16.08	24.27	34.89	83.83	1.69	5.4
9.33	1.905	19.01	24.27	34.9	77	1.7	6.5
9.32	1.945	14.11	24.27	34.9	83.92	1.71	4.8
9.28	1.985	15.26	24.28	34.9	72.54	1.71	5.6
9.25	2.025	18.79	24.28	34.9	72.79	1.72	6.6
9.23	2.065	20.08	24.29	34.91	77.46	1.72	6.8
9.2	2.115	20.26	24.3	34.91	76.75	1.73	6.8
9.17	2.155	19.65	24.3	34.91	76.96	1.73	6.7
9.13	2.205	20.77	24.31	34.91	72.33	1.74	7.2
9.1	2.245	19.25	24.31	34.91	79.67	1.74	6.4
9.07	2.295	7.88	24.32	34.91	88.46	1.75	2.9
9.03	2.345	20.91	24.33	34.91	81.29	1.76	6.8
9	2.395	20.74	24.33	34.91	77.67	1.76	7.0
8.97	2.445	17.33	24.34	34.91	82.63	1.76	5.8
8.93	2.495	21.38	24.34	34.92	76.13	1.77	7.2
8.9	2.545	20.65	24.35	34.92	73.79	1.78	7.1
8.87	2.605	20.48	24.36	34.92	72.17	1.78	7.1
8.83	2.655	18.52	24.37	34.91	74.58	1.79	6.5
8.8	2.705	20.51	24.37	34.91	71.25	1.79	7.2
8.77	2.765	18.46	24.38	34.91	73.67	1.79	6.5
8.73	2.815	18.16	24.39	34.91	68.92	1.8	6.6
8.7	2.875	21.72	24.39	34.91	70.21	1.81	7.6
8.67	2.935	19.02	24.4	34.91	74.33	1.81	6.6
8.63	2.985	18.48	24.41	34.91	70.58	1.81	6.6
8.58	3.045	19.3	24.42	34.9	71.21	1.82	6.8
8.55	3.105	20.38	24.42	34.9	75.83	1.82	6.9
8.52	3.165	18.94	24.43	34.9	81.92	1.83	6.3
8.48	3.225	20.01	24.44	34.9	76.71	1.83	6.8
8.45	3.285	20.91	24.44	34.89	71.96	1.84	7.3
8.42	3.345	21.85	24.45	34.89	74.04	1.84	7.4
8.38	3.415	21.68	24.46	34.88	73.42	1.84	7.4
8.35	3.475	19.34	24.46	34.88	78.13	1.85	6.6
8.32	3.535	23.84	24.47	34.87	66.67	1.85	8.3
8.28	3.605	21.31	24.48	34.87	77.08	1.86	7.2
8.25	3.665	17.04	24.48	34.86	83.13	1.86	5.7
8.22	3.735	21.49	24.49	34.86	73.17	1.86	7.4
8.18	3.795	22.38	24.49	34.85	73.04	1.86	7.6
8.15	3.865	22.64	24.5	34.84	71.92	1.87	7.8
8.12	3.925	20.58	24.51	34.84	74.17	1.87	7.1

8.08	3.995	21.86	24.51	34.83	71.21	1.88	7.6
8.05	4.065	20.83	24.52	34.82	72	1.88	7.2
8.02	4.135	21.88	24.52	34.81	76.79	1.88	7.3
7.98	4.195	17.03	24.52	34.8	83.38	1.88	5.7
7.95	4.265	12.35	24.53	34.79	76.08	1.88	4.7
7.92	4.335	22.64	24.53	34.78	69.17	1.89	7.9
7.88	4.405	23.55	24.54	34.77	67.75	1.89	8.2
7.87	4.475	23.24	24.54	34.76	73.21	1.89	7.9
7.83	4.545	22.16	24.54	34.75	72.04	1.89	7.6
7.8	4.615	15.93	24.54	34.74	81.17	1.89	5.5
7.77	4.695	22.57	24.55	34.73	76.13	1.9	7.5
7.75	4.765	21.34	24.55	34.72	75.21	1.9	7.2
7.72	4.835	15.36	24.55	34.7	73.58	1.9	5.6
7.68	4.905	21.67	24.55	34.69	73.08	1.9	7.4
7.67	4.975	19	24.55	34.68	75.38	1.9	6.6
7.63	5.045	23.81	24.56	34.66	69.08	1.91	8.2
7.62	5.115	19.59	24.56	34.65	76.54	1.91	6.7
7.58	5.195	20.13	24.56	34.63	74.79	1.91	6.9
7.57	5.265	20.29	24.56	34.62	74.13	1.91	7.0
7.53	5.335	20.05	24.56	34.6	71.63	1.91	7.0
7.52	5.405	20.13	24.56	34.59	73.17	1.91	7.0
7.48	5.475	24.96	24.56	34.57	72.71	1.91	8.4
7.47	5.545	21.16	24.56	34.55	79.58	1.91	7.0
7.45	5.615	23.91	24.56	34.53	70.75	1.91	8.1
7.42	5.685	24.5	24.56	34.52	65.04	1.91	8.6
7.4	5.755	25.31	24.56	34.5	70.17	1.91	8.6
7.38	5.825	23.9	24.55	34.48	75.67	1.91	7.9
7.35	5.895	18.44	24.55	34.46	74.38	1.92	6.5
7.33	5.965	23	24.55	34.44	70.04	1.92	7.9
7.32	6.035	24.39	24.55	34.42	69	1.92	8.3
7.3	6.095	22.71	24.55	34.4	73	1.92	7.7
7.28	6.165	24.84	24.55	34.38	68	1.92	8.5
7.27	6.235	21.92	24.55	34.36	69.08	1.92	7.7
7.23	6.295	18.89	24.54	34.34	70.83	1.92	6.7
7.22	6.365	24.61	24.54	34.32	67.88	1.92	8.4
7.2	6.425	24.68	24.54	34.3	66.96	1.92	8.5
7.18	6.485	19.29	24.54	34.28	70.08	1.92	6.9
7.17	6.555	20.53	24.54	34.26	69.67	1.92	7.2
7.15	6.615	17.91	24.53	34.23	73.42	1.92	6.3
7.13	6.675	22.57	24.53	34.21	71.13	1.92	7.7
7.12	6.735	21.78	24.53	34.19	72.04	1.92	7.5
7.1	6.785	24.69	24.53	34.17	69.54	1.92	8.4
7.08	6.845	26.08	24.52	34.14	67.04	1.92	8.9
7.07	6.905	23.77	24.52	34.12	69.58	1.93	8.1
7.05	6.955	23.59	24.52	34.1	72.08	1.93	8.0
7.03	7.015	24.74	24.51	34.07	70.96	1.93	8.3
7.02	7.065	24.7	24.51	34.05	68.29	1.93	8.4
7	7.115	22.63	24.51	34.02	70.92	1.93	7.7
6.98	7.165	23.76	24.5	34	70.46	1.93	8.1
6.97	7.225	23.65	24.5	33.97	72.13	1.93	8.0

6.95	7.265	24.54	24.49	33.95	65.88	1.93	8.5
6.93	7.315	25.66	24.49	33.92	67.63	1.93	8.7
6.92	7.365	24.57	24.48	33.9	72.33	1.93	8.2
6.9	7.415	22.81	24.48	33.87	71.71	1.94	7.7
6.88	7.455	24.48	24.47	33.85	68.83	1.94	8.3
6.87	7.505	25.45	24.46	33.82	68	1.94	8.6
6.85	7.545	25.15	24.46	33.79	69.54	1.94	8.5
6.83	7.585	23.58	24.45	33.77	70.83	1.94	8.0
6.82	7.625	24.62	24.44	33.74	66.42	1.94	8.5
6.8	7.665	24.58	24.43	33.71	66.71	1.95	8.4
6.77	7.705	25.08	24.43	33.68	67.33	1.95	8.5
6.75	7.745	20.61	24.42	33.66	71.33	1.95	7.1
6.73	7.785	25.04	24.41	33.63	66.33	1.95	8.6
6.72	7.815	23.66	24.4	33.6	69.58	1.96	8.0
6.7	7.855	25.43	24.39	33.57	66.63	1.96	8.7
6.68	7.895	22.6	24.37	33.54	68.38	1.96	7.8
6.67	7.925	24.59	24.36	33.51	65.54	1.97	8.5
6.65	7.955	21.65	24.35	33.49	69.63	1.97	7.5
6.63	7.995	24.69	24.34	33.46	69.21	1.97	8.3
6.62	8.025	25.82	24.32	33.43	65.63	1.98	8.8
6.6	8.055	23.69	24.31	33.4	68.83	1.98	8.1
6.57	8.085	25.93	24.29	33.37	67.88	1.98	8.7
6.55	8.115	25.59	24.27	33.34	65.17	1.99	8.8
6.53	8.155	20.6	24.26	33.31	68.38	1.99	7.2
6.52	8.185	23.7	24.24	33.28	70.04	2	8.0
6.5	8.215	23.08	24.22	33.25	70.5	2	7.8
6.48	8.245	22.32	24.2	33.22	70.88	2.01	7.6
6.47	8.265	24.03	24.18	33.18	71.42	2.01	8.0
6.45	8.295	21.37	24.16	33.15	75.38	2.02	7.1
6.43	8.325	15.29	24.14	33.12	76.25	2.02	5.4
6.42	8.355	16.18	24.11	33.09	78.38	2.03	5.6
6.4	8.385	17.04	24.09	33.06	78.96	2.03	5.8
6.38	8.415	17.55	24.07	33.03	72.5	2.04	6.2
6.37	8.445	23.69	24.04	32.99	69.54	2.04	8.0
6.37	8.475	25.7	24.02	32.96	70.08	2.05	8.5
6.35	8.505	23.27	23.99	32.93	71.58	2.06	7.8
6.33	8.535	22.63	23.96	32.9	75.46	2.06	7.4
6.32	8.565	23.68	23.93	32.87	72.25	2.07	7.9
6.32	8.595	22.81	23.9	32.83	71.67	2.08	7.6
6.3	8.625	24.47	23.87	32.8	72.96	2.08	8.0
6.28	8.665	23.45	23.84	32.77	75.21	2.09	7.6
6.28	8.695	24.28	23.81	32.74	69.88	2.1	8.1
6.27	8.725	25.26	23.78	32.7	70.71	2.11	8.3
6.25	8.755	22.59	23.75	32.67	73.83	2.11	7.5
6.25	8.795	22.93	23.72	32.64	76.46	2.12	7.4
6.23	8.825	23.76	23.68	32.6	69.33	2.13	8.0
6.23	8.865	16.38	23.65	32.57	71.5	2.14	5.9
6.23	8.895	23.29	23.62	32.54	70.88	2.14	7.8
6.22	8.935	25.07	23.58	32.51	66.13	2.15	8.5
6.22	8.965	27.13	23.55	32.47	62.33	2.16	9.2

6.22	9.005	23.72	23.51	32.44	65.58	2.17	8.2
6.2	9.045	19.18	23.48	32.41	80.83	2.18	6.2
6.2	9.085	16.17	23.44	32.38	73.33	2.19	5.8
6.2	9.115	25.81	23.41	32.35	64.58	2.19	8.7
6.2	9.155	23.72	23.37	32.31	68.5	2.2	8.0
6.2	9.195	23.86	23.33	32.28	68.42	2.21	8.0
6.2	9.235	23.69	23.3	32.25	70.83	2.22	7.9
6.2	9.275	23.7	23.26	32.22	70.08	2.23	7.9
6.2	9.315	14.71	23.22	32.19	70.25	2.24	5.5
6.2	9.355	24.97	23.19	32.16	66.29	2.25	8.4
6.2	9.395	25.62	23.15	32.13	62.96	2.26	8.8
6.2	9.425	23.59	23.11	32.1	68.25	2.27	8.0
6.2	9.465	25.16	23.08	32.07	70.92	2.28	8.2
6.2	9.505	26.32	23.04	32.04	65.96	2.29	8.8
6.2	9.545	27.13	23	32.01	64.75	2.29	9.1
6.22	9.575	26.19	22.97	31.98	73.33	2.31	8.4
6.22	9.615	20.07	22.93	31.96	75.63	2.31	6.6
6.22	9.645	23	22.89	31.93	72	2.32	7.6
6.22	9.675	24.48	22.86	31.9	67.21	2.33	8.2
6.23	9.705	22.3	22.82	31.87	70.25	2.34	7.5
6.23	9.735	16.24	22.79	31.85	72.21	2.35	5.8
6.23	9.765	19.1	22.75	31.82	69.38	2.36	6.7
6.25	9.785	21.28	22.72	31.8	73.96	2.37	7.0
6.25	9.805	19.61	22.68	31.77	69	2.38	6.9
6.27	9.825	22.14	22.65	31.75	67.04	2.39	7.6
6.27	9.845	25.24	22.62	31.73	65.88	2.4	8.5
6.28	9.855	23.75	22.59	31.71	72.83	2.41	7.7
6.28	9.875	6.21	22.55	31.68	84.58	2.42	2.6
6.3	9.875	23.53	22.52	31.66	79.67	2.43	7.3
6.3	9.885	23.61	22.49	31.64	74.54	2.43	7.6
6.32	9.885	24.21	22.46	31.62	70.29	2.44	8.0
6.33	9.885	25.56	22.43	31.6	73.17	2.45	8.2
6.33	9.875	24.02	22.4	31.58	73.46	2.46	7.7
6.35	9.865	25.85	22.37	31.57	69.38	2.47	8.4
6.37	9.855	25.41	22.34	31.55	72.33	2.48	8.2
6.37	9.835	24	22.31	31.53	72.96	2.48	7.8
6.38	9.805	23.85	22.29	31.52	67.38	2.49	8.0
6.4	9.785	20.3	22.26	31.5	70.29	2.5	7.0
6.42	9.755	26.94	22.23	31.49	65.46	2.51	8.9
6.42	9.715	25.77	22.21	31.48	66.67	2.51	8.5
6.43	9.675	26.98	22.18	31.47	65.67	2.52	8.9
6.45	9.625	9.96	22.16	31.45	80.83	2.53	3.7
6.47	9.575	25.05	22.14	31.44	73.54	2.54	8.0
6.48	9.525	13.08	22.11	31.43	82.46	2.54	4.5
6.5	9.465	24.28	22.09	31.42	73.83	2.55	7.8
6.52	9.395	23.93	22.07	31.42	70.29	2.55	7.9
6.53	9.335	27.92	22.05	31.41	72.96	2.56	8.7
6.55	9.255	24.79	22.03	31.4	69.54	2.57	8.1
6.57	9.185	29.04	22.01	31.4	71.92	2.57	9.1
6.58	9.095	9.74	21.99	31.39	86.17	2.58	3.4

6.6	9.015	21.06	21.98	31.39	85.33	2.58	6.3
6.62	8.925	9.49	21.96	31.39	87.42	2.59	3.3
6.63	8.825	7.21	21.95	31.38	85.71	2.59	2.8
6.65	8.725	28.05	21.93	31.38	71.75	2.59	8.8
6.67	8.625	22.01	21.92	31.38	73.67	2.6	7.2
6.68	8.525	21.86	21.9	31.38	70.71	2.6	7.3
6.72	8.415	30	21.89	31.39	69.83	2.61	9.4
6.73	8.305	9.95	21.88	31.39	74.13	2.61	4.1
6.75	8.185	11.86	21.87	31.39	78.08	2.61	4.4
6.77	8.075	10.39	21.86	31.39	89.29	2.61	3.4
6.8	7.955	25.25	21.86	31.4	79.5	2.61	7.7
6.82	7.825	15	21.85	31.41	79.17	2.62	5.1
6.83	7.705	18.89	21.84	31.41	81.71	2.62	6.0
6.85	7.575	15.54	21.84	31.42	85.33	2.62	4.9
6.88	7.455	24.94	21.84	31.43	78.83	2.62	7.7
6.9	7.325	21.02	21.83	31.44	76.33	2.62	6.8
6.92	7.195	17.97	21.83	31.45	75.04	2.62	6.1
6.95	7.065	29	21.83	31.46	70.04	2.62	9.2
6.97	6.935	19.54	21.83	31.47	73.67	2.62	6.6
6.98	6.805	20.05	21.83	31.48	74.58	2.62	6.7
7.02	6.665	13.92	21.84	31.5	76.29	2.62	5.0
7.03	6.535	30	21.84	31.51	75.04	2.62	9.2
7.07	6.405	10.79	21.85	31.53	77.33	2.61	4.2
7.08	6.275	15.56	21.85	31.54	71.92	2.61	5.7
7.1	6.145	18.86	21.86	31.56	70.25	2.61	6.6
7.13	6.015	12.8	21.87	31.58	76.46	2.61	4.7
7.15	5.885	11.38	21.88	31.6	81.54	2.61	4.1
7.18	5.765	8.64	21.89	31.62	86	2.6	3.2
7.2	5.635	11.2	21.9	31.64	82.25	2.6	4.0
7.23	5.515	25.58	21.91	31.66	70.75	2.59	8.3
7.25	5.395	27.62	21.93	31.68	68.63	2.59	8.9
7.28	5.275	20.11	21.94	31.7	73.63	2.58	6.8
7.3	5.155	26.96	21.96	31.72	72.29	2.58	8.6
7.33	5.045	20.04	21.98	31.75	71.88	2.57	6.8
7.35	4.925	22.22	22	31.77	70.63	2.57	7.5
7.38	4.815	7.73	22.01	31.8	78.38	2.56	3.3
7.4	4.705	12.49	22.03	31.83	80.83	2.56	4.4
7.43	4.595	18.37	22.05	31.85	81.17	2.55	5.9
7.45	4.495	19.24	22.08	31.88	79	2.54	6.3
7.48	4.395	18.24	22.1	31.91	71.21	2.53	6.4
7.5	4.295	21.9	22.12	31.94	76	2.53	7.1
7.53	4.195	10.15	22.15	31.97	85.08	2.52	3.6
7.57	4.095	12.18	22.17	32	86.75	2.51	4.0
7.58	4.005	30	22.2	32.03	76.13	2.5	9.2
7.62	3.915	15.72	22.22	32.06	80.71	2.49	5.3
7.65	3.825	22.96	22.25	32.1	78.42	2.48	7.3
7.67	3.735	23.42	22.27	32.13	76.79	2.48	7.5
7.7	3.655	23.38	22.3	32.16	78.42	2.46	7.4
7.73	3.565	27.19	22.33	32.2	74.21	2.46	8.6
7.77	3.485	19.92	22.36	32.23	80.67	2.44	6.4

7.78	3.405	12.74	22.39	32.27	84.83	2.44	4.3
7.82	3.335	8.99	22.41	32.3	87.75	2.43	3.2
7.85	3.255	10.07	22.44	32.34	87.96	2.41	3.4
7.88	3.185	10.63	22.47	32.38	88.13	2.4	3.6
7.92	3.105	11.63	22.5	32.42	87.38	2.39	3.9
7.95	3.035	6.34	22.53	32.45	90.42	2.38	2.3
7.98	2.965	13.24	22.56	32.49	87.5	2.37	4.3
8.02	2.895	23.4	22.59	32.53	79.17	2.36	7.4
8.03	2.825	20.24	22.62	32.57	82.46	2.34	6.4
8.07	2.765	21.81	22.65	32.61	80.96	2.33	6.9
8.1	2.695	21.47	22.68	32.65	75.96	2.32	7.1
8.13	2.635	18.02	22.71	32.69	79.38	2.31	6.0
8.17	2.565	18.16	22.74	32.73	76.17	2.29	6.2
8.2	2.505	22.19	22.76	32.77	74.38	2.28	7.3
8.23	2.445	23.72	22.79	32.81	73.42	2.27	7.8
8.27	2.375	20.88	22.82	32.85	73.21	2.26	7.1
8.3	2.315	9.04	22.85	32.89	84.79	2.24	3.3
8.33	2.255	10.14	22.88	32.93	91.04	2.23	3.3
8.37	2.195	17.46	22.9	32.97	77.79	2.22	5.9
8.4	2.145	22.22	22.93	33.01	78.5	2.21	7.2
8.43	2.085	22.07	22.96	33.06	80	2.19	7.1
8.47	2.025	20.65	22.98	33.1	76.92	2.18	6.8
8.5	1.965	22.21	23.01	33.14	78.92	2.16	7.1
8.53	1.915	20.83	23.03	33.18	77.38	2.15	6.9
8.57	1.855	13.02	23.06	33.22	82.54	2.14	4.5
8.6	1.805	9.97	23.08	33.26	88.04	2.13	3.4
8.63	1.755	19.07	23.11	33.3	76.88	2.11	6.4
8.67	1.705	18.03	23.13	33.34	80.54	2.1	6.0
8.7	1.655	19.54	23.15	33.37	81.5	2.08	6.3
8.72	1.605	18.52	23.18	33.41	78.63	2.07	6.2
8.75	1.555	17.18	23.2	33.45	79.92	2.06	5.8
8.78	1.505	17.44	23.22	33.49	78.08	2.04	5.9
8.8	1.465	17.81	23.24	33.53	75.33	2.03	6.2
8.83	1.415	18.18	23.27	33.56	81.38	2.02	6.0
8.87	1.375	16.09	23.29	33.6	83.67	2	5.3
8.88	1.335	23.27	23.31	33.64	76.5	1.99	7.6
8.92	1.295	15.41	23.33	33.67	72.38	1.98	5.6
8.93	1.255	21.68	23.35	33.71	68.92	1.96	7.5
8.97	1.215	13.62	23.37	33.74	70.13	1.95	5.2
8.98	1.175	30	23.39	33.78	70.58	1.94	9.7
9	1.145	8.54	23.41	33.81	77.67	1.93	3.5
9.02	1.115	6.58	23.42	33.84	84.42	1.91	2.7
9.05	1.085	9.88	23.44	33.88	88.13	1.9	3.4
9.07	1.055	17.37	23.46	33.91	85.38	1.89	5.6
9.08	1.035	18.55	23.48	33.94	77.13	1.88	6.3
9.1	1.005	15.55	23.5	33.97	75.75	1.86	5.5
9.12	0.985	13.16	23.51	34	75.96	1.85	4.8
9.13	0.965	14.42	23.53	34.03	81.13	1.84	5.0
9.15	0.945	17.46	23.55	34.05	80.08	1.83	5.9
9.15	0.925	19.52	23.57	34.08	78.13	1.82	6.5

9.17	0.915	18.81	23.58	34.11	78.17	1.81	6.3
9.18	0.905	17.08	23.6	34.13	74.25	1.8	6.0
9.2	0.895	19.14	23.62	34.16	72.58	1.79	6.6
9.2	0.885	24.17	23.63	34.18	75.92	1.78	7.9
9.22	0.875	13.69	23.65	34.21	84.17	1.76	4.6
9.23	0.865	13.91	23.67	34.23	82.88	1.76	4.8
9.23	0.865	19.65	23.68	34.25	78.46	1.74	6.5
9.25	0.865	16.94	23.7	34.28	76.54	1.74	5.9
9.27	0.865	12.72	23.72	34.3	80.67	1.73	4.5
9.27	0.865	16.98	23.73	34.32	73.46	1.72	6.0
9.28	0.865	18.87	23.75	34.34	80.88	1.71	6.2
9.28	0.865	15.93	23.76	34.36	83.25	1.7	5.3
9.3	0.865	12.86	23.78	34.38	81.79	1.69	4.5
9.3	0.875	26.03	23.79	34.39	76.08	1.68	8.4
9.32	0.885	17.11	23.81	34.41	80.17	1.68	5.8
9.32	0.885	16.81	23.82	34.43	82.46	1.67	5.6
9.33	0.895	5.38	23.84	34.45	83.33	1.66	2.3
9.33	0.905	17.81	23.85	34.46	74	1.66	6.2
9.35	0.915	18.24	23.87	34.48	71.21	1.65	6.4
9.35	0.925	25.02	23.88	34.49	69.5	1.64	8.4
9.37	0.935	18.06	23.89	34.51	76.13	1.64	6.2
9.37	0.945	21.19	23.91	34.52	73.96	1.63	7.2
9.38	0.955	12.3	23.92	34.53	77.29	1.63	4.5
9.38	0.965	14.75	23.94	34.55	74	1.62	5.3
9.4	0.975	21.51	23.95	34.56	74.83	1.62	7.2
9.4	0.995	14.58	23.96	34.57	80.13	1.61	5.1
9.42	1.005	9.32	23.97	34.58	80.96	1.61	3.5
9.43	1.015	12.21	23.99	34.6	81.42	1.6	4.3
9.43	1.025	5.89	24	34.61	91.79	1.6	2.1
9.45	1.035	7.48	24.01	34.62	88.17	1.6	2.7
9.45	1.045	12.65	24.02	34.63	81.71	1.59	4.4
9.47	1.065	6.43	24.03	34.64	90.88	1.59	2.3
9.48	1.075	3.13	24.04	34.65	93.75	1.59	1.3
9.48	1.085	7.78	24.05	34.66	91.38	1.59	2.7
9.5	1.095	11.68	24.06	34.67	85.17	1.58	4.0
9.52	1.105	12.38	24.07	34.68	83.33	1.58	4.3
9.52	1.115	18.83	24.08	34.69	76.13	1.58	6.4
9.53	1.125	24.41	24.09	34.69	71.88	1.58	8.2
9.53	1.135	8.9	24.1	34.7	74.04	1.58	3.7
9.55	1.145	15.96	24.11	34.71	77.75	1.58	5.5
9.57	1.155	14.5	24.11	34.72	81.38	1.58	5.0
9.57	1.165	15.32	24.12	34.73	84.17	1.58	5.1
9.58	1.175	12.07	24.13	34.73	82.92	1.58	4.2
9.58	1.185	14.51	24.13	34.74	75.46	1.58	5.2
9.6	1.195	19.35	24.14	34.75	76.21	1.58	6.6
9.6	1.205	19.22	24.15	34.75	74.88	1.58	6.6
9.62	1.215	15.81	24.15	34.76	77.13	1.58	5.5
9.62	1.225	22.1	24.16	34.77	79.58	1.58	7.2
9.62	1.235	4	24.16	34.77	87.58	1.58	1.8
9.63	1.245	22.31	24.17	34.78	86.21	1.59	7.0

9.63	1.255	18.05	24.17	34.78	78.96	1.59	6.1
9.63	1.275	17.78	24.18	34.79	74.83	1.59	6.2
9.63	1.285	17.76	24.18	34.8	76.54	1.59	6.1
9.63	1.295	17.55	24.19	34.8	79.42	1.59	5.9
9.63	1.315	8.26	24.19	34.81	87.04	1.6	3.0
9.63	1.325	27.03	24.19	34.81	76.71	1.6	8.7
9.63	1.345	0.37	24.2	34.82	84.38	1.6	0.9
9.63	1.355	30	24.2	34.82	69.04	1.61	9.9
9.63	1.375	17.84	24.2	34.83	80.42	1.61	6.0
9.63	1.395	14.02	24.21	34.83	85.58	1.61	4.7
9.62	1.415	18.9	24.21	34.84	79.17	1.62	6.3
9.62	1.435	14.5	24.21	34.84	79.71	1.62	5.1
9.6	1.455	11.76	24.22	34.85	79.83	1.63	4.3
9.6	1.475	22.86	24.22	34.85	77.04	1.63	7.5
9.58	1.495	11.93	24.22	34.85	80.71	1.64	4.3
9.57	1.525	10.41	24.23	34.86	82.88	1.64	3.8
9.55	1.545	16.09	24.23	34.86	80.83	1.64	5.5
9.55	1.575	11.87	24.23	34.87	86.08	1.65	4.1
9.53	1.605	11.87	24.23	34.87	86.08	1.65	4.1