UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN INTELLIGENT WATER BLENDING SYSTEM FOR IRRIGATION OF CROPS WITH VARIOUS SALINITY TOLERANCE AND AQUACULTURE

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By

ABDULLAH SULAIMAN ABDULLAH AL-JUGHAIMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2008

DEDICATION

With appreciation and respect

this thesis is dedicated

to my parents,

my wife, sons, daughters, brothers and sisters.

I owe my country a great debt.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of PhD

DEVELOPMENT OF AN INTELLIGENT WATER BLENDING SYSTEM FOR IRRIGATION OF CROPS WITH VARIOUS SALINITY TOLERANCE AND AQUACULTURE

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The application of Artificial Intelligence (AI) systems in decision-making and intelligent control systems has recently gained attention of researchers. One such application is to optimize the water quality and distribution, and to ensure reliable water supply for different consumers. Irrigation is among the important water consumers due to the large amount required to supply the increasing needs for agriculture, and due to the crop yield-salinity tolerance. AI methods such as goal programming have been used for irrigation scheduling and stochastic goal programming for modeling of future water consumption needs. Water blending in pipes has also been addressed to balance the salinity of irrigation water. Desalination plants use different methods of desalination, which usually produce pure water, but they are expensive. In most cases the desalination plant is integrated with a blending system to blend the pure water with other sources of water for balancing the ingredients, including the salinity, to be suitable for human use and to increase the volume of water. In a typical arid agricultural area, there will be abundant low quality ground water and little quantities of good quality water. There is a need for water blending systems suited for smaller farming communities in arid areas such that more water is made available for crop irrigation depending on the salinity tolerance and also water for aquaculture or livestock. The aim of this work was to propose an artificial intelligence solution to connect many tanks in a network topology, where each tank supplies water with a specific salinity tolerance. The water from two source tanks (one saline groundwater, and the other fresh water) is mixed inside the sink tanks to provide the required salinity in each tank and consequently reduce the fresh water consumption. A mathematical model for water blending was developed to simulate mixing water in a network of tanks. Genetic algorithm (GA) was used as a search engine to find the optimized solution for the amount of water needed to be transferred from one tank to another to balance the salinity that ensure the minimum usage of fresh water. Two cases were simulated involving two source tanks and four sink tanks with various salinity tolerances. One case was for crop irrigation and the other for aquaculture. Laboratory calibrations on the results produced by the GA indicate less than 10% error between simulated and measured EC of the blended water. Further simulation results showed that blending water with different salinities in a network of connected tanks can balance the salinity of each tank according to the crop salinity-tolerance data extracted from FAO reports. The blending system allows the salinity level that minimizes the use of good quality water while the crops can still attain 100% yield potential. This is achieved when sink tanks are connected to each other and GA is used to determine the volume of inter-tank water transfers. The intelligent water blending system developed in this study provides a mechanism to extend the blending unit to produce water with different salinity levels to meet different standards for use in irrigation or aquaculture. This system will help water managers make better use of various water sources to produce more water for expanding agriculture, aquaculture or industrial use in arid areas.

Abstrak tesis yang dikemukakan kepada Senat Unversiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN SISTEM CERDIK MENGADUN AIR UNTUK PENGAIRAN DENGAN PELBAGAI TOLERANSI KEMASINAN TANAMAN DAN AKUAKULTUR

Oleh

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Aplikasi sistem cerdas buatan (AI) dalam membuat keputusan dan sistem kawalan pintar telah mendapat perhatian para penyelidik mutakhir ini. Suatu aplikasi ialah untuk mengoptimumkan pengagihan dan kualiti air, dan memastikan bekalan yang boleh diharapkan kepada pelbagai pengguna. Pengairan tanaman adalah pengguna penting kerana jumlah air yang banyak diperlukan untuk pertanian yang pesat berkembang, dan juga kerana hubungan di antara toleransi kemasinan air dan hasil tanaman. Kaedah AI seperti pengaturcaraan matlamat telah digunakan untuk penjadualan pengairan, dan pengaturcaraan matlamat stokastik untuk pemodelan keperluan penggunaan air dimasa hadapan. Pengadunan air dalam paip telah dilakukan untuk mengimbang kemasinan air untuk pengairan. Loji nyahmasin menggunakan banyak kaedah yang akhirnya menghasilkan air tulen tetapi loji tersebut adalah mahal. Dalam banyak keadaan, loji nyahmasin menggembleng sistem mengadun air tulen dengan air lain untuk mengimbangi ramuan, termasuk kemasinan supaya sesuai dengan keperluan manusia di samping meningkatkan jumlah air. Dalam kawasan pertanian biasa di gurun, akan terdapat banyak sumber air bumi yang biasanya masin tetapi kurang air tulen. Oleh itu sistem mengadun air amat diperlukan bagi menambah bekalan air untuk masyarakat tani, pengairan, dan air untuk akuakultur serta haiwan ternakan. Kajian ini adalah untuk mencadangkan penggunaan penyelesaian AI bagi menyambung beberapa buah tangki dalam satu topologi rangkaian di mana setiap tangki membekal air kepada tanaman yang mempunyai toleransi kemasinan tertentu. Air dari dua tanki bekalan (air masin dan air tawar) dicampurkan dalam tangki penerima untuk membekal kemasinan yang diperlukan dan seterusnya mengurangkan penggunaan air tawar. Satu model matematik untuk mengadun air telah dibangunkan untuk mensimulasi pencampuran air dalam satu rangkaian tangki. Algorithme Genetik (GA) telah digunakan sebagai enjin pencari yang menentukan penyelesaian optimum untuk jumlah air yang perlu diagihkan dari satu tangki ke tangki yang lain demi mencari imbangan kemasinan yang memastikan penggunaan air bersih yang minimum. Dua kes yang telah disimulasi melibatkan dua tangki bekalan dan empat tangki penerima yang mempunyai toleransi kemasinan yang berbeza. Satu kes adalah untuk pengairan tanaman dan satu kes lagi untuk akuakultur. Kalibrasi di makmal ke atas keputusan diperolehi oleh GA menunjukkan ralat kurang daripada 10% di antara EC simulasi dan EC diukur. Keputusan simulasi kajian seterusnya mendapati pengadunan air dengan pelbagai toleransi kemasinan dalam satu rangkaian tangki yang bersambung boleh mengimbang kemasinan setiap tangki berasaskan data toleransi tanaman terhadap kemasinan air yang terdapat dalam laporan FAO. Sistem pengadunan membolehkan tahap kemasinan yang meminimumkan penggunaan air berkualiti baik tetapi masih boleh mencapai potensi hasil 100%. Ini dapat dicapai bila tangki penerima disambungkan sesamanya dan GA yang dibangunkan diguna untuk menentukan pemindahan air antara tangki. Sistem pengadunan air pintar ini boleh menyediakan mekanisme untuk melanjutkan unit pengadun menghasilkan air dengan tahap kemasinan yang berbeza bagi memenuhi keperluan pengguna yang berbeza sama ada untuk pengairan tanaman, akuakultur atau keperluan industri.

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I certify that and Examination Committee has met on 18 April 2008 to conduct the final examination of Abdullah Sulaiman Abdullah Al-Jughaiman on his Doctor of Philosophy thesis entitled “Development of an Intelligent Water Blending System for Irrigation of Crops with Various Salinity Tolerance and Aquaculture” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously concurrently submitted for any other degree at UPM or other institutions.

ABDULLAH SULAIMAN ABDULLAH AL-JUGHAIMAN

Date: 10 July 2008

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter highlights the review of water salinity, water blending station, salinity levels, expert systems and natural resources management, and artificial intelligence in water management.

2.2 Use of Unconventional Water for Irrigation

The world's irrigated area is currently estimated to be 250 million hectares (Willardson, *et al.*, 1997). Its rate of growth, which in the past averaged about 2 percent per year, has fallen to a growth rate less than 1% per year. While only about 17 percent of the world's cultivated land is irrigated, it produces one-third of the world's fresh food harvest and about half of its wheat and rice production. However, it is predicted that at least half of the required increase in food production in the near-future decades must come from the world's irrigated land. In view of the role of irrigated agriculture as the competition for water cannot be allowed to result in even lower food production growth rates, or an absolute reduction, of the world's irrigated area. The challenge to the irrigation sector of agriculture is therefore clearly to produce more food by converting more of the diverted water into food. Increased food production will leave even less water for other uses.

One of the obvious ways to meet the challenge for better fresh water management is to reduce the amount of irrigation water applied. Another way is to reuse the non-consumed fraction of the irrigation water already diverted. It is well documented that, at the field level, a large part of the applied irrigation water is not actually consumed by a given crop and therefore ends up as drainage water (Hill, 1994 and Frederiksen, 1992).

Since much of the drainage water becomes the source of the water for downstream irrigation schemes and for other uses, the water use efficiency computed at the basin level is usually much higher than the field or irrigation scheme level. In many irrigated areas, however, there is ample scope for planned reuse of drainage water and both water users and policy makers are showing increasing interest in drainage water reuse as means of augmenting dwindling useable water supplies (Tanji and Dahlgren, 1990).

Sharma and Sharma (2004) mentioned about the irrigation system types depending on the nature of the water source and location such as gravity, lift, infiltration, sewage, supplemental, tank irrigation and others. The methods by which these systems deliver irrigation water include sub-surface, surface, overhead, buried, drip, seepage and suction irrigation.

Water supplies for any irrigation scheme come from a water source. The two main sources of water for irrigation are surface water, which commonly include rivers, reservoirs and lakes and groundwater (Brouwer *et al*., 1992). The reuse of water has also been on the increase especially where water scarcity is prevalent. However, these water sources can be of poor quality, particularly ground and drainage waters. The quality of water for irrigation is determined by its physical, chemical and biological characteristics. Poor quality irrigation water will adversely affect soil, crops and animals as well. The quality of irrigation water from any source can be indexed based on its dissolved sodium and calcium salts, boron content, electrical conductivity (EC), pH, crop sensitivity to salts, microbiological content. Physical properties include the colour, taste, odour, temperature, and turbidity (Bernstein, 1981and Sharma, 2004).

Moreover, water quality related problems in irrigated agriculture are not new. Salinity, water logging, soil erosion and sedimentation, the spread of disease carrying organisms and water pollution (specific ion toxicity to crops) are a few of the serious problems that have gone hand-in-hand with irrigation (Ayers and Westcot, 1985). Irrigation induced salinity is a very serious problem to crops, soil and the environment and needs serious attention. There are various methods of measuring salinity levels of water or soil. The EC-meter method is the most commonly used for in-situ measurement of water salinity. A more costly and less used device is the neutron probe (FAO, 1997).

There are various ways of improving low quality water such as saline water to reduce, minimise and where possible eliminate its effects on crops, soils and the environment. These methods can be used individually but much better in combination where possible. The methods include breeding of salt tolerant crops, water quality management, improved drainage, leaching with water, improved cultural practices, changing irrigation methods, land development for salinity control and last but by no means the least, the changing or blending of water supplies (Ayers and Westcot, 1985).

Some researches such as Willardson *et al*. (1997); Oster and Grattan (2002); Alhumoud *et al*. (2003); Fadlelmawla and Al-Otaibi (2005) noticed about the reuse of unconsumed fraction of irrigation water is one way of managing and meeting the challenges posed by scarcity of irrigation water. Drainage water can be mixed or blended with residual irrigation water, surface runoff, effluents from water purification plants, domestic waste water and others. Usually drainage water is saline and has to be mixed with non-saline water before irrigation reuse so that crop yield is not adversely affected. Reuse practices include direct, sequential, cyclic, intermittent and natural reuse or continuous mixing or blending have been sustainable practised in India, Egypt, and the United States.

In most countries, especially semi-arid and arid regions, salinity is the major limiting factor in the utilisation of groundwater resources and drainage water. Therefore blending, which is one of the options for improving the quantity as well as quality of irrigation water supply can be implemented. However, consideration should be given to the fact that plants must have the access to water of a quality that permits consumption and growth without loss in yield. Blending excessively saline water with good quality water may prevent plants from getting the opportunity to use good quality water fully. Therefore, blending in this case would not stretch the water supply for crops. On the other hand, blending moderately saline water with good water could expand beneficially the water supply for crops if these crops are more salt tolerant than the previous one (Rhoades, 1990; Salman *et al*., 1999).

Various other commercial methods exist for desalination of water such as distillation and membrane processes, which include ion-exchange membranes, electro-dialysis, semi-permeable membranes and reverse osmosis (Deliyannis, 1978). These processes can be very expensive especially when electrical power is needed for the process. Solar energy has been tried in the process of desalination in the glasshouse (Chaibi, 2003) as well as effects of different designs of solar stills (Al-Hayek and Badran, 2004). The limitation of this system is the low rate of water volume production, which although high in quality may be insufficient to meet irrigation requirements on a large scale. It is imperative that both economic and agronomic factors are taken into account in planning strategies for any sustainable irrigation technology (Oster and Wichelns, 2003).

Blending of drainage saline and non-saline waters offers such a possibility in areas with limited water. However, caution must be taken as blending does not unconditionally increase the usable water supply nor is it always economically feasible (Grattan and Rhoades, 1990; Oster and Grattan, 2002). Reuse strategy is to blend supplies before or during irrigation. This strategy requires adequate control of mixing of the water supplies (Ghassemi and Jakeman, 1995).

Various studies have been done where different forms of blending methods have been employed. Some have focussed only on meeting the agronomic management requirements aspect in regards of crop tolerance to salinity (Sharma *et al*., 1994; Tsakiris and Spiliotis, 2006). Others have dealt with the engineering management regarding control of water volumes, water salinity and water distribution (Jury *et al*., 1980; Sinai *et al*., 1985; Shah and Sinai, 1985). Work on various mathematical and programming techniques also been done to optimize the blending process and requirements (Yang *et al*., 2000; Al-Zahrani and Ahmad, 2004). It is worth noting that all these studies are fragmented and do not integrate the agronomic and engineering managements into a holistic system for crop irrigation using saline and non-saline waters through blending. This study will attempt to do just that by borrowing, modifying, integrating, consolidating current knowledge as well as using present technology to develop an improved all-in-one system.

Another computer algorithm was developed by Savvas and Manos (1999) to maintain a target electrical conductivity in the irrigation solutions of the soilless culture system by dispensing as many nutrients as needed. The developed algorithm automatically adjusts the dilution ratios of the concentrated fertilizers in relation to the volume and the electrical conductivity. They managed using the developed algorithm and model to reduce the salinity of the soilless culture by using the drain solution not by adding the nutrients solutions. The aim of their study is to control the concentration of P, Zn and Mn in the soilless culture (Savvas and Manos, 1999).

2.2.1 Types of Reuse Practices

Hill (1994) and Frederiksen (1992) defined the drainage water as the unconsumed part of the irrigation water applied to crops. Drainage waters intended for reuse can be mixed or blended with residual quantities of irrigation water such as operational spills and tail end losses from irrigation canals, surface runoff from irrigation, and with effluents from water purification plants, industrial and domestic waste water.