INTELLIGENT DECISION SUPPORT MULTI AGENT SYSTEM IN IRRIGATION WATER MANAGEMENT

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Declaration

I declare that this dissertation does not incorporate, without acknowledgment, any material previously submitted for a Degree or a Diploma in any University and to the best of my knowledge and belief, it does not contain any material previously published or written by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, to be made available for photocopying and for interlibrary loans, and for the title and summary to be made available to outside organization.

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Dedication

I dedicate this thesis to my family and friends. A special feeling of gratefulness to my dearest mother who shadow my life when need the encouragements. I will always appreciate the help of other family members for the things all they have done and their valuable thoughts. I dedicate this work and give many thanks to people at Rajarata University for their help and especially for the library staff.

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Abstract

Hydrology and water resources research have some interested in to look for new methodologies that help to address current and future water conflicts over freshwater. The aim of this thesis is applied multi-agent approaches in the water resource research as a valuable tool. Multi-agent systems that are frequently applied in various academic disciplines represent the system based on more or less autonomous and cognitive agents.

In the first part of the thesis, the method is critically reviewed. Applications conducted in hydrology, water sciences and related areas are considered for this purpose. In addition, existing software systems for multi-agent modeling are discussed. Since the representation of the environment has proved itself one of the most important points for applications in hydrology and water resources research, recent developments in this field of research are taken into account.

In the second part of this thesis, a prototype of a multi-agent model of the water supply in the area of Mahaweli H System was developed using the Java Agent Development Framework (JADE) and consist of diverse methods to support in Irrigation Water Management. The model aims at exploring the way the irrigation population handles this situation and manages to satisfy its cultivation demand of the water. Thereby, the representation of the natural water resources is based on empirical data and hydrological assumptions. In here highly concern about the water control technique used in irrigation system named as the Bulk Water Allocation system. The system was evaluated using the existing data from the Irrigation Department. It has resulted that the water wastage by the system was 72.04% and the natural phenomena was 74.00%. This result concluded that the automated software component of water management functions using multi agent technology as an effective solution for eliminating limitations in decentralized communication.

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Chapter 1

Introduction

1.1. Prolegomena

The North Central Province in Sri Lanka equipped with only scarce natural resources. Rural population sometimes affected by an extreme uncertainty in the precipitation regime with recurrent drought periods. Moreover, water quality problems deteriorate the conditions partly. But most of the paddy production in these areas straightly subjected to national income. Though parts of the dry climate effected in these areas the cultivation remains considerable level during the year[1].Basically, the practice techniques, land use patterns, cropping patterns and the water management systems are the main factors that affecting the productivity[2].Among them the major problem is the water management in the area because of the critical climate affected in. For the last research projects are based on the numerous studies in the Water Management Systems in global and local perspectives in Irrigation Department and the Academic Institutions.

However, this is one of the major areas in the Sri Lanka where individuals are affected by today's water crises and conflicts over freshwater. This area consists of separated tanks and cannel systems to the integrated network of water. These water-sheds are mainly for domestic purpose and the irrigation purpose. Barely anyone would doubt that hydrological sciences should feel duty-bound to help to solve such conflicts and support the people concerned. Answering the question which methodologies hydrology should apply to face the challenges of the future is more complicated. Nowadays, hydrological modeling is possibly the most powerful tool in water sciences for both, research and practical work. However, there is an increasing uneasiness among researchers about some of the limitations and problems of classical deterministic models.

In respect to these aspects, hydrologists should feel obliged to look for new ways of modeling and new research tools. Particularly the exclusion of human decisions and of socio-economic topics is a problematic limitation in classical models when the research question includes issues of water resources management. Due to an increasing demand for clean water by the growing human population, the world is likely to face a higher number of resource conflicts within the next decades and centuries. Hydrologists are forced to integrate social and socio-economic issues into their attempts to model reality.

Multi-agent approaches provide a valuable framework for such new kinds of hydrological models. Originally developed in the context of Distributed Artificial Intelligence, Multi-Agent Systems are widely adopted across academic disciplines. They are meant to be especially capable of modeling complex systems which are a valuable characteristic in the context of Integrated Water Management. Additionally, their ability to represent individuals explicitly in the models is promising for applications related to water resources management.

However, promising methods should be reviewed critically before they are adopted in a scientific community. The primary objective of this thesis is to develop an intelligent decision support multi agent system in water management in irrigation sector of Sri Lanka related the Mahaweli H-system. Its obtain the heights paddy cultivation in the country and contributes the highest productivity to the national income[3].It uses good water practice through the fields with the contribution of the officers and the farmers. During the process it is identified the process is onwards within the communication network among the agents of the system to obtain the success.

The major objective of this is to develop a multi-agent simulation of the water distribution system in the Mahaweli H- system that uses the naval technique called Bulk Water Analysis. Based on empirical data, an explicit representation of some of the local water users and their available water sources is implemented. Hopefully, this is one step towards finding the best option for the water supply crucial for the irrigation environment. During the process it is identified the possibilities of the use of multi-agent systems in hydrology on the one hand and limitations and drawbacks on the other hand.

1.2. Research Question

This consists of two major parts, the background of the problem with the theoretical part (chapter 3 and 4) and a practical application. The objective of the theoretical part is to provide an elaboration of the existing water resources management of the region. To achieve this goal, it is necessary to discuss and classify applications conducted in hydrology and water sciences related areas. The characteristics of multi-agent modeling have to be considered based on a review of the literature as well as on personal reflections. Of interest are the requirements of hydrology from such an approach, the potential for applications in this scientific field as well as inherent problems. In this context, possible future applications and aspects of adapting the methodology to hydrological applications are considered as well. Additionally, the theoretical discussion aims at providing an overview of some of the existing software systems for multi-agent modeling with a special focus on systems that are interesting from a hydrological point of view. Features of the systems that are discussed include their availability, their adequateness for hydrology and water resources and their flexibility.

The objective of the second part of this thesis is to develop a practical application of a multi-agent model addressing the water supply in the area of Mahaweli H-System. This area is characterized by the presence of a public water supply infrastructure on the one hand and a semi -arid climate on the other hand. The aim is to consider explicitly the representation of the natural water resources as well as the behavior of the water consumers. The most suitable of the discussed software systems is chosen for this purpose. Using this practical example, the application of a multi-agent system is demonstrated and practical problems in using such methodologies are discussed, e.g. include advances and drawbacks in working on such questions.

1.3. Aim and Objectives

The aim of this project is to develop Multi Agent System solution for Irrigation Water Management. In order to reach this aim the following objectives are identified.

- To critical study of the Irrigation Water Management domain with a view to identify current practices and issues.
- Analyze the existing solution in Irrigation Water Management with the view to define the research problem and possible technology.
- Study about Multi Agent System and its applications in Irrigation Water Management.
- Design and implement Multi Agent Solution for Irrigation Water Management.
- Evaluate the MAS using a real world scenario.

1.4. Background and Motivation

Water management in irrigation system is identified as the network of entities and working together with collaboration and sharing information to achieve intended goals for an organization to success is an essential requirement of a system. These entities consist of number of contributors to the system: Farmers, Agriculture Inspectors, Water Distribution agents (Water Masters), and Irrigation Engineers. They work together as network of agents in irrigation water management.

There are some developed systems that model and simulated the hydraulic managements and optimization the distributed watershed management in hydrology[4][5]. Nowadays, instead of centralized information processing systems, has replaced with decentralized complete software applications and Multi Agent Systems provides powerful modeling and analytical tool to drive the concepts hence naturally allows representing the scenarios. The both Distributed Constraint Satisfaction and Distributed Constraint Optimization frameworks are different strategies that used in fully distributed managements in watersheds[5].

However for last two decades there are numerous conventional software systems has been incorporated in finding improved solutions for solving complex system problems. On the other hand multi agent technology has emerged as the novel approach for solving complex system problems, even though the entities are located in distributed nature. The water distribution mechanism in an irrigation system is a decision making process of an Agent with the different behaviors and responsibilities with the levels of coordination with in a complex environment. In addition to this due to the uncertainty of the decision making process and different behaviors of the entities in a complex systems and their activities have been identified as rather complex in nature. Therefore it is hard to find proper evidence of complete software application which has implemented for eliminating complexity in water management. As a result of this Multi Agent System (MAS) technology has been used throughout this project to eliminate the complexity and to offer effective communication mechanism for the process.

It is argued that the importance of effective communication architecture in water distribution while enabling the entities to communicate coordinate and negotiate in operation. With the introduction of Multi Agent System has accommodated these facilities needed to communicate in distributed environment. Each agent in the network has different responsibilities according to the ontology they access and work together while planning and executing their tasks. In addition to this inter organizational coordination and collaboration were not sufficiently achieved by traditional information systems and their successfulness depend on collaboration, information sharing and effective technology support. It is reviewed that legacy systems, and current software applications that developed using client server architecture are lacking in effective communication and failed to perform accurately when they are in distributed nature.

1.5. Problem in Brief

Lack of proper coordination and communication in Irrigation Water Management environment have resulted in malfunctioning of whole Water Distribution process leading to Farmer dissatisfaction, Crop reduction, increased water wastage and profit loss affects the income of the country.

1.6. Novel Approach to Irrigation Water Management

Communication complexity is a predominant problem in irrigation water management due to entities, which operate in isolated environments and are lacking from information sharing and collaborative planning. Therefore in this approach a multi agent system has been introduced as an innovative technology to provide dynamic solutions for the concept. There are various requirements from the entities operate in water management process the required water quantity, crop type, field size has taken as inputs to the system while providing gate operation and water controlling are delivered as outputs from the system. System can be evaluated using the Farmer satisfaction, calculating the profit margin and calculating the water wastage. These Timely responses, information sharing, high performance under limited resources are identified as high-level features of the system. Yet another explanation about novel approach is included in a real world problem using novel approach chapter.

1.7. Structure of the Thesis

Rest of the thesis is organized as follows. Chapter 2 critically reviews the domain of Irrigation Water Management (IWM) by highlighting current solutions, practices, technologies, limitations defining the research problem. Chapter 3 describes the essentials of Multi Agent technology showing it is relevant to solve the IWM domain. Chapter 4 presents our novel approach to IWM with Multi Agent technology.

Chapter 5 is on the design of MAS for IWM. Chapter 6 comprises details of implementation of the MAS solution for IWM. Chapter 7 illustrates a real world problem using novel approach. Chapter 8 reports on evaluation of the new solution by explain evaluation strategy, participants, data collection, representation and analysis. Chapter 9 concludes the outcome of the research with note on further work.

1.8. Summary

This chapter describes the full picture of the whole project showing research problem, objectives, hypothesis and the novel solution. Next chapter will be on literature review of Irrigation domain practices, technologies and issues with a view to define the research problem.

Chapter 2

Current Trends and Issues in Irrigation Water Management (IWM)

2.1 Introduction

This Chapter describes the background for this project and identified the main research question, trends and various kinds of multi agent systems in hydrology and water science area. It classifies the benefits limitations and drawbacks that faced with in the research field.

2.1.1 Multi-agent Systems and Hydrology

A high number of studies exist that apply multi-agent modeling to water resources research. The general idea thereby is to simulate the responses of the households to changes in their environmental with quantitative models and to support policy formulation. To achieve this, ideally models integrate biophysical as well as socio-economic processes[6].The problem at the moment is that most models do not address interrelations between evolution of water resource and human development in a balanced way. For managing processes at the river-basin level for example, the emphasis is commonly placed on one side, either on accurate modeling of the water dynamics or of the human activities.

The current trend towards application of multi-agent methodology in water management corresponds to current trends in water management, e.g. towards decentralization. For example, many of the examples modeled in the French research community are related to the 1992 French water law that emphasizes decentralized approaches to water management. The initiated process of negotiating local water management rules contributes to the growing interest in analytical tools for supporting the processes of negotiation and decision making In this context, simulations can be a helpful tool for illustrating the probable consequences of different actions to the stakeholders, especially concerning interactions and second-order effects. Thereby, it is not the aim to predict the future outcomes exactly, which would be over-ambitious anyway, but to foster the stakeholder understands of possible scenarios. Consequently, models in water resources management aim not only at helping the authorities to evaluate possible effects of different kinds of water management actions, but are also used sometimes to foster communication with stakeholders as well. In both cases, the socials aspects have to be represented realistically in the dynamics of the hydrological system[7].

All in all, water resource problems not only demand the integration of hydrological and social models, but also the communication of the models to stakeholders or even their involvement in creating and interpreting it. All these requirements go beyond the scope of classical hydrological models. Multi-agents models in contrast may be suitable for building models with these characteristics. Support for this assumption is sought in the literature and described below.

2.1.2 Urban Water Management

Peri-urban areas serve as catchment areas and space for drinking water reservoirs to the cities, but face specific challenges such as urbanization dynamics, illegal settlements and the absence of basic infrastructure and public facilities. A multi-agent model of the metropolitan watershed of aims at representing the hydro- social functioning of the catchment Sao Paulo, Brazil[8]. The prototype of the agent-based model includes legal and illegal market processes as well as the competition for water by rural and urban land owners and pollution. The main activity of the producer and speculator agents is to decide on the use of their plots. Hydrological processes are represented in a spatially distributed manner and the pollution is monitored along the rivers. Furthermore, the availability of water and its pollution influence the decisions of the agents. First results indicate for example the time at which the water reservoirs reach a critical level[9].

2.1.3 Integrated Natural Resources Management

Integrated Natural Resources Management (INRM) challenges traditional approaches because it considers scale issues, i.e. interrelations between temporal, spatial and social scales, as well as various organizational levels. The research in natural resources management shows a growing interest in modeling artificial societies due to the ability of this approach to conceptualizing entities. A great part of the literature on multi-agent modeling dealing with natural resources takes place in the context of Integrated Natural Resources Management. The French research community that developed the modeling platform COMAS[10]realized many applications of multi-agent modeling in this context[11].A general problem in integrated management is to match the scales of social and ecological dynamics. In agent-based modeling, it is possible to operate on different levels, which is useful for agent-agent and agent-environment interaction.

The main topics of the simulation are conditions under which farmers build wells and social influences, e.g. teaming up of two neighbors for building a well[12].The entities represented are the farmers as social entities, spatial entities such as their plots and finally wells and boreholes as located entities. The interactions between the farmers concern the construction of wells and the exchange of land. First tests of the model reveal that the dynamics in the field are comparably well reproduced for the near future and that logic and realistic tendencies are observed for the long-term

2.1.4 Integrated Watershed Management

In the last years, Integrated Watershed Management has been of growing importance as a specific form of the more general Integrated Natural Resources Management (INRM) mentioned above. It is of particular interest to hydrologists who are working traditionally in reference to watersheds. Integrated Watershed Management is characterized by its complexity and is faced with conflicting interests, e.g. water supply, flood control and recreation, just to mention some [13]. The aim is generally to develop and execute a sustainable and equitable strategic program for utilizing and conserving natural resources at all scales in a watershed, thereby integrating different interests [13].Models for this purpose should be integrative as well as spatially distributed and large-scale representations in order to represent the whole system including interactions between natural and other resources and between all relevant processes.

2.1.5 Lake Management

A model of the dynamics of a lake subject to phosphorus pollution includes the cycle between water and sediments[14]. Related to the different states of the system are different economic benefits. The modeled agents decide upon the level of input pollution according to their expectations about the dynamics of the system, the markets and the actions of other agents. Thereby, the agents are heterogeneous in their beliefs and in their access to information and adapt to changes in the ecosystem[14].A similar piece of work is done based on a conventional computer model of hydrological and immunological processes in Lake Anderson, they created the multi-agent model MIMOSE with the aim to represent potential polluters and local administration directly. For this purpose, they implemented farmer agents and a local government applying different policies against the eutrophication of the lake.

An advantage of multi-agent modeling is the possible inclusion of the parameters influencing the water users' decision-making process, for example environmental awareness and social responsibility. The agent-based social simulation DAWN (Distributed Agents for Water Simulation) aims for example at predicting the effects of a public conservation campaign on residential water demands[15]. Focusing on the influence -diffusion mechanisms among water user, it represents a community of interacting, autonomous consumer agents including some so called opinion leaders. The agents decide about actual consumption influenced by their social neighbors, whereby each actor has a different power of persuasion and an individual sensitivity to social influence[16]. A first application of the model in Thessaloniki, Greece delivers some interesting quantitative results, e.g. that the impact of information and education campaigns is less effective than increasing water prices at the beginning, but more intense in the long term [16].

2.2 Benefits of multi-agent system in hydrology and water resources research

The discussed models and case studies provide first impressions on possibilities and limitations of multi-agent modeling for hydrology and water resources research. It remains to discuss which conclusions can be drawn based on the literature review. For this purpose, it may not be sufficient to ask what the methodology has to offer. Rather, criteria for judging the suitability of the methodology derive from the question what hydrologists expect from such a methodology. Although multi-agent systems can be considered as a very innovative new modeling approach, their advantages do not necessarily have to fulfill the requirements of hydrological research for new modeling approaches. According to Bankes[17], not the virtuosity of a technology, but the needs in sciences determines whether an innovation tool is revolutionary or not. Regardless of the greatness of advances in computer sciences that made agent- based modeling possible, what matters the challenges in the sciences are adopting it, which make it necessary.

For the area of social sciences, Bankes found three often cited reasons why agent-based modeling is potentially important, namely "the unsuitability of competing modeling formalisms to address the problems of social sciences, agents as a natural ontology for many social problems, and emergence". These reasons partly apply to hydrology as well and serve as a guideline for the discussion in the following sections. Additionally, the multi-disciplinary nature of multi-agent modeling is another advantage.

2.3 Limitations for hydrology and water resources research

When the limitations of multi-agent systems for hydrology and water resources research are discussed, general limitations of the approach have to be included naturally, e.g. the lack of standards and of techniques for validation and verification. Furthermore, some issues are identified that are specifically problematic for applications in hydrology and water resources management. If they are not addressed in the right way, they have the potential to limit the applicability of the approach.

2.4 Summary

Regarding the applications of multi-agent systems discussed above as well as the consequent discussion of its possibilities and limitations, it is reasonable to conclude that the approach has some qualities promising for hydrology and water resource management, although some issues remain to be clarified or improved.

When discussing multi-agent systems, it has to be emphasized that this term summarizes different types of agents and applications. Clearly, applications in hydrology and water resources research are possible with different types of agents. In water resources research, the typical multi-agent model is based on cognitive agents, although only few agents with higher skills and abilities are represented.

Chapter 3

The Multi Agent Technology

3.1 Introduction

This chapter represented the major technologies associated with the project. Definition of Multi Agent Systems, its characteristics and behaviors are described in detail with the various types of systems.

3.2 Short History of Multi agent Systems

Writing an objective, unchallengeable history of multi-agent systems may not be possible, mainly since the roots of the approach are spread into different academic disciplines. However, it is thought that providing at least a sketch of the history and mentioning some of its milestones is necessary to improve the understanding of multi-agents systems and their development. If not indicated otherwise, the following section is based on [18]. In their compact and useful review of multi-agent simulation and ecosystem management provide a short overview on the history of multi-agent system as well.

Doubtlessly, the most obvious root of multi-agent systems lies in the field of Artificial Intelligence (AI)[19]. Agents appear already in the earliest AI literature in the middle of the 20^{th} century. Nevertheless, agents as holistic entities did not play an important role until the mid-1980s. In the classic period of AI planning between 1969 and 1985, they were instead mainly used as systems capable of independent actions in the context of reasoning and planning. Besides, a great deal of skepticism existed, whether computers would ever be able to show intelligent behavior such as problem solving, learning or communicating in natural languages. Some scientists tried hard to prove the critics wrong and subsequently topics as planning, learning or communication emerged as sub-disciplines of AI[20].

However, although these disciplines were rather highly developed by the mid-1980s, attempts to integrate these single skills into whole entities were actually missing. As a result, a completely new approach of building agents emerged, which was called Behavioral AI, Reactive AI or simply New AI[19]. In this context, the idea developed that intelligent behavior may emerge through interactions between simpler behaviors. Additionally, more attention was given to the agent's environment and its influence on the actions of agents. Of course, these new ideas challenged scientists working in the field of classical AI and led to the splitting of the AI community into classical and behavioral scientists. The latter took inspiration from biology, emphasized reactive behavior and worked mostly in an area that is called Artificial Life today [21]. Mainstream AI started to consider the integration of components of intelligent behavior into agents and accepted the value of testing and deploying agents in realistic scenarios. Nowadays, most kinds of agent architectures are based on reasoning and reactive behavior likewise, since such a hybrid structure seems necessary for creating intelligent autonomous agents.

Another distinction in the terminology is made between AI and Distributed Artificial Intelligence (DAI), whereby the latter is considered the root of multi -agent systems by some authors, e.g. by Bousquet and LePage[11]. They state that AI mainly aims at representing the knowledge and reasoning of one intelligent agent. In contrast, the aim of DAI is to reproduce the knowledge and reasoning of several heterogeneous agents that solve planning problems by coordinating their actions. Whereas researchers in AI are more interested in the agent and its autonomy, the DAI research focuses on interactions of multiple agents and how to organize them. The latter kind of research became influenced by social and life sciences, especially by the aforementioned Artificial Life approach. Artificial Life is based more on physics and the sciences of complexity and tries to examine scientific questions while focusing on the interactions between elementary entities and their mode of organization [22]

Research of multi-agent systems developed independently and simultaneously until about the early 1990s. Its roots are production systems that consist of rules and a working memory for facts and match patterns to actions. The main drawback of this approach is the unstructured knowledge of the system. The first solution to this problem has been provided by blackboard systems.Which are most likely the first approach that deserves being called multi-agent systems. The main components of blackboard systems are a knowledge source, i.e. a collection of independent entities with rules expressing a specialized knowledge, and a blackboard as a shared data structure. Knowledge sources that happen to know a solution to a partial problem write it on the blackboard, until the problem is solved. Within the 1970s, other prototypical multi-agent systems developed that realized issues such as actors receiving and sending messages, delegating sub-problems to other agents or negotiation. The common feature of these systems is that a common interest of the agents is implicitly assumed. This means that until the mid 1980s, parallelism in problem solving or distributed problem solving were the main focus of interest. However, agents are not necessarily benevolent as these agents, but can be self-interested instead.

An interesting decade for multi-agent modeling began in the 1990s. Interest in agents grew steadily, corresponding to their increasing application in industry. Especially the growing importance of the internet supported this trend, because it indicated that distributed, networked systems might be the future of computing and require appropriate methodologies. Later in the 1990s, agents became important in the booming area of electronic commerce for automating many tasks. Parallel to this trend, the idea of the mobile agent developed, i.e. an agent able to transmit itself across electronic networks and to recommence execution at a remote site. From the mid-1990s onwards, interest in standardization increased as well, since a lack of international standards hinders the spreading of a methodology. At the same time, the first researchers started to apply multi-agent systems to the modeling of natural societies and initiated the first workshops on this topic. Recently, researchers tend towards applying the multi-agent system to increasing realistic domains, as soccer contests for robots indicate[18].

Today, the remarkable number of conferences indicates the importance of multi-agent systems in different academic fields conferences, e.g. MABS (workshop on multi-agent systems and agent-based simulation), AAMAS (Conference on Autonomous Agents and Multi-Agent Systems) or ABS (Agent-Based Simulation), among others. Furthermore, special forums for multi-agent researchers exist, e.g. AgentLink (European co-ordination action for agent-based computing).

All in all, it cannot be denied that the history of multi-agent systems is influenced by their multidisciplinary nature. The development of the methodology lived and lives out of the mutual influence of scientists from different academic communities. On the one hand, the approach that originally developed in computer sciences induces scientists in social and natural sciences to reformulate some of their research questions. On the other hand, computer scientists are getting influenced by some concepts of cognitive psychology, sociology, linguistics and other social sciences [22].

3.3 Definition of Agents and Multi Agent System

Agent in a Multi Agent System can be identified as "a computer system that is situated in some environment, and that is capable of autonomous action in the environment in order to meet its design objectives"[21].However, the characteristic of multi-agent methodology is varying in different contexts and leads to a great variety of slightly different definitions. Accordingly, agent's attributes can be identified as intentionality, autonomy, reactivity, flexibility, communication, learning and self- actuation[23]. Especially the aspect of flexibility is interesting, since it is related to two different abilities, namely goal-directed behavior, i.e. the drive of the agent to satisfy or maximize its utility function, and reactive behavior. The latter means that the agent reacts to its environment and interacts with other agents. Reactive and goal-directed behavior is somehow contradictory, although both of them determine human behavior. It is one of the challenges in modeling individuals to balance these two tendencies.

The term 'multi-agent system' is not strictly defined, but used as an umbrella term for different types of systems. One of these systems consists of interacting hardware agents, a phenomenon that is also known as collective robotics. Another type of system is built by interactive software agents, also known as soft-bots, and is mainly used in distributed planning tasks, for example for scheduling applications of telephone companies. Simulations with multi-agents, also called multi-agents simulations, are another possibility[24].An appropriate definition of multi-agent systems may be even harder to achieve than defining agents. Figure 3.1 provides a graphical illustration of such a multi- agent system.

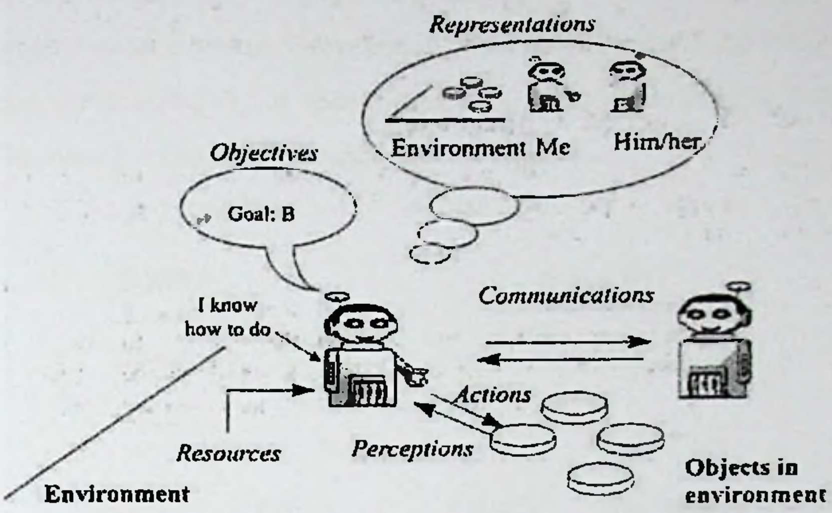


Figure 3.1: Illustration of a multi-agent system

3.4 Architecture of a MAS

A simple description of agents in the field of environmental modeling is given in Figure 3.4. One of the most important aspects of the architecture is the duality between the agents and their environment. Agents perceive the state of the environment and influence it in turn through their actions. Thereby, their actions depend on their internal goals and attributes. The interaction between agents takes place either directly by communication or indirectly, for example when different agents affect a common environment. The communication can have different goals, e.g. negotiation of possible solutions or exchange of information about resources or strategies.

The individual agents in agent-based models have particular states and rules of behavior. The typical steps in running such models are instantiating an agent population, letting it interacts and monitoring what happens. In other words, solving such models means simply running them, i.e. spinning them forward in time[25].Related to this kind of design are some key issues in creating multi-agent systems, which all belong to the problem of specifying the coordination among agents, namely decision-making, control and communication[22].It is beyond the scope of this thesis to discuss these and similar aspects related to the architecture of multi-agents model in detail. However, in order to understand the following cases the discussion thereof[26][21], it seems necessary to have an insight into some of the aspects involved in designing a multi-agent system.

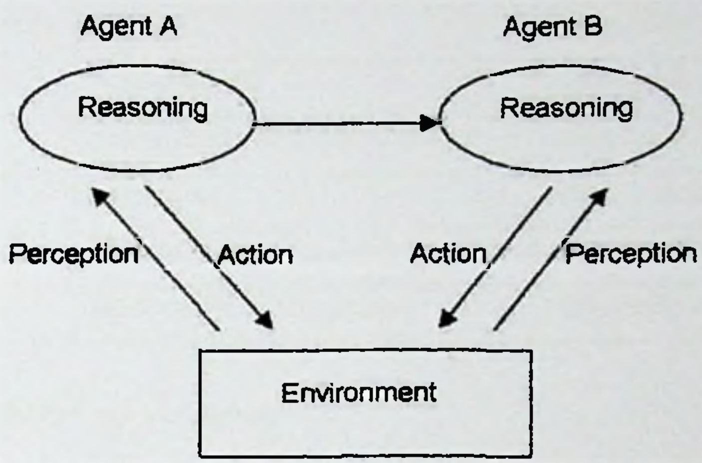


Figure 3.2: A Scheme of two agents, their environment and the included interactions

Multi-agent systems are as various as their definitions, their purposes and the areas they are applied in. Mainly, they can differ in the attributes of agents, interactions and environment. Table 3.1 provides an impression of the high number of attributes that characterize multi-agent systems and their range of variation. Due to this diversity, it is not possible to provide more than a coarse overview of the architecture of multi-agent system in this thesis.

Table 3.1: Some attributes of multi-agent systems together with their potential range

	Attribute	**Range**
Agents	Number	from two upward
	Uniformity	homogeneous…heterogeneous
	Goals	contradicting…complementary
	architecture	reactive…deliberative
Interactions	abilities (sensor,effectors,cognition)	simple…advanced

	Frequency	low...high
	persistence	short-term...long-term
	Level	Signal passing. Knowledge intensive
	pattern (flow of data and control)	decentralized...hierarchical
	Variability	fixed...changeable
Environment	Purpose	competitive...cooperative
	predictability	foreseeable...unforeseeable
	accessibility and know ability	unlimited...limited
	Dynamics	fixed...variable
	Diversity	poor...rich
	availability of resources	restricted...ample

3.5 Different types of Agents

To avoid confusion, it is important to differentiate between very different types of agents. The field of Artificial Intelligence, where agents originate from, is very diverse. Moreover, the term 'agent' is used nowadays for work in many different areas. As mentioned before, one fundamental distinction has to be made between scientific studies on the behavior of agents in the physical world, working on robots, and studies with agents in cyberspace, i.e. software agents. Only the latter is dealt with in this thesis. However, not all software agents have the same purpose. In multi-agent modeling, most agents normally represent actors of the real system. It is important to note at this point that one should not confuse the terms 'agent' and 'individual'. An agent does not have to represent an individual. It can as well represent any other level of organization, e.g. a swarm or an institution. Consequently, the actors are either represented personally or summarized in groups or institutions. As an example, in this research the task is to model the water distribution system, one option is to represent all the water users in the system. Another possibility is to include the water supply cannels as one agent and the operated gates as another one.

There are numerous agents and some group of software agents is not part of the model in terms of content. Such agents that are called 'service agents' in the following text do not represent real beings, but are utilized to support and organize the running of the model. The software system DAWN [16]for example contains a Simulator Agent for moderating and synchronizing the system. The 'directory facilitator' in some model manages a list of the various agents in the system together with their competences. The decision support system for water mains rehabilitation strategies by Davis [23]includes several of these service agents, e.g. an Interface agent with the ability to learn the language of the users for communication between user and model. Other service agents are for example a data-warehouse agent that manages data out of different data-bases, a data-mining agent, a strategy agent and a communication agent.

Figure 3.3 illustrates this structure, As a consequence of these different types of agents, the modeler has to decide which parts of the natural system shall be included as agents into the model, which service agents shall be implemented and which functions are to be handled without agents. For example, the delivery of information to agents in the system can be realized conventionally via a data file. Alternatively, it is possible and more realistic to implement an agent that represents an organization delivering the information to the agents, possibly the same institution as in reality. An example is the representation of a meteorological institute as an agent providing knowledge about meteorological conditions[15].However, another type of service agents is not limited to providing services within a simulation environment. Maybe the best known example for such service agents in everyday life is software demons, e.g. programs managing background processes in operating systems or looking for information on the internet. They monitor the state of a software environment for example and act in order to modify it [21].Service agents within multi-agent simulation should not be confused with this type of agents.

Multi-agent systems differ furthermore in the degree of complexity and intelligence that is implemented in every single agent. Ferber differentiates between cognitive and reactive agents. Multi-agent systems with cognitive agents consist normally of few, but 'intelligent' agents with individual knowledge bases and intentional behavior[24].

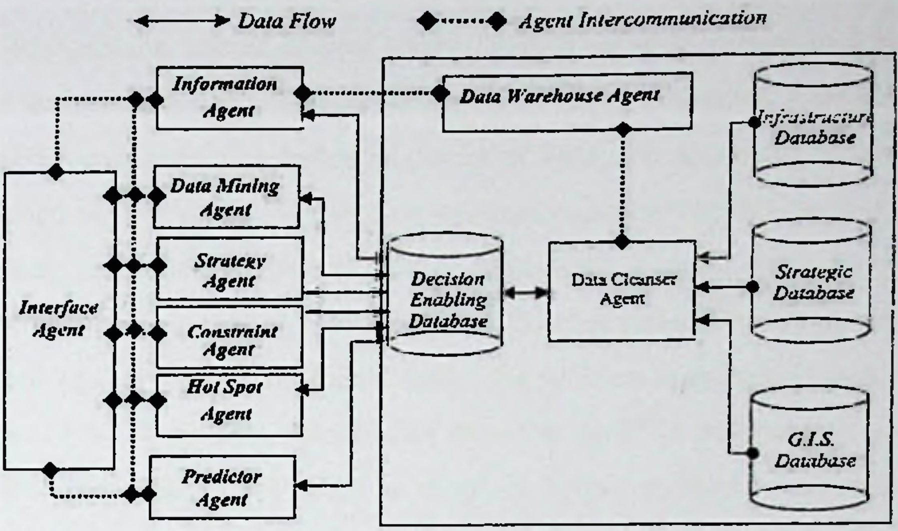


Figure 3.3: Schematic perspective on the agent-based framework for water mains rehabilitation decision support

This is a typical approach in social sciences and closely related to expert systems and distributed artificial intelligence. In the reactive school, the idea prevails that individual intelligence is not a prerequisite for intelligent behavior of the whole system. This approach is chosen more often in biological applications, e.g. for simulating the behavior of ants [24]. A similar distinction is that between weak and strong agents. Whereas weak agents are simple, more or less intelligent information-processing systems, strong agents are computational cognitive models that are able to some degree to explain or simulate reported findings and theories in studies on minds or life[23].Obviously, this notion is closer related to Artificial Intelligence. Whether agents are used as a paradigm for software engineering or as a tool for understanding human societies[21]depends mainly on the field of application. In hydrology and water sciences, the purpose of the research is not to create agents being as intelligent as possible. Although in some cases water users are represented with some cognitive abilities, say the ability to make decisions, these cognitive aspects are rather simple. Consequently, the agents in these contexts are likely to be weak agents only, whereas it may depend on the actual model whether they are rather cognitive or more reactive.

3.6 Defining agent behavior

Generally speaking, agents possess states, i.e. data, as well as rules of behavior[27]. For the definition and implementation of the behavior of agents, a great variety of possibilities exists. From a theoretical point of view, the actions of an agent can be approached with a variety of more or less mathematical formalisms. For example, action can be modeled either as transformation of a global state, as a physical displacement or as a local modification, such detailed reflections are not in the focus of interest of this thesis. Less theoretically, the problem is to specify what the agent is supposed to do without determining how the agent is supposed to do it, since otherwise emergence is not likely to occur. A simple method to achieve this is to specify the behavior indirectly, by applying some sort of performance measure. One possibility to do this is to create a utility function for associating utilities with states of the environment. The numeric utility values specify how desirable a state of the environment is and the agents try to maximize their utility. However, it is often difficult to find an appropriate utility function and the approach is not very suitable for specifying long-term goals, since the utilities are assigned to local, individual states.

Another common and simple way to determine the activities of agents is to specify a number of condition-action rules [13]. Thereby, the modeler creates some 'if – then' statements, Figure 3.6 gives an example how such procedures specifying agent behavior may be realized. Unfortunately, these rules are normally fixed and the architecture is thereby inflexible, since the agents themselves are not able to change or vary the rules [13]. The approach is therefore more suitable for reactive agents, since it may limit the autonomy of the agent and it is difficult to specify long-term goals or plans in such a way. Consequently, such an approach is often combined with other forms of specifying agent behavior, e.g. defining a satisfaction matrix. The satisfaction matrix defines the satisfaction values for all possible combinations of the two relevant factors, i.e. salinity and water level, and for the all three types of agents (Table 3.2). The matrix is applied in a negotiation process for specifying the preferences and the subsequent behavior of the agents. State transition graphs provide a method for illustrating the behavior of agents and describing it formally. Afterwards, the specified behavior converts almost automatically into applicable condition rules. An example of this approach is the Agent Behavior Representation (ABR) method. Symbols for different state types (e.g. initial states, communication states or unlimited wait states) and two kinds of transition types (internal vs. external transitions) allow it to describe how the agents react when interacting with other agents or to changes in its environment [4].Besides these comparably simple approaches, other approaches and formalisms for specifying the behavior of agents exist that are too numerous and complex to be described. The architecture has to be more complex, if beliefs, goals, internal representations of social contexts and speech-acts are to be included to some degree. A possible implementation is a Belief, Desires and Intentions (BDI) architecture[26]. The advantage of this approach is that it is more sophisticated and realistic to implement agents with self-interested goals. The activities of agents then depend on their goals, the plans they create and execute to achieve the goals and their beliefs about the environment. However, such architectures have seldom been realized for agent-based social simulation, although for example some attempted such an implementation[13].

Table 3.2: Satisfaction values for the different agent types

Water Level (cm)	Salinity (g/l)						
	5	10	15	20	35	>35	
<–30	5	4	4	3	2	1	AgricultureAg
-10	5	4	4	3	2	1	
0	5	4	4	3	2	1	
20	5	4	3	2	1	1	
40	3	3	2	1	1	1	
>40	1	1	1	1	1	1	
<–30	2	2	2	3	2	1	FishingAg
–10	2	2	2	4	2	1	
0	3	3	3	5	2	1	
20	3	3	4	4	2	1	
40	2	2	3	3	2	1	
>40	2	2	2	1	1	1	
<–30	1	1	3	5	5	3	NaturConsAg
–10	1	1	4	5	5	2	
0	1	1	3	4	3	1	
20	1	2	3	4	2	1	
40	1	1	1	1	1	1	
>40	1	1	1	1	1	1	

3.6.1 Decision Making

Modeling water resources issues includes most likely the representation of some sort of human decision making. Therefore, different possibilities exist, depending on the focus of interest in the study and the level of aggregation that is chosen for the representation of the behavior of the agents.

Mathematical programming is one possibility for modeling the decision rules of human agents, based on a socio-economic background. For example represents the decision making of land managers with this methodology. Mathematical programming is a constrained optimization technique[28]. A function of independent variables, e.g. the size of the area assigned to a certain land use type, is optimized depending on a priori limitations for the values of the independent variables. For example, the total size of farmed areas is limited by the total area of arable land. The 'objective function' is characteristic for different decision rules, e.g. if profit-maximization is aimed at, it is the sum of profits of all land use activities. Berger argues that formalization in mathematical programming is possible for all sorts of decision rules.

3.6.2 Negotiation

Many multi agent models contain elements of negotiation. For this purpose, special interaction or negotiation protocols exist, e.g. the Contract Net Protocol[23].Two of the most important issues in this context are the organization of the exchange of proposals between the participants and the way an agreement is reached. Figure 3.4 illustrates the example of a negotiation management protocol based on the Contract Net Protocol Modeling a negotiation process leads to the problem of defining the goals or aims of the agents for the negotiation. One possibility is the aforementioned satisfaction matrix. In some modeling tasks, a solution with or without negotiation process may be possible. Negotiation might be costly, but it preserves the autonomy of the agents, for example because they are able to apply individual strategies.

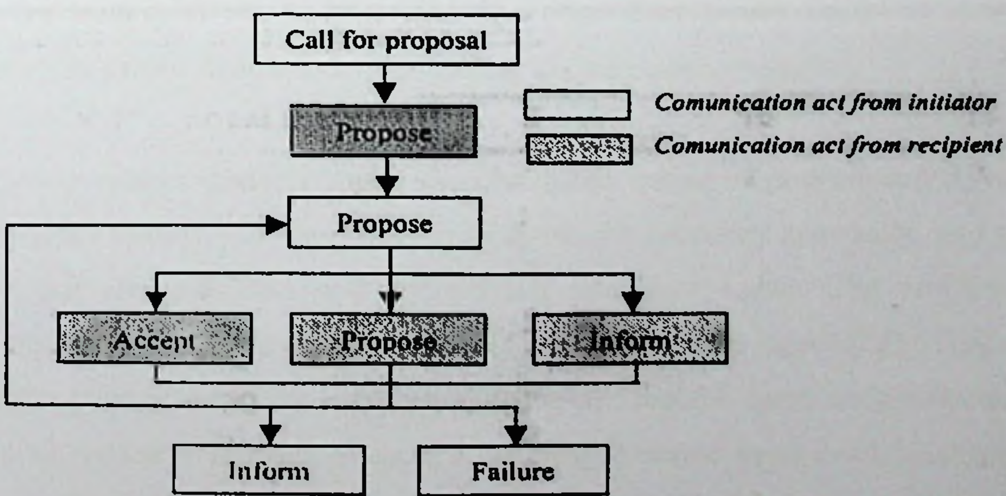


Figure 3.4: Water council negotiation protocol

3.7 Software and output of data

Two general possibilities exist for implementing a multi -agent model as a computer model. One option for the modeler is to choose the most suitable of the software platforms available for multi-agent modeling. Alternatively, the whole system can be implemented in a standard programming language in combination with different suitable software systems or packages for specific tasks, e.g. for inter-agent communication. Among the programming languages, an object-oriented language as Java is often chosen nowadays.

3.8 Characteristics of multi-agent systems

Of course, the question arises why multi-agent modeling approaches are of increasing interest in different academic disciplines. To answer this question, it is necessary to evaluate characteristic aspects of multi-agent modeling.

One of the most striking features of agent- based systems is the phenomenon of emergence. The idea is to explain even complex behavior with simple rules. The interest of the researcher is to explore the emergence of macro phenomena based on behavior among interacting heterogeneous agents on micro level[29]. Consequently, a system shows features that are not specified in the behavior of the single agents. For the context of social sciences, this phenomenon can be expressed as micro motives leading to macro behaviors. For other than human agents it is more appropriate to talk about micro rules leading to macro phenomena[30].

A closely related characteristic is the distributed nature of problem-solving with multi-agent models. One possibility is to divide the necessary knowledge into sub-units that are associated with independent intelligent agents. The problem is consequently solved by coordinating the activities of the agents[22]. This can consider as an aspect of decentralization, in the case that the agents are distributed in space or represent different levels in a hierarchy. Because most real life situations include decentralization to some degree, it is reasonable to choose methods that follow decentralized approaches.

Another feature of multi-agent modeling is that agents are a comparably natural analogy for simulating human behavior. When compared with other styles of modeling, this will hopefully result in refined and detailed representations of the individuals and consequently greater realism of the model. Multi-agent modeling is not a top-down process in most cases, but a kind of bottom- up approach. Starting from the attempt to understand the processes on the small scale, it is tried to understand the processes at the higher scales as well. Contrarily, in traditional equation-based modeling the problem is addressed as a whole. It is tried to find an equation that approximates the dynamic of the system under study. For the context of ecological modeling, there are many differentiations between modeling with differential equations and computer simulation. They distinguish between two different perspectives on complexity, dynamic vs. organizational.

These traditional models are generally equation- based models. The fundamental difference between agent-based and equation-based modeling is the different representation of individuals, i.e. entities showing behaviors as time passes, and observables, i.e. measurable characteristics of interest whose values change over time[31]. Equation-based modeling starts with expressing relationship among observables through a set of equations that are either algebraic or capture variability over time or over time and space. In contrast, agent-based models represent behaviors through which individuals interact with each other directly or indirectly. Relationships between observables are an output, not an input of such models[32]. In addition, agent-based models have the natural tendency to focus on observables available to the individual agent, not on a system-level information. Equation-based models consider observables on system-level as well as on individual level, but tend to make extensive use of system-level observables[31].

Table 3.3: Two systems of interpretation representing two concepts of complexity

	Dynamic view	**Organizational view**
system conceptualization	state variables	lower level processes/entities
suitable metaphors	cybernetic systems	parallel computers
specifications of mechanism	Centralized	distributed

means of analysis	differential equations	computer simulations
key behaviors	equilibrium, dynamic complexity	self-organization, structural
system organization		complexity
	fixed, single level	variable, multilevel

3.9 Various Type of use of MAS

The numerous applications of multi-agent systems can be categorized. For example differentiates between five main categories: problem solving in the broadest sense, multi-agent simulation, building artificial worlds, collective robotics and program design. Of these categories, the last three are not relevant to applications in hydrology and water resources research.

Problem solving is defined in as "concerning all situations in which software agents accomplish tasks which are of use to human beings". This definition includes the concepts 'distributed solving of problems', 'solving distributed problems' and 'distributed techniques for problem solving'. The first concept takes the fact into account that in some cases the expertise of different persons – or agents –has to be combined in order to maintain satisfying results. Such a kind of automated expert system may be relevant for hydrological purposes as well, although no case study or model is known applying multi -agent modeling in this sense in a hydrological context. 'Solving distributed problems' applies if the area in question is itself distributed. A typical example is the monitoring of a telecommunication network[33]. Accordingly, such an approach may be applied to hydrological distributed systems as well, e.g. river networks or runoff generation processes. Again, no example is known following this idea. The last technique that belongs to the category 'problem solving' has been discussed before: 'Distributed techniques for problem solving' refers to the general idea to assign agents to smaller units of the problem . Surely, this would be an interesting approach for addressing the complexity involved in hydrology and water resources research.

However, multi-agent simulation is the most common technique in applications related to natural systems, whereby multi-agent systems are used as representations of real ecosystems, i.e. as kinds of virtual ecosystems. It is possible that the users define different scenarios and experiment with them. Similar to small-scale physical models, the evolution of the ecosystems under given hypotheses can be tested. Such simulation models may serve different purposes, e.g. as research tools, as training tools and decision support tools. Particularly common is the use of simulation tools for water management. Since policy making is principally difficult in this sector, it is useful to support this process with tools that simulate the water management cycle. The goal thereby is not to predict the exact state of the modeled system, but to explore the system's evolution caused by these policies [15].This corresponds to the application of multi-agent simulations as training tools. In the context of managing natural resources, different schools of thoughts exist with the purpose to ensure the viability of the systems. Naturally, each of the schools has its own specific weakness. In the past, the testing of different approaches to managing water resources has been done mostly by learning by doing. As a result, errors in the management had severe consequences for the persons in the system. In this sense, learning by simulation instead of trial and error methods would be very helpful for the affected people. Multi-agent simulation models may well be used in this way. However, they must be legitimated and partly validated, if they are supposed to be useful and relevant.

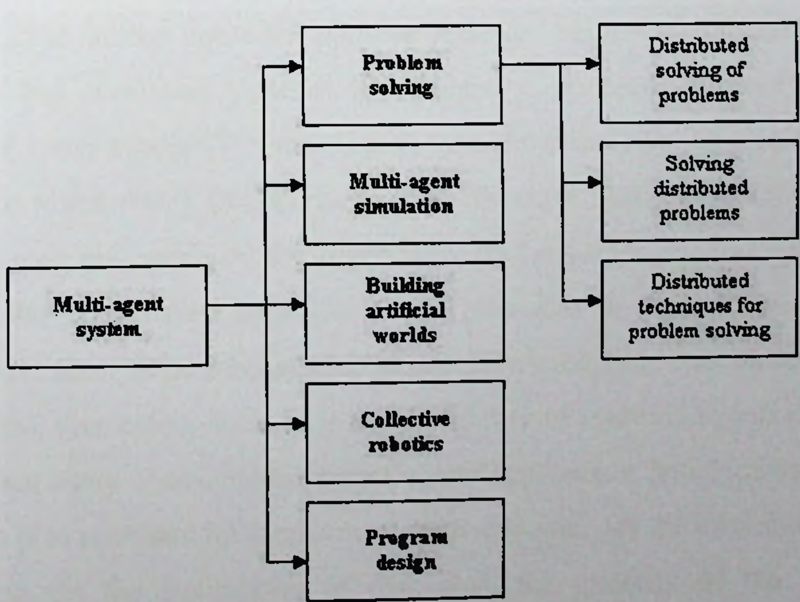


Figure 3.5: Various types of application for multi-agent systems

Chapter 4

Water supply in Mahaweli H-system

4.1. Introduction

The discussion of multi-agent methodology in the first part of the thesis gives reason to assume that water resources research benefits from applying such approaches. The aim of this part of the thesis is the practical application of multi-agent modeling to a suitable research question. Concluding from the discussion, multi-agent modeling is possibly more suitable than any conventional approach if a research question involves hydrological and socio-economic aspects likewise. Moreover, a model should correspond to the idea of multi-agent modeling to represent the problem by simple rules on a minor scale. The idea of this study is accordingly to represent an existing water supply system with the corresponding human agents, as are the water users and responsibilities in the context of water management. The water supply situation in the irrigation of H-System seems to be a suitable case study for different reasons. It is among the regions with the best management system in the country. The bad practices of the water prevent the local population from obtaining sufficient water for their daily needs in addition to the irrigation. The water supply infrastructure in the domestic purpose and the irrigation purpose is comparably different but combined together with quantity. In here separately focus on the irrigation water supply. The question is how the people in the area deal with these issues. In Mahaweli-H System the water separation from the reservoir to the fields are arranging via canals by the supervision of the human agents. To model such as system, the hydrological situations of the resources as well as the behavior of the water users have to be represented. Multi-agent modeling may more easily manage such a task than other, because it has the ability of multiple agents contribution for the system more conventional hydrological approaches and models. The research question is to represent the decision of the water users for the available water sources depending on the availability of resources, the quantity of the water and the background of the water users. Representing the decision-making process of the agents in such a simple context is seen as means for exploring the roots of complexity in water supply management.

Additionally, the flexibility of multi-agent modeling is used to include water quantity as well as water quality issues in the model. Besides water allocation, the quality of water is among the most important topics for the future in water resources management. Especially where water or financial means for treating waste water are scarce, as it is often the case in developing countries, not all the available water is of sufficient quality. Nevertheless, many models are not combining both topics, possibly because each of them alone is rather complex. However, in order to create realistic models, it is necessary that researchers accept this challenge. Mahaweli H-System has been chosen because of the comparably existing best water practice among other regions. Besides these arguments, choosing H-System makes sense because it gives the heights paddy production during the year to local economy. To explore the behavior of the water users and their interactions with the water resources in detail may be one of the necessary steps towards improving these facts. For this purpose, the model can simulate the best scenario that helps the consumers before involving the problem, not only that for example the reaction of the system can be implemented in different climatic situations, e.g. wet vs. dry years, or to different states of the water resources.

4.2. Study Area

The Mahaweli H-System area surrounded by Mathale, Kurunegala and Anuradhapura districts (Figure 5.1). It was built in 1974-1980 period and it covers 31,500 ha of irrigated land extent benefitting 30,000 farmer families. Less than 18 years. Mahaweli H has deteriorated to level that needed rehabilitation. During the rehabilitation program 250distributing channel farmer organizations have been strengthened and an action plan has been prepared and implemented to ensure farmer participation at pre construction, construction and post construction stages of the project.

Bulk Water allocation program implemented in Mahaweli H is an out comes of MRRP coordinating committees established at the unit block and project levels to facilitate conflict resolution and decision making in respect of scheduling seasonal agricultural plans, operation and maintain, water distribution, extension and marketing and to help implementation and monitoring of those activities. A well planned institutional development program was launched to improve the coordination of farmers by changing their attitudes and to make them volunteer to accept operation and maintain responsibilities of rehabilitated channels. In order to follow the participatory rehabilitation planning process within a limited time, 8 multidisciplinary survey team consist of 3-4 Engineering assistants, two AIs with supporting staff were formed and assigned to each management block. Those team consulate by holding participatory rural Appraisal sessions, and each team was assigned to hold ratification meetings to get the concurrence of the farmers for final decision.

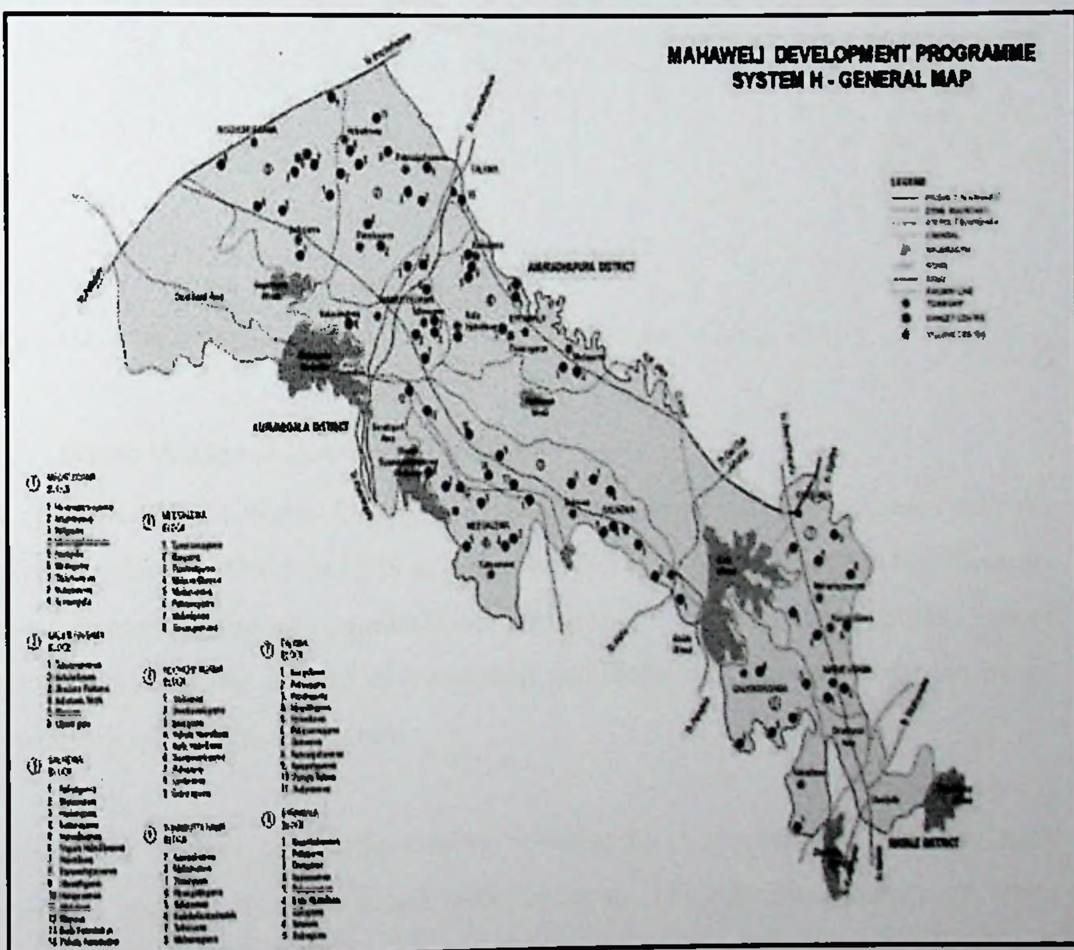


Figure 4.1: Position of the Mahaweli H- System

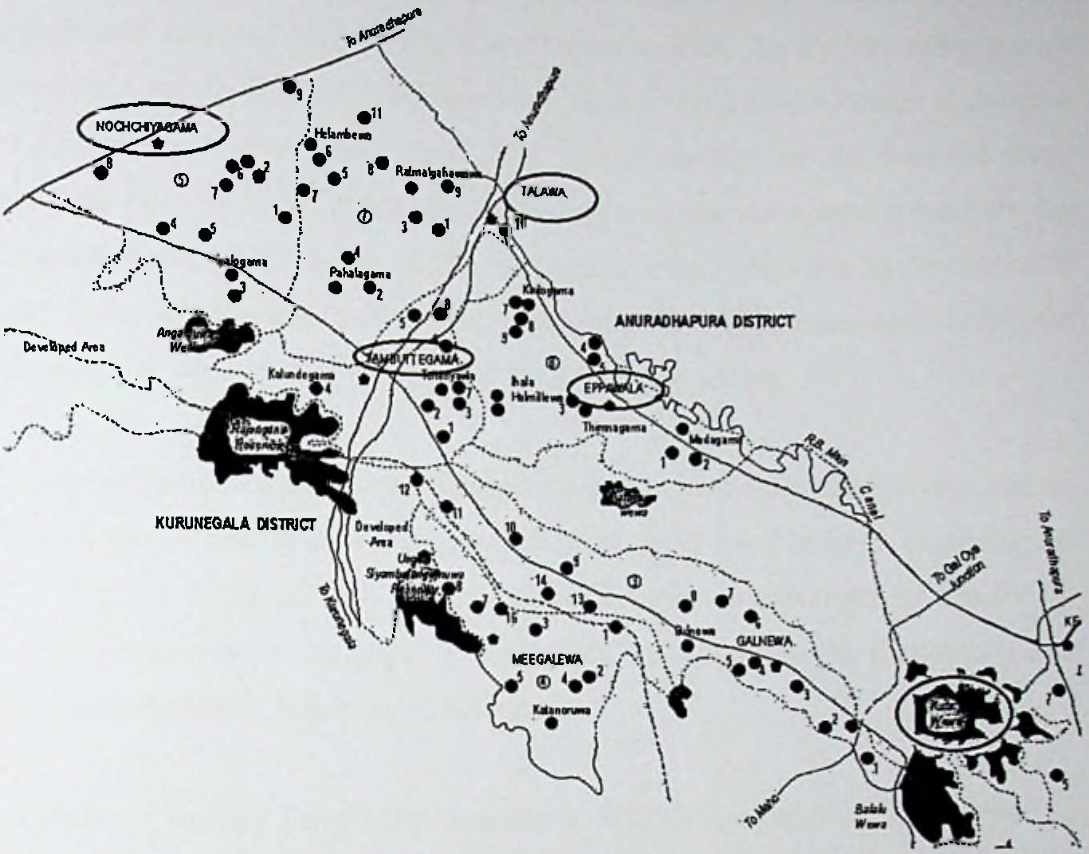


Figure 4.2: Map of Mahaweli System H (modified from MASL, 2013)

4.3. Bulk Water Allocation (BWA)

The concept of Bulk Water Allocation (BWA) was introduced in Sri Lanka with the implementation of MRRP in 1998 as a pilot project in Mahaweli system H efficiently use of water resources equitable distribution of water with active farmer participation, creating a sense of ownership and attitudinal changes were the major expectations of the BWA program.

Under BWA System, a specific quality of water for a season was fixed for each Distributor channel in consultation with farmers. The specific quantity of water which is allocated for a DOC was decided on the basis of the total irrigated land within the DOC command area types of crops to be cultivated and the quantity of water required per rotation to meet the crop water requirement.

BWA was designed to implement at three levels System level allocation by water management panel of MASL, Block level allocation by the Project Managemant Commitees and D- Channel level allocation by the Block Level Farmer Federation (BLEF) or Block level PMC. Each DOC had to request for the seasonal water allocation from BLEF or PMC. The BCEF prepared the water requirement for the entry block and submit to the MASL via system level PMC. The Mahaweli water panel at MASL adjusted the bulk water allocation for each system considering the availability of water in the reservoir and fixed it for the season.

The farmer participation in water management was carried out at three levels, names, fixed channel levels, D Channel level and Block level fixed channel organizations consists either 10-15 farmers. A fixed channel leader was appointed informally for distribution of water. The leader is responsible for organizing the rotational water issues and scheduling within the field channels.

Distributory Channel Farmer Oraganizations (DCFO) consisted of about 100-150 farmers. The farmers in the relevant DCos had to bear the O & M cost of turned over irrigation systems through a maintenance fund and they had to involved in management and the O & M of their own irrigation System through mobilization of cash labour and materials. Each farmer had to pay Rs. 250/- season for hectare of low land to DCFO maintenance fund in order to ensure the adequacy and timeliness of water issues, a water master was appointed by the DCFO on payment of an honorarium for his service, from the maintenance fun. Water Master was also responsible for keeping records on water issues to each channel and maintaining the notice board at the head end of D- Channel to inform the farmers of the water schedule.

The Bulk Water Allocation system attempts to simulate a water storing tank, where a fixed amount of water is available for farmers at the beginning of a season. Like a bank account, any withdrawal or deposit would directly affect future availability of water. Engineers are responsible for updating the balance. Farmers learn to manage water with these virtual figures as guidance.

Concept

- To involve farmers in planning
- To obtain a gross idea of how much water allocated for the season.
- The D-Canal Farmer Organization (DCFO) has the flexibility of adjusting the issues as required by the farmers within the allocation.

Bulk water allocation is practiced at three levels

- System Level Allocation at Water Management Panel
- Block level allocation by the Project Management Committee.
- DCFO level allocation by the Block level sub Committees

Based on the Integrated Seasonal Allocation Plan (ISAP)

- Crop Types
- Extent

Main objects in bulk water allocations.

1. Directly participate farmers for the water management.
2. Farmers know their allocated water quantity and use their water quantity.
3. Farmers train to cultivate according to the plan.
4. Train to save water.
5. Train to prepare a suitable cultivation plan

Stages of Bulk Water Allocations.

1. Farmer prepares a suitable cultivation plan for the season.
2. Field Canal Group prepares FC canal cultivation plan for the season
3. DCFO prepares D canal cultivation plan for the season.
4. Subcommittee prepares block cultivation plan for the season.
5. Forward and getting approval for the special project meeting.
6. Arrival for water service agreement.
7. Forming the water time table.
8. Requesting of water.
9. Noted the water name board.

10. Recording jointly water measurement.
11. Follow up the balance water.
12. The Dividing of water according to the water management plan for the D canal.
13. Proper water management in the farm.
14. Preparing Cultivation progress report and water management progress report

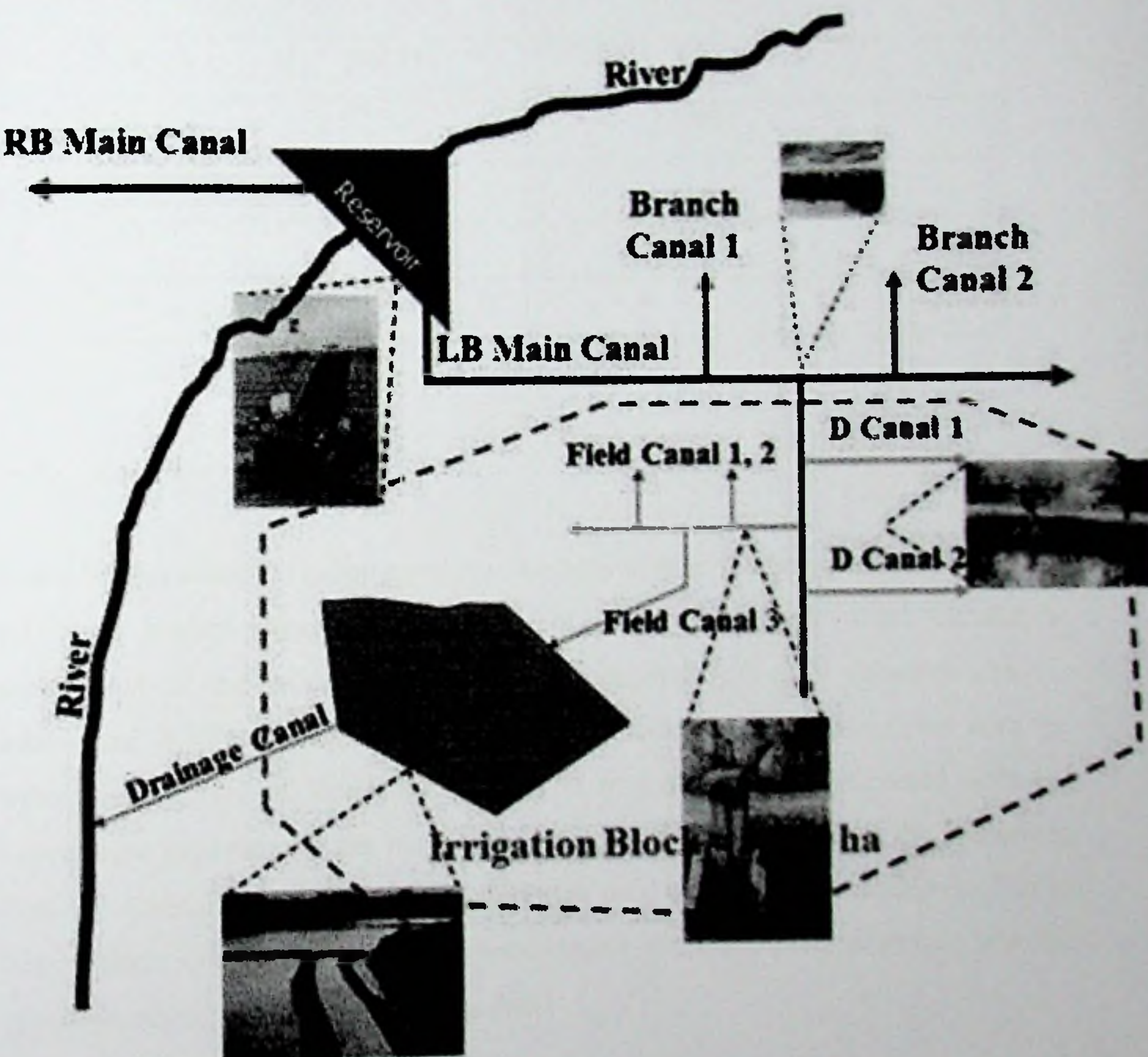


Figure 4.3: Structure of water distribution in the fields

Canal Details and Total Irrigable Extent in "H" Area

Regarding the Channel distribution of H- system the total length of the structure and the irrigable areas can be classified in to the below table.

Table 4.1 The canal details of the Mahaweli H- System

Type of Canal	Length (km)	Total No of Irrigable Ext (Ha)
Main	149.79	
Branch	97.55	25390
Distribution	625.47	
Field	1608.24	
Total	2481.05	

4.4. Structure

Based on this source of information, the question is which factors generally influence the water supply system in the region of Mahaweli H and which should be represented in the model. At least three categories of such variables can be established. Within the region there are numerous factors can be identified with the water consumption of Mahaweli River. The first category is concerned with the expenditure necessary to get the water in the irrigation. Other than the Mahaweli flow the Agriculture wells and rain water also used in the irrigation purpose. But in this scenario only considering the containments from the main reservoir and the operation among the officers are considered

Table 4.2: Factors relevant to the water supply system in Mahaweli –H , partly implemented in the current version of the model

Category	Subclass	Implemented factors	Factors not implemented
I. Expenditure and risks	Energy and time	Distance	-
	Economical aspects	Wastage of the water	-
	Reliability of the resource	Credit of the agents	-
		Hydrochemical quality of the water	Hygienic quality
II. Interactions between agents	Indirect interactions	Use of shared resources	
	Neighbourhood, density	-	Population density (urban vs. rural) influences consumption
		Utilization of the resource	Hierarchy of Knowledge and education
	Imitation	-	Preferencesfor sources are influenced by neighbours
III. Organizational issues	Organisation of the resources	-	Nesting (feedback between upstream and downstream users)
	Social organisation	-	Water rights
		-	Collective actions of communities
	Mobility	-	Water transportation
		-	Moving of agents to other areas

4.5. Design of the Model

Generally, the model consists of two different parts, the physical environment and the agents as the entities living in this environment and interacting with it. Figure 5.7 gives an overview on the principal structure of the model that is described in further detail in the following chapters

4.6. General Assumptions

In the current version it includes water for irrigation purposes only, it didn't focuses on domestic use including the amount of water used for drinking.

4.7. Physical Environment

The physical environment consists of the spatial distributed water sources. For the sake of simplicity, the inclusion of all the water sources into the model is not thought to be useful. Consequently, only the four most frequently used water sources are reservoir and dam. Water holes and water holes in the river are not differentiated in the model. The evaporation and the seepages of the reservoir aren't considered in the concept. The main task for the physical environment is to provide the water resources that the agents can use. For this purpose, the capacity of the water resources is calculated based on precipitation data and hydrological assumptions about the involved processes.

4.8. Agents

In the current version, the model contains seven kind of active agents: Irrigation Engineer, Agriculture Inspector, Water Master and Farmer and the Channel agents: The Main Cannel, D- Cannel and the Field Cannel. Since the model attempts to represent the water resources in the whole Mahaweli H System, it is important that a realistic number of agents is created in order to model the usage of the resources and the water balance correctly. Therefore, the domestic areas have to be represented as well, since they get their water out of the water sources in the hinterland. However, the model focuses on irrigation areas only being characterized by the water supply.

4.8.1. Farmer Agent

The behavior of the farmer agents is based on their two attributes size of the field, crop of the season and location within the system. The location of the agents in conjunction with the spatial distribution of the water sources determines which sources are available for an agent and how far to travel to reach it. For the size of the field, an owner detail of the lands in a Block was taken as an indicator. The size of the field is therefore allocated randomly to all other farmer agents. The seasonal crop was taken in the summarized data sheet of the irrigation department. Below Table refer the seasonal crop of the farmers.

Table 4.3.:Some Seasonal Crops of Mahaweli H System.

Crop Type
Paddy
Maizse
Soya
Ground nut
Cowpea
Kurakkan
Chilies
Banana
Papaw

4.8.2. Water Master Agent

The water master agent calculates the total quantity of water that should be release in a gate according to the farmers' requirement of a block. There are number of leaders in a cannel basis to open the gates in turn out. The major functionality is the maintain water issuing time table in the D Cannel position to refer the farmers.

4.8.3. Irrigation Engineer Agent

The Irrigation Engineer agent plans, designs, and construction of irrigation projects for transporting and distributing water to agricultural lands. Further responsible for opening and closing duration of the Dam according to the relevant gates. He directs, through subordinate supervisors, construction of such irrigation systems as dams, canals, and ditches, according, water supply, return flow, and other factors affecting irrigation requirements.

4.8.4. Agriculture Inspector Agent

The functionality of the agriculture agent is described as the responsible person for the information to the Irrigation engineer. Its only activity is to decide whether the water trucks are needed to deliver the water to the agents and to monitor how much cost this program causes. With the time step of a month the problem arises to realize a realistic representation in this rather low resolution. In the version chosen, the government checks at the end of a time step if a supply by water trucks is necessary. An alternative approach will be to provide water in the next time step, if there is a shortage in the previous step. However, when there is a drought situation, a month is thought to be too long for the people to be changing the cultivation and this version is moreover easier to realize since the usual activities of the agents are not affected.

4.9. Software

Overall features of the proposed system are not derive from the inputs and outputs and are basically nonfunctional requirement of the system. Agents are created using Java Agent Development Framework (JADE) therefore each agent in the framework consumes limited resources and produce high performance. Despite of other multi agent technologies JADE is available as free software component hence development cost is marginal. Ability to perform under limited resource environment, installation and access through the mobile devises are increased the rapid growth of multi agent technology. Instead of the standalone environment the agent are accessible through the web interface with minimum bandwidth.

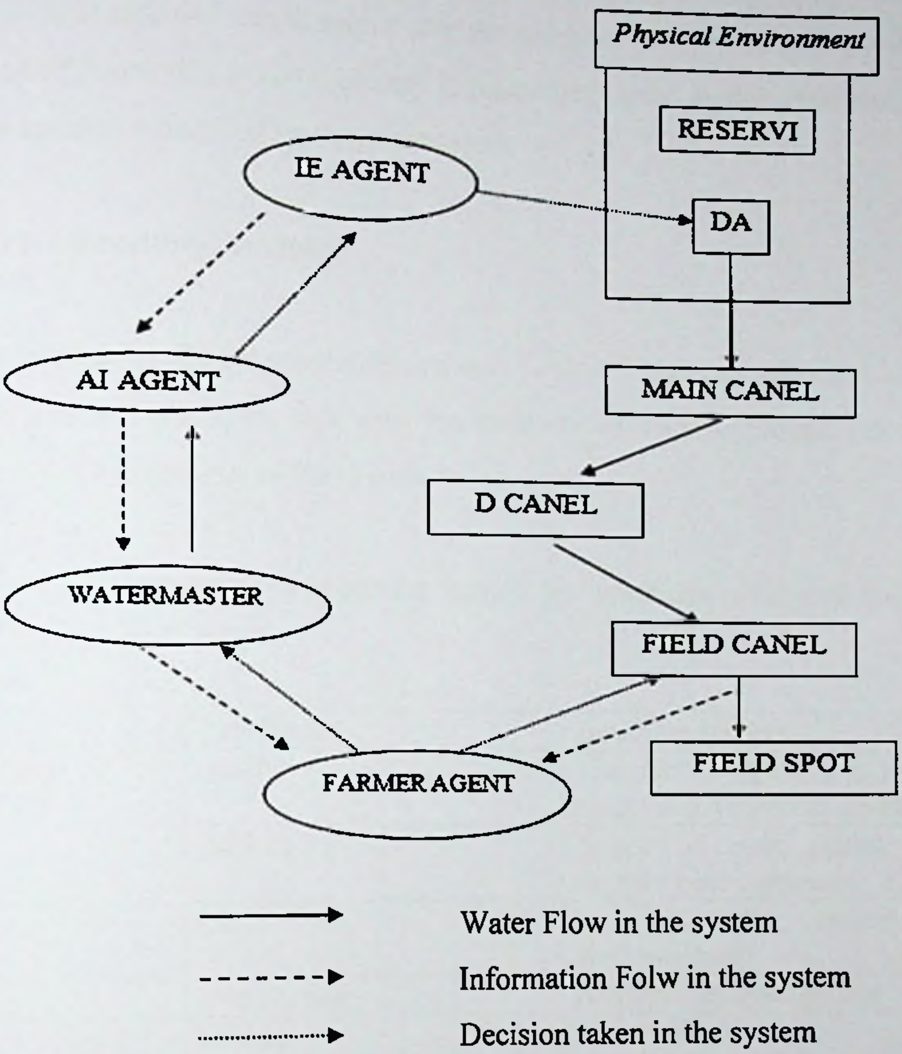


Figure 4.4: Principal structure of the mode

4.10. Decision model

As mentioned before, the decision of the water users for certain water sources is meant to be influenced by the quantity of the water in the source, crop pattern, crop type, rough estimation of the water estimation cultivation time table, Repair and maintains of cannels. To implement such a decision making process, the values of the different water requirements in these categories have to be defined or estimated first. The first step in the behavior of the agents is choosing which of the existing crop they consider to cultivate. Then the size of the field that is cultivated. If the agent gets all the water he demands, he will not undertake any action until the next time step starts. If he happens not to have enough control to pay attention on his water demands or not to find a suitable source at all, he will stay without water for now. It is assumed that in such a case the neighbors support each other, although this kind of interaction is not explicitly implemented in the model. However, the state of the agent is monitored by the government.

4.11. Resulting Structure

To summarize the structure of the model, Table 4.3 gives an overview on some of its features and attributes, following the structure of some important information that useful in the analysis of the system.

Table 4.4:Description of important features and attributes of the realized multi-agent system

	Attribute	Implementation
Agents	number	125 farmer agents; 5 water master agent; 2 government agent
	uniformity	3 types of cannel agents; water users slightly heterogeneous
	goals	homogeneous (minimize the waterwastage)
	architecture	reactive, but goal-driven
	abilities (sensor,effectors,cognition)	rather simple
Interactions	frequency	rather low
	persistence	short-term
	level	indirect
	variability	fixed
Environment	purpose	competitive
	predictability	unforeseeable (precipitation, resources)
	accessibility and knowability	limited to the water sources in the neighborhood (agents without knowledge about system)
	dynamics	comparably fixed (dynamic of rainfall, but resources not nested)
	diversity	medium (low number of different sources, but high number of specimen)
	availability of resources	restricted

4.12. Summary

In this chapter the real world scenario of the model question was illustrated descriptively. Among the Mahaweli System H the water management was moderated as the novel concept named Bulk Water Allocation. The model was developed under the basement of this water allocation concept and it was clearly clarify with in the section.

Chapter 5

Realizing multi-Agent Approach in IWM

5.1. Introduction

In the previous two chapters describe the research problem and potential of development, the requirement, the importance of MAS technology to develop novel solution for IWM. This chapter presents the approach of the thesis by describing the hypothesis, inputs, outputs, process, features and users for solution of MAS based IWM. The new solution has been named as IWM_MAS and acronym for automated Multi Agent System for Irrigation Water Management.

5.2. Hypothesis

Multi Agent Systems are able to model complex system in Irrigation Water Management to address the issues of communication among the parties involved in the process.

5.3. Inputs to the System

Table 5.1 Inputs by Various Agents

Inputs	**Agents**
Field No, Field Size, Crop Type	Farmers
Reservoir Capacity	Irrigation Engineer
Required Water Amounts, Cannel and Gate Details	Water Master
Maximum and Minimum Water Levels	Cannels
Status	Gates

A MAS for IWM has been designed to accept multiple inputs coming from different entities of the supply chain process. The table 4.1 shows the inputs from corresponding agents.

5.4. Outputs to the System

There are two modes of output generated by the system. These outputs are coming as organizational related and the customer related aspects.

Table 5.2 Outputs of the System

System Out Puts
Opening Gates for the System
Time Duration For the Gates
Water flow capacity of the Cannels.

5.5. Process of IWM

In this process seven major types of agents are defined to the system while four of them are Active agents and three of them are Passive agents. In particular, the agent categories and their contribution are explained under section of No of Agents Join with Communication Process in chapter six. The knowledge required these agents to operate are stored in a common domain ontology and personal ontology. Agents are autonomous and work together with collaboration and information sharing to complete given tasks. Therefore agents are basically access their personal ontology to generate decision about water quantities, what are the flow cannels, number of gates, length of the cannels, status of the gates, maximum and minimum water levels, and the past records of entities in IWM. However agents are access common domain ontology which has broad description of the entire process and made available to any agent with define permissions.

Normally, agent-based models are implemented in object-oriented programming languages. As a promising technology Java Agent Development Framework (JADE) has been used to automate entire water management process and Net Beans IDE 8.1 has used as development environment. This kind of programming language is especially suitable to manage large amount of data in order to deal with complex model dynamics. Additionally, the flexibility of these languages allows the user to incorporate a wide range of agent decision rules. The modular form of the computational models provides these models with more transparency and a clear structure and reduces model development costs and numerical difficulties. In addition, the code is more extendable and portable.

5.6. Summary

This chapter discuss the overall picture about the novel approach to the supply chain management and showing that hypothesis, inputs, outputs, process, users and finally what are the nonfunctional requirements are been achieved throughout the system. Next chapter will be illustrates the major design architecture of the IWM and who are the entities involve in the process and their relationships.

Chapter 6

Design of MAS for IWM

6.1. Introduction

The previous chapter described the approach to the irrigation water management in Multi Agent Systems and this chapter mainly concern of the high-level understanding of the design architecture, modules and relationships among the different entities are involved in the system.

6.2. The Architecture of IWM

In the context of the IWM information sharing and collaborative planning are the most principal features have been used for to eliminate complexity in distributed communication. In addition to that it can be introduced as parallel components and are highly coupled each other in communication.

This is presented as fundamental understanding of information sharing and collaboration to achieve projected goals. Each agent in process have to complete their assigned tasks while enabling common features such as coordination, communication and negotiation.

6.3. Essential Entities in IWM

There are seven main categories of entities have been identified namely Farmers, Agriculture Inspectors, Water Master, Irrigation Engineer, Cannels, Gates and Fields. All of these entities are access common domain ontology and their personal ontology while information sharing and collaborative planning. They sometimes found as hierarchical within the process, but in most cases they have a parallel behavior. Therefore figure 6.1 illustrated the different entities (modules) are operated in the process and their contribution in number of agents.

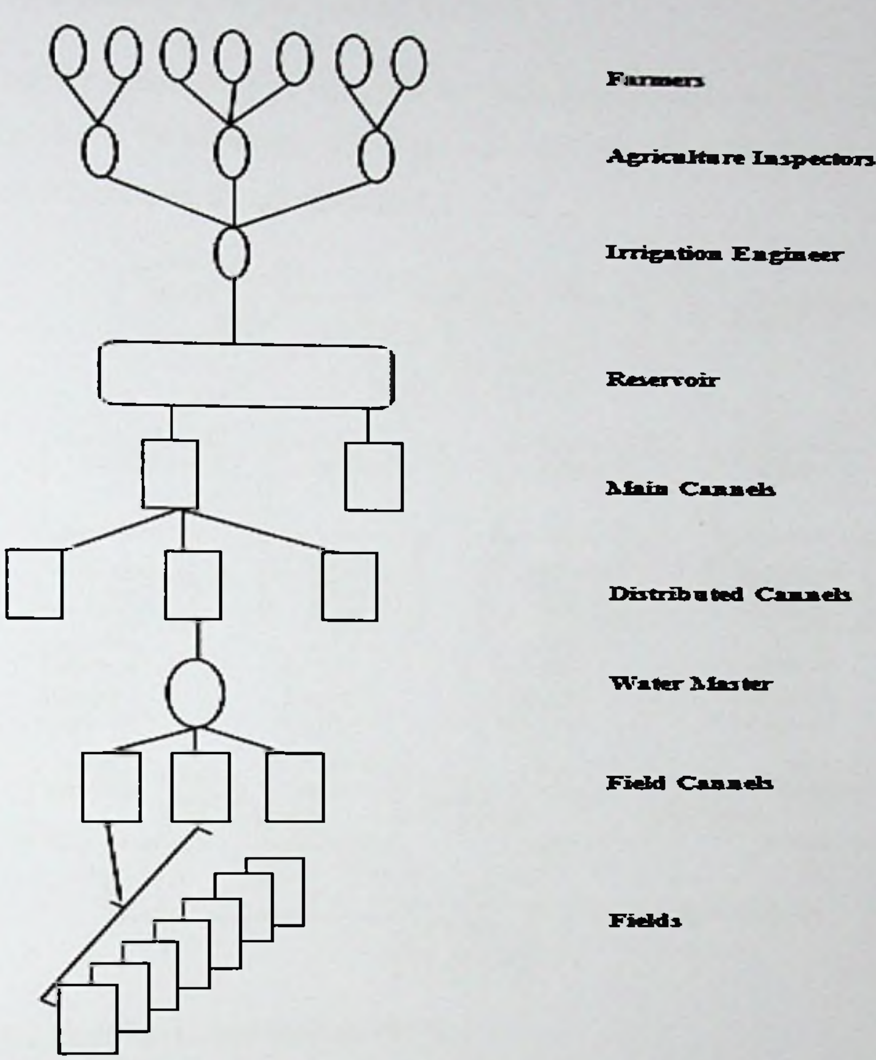


Figure 6.1 Module Based Architecture of IWM

The above diagram illustrate about the responsible entities that involve in water management process and their dependencies. According to the figure 6.1 there are number of Farmer agents are trigger the event and water master agent hold significant responsibility by compare to other agents. In other words they have more control over the entire process. However water master agents are dealing with the cannel and it operates gates of the field end will leads to substantial change in whole water management process. Therefore handling the behaviors of each entity (module) group is found as demanding tasks and essential to implement comprehensive ontology including domain and personal to smooth functioning of the system.

6.4. Relationship between Entities in IWM

In this chapter a main purpose is to illustrate relationship among the entities (agents) are associated in IWM process. The Figure 5.3 describes the overall architecture of IWM and relationship among each agent.

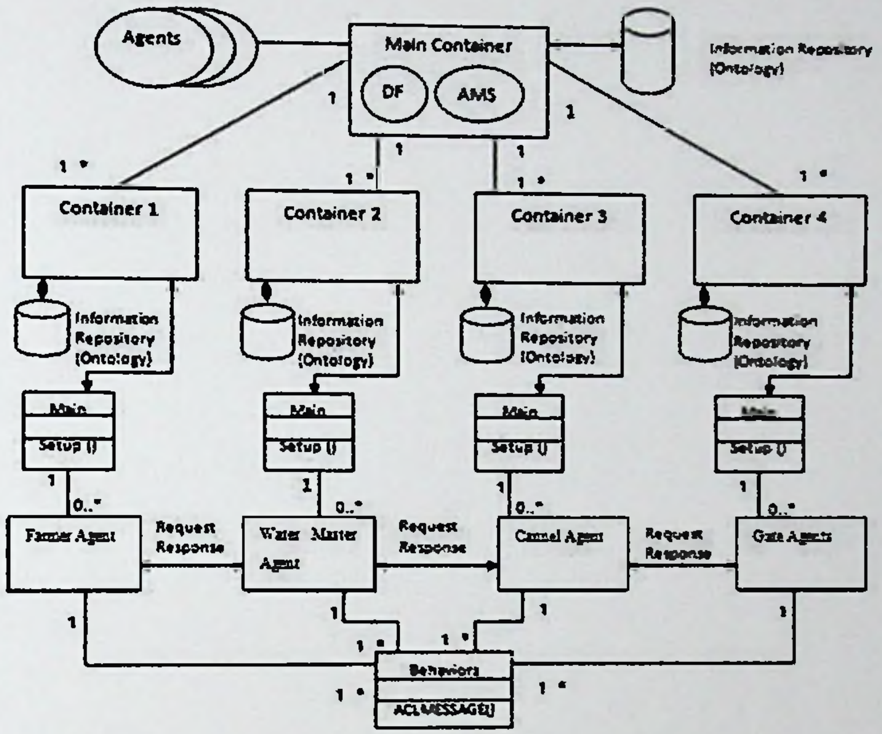


Figure 6.2 High-Level Architecture of IWM

According to the Figure 5.3 illustrates those different entities and their behaviors roles and responsibility. Each agent are attached to different containers and are authenticate by main container of the system. Java Agent Development Framework (JADE) has been used to implement containers. This diagram also explains that each agent is connected to sub containers to access their personal ontologies, and agent who are attached to main container also access domain ontology. Behaviors of the agents are highly coupled with connected ontologies, but main container has authority for agent administration such as transfer agent from one location to another (agent migration), suspend agent whenever it's necessary and terminate agent. Agent to agent communication happen via message passing that is included in the above diagram as request and response.

6.5. Summary

In this section the structure of the model was classify and the process of the system was illustrated. Each and every entity that is required in the model was identified clearly for the purpose of model design.

Chapter 7

Implementation of the MAS Solution for IWM

7.1. Introduction

In the previous chapter illustrated that the design architecture of water distribution complexity using multi agent technology. In this chapter shift the emphasis from design to practice. Therefore, throughout this chapter will discuss the implementation of the complete software component which handles the complex communication in distributed environment. According to the design chapter the agents are shared and access the knowledgebase defined in personal ontology and common domain ontology. Since a great deal of attention was paid to the implementation of ontology using XML file system and MYSQL as knowledge base.

7.2. Agent Categorizations

To maintain simple implementation mechanism and to enhance modularization of components we have separated the agents in to seven major categories as shown in Figure 5.2 in design chapter. Therefore, implementation has started with identified primary two components of Farmer and Water Master agents. According to the domain Water Master have control over the most functions rather than other agents.
In the natural system we can be identified as number of farmers requested for water consumption according to the fields. However, their requirements have decided by Water Master due to priority among according to the reservoir capacity. In order to start water distribution depends on the requirement of cannel structure. Fields have direct relationship with Cannels and then identify what is the requirement of the selected field and the crop. Finally Fields received the requirements from water master and they demand the required quantities and varieties from Farmers. In any stage anomalies may arises due to poor design architecture have mentioned in design chapter under Figure 5.3.

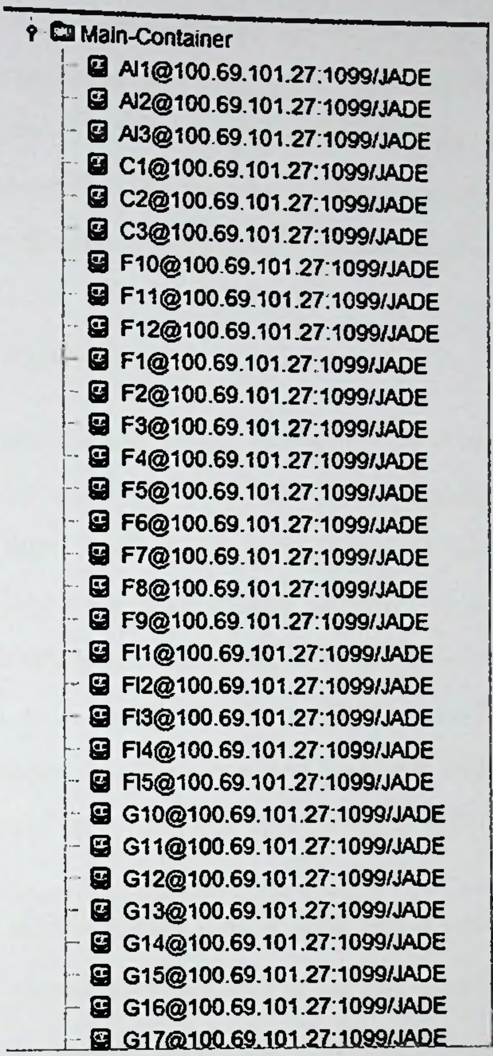


Figure 7.1 Agents joined with communication process

The Figure 7.1 describes the number of agents are joined with communication process. A letter "AI" is denoted Agriculture Inspector agents while letter "F" denoted Farmer agents. Further details about agent representation letters are described under section 6.3 in this chapter. Communication among the distribution therefore, agents have implemented according to the behavioral activities of them.

However, as an example Water Master "WM1" fails to release the water on time due to Cannel failure as break down and problems with Gates. In such condition Water Master Agents can communicate with both Cannel and Gate agents and Field to overcome wastages of water. The strong point of this multi agent system is continuous communication and coordination to resolve anomalies. Therefore all required parameters have been identified among the agents by the system such as number of Hectares have allocated for each Field, Crop Type, daily input and output water quantities and are reflected to other agents to prevent wastage. The system have introduces the proper rules and ontologies for to shift the distribution duties from Water Master agent "WM1" to "WM2" according to their availability of capacity. The entire communication process is handle monitored by message space agent and has the responsibility of handling the messages whenever necessary.

7.3. Alias of Agent Representation

When implementing agents using JADE framework is recommend renaming their original names to a short uniquely identifiable alias. Because, each agent category consists of substantial number of agents for to represent entire supply chain. No of agents used in this project is explained under Table 6.2 in this chapter. The process of agent message multicasting is identified as sender and receiver. It is proposed that to use agent id (AID) as a key components to uniquely identify and distinguish agents among other agents. As an example if there are twelve farmer agents have implemented in the system their AID will range from F1 to F12.

```
----------------------------------------------------------------------
 - WM1 Offer First Priority to F9.  Will answer quantity50 in 2421 ms, and the sender is Farmer:F9
Proposed quantity is: 221 from WM1
 - WM3 Offer First Priority to F9.  Will answer quantity50 in 2368 ms, and the sender is Farmer:F9
Proposed quantity is: 356 from WM3
 - WM4 Offer First Priority to F4.  Will answer quantity16 in 2034 ms, and the sender is Farmer:F4
Proposed quantity is: 158 from WM4
This is special situation because Farmer agent has decided to supply water from other contaminents...!
( agent-identifier :name WM5@100.71.114.205:1099/JADE  :addresses (sequence http://Nerandi-PC:7778/acc )) **** Agent Local Name is: WM5
Current offer is : 21
 = AGREE
Got AGREE from Water Master Agent:- WM5
-------------------------------- Crop Negotiation is Completed ----------------------------------
```

Figure 7.2 Farmer (Sender) and Water Master(Receiver)

According to the Figure 6.2 there are two agents join with the communication process. The letter WM represents Water Master Agent while letter F1 denotes the Farmer agent. WM2 represent second Water Master Agent from Water Master Agent category and F1 is the first agent from Farmer agent category. In this stage F4sends the message to WM4 about schedule of the water allocation. Therefore, F2 is the sender while WM4 is the receiver. Additional details about agent alias are explained in Table 7.1.

Table 7.1 Agents in Water Management

Agent Name	Alias
Farmers	F
Water Masters	WM
Agriculture Inspectors	AI
Irrigation Engineer	IE
Cannels	C
Gates	G
Fields	FI

The benefits of the multi agents by compared to humans their communication, negotiation and coordination rather fast and decisions are accurate. In order to maintain correctness of the communication their identification is must. The table 6.1 defined agent category alone with their alias. These aliases are been used throughout this project for uniquely identification of agents.

7.4. Agents Join with Communication Process

The Table 7.2 describes seven agent groups and number of agents is associated with under each category. According to the JADE framework is sufficient enough to create large number of agents under different containers of the system. Each container includes one or more agents while main container has the facility of agent administration. Therefore, such as agent termination, migration, and suspension are the major activities associated with main container of the system. In IWM different Farmers are communicate in an operation and among others field is the large category. Their inputs are strong enough to deploy butterfly effect in any moment in the process because they consist of changing requirements all the time. Once the Farmer requirement has changed in one end will leads to larger modification in other end of the process. However, this sudden change is accommodated with an introduction of multi agent in this implementation stage with advance feature provided by the framework.

Table 7.2 Number of Agents in Water Management

Agent Category	Number of Agents
Farmers	12
Water Masters	5
Agriculture Inspectors	3
Irrigation Engineer	1
Cannels	3
Gates	23
Fields	20

7.5. Configuration and Initializations of Agent

Agent configuration and initialization have automated using JADE and java technology. One java class have been created for agent initialization. When system starts to run all agents have automatically configured and attached to their own containers according to the initialization parameters

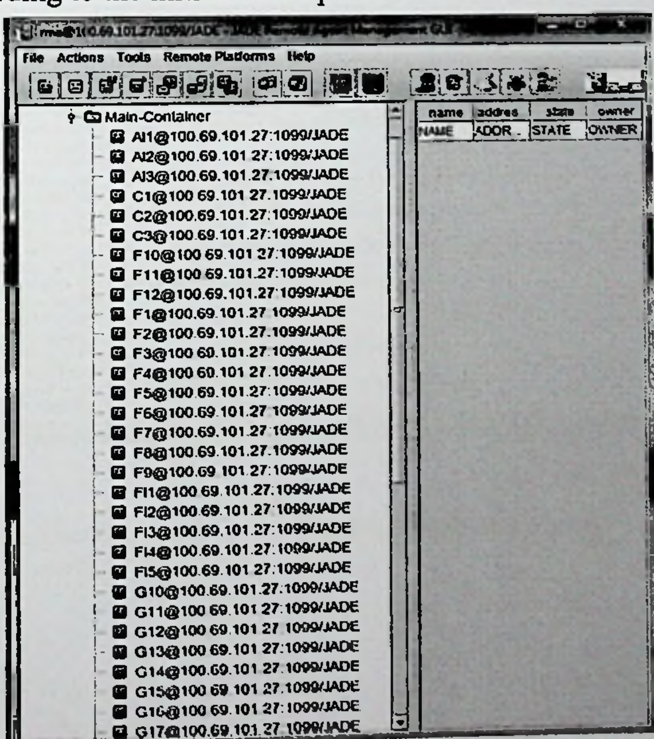


Figure 7.3 Agent Initializations

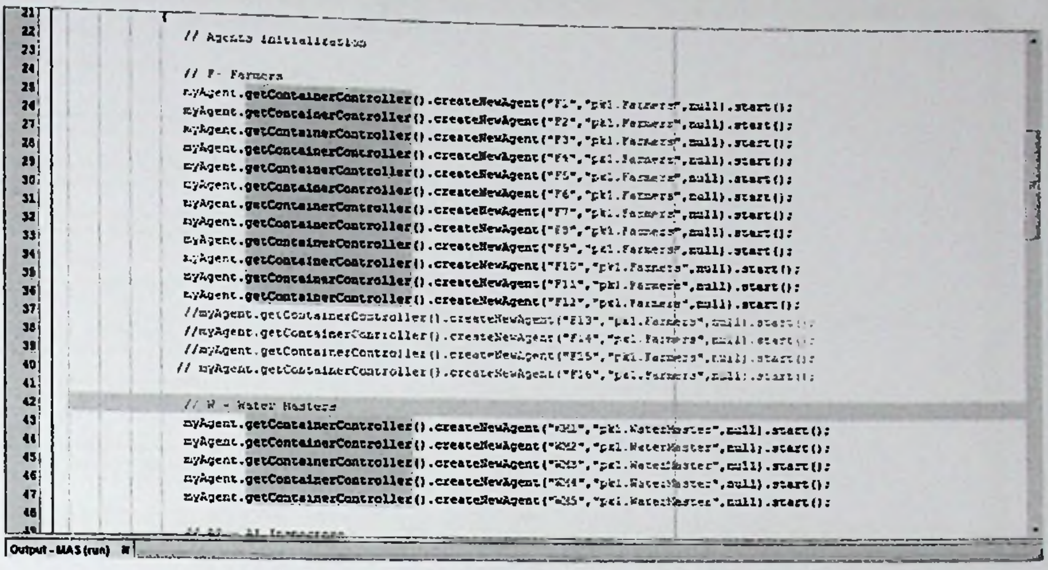


Figure 7.4 Agent Initializations

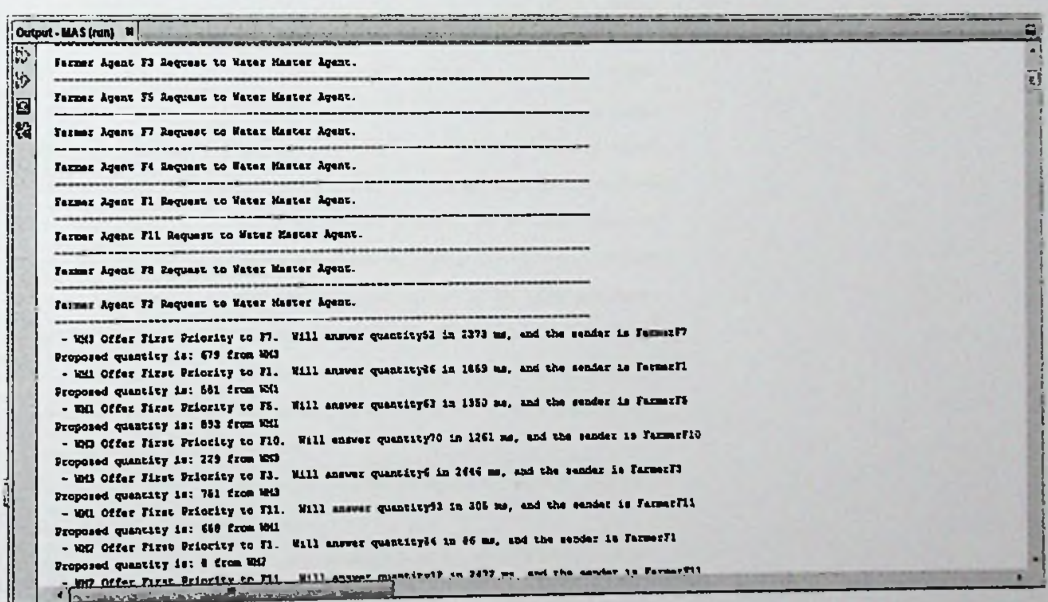


Figure 7.4 Farmer(Sender) and Water Master(Receiver) Agent

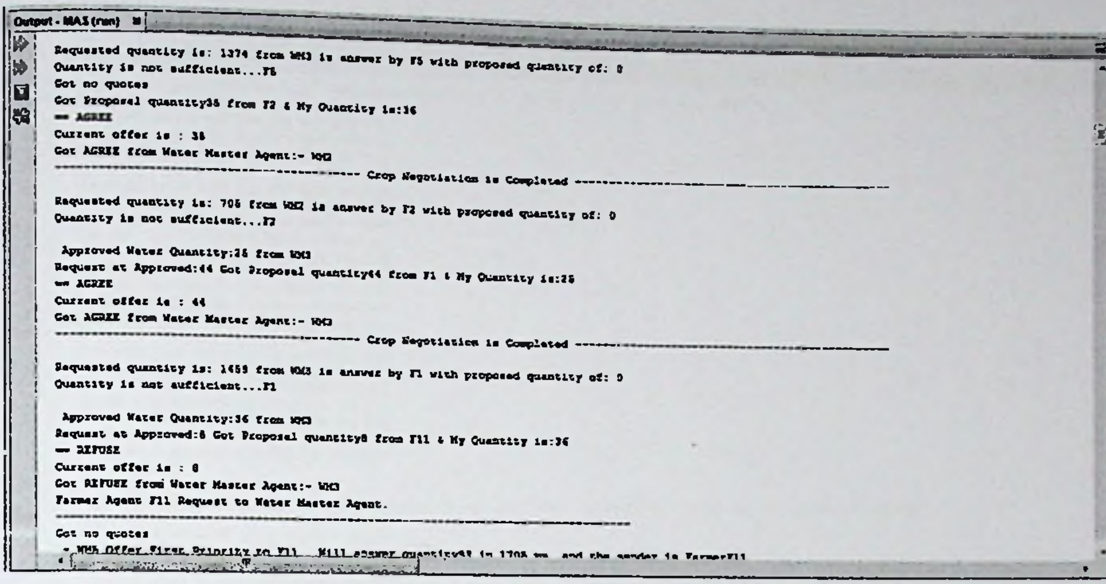


Figure 7.5 Farmer(Sender) requesting process

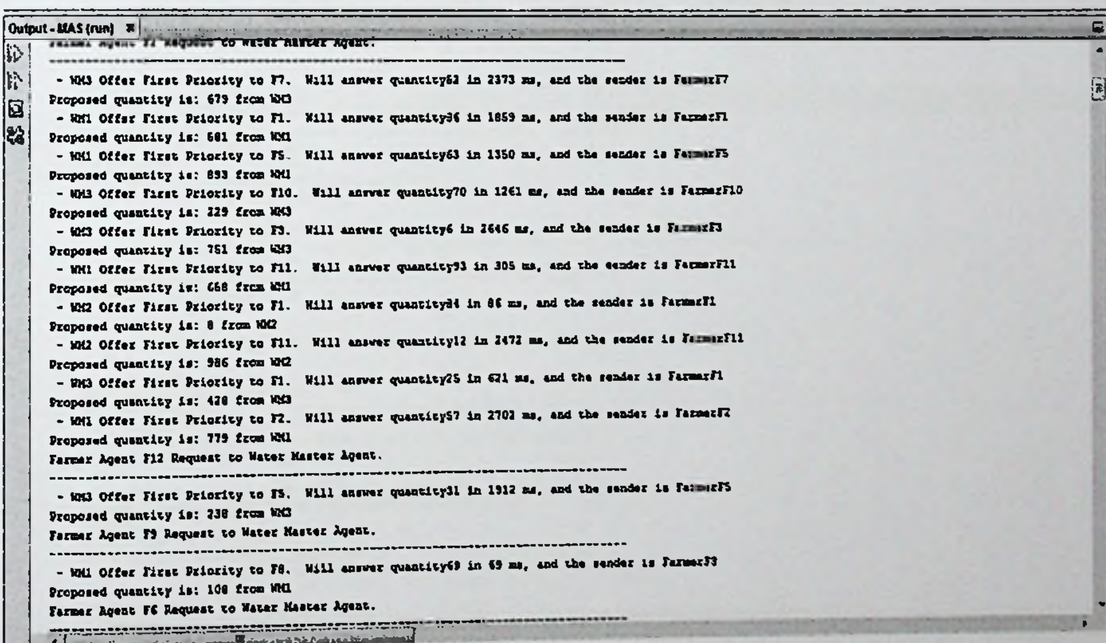
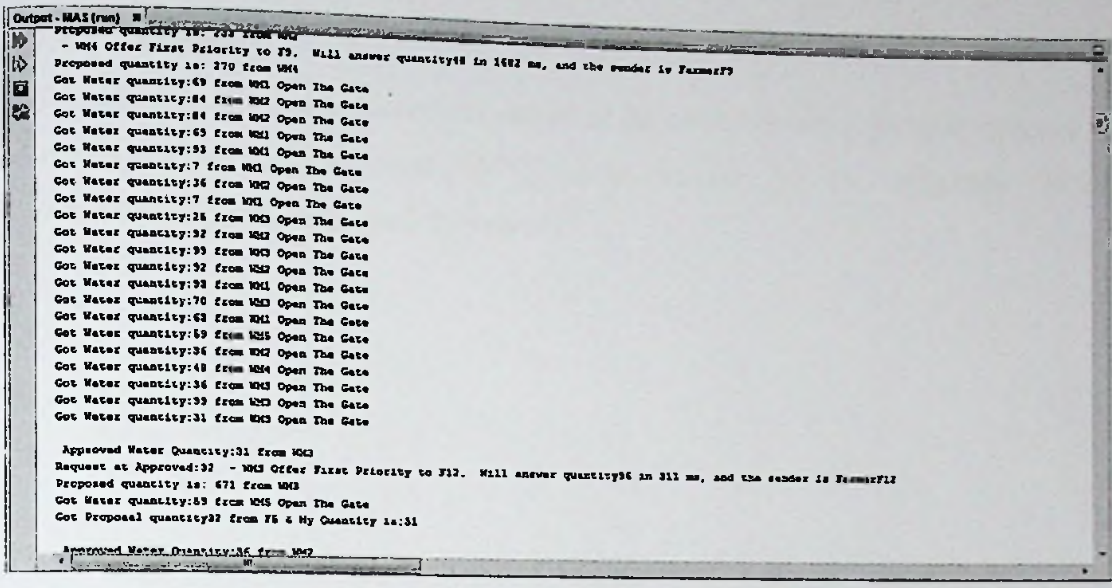


Figure 7.6 : Agent Communication Process

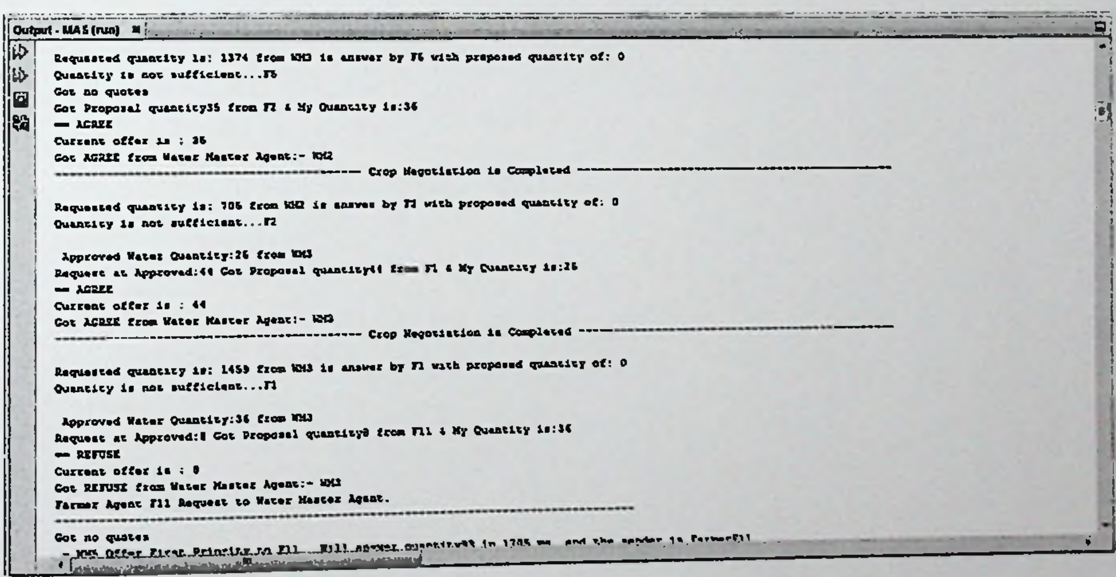


```
Output - MAS (run)
Proposed quantity is: 233 from WM2
 - WM4 Offer First Priority to F9.  Will answer quantity48 in 1682 ms, and the sender is FarmerF9
Proposed quantity is: 270 from WM4
Got Water quantity:69 from WM1 Open The Gate
Got Water quantity:84 from WM2 Open The Gate
Got Water quantity:84 from WM2 Open The Gate
Got Water quantity:65 from WM1 Open The Gate
Got Water quantity:53 from WM1 Open The Gate
Got Water quantity:7 from WM1 Open The Gate
Got Water quantity:36 from WM2 Open The Gate
Got Water quantity:7 from WM1 Open The Gate
Got Water quantity:25 from WM3 Open The Gate
Got Water quantity:32 from WM2 Open The Gate
Got Water quantity:99 from WM3 Open The Gate
Got Water quantity:92 from WM2 Open The Gate
Got Water quantity:93 from WM1 Open The Gate
Got Water quantity:70 from WM3 Open The Gate
Got Water quantity:62 from WM1 Open The Gate
Got Water quantity:59 from WM5 Open The Gate
Got Water quantity:36 from WM2 Open The Gate
Got Water quantity:48 from WM4 Open The Gate
Got Water quantity:36 from WM3 Open The Gate
Got Water quantity:39 from WM3 Open The Gate
Got Water quantity:31 from WM3 Open The Gate

 Approved Water Quantity:31 from WM3
Request at Approved:32  - WM3 Offer First Priority to F12.  Will answer quantity36 in 311 ms, and the sender is FarmerF12
Proposed quantity is: 671 from WM3
Got Water quantity:53 from WM5 Open The Gate
Got Proposal quantity32 from F6 & My Quantity is:31

 Approved Water Quantity:36 from WM2
```

Figure 7.7 Decision Making Process



```
Output - MAS (run)
Requested quantity is: 1374 from WM3 is answer by F6 with proposed quantity of: 0
Quantity is not sufficient...F6
Got no quotes
Got Proposal quantity35 from F2 & My Quantity is:36
— AGREE
Current offer is : 35
Got AGREE from Water Master Agent:- WM2
----------------------------------------- Crop Negotiation is Completed -----------------------------------------

Requested quantity is: 705 from WM2 is answer by F2 with proposed quantity of: 0
Quantity is not sufficient...F2

 Approved Water Quantity:26 from WM3
Request at Approved:44 Got Proposal quantity44 from F1 & My Quantity is:26
— AGREE
Current offer is : 44
Got AGREE from Water Master Agent:- WM3
----------------------------------------- Crop Negotiation is Completed -----------------------------------------

Requested quantity is: 1459 from WM3 is answer by F1 with proposed quantity of: 0
Quantity is not sufficient...F1

 Approved Water Quantity:36 from WM3
Request at Approved:8 Got Proposal quantity8 from F11 & My Quantity is:36
— REFUSE
Current offer is : 8
Got REFUSE from Water Master Agent:- WM3
Farmer Agent F11 Request to Water Master Agent.
---------------------------------------------------------------------------------
Got no quotes
 - WM5 Offer First Priority to F11.  Will answer quantity83 in 1785 ms, and the sender is FarmerF11
```

Figure 7.7 Massage Passing Process

7.6. Summary

This Chapter represents the content output of the model system. The main features of the developed computerized Multi Agent System for the Irrigation Water Management in the Mahaweli System- H.

Chapter 8

Evaluation

8.1. Introduction

In this chapter evaluated the designed software using the past data set. Here discussed whether the objectives mentioned in earlier chapters are met and to what extent.

8.2. Experimental Design

This system was experimented by a monthly water issuing and requirement chart for a distributor channel for 12 fields that only used to paddy harvesting in the Yala session in System H. In here used 8 Field Cannels details of harvested land and water requirement of the crops with the released water amount to the field cannel via the distributed cannel. The required details are input in to the system using text file. The field Cannels are involved in to the process via communication among the Gates and the relevant Field sections. The Field section manipulated the system water requirement for specific crop production. According to the harvested land and the ontologies the required water quantity was output by the system. These processes are handled by the Field and Gates communication and individual knowledgebase that related to the agents. Finally the existing data in manual system was compared with the IWM_MAS.

In here basically consider the manual and system water wastage as the key point to monitor the system evaluation task. To overcome these result the information given by the Irrigation department in a Yala season in Year 2015 was taken. The Department has only the basic details of Cannels, Field Section, calculated water requirement for the specific Filed sections and released water amount by the relevant cannels. The wastage of the manual system was calculated according to the information and that data was comparably analysis with the system related data.

Table 8.1: Existing data from the Department of Irrigation

No of Field Cannel	Field Section /Ac	Water Requirement for Crop/Ac per feet	Release Water Amount By Cannel/Ac per feet	Water Wastage
1	36	82.08	320	237.92
2	24	54.72	360	305.28
3	40	91.2	405	313.8
4	30	68.4	420	351.6
5	36	82.08	100	17.92
6	24	54.72	385	330.28
7	30	68.4	105	36.6
8	30	68.4	105	36.6
Total		570	2200	1630

To estimate the result of the model above past data collected from the irrigation department was entered to the database of the system. Then the model was activated and results were generated in to a text file. Both input data and the output data was attached in the Appendices as last in this thesis.

There were two scenarios involved in the experiment: Estimate the minimum requirement of water capacity to the field and compare the result with the real time data. Calculate the drainage water capacity from the Field Cannels.

8.3. Experimental Results

Table 8.2: Resulted Data from the System

No of Field Cannel	Field Section /Ac	Water Requirement For Crop/Ac per feet	Release Water Amount By Cannel/Ac per feet	Water Wastage
1	36	82.08	298	215.92
2	24	54.72	340	285.28
3	40	91.2	371	279.8
4	30	68.4	394	325.6
5	36	82.08	94	11.92
6	24	54.72	362	307.28
7	30	68.4	95	26.6
8	30	68.4	85	16.6
Total		570	2039	1469

8.4. Conclusion from the Experiment

Using the generated data sample the variation was figured using the column and line graphs to representing comparisons of the data.

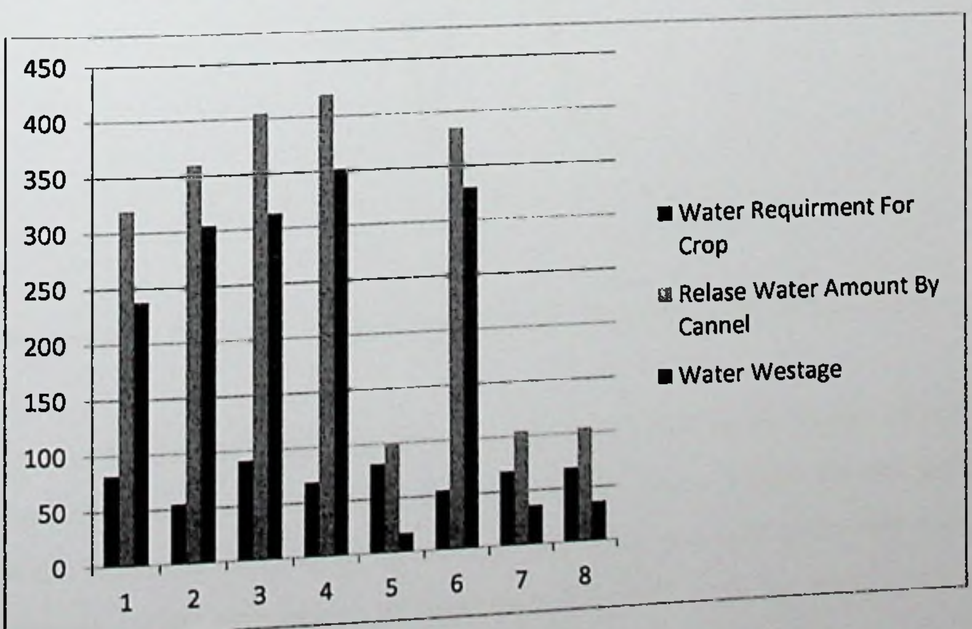


Figure 8.1: Comparison of the past data collected from the Irrigation Department

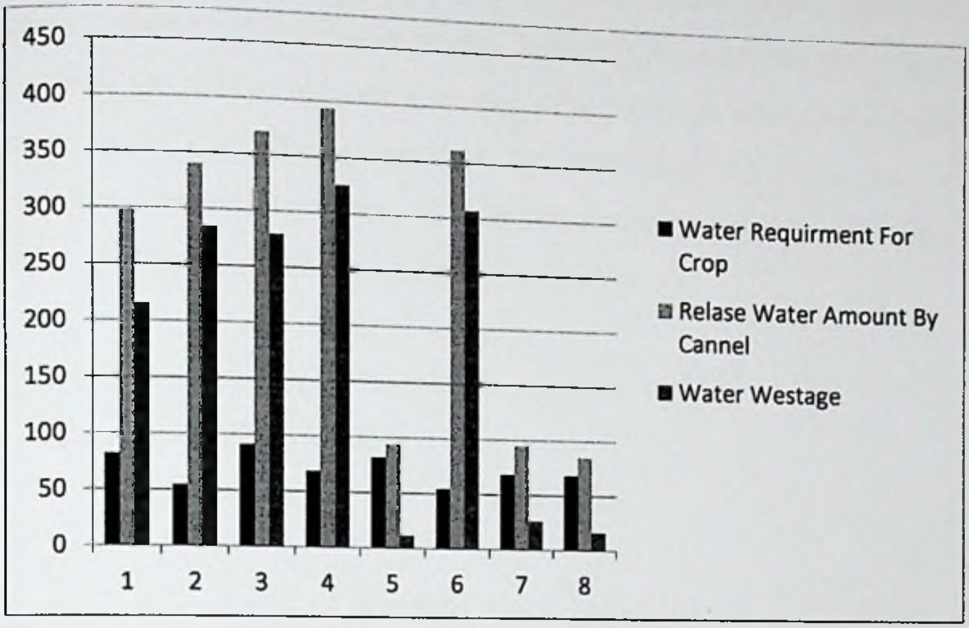


Figure 8.2: Comparison of System Data generated by the Model

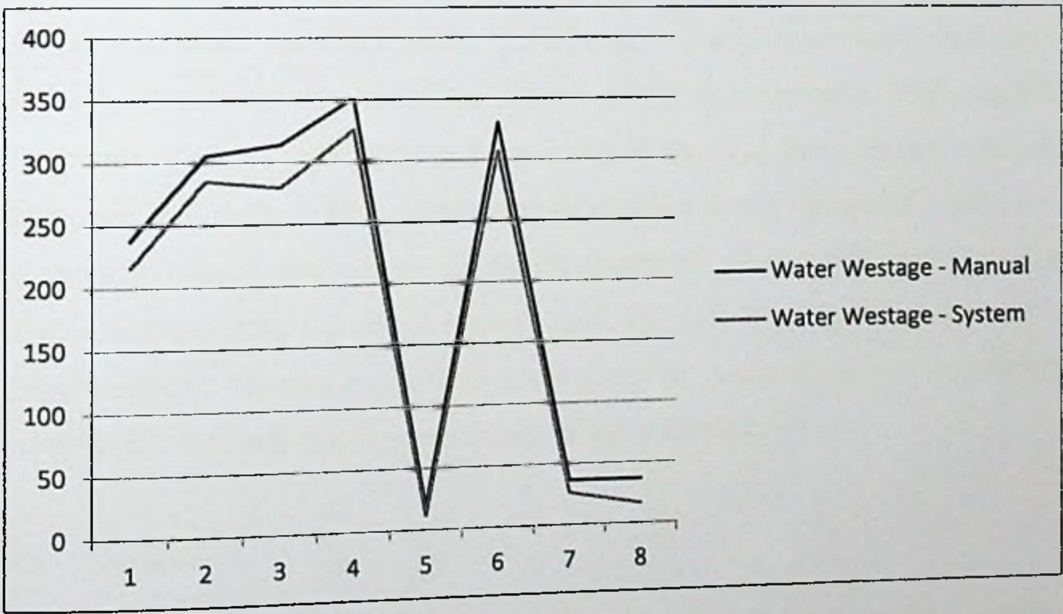


Figure 8.3 : Drainage Water Comparison of Row Data and System Data

In this Model the water requirement was operated with the highly effectiveness via on time operation of the field Gates. From the above results we can notice that the water releasing capacity of the cannels was decreased to minimize the wastage of the cannels. With comparison of raw data it is seems to be most equal the model generated data. This Model is successful in identifying attentive and non-attentive parameters correctly in most cases. These results are mostly based on the paddy water requirement and this may vary in the off sessions. We have same number of Acres of the paddy fields and crop type in the test pool. So the experiment results are more generalized. The accuracy can be further improved if we can lead to the off seasonal crops of larger data set. Crop water requirement was remain as the constant value for the both manual and system calculation.

Manual water wastage by the Irrigation System:

= (1630/2200) x 100

=74.00 %

System water wastage by the Multi Agent system:

= (1469/2039) x 100

=72.04 %

Calculated water wastage by the manual system was 74.00 % and the automated system was nearly estimated as the 72.04 % value. Hence it was concluded that the Multi Agent System was model the natural system approximately. When analyzing the results closely; it reflected the dependency of time that gates operate may create major role within the system. Reason for this may be due to background interference of manual system because in an automated system the process will operated without any time out or intervals. So it is more accurate with the system but not with the manual concept because in the system the gates are automatically closed when the required job duty was finalized and send the information on time.

8.5. Summary

In this chapter we have evaluated the software solution using proper experiment mechanism. We have designed and conducted experiment to measure the success of the application and presented the results.

Chapter 9

Conclusion

9.1. Introduction

This report presents the results that show it is possible to build an Agent communication automated system to manage the Irrigation water system in the fields. This has been achieved by using the new paradigm of Computer Science called Multi Agent Technology. The JADE Multi Agent framework is used to model the System and it was evaluated using the raw data in the natural field. This information is used as input to the system that is resulted the outcome nearly calculated as same in the natural system. It has resulted that the water wastage by the system was 72.04% and the natural phenomena was 74.00%. This result concluded that the automated software component of water management functions using multi agent technology as an effective solution for eliminating limitations in decentralized communication. Not only has that it given suggestions to classify whether Gates in the system can be operated. Then this classification can be used to the Irrigation Engineers or the decision makers to when the decisions are taken.

9.2. Conclusion

When comparing the manual system identified as same communication channels and the knowledge can be implemented through the Multi Agent systems as the Model. The estimated results by the system approximately same the manual system that in Irrigation Department. In the system communication process the decisions can be identified as the pre orders to the manual system.

Besides that following objectives also covered,

1. The domain knowledge of Irrigation Water Management field.
2. Recognizing the decisions that are taken in the management process in the suitable field environment.

9.3. Limitation and Future Work

This application is only developed to monitor the water management in the field of agriculture environment. The system was developed only for sample section of the cannel distribution in research area. As the section was huge variation of the seasons and the crop patterns as per further work one can extend this research to monitor the overall water distribution not just in the sample section. We are only using specific crop as Paddy for our purpose. With more crops we can achieve more accuracy in the future. Not only can that in the natural hazards like flood conditions the system be modified to tolerate such incident.

This can also be used as commercial application where decision makers can use this as a tool to have the mind map before entering the field. It is very hard to say whether it is totally equals the situation with the natural environment but with this kind of application, we can easily get to know the real utilization of the system. Hence they can advise coworkers on how to focus on the operations in the field to achieve the common goal of success.

9.4. Summary

In this chapter we have discussed the conclusions that we can finally derived from the research. We consider all the aspects of the project, design, implementation, evaluation. Based on all the facts, we made some final conclusions here. Problems encountered, limitations of the solution and further work are also discussed here.

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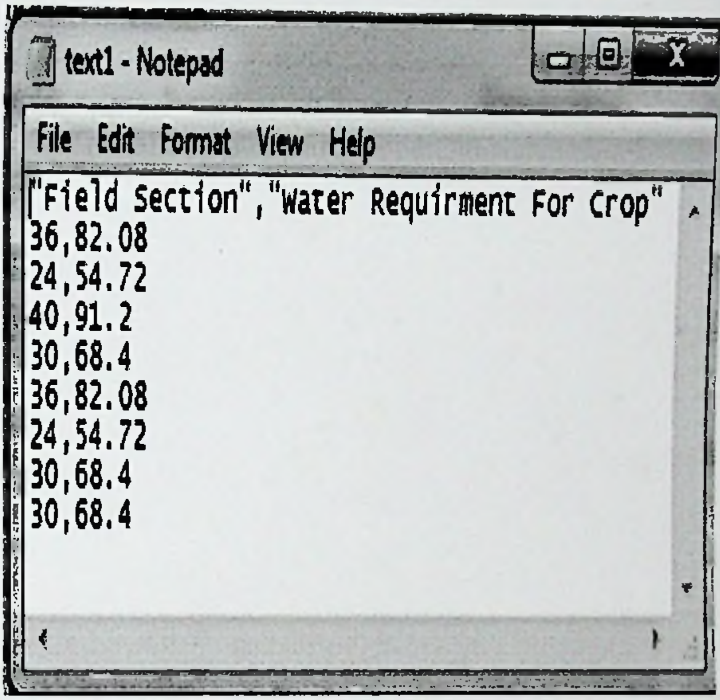
Appendices

Appendix A:

A.3 Input text file to the System




```
"Field Section","Water Requirment For Crop"
36,82.08
24,54.72
40,91.2
30,68.4
36,82.08
24,54.72
30,68.4
30,68.4
```

A.4 Output System values by the System

```
Current Amount is : 52
Got Proposal quantity4 from F4 & My Quantity is:16

 Approved Water Quantity:16 from WM1
Request at Approved:31 Requested quantity is: 1919 from WM2 is answer by F11
Water Quantity is not sufficient...F11
Got Proposal quantity4 from F6 & My Quantity is:32
"Field Section",          "Water Westage - System "
        36,                      215.92
        24,                      285.28
        40,                      279.8
        30,                      325.6
        36,                      11.92
        24,                      307.28
        30,                      26.6
        30,                      16.6
```