Multiagent System in Irrigation Management. A Review*

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Abstract— **The risk of climate change in the sustainability of humanity, especially in the availability of water, is one of the most important premises in the 21st century. In this paper we explain the concepts of Multiagent Systems and Agent Based Modeling, together with their applications in the analysis and management of freshwater. This document is a synthesis review of projects related to this topic, especially in systems to support decision making on water in agriculture. Multi-agent systems are a great technology that has advantages for the study, modelling and control of irrigation systems. SMAs are a powerful Intelligent Environmental Decision Support System, which are evolving in tasks related to negotiation, reactive behaviors, proactive behaviors and learning of intelligent agents, with application in the management of natural resources. Some of the most well-known methodologies, frameworks and technologies of MASs and agent-based modeling are also explained and the most important challenges - research opportunities in this field are mentioned.**

I. CLIMATE CHANGE

The Food and Agriculture Organization (FAO) defines food security as a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life". This definition comprises four key dimensions of food supplies: availability, stability, access, and utilization [134]. In the 21st century, we now face an environmental threat induced by the increase in carbon dioxide and other radioactive trace gases in the atmosphere [145], which could cause irreversible damage to land-water ecosystems and loss of production potential [56]. Farming activities rely on favorable climate conditions and are at risk under a changing climate [108].

Nowadays climate change is expected to affect society in a number of ways ranging from food security to water resources [119], [20]. Water supply is of great importance for the sustainability of both urban and rural areas throughout the world. Climate change projections suggest that historical water conditions may change significantly and seriously affect irrigators [44] due to its influences in the natural hydrological cycle which can contribute to water scarcity [136] and increasing and more frequent pollution of groundwater and surface water [46].

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Climate change could exacerbate water availability and the demand for water calculated a general increase in water use for crop irrigation and an according decrease in water availability for several regions, [125]. Such effects may include the magnitude and timing of runoff, the frequency and intensity of floods and droughts, rainfall patterns, extreme weather events, and the quality and quantity of water availability; these changes in turn influence the water supply system, power generation, sediment transport, deposition, and ecosystem conservation [145].

Future adaptation and mitigation strategies [82] are essential ingredients in impact and vulnerability (exposure to climatic stress, sensitivity and adaptive capacity [40]) assessments. Adaptation refers to include the actions of adjusting practices, processes, structures and capital in response to the actuality or threat of climate change, as well as responses in the decision environment [74]. Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting [141].

The strong trends in climate change already evident, the likelihood of further changes occurring, and the increasing scale of potential climate impacts give urgency to addressing agricultural adaptation more coherently [74]. The impact of climate change occurs at multiple scales (global, regional and national) and sectors (including agriculture) [111]; nevertheless it is particularly important to align the temporal and sectoral scales. Global climate change presents challenges for mitigating and adapting natural resource use and management locally and regionally. This is particularly true in subsistence agriculture areas where natural and economic resources are limited [146]. A significant benefit from adaptation research may be to understand how short-term response strategies may link to long-term options to ensure that, at a minimum, management and/or policy decisions implemented over the next one to three decades do not undermine the ability to cope with potentially larger impacts later in the century [74]. Successful adaptation requires a recognition of the necessity to adapt, knowledge about available options, the capacity to assess them, and the ability to implement the most suitable ones [141].

The understanding of complex water resource systems under combined and interdependent climatic and anthropogenic forcing is the key for feasible adaptation strategies and should be tackled under a comprehensive modeling framework able to include possible variations of the irrigation water demand and consequent adaptation options [67]. Hence, the current level of technology in the communities and its ability to develop technologies are important determinants of adaptive capacity. These adaptations include a wide array of engineering measures, improvements, or changes, including: negotiating regional water-sharing agreements, providing efficient mechanisms for water management, developing desalination techniques and improving drainage facilities [141]. Farmers need to be actively involved and to make capital contributions towards the establishment, rehabilitation and water management of their irrigation schemes. This was found to inculcate, onto the farmers, the sense of ownership and responsibility needed for sustainable water management [105].

To feed 9 billion people nutritiously by 2050 we need to make agriculture resilient, more productive in changing landscapes, and aggressively reduce food waste. Making agriculture work for the people and the environment is one of the most pressing tasks at hand. We need climate-smart agriculture that increases yields and incomes, builds resilience, and reduces emissions while potentially capturing carbon [90]. Optimal irrigation is of critical importance for agriculture with decreasing freshwater resources in times of climate change. About 70% of the global water withdrawal and 85% of the consumptive water use is for irrigation. Approximately 40% of the total food production relies on supplemental irrigation. Unfortunately water use efficiency (WUE) in the agricultural sector is very poor with more than 50% water losses [64].

II. IRRIGATION AND THEIR AUTOMATION

Irrigation is the process of application of water to a land or soil. It is used for enhancing the growth of agricultural crops, maintaining landscapes, and revegetation of degraded soils in dry areas and periods of inadequate rainfall [104]. Economical, water management and ecological criteria are used in definition of decision making on irrigation systems [162] and these decisions depends on how much water the cultivation of a particular crop species requires and how much water is available from local sources [125]. A plant uses only part of the applied water, the difference between the potential evapotranspiration and the evapotranspiration that would occur without irrigation, is the net irrigation requirement. The other part of the added water serves to leach salts from the soil, leaks or evaporates unproductively from irrigation canals, or runs off; this amount depends on irrigation technology and management. The ratio of the net irrigation water requirement and the total amount of water that needs to be withdrawn from the source, the gross irrigation requirement, is called irrigation water use efficiency. Under conditions of restricted water availability, farmers may choose to irrigate at a lower than optimal rate [44].

Water content in effective root zone is estimated by using the water balance approach, where precipitation is equals the sum of evapotranspiration, streamflow and the change in storage (in soil or the bedrock / ground water) (1) and is often used in irrigation modelling and simulation, but a permanent recalibration is required [24].

$$WC_t = WC_{t-1} + IRR + RAIN - AET - DP \qquad (1)$$

Where WC_t is soil water content today (mm), WC_{t-1} is soil water content yesterday (mm), IRR is irrigation depth since yesterday (mm), $RAIN$ is rain since yesterday (mm), AET is actual evapotranspiration (mm) and DP is deep percolation (mm).

Temperature, Relative humidity, soil moisture, pH, solar radiation among others, are environmental parameters that plays very important role in overall development of the plant. Increasing temperature will lead to higher evapotranspiration and could generate soil moisture deficits followed by a growing risk of vegetation desiccation and decreasing plant development [125]. Also at higher temperature, respiration rate increases that result in reduction of sugar contents of fruits and vegetables. At lower temperatures photosynthesis activity is slowed down. Usually canopy temperature measurements are compared to those obtained from a non-water stressed and a non-transpiring crop, and most commonly expressed as a crop water stress index (CWSI) [143] [104], parameter usually used for scheduling the irrigation for the crop [104]. Relative Humidity is responsible for moisture loss and temperature management of the plant. For high humidity environment, evapotranspiration will be less and more water will saturated in the leaf area. This results in enlargement and formation of fungus in the porous area of the leaf [58].

Depending on the soil coverage and associated physical characteristics such as the water holding capacity of soils the necessity of land use adaptations might arise to cope with climate change [125]. The plant-available water content (PAWC) between the wilting point (θ_{WP}) and the field capacity (θ_{FC}) is decisively influenced by the soil composition and can be perceived as the most important component for high irrigation efficiency [64]. Soil moisture ensures healthy growth of the root and overall development of the plant [58] and its deficits can arise in times when evapotranspiration is higher than precipitation and soil water storage is not sufficient to maintain plant provision [125]. Hence, important parameters like soil textures and corresponding water retention functions should be considered in the irrigation strategies [64].

Excess water may stop gaseous exchange between soil and the atmosphere which reduces root respiration and root growth. Over-irrigation is also accompanied by problems of soil degradation like surface runoff, soil erosion and nutrient leaching [64]. Inappropriate irrigation practices that systematically deliver salt to soils will eventually be disastrous for the environment. One estimate suggests that at least 20% of irrigated lands on the planet suffer from significant soil salinization and climate change in many regions threatens to exacerbate salinization phenomena [144].

A. Automation and Control

Wastage of water in irrigation is mainly caused by the use of traditional techniques which are based on timers and water loss through ground evaporation and crop transpiration (evapotranspiration ET). In the first case, people over-irrigate crops due to the misunderstanding of seasonal water need or the impracticality of updating the irrigation schedule to reflect actual water needs of the landscape (farmers adjust timers by observing the crop and irrigating when it looks stressed). On the other hand, the loss by evapotranspiration is inevitable and accentuated by the hyper-arid environment under untapped ambient temperature and solar radiation. Because of this, the automated irrigation systems' need, that are able to deliver the exact quantity of water required by the crop for proper irrigation while reducing ET losses [149].

This leads directly to the conceptualization of a best irrigation system that determines the timing, magnitude and spatial pattern of applications for the next irrigation, controls the application of correct water requirements, through simulation or direct measurement knows the magnitude and spatial pattern of the actual irrigation applications, including soil-crop responses to those applications and utilize these responses to improve the next irrigation plan (learning) [143]. The Smart Water Application Technology (SWAT) committee of the Irrigation Association defines *Smart controllers* as those technologies that "Estimate or measure depletion of available plant soil moisture in order to operate an irrigation system along with replenishment of water as needed while minimizing excess water use. A properly programmed smart controller requires initial site specific set-up and will make irrigation schedule adjustments, including run times and required cycles, throughout the irrigation season without human intervention" [106],[126].

A more rational approach for optimizing irrigation is the use of automatic irrigation controllers and their adoption, aimed at attaining the desired level of humidity for each plant type, can improve the costs and energy consumed in small-scale site-specific irrigation systems [79]. In this systems exist a need to sense the water application and crop response at a scale appropriate for management, make a decision for improved irrigation management using both historical data, and control either the current or subsequent irrigation applications at an appropriate spatial scale [143]. There are four essential steps in the process and technologies or automatic irrigation: data acquisition, interpretation, control and evaluation.

1) Data acquisition: A variety of technologies are available that seeks to reduce irrigation water use associated with soil, plant and atmosphere system:

- Scheduling irrigation using soil water balance (estimations of evaporation and rainfall) [106].
- Scheduling systems using soil moisture sensors (SMS), basically: soil water measurements (soil water Tension (SWT) or soil water content (SWC) [104], [95]. But mostly the nonlinear relationship between SWC and SWT is neglected. In fact, the amount of water is mostly given according to subjective irrigation schedules [64].
- Scheduling irrigation using Plant-based measurements (dendrometer, xylem cavitation, sap flow sensors, tissue water status or stomatal conductance) [64].
- Scheduling irrigation using spectral information [71] and vocal commands [43].

2) Interpretation: The use of information and communication technologies (ICTs) in irrigation, requires the integration of sensors using a software that controls the system. This software has to be able to take data in real time, analyze it, and make decisions. In the case of hidric resource management this means that the software has to decide when to irrigate and how much water to apply. These systems should consider the quality of irrigation water, cultivation system, phenological state of the plants, irrigation system, electrical conductivity (EC) of the nutrient and drainage solutions, quantity of nutrients required by the plants, solar radiation, vapor pressure deficit, and ambient temperature observed. [126]. A tool useful to obtain better performance of the irrigation activities is a Decision Support System (DSS), that is able to estimate if some process (irrigation) is required or not, and the agricultural input necessary. [79]. The implementation of Artificial intelligence in Decision Support systems is used in the study on rational use of water resources to interpret and analyses information acquired of sensors in field, making water resources planning more scientific and more accurate [32].

Artificial Intelligence technology (AI) was born in 1950s, which aims were how to use a machine to simulate the intelligent behaviors of human beings [32]. For a machine to exhibit intelligence, it has to interpret and analyze the input and result data apart from simply following the instructions on that data. Data mining algorithms can analyze data records and identify Models or transform data to supporting processes and identify missing properties or parameters of a system [95]. This is what the machine learning algorithms do, using supervised Problems like classification and regression come under this category. Popular supervised learning algorithms are artificial neural networks, decision trees, K-means clustering, support vector machines, bayesian networks among others, and unsupervised learning: self organized feature maps, COBWEB, DBSCAN and reinforcement learning: feedback received, genetic algorithms, markov decision algorithms. These techniques will enhance the productivity of fields along with a reduction in the input efforts of the farmers

[85]. Some techniques and fields of AI are explained in the next section [26].

- **Machine Learning.** Is a branch of AI that aims to develop techniques that allow computers to learn.
- **Knowledge Engineering.** Analyze learning methods and apply them to computers so that it is possible to develop a system capable of learning by itself, is to extract knowledge from human experts and to encode knowledge in a way that can be processed by a system.
- **Fuzzy Logic.** Multi-valued logic which includes logical systems that support several possible truth values.
- **Artificial Neural Networks.** Are programs of learning and automatic processing inspired by the way the nervous system of living beings function. It consists of simulating the properties observed in biological neuronal systems through mathematical models recreated by artificial mechanisms.
- **Case-Based Reasoning.** Seeks to provide solutions based on similar problems in the past, which are called cases, to find solutions to them, modify solutions and explain anomalous situations. Case-based reasoning systems are able to use specific knowledge of previous experiences to solve a problem. They capture the characteristics of this problem, look for historical cases with similar values for these characteristics, analyze the solutions of these cases and propose a solution to the problem, and finally learn from the current problem for future problems.
- **Expert Systems.** Are programs that mimic the behavior of a human expert, manipulating codified knowledge to solve problems in a specialized domain in order to solve a problem in a particular domain through logical deduction of conclusions.
- **Bayesian Networks or Probabilistic Networks.** Graphical representation of dependencies for probabilistic reasoning in expert systems. It consists of a representation in an acyclic graph and a set of conditioned probability distributions (one per node) where the distribution at each node is conditioned to the possible value of each of the parents.
- **Artificial Life** is the study of life and artificial systems that exhibit the behavior characteristic of living beings through simulation models, pretending to reproduce the typical processes and behaviors with the aim of solving problems.
- **Evolutionary Computation.** Takes up concepts of nature, evolution and genetics to solve computer problems. This branch of AI has its roots in three related but independent developments: 1) Genetic Algorithms: These algorithms evolve a population of individuals by subjecting it to random actions similar to those that act in biological evolution (mutations and genetic recombination) As well as to a selection according to some criterion, according to which it is decided which are the most adapted individuals, who survive and which are the least fit that are discarded. 2) Evolutionary Strategies: computational methods that work with a population of individuals that through the processes of mutation and recombination, and using selection techniques (probabilistic or deterministic) eliminates the worst solutions of the population, evolving to reach the optimum of Objective function. 3) Evolutionary Programming: it is a variation of the evolutionary strategies, only that it does not use recombination techniques and mutation to find the solution.
- **Data Mining or KDD (Knowledge Discovery in Databases)** can be defined as "non-trivial extraction of implicit information, previously unknown, and potentially useful from the data", and consists of the set of advanced techniques for the extraction of information hidden in large databases.
- **Multi Agent Systems or Distributed Artificial Intelligence:** A multi agent system is a distributed system in which nodes or elements are artificial intelligence systems, or a distributed system where the combined behavior of those elements produces a intelligent result.

3) Control and evaluation: The system could apply irrigation to refill water used by plants the previous day, using crop potential evapotranspiration (ETc), changes in the soil water content or plant-based measurements using an open-loop controller in which no measurements of the field are used to modify the inputs and the decisions are taken based on heuristics, expert knowledge or a system model. Open-loop controller presents some limitations that can be overcome by the use of feedback (closed-loop controllers), mathematical models and additional information provided by plant measurements [128]. The most deployed method of irrigation control is the closed-loop which splits into two categories: feed-forward and feedback control. In feedback control, the idea is to maintain soil moisture within a specific range by measuring crops needs from soil moisture levels using instruments such as tensiometers or dielectric probes. However, in the feed-forward control (known as ET control), controllers use the crops reference evapotranspiration (ETo) to schedule irrigation compensating then for ET water loss through the water balance technique. Climatic conditions have direct influence on ETo, which can be calculated by using Penman Monteith model as this has been officially adopted by the FAO [149].

Some control strategies with application in irrigation that are able to switch on/off the irrigation pump and to open or close the valves to apply the irrigation doses to every sector of the crop are:

- **On-Off control**. Consisting on switching the controller output between maximum and minimum output according to a error signal. Examples of this kind of strategy are: soil water content [23], [29], [101]; canopy temperature [114], [122]; soil matric potential [27],

[127] and sap flow [54].
- **PID (Proportional-Integral-Derivative) control**. The control signal depends of the weighted sum of three terms: the error between the variable and the set-point, the integral of recent errors, and the rate by which the error has been changing. PID control utilize measurements of a single output variable (temperature, relative humidity, soil moisture or meteorological conditions) to compute the control action needed to be implemented by a control actuator so that this output variable can be regulated at a desired set-point value. The application of a PID strategy, has not yet been extensively considered in commercial irrigation controllers. An example using soil water content is shown in [129].
- **Fuzzy logic control**. Fuzzy logic interprets real uncertainties and becomes ideal for nonlinear, time-varying and heuristic knowledge to control a system. Examples using soil water content, air temperature and light intensity in [158], using soil measurements (moisture and temperature) and solar radiation in [149], with multi-agent architecture in [131].
- **Genetic algorithms**.
- **MPC (Model predictive control)**. There are few agricultural applications (mainly for regulating weather conditions in controlled environments such as greenhouses) because it is difficult to obtain precise models appropriate for control purposes; however, it is a promising methodology for the design of irrigation controllers. An example using soil water content in [129].
- **Non linear control**.
- **Artificial neural networks**. ANN are not really a class of controllers, but a modeling framework which can be used in advanced model based controllers. Examples using soil water content in [28] and Back-Propagation Neural Network (BPNN) in [71], using Neural Network and Fuzzy Logic in [151].
- **Commercial automatic controllers**. These controllers apply irrigation when sensors detect that the measurements are below a certain predefined threshold until another predefined threshold is overcome (on-off control). Examples using soil water content are Acclima [1], Watermark [3], Rain bird [2], Water Sense [4].

III. MULTI-AGENTS SYSTEMS (MAS)

Intelligent agents (also known in literature simply as agents) are problem solving software entities, which possess human like intelligent properties such as: autonomy, reasoning, sociability, learning ability, among others. Agents differ from objects (as in object oriented programming) in their degree of autonomy. Objects have control over their methods, but they do not exhibit control over their own behavior [48]. Intelligent agents are autonomous entities (software or hardware) capable of exercising choices over their actions and interactions [107]. Each agent is composed of sensors (senses the information of external environment), behaviors (exert influences on the external environment), communication components (exchange information with other agents), and attribute functions (so it has an ability of learning, evolution, coordination and planning). Four active research areas on MAS are found: protection, monitoring and diagnostics, modeling and simulation, and distributed control [70]. Agents have been used to represent a wide variety of entities, including: atoms, biological cells, animals, people, and organizations [117].

Multi-Agent systems (MAS) are Agents groups that seeks solve some tasks or achieve some goals through cooperating, these Agents should cooperate and solve complicated problems that exceed each individual ability while exchanging information between them [19]. This Agents in Multi-Agent systems have the following features: each agent, on its own, does not have the capability to solve the main problems, there is no control over the whole system and information (data) is distributed [137]. They are independent and distributed to run, and coordination and service each other, the goal and behavior between Agents contradiction and conflict, which is coordinated and solved through the means such as negotiation, competition or consulting, to finish a task together [161]. In MAS, agents interact and exchange information in a decentralized and somewhat *social* manner instead, which explains why the term *Distributed Artificial Intelligence* was coined [19].

Multi-agent systems have several features that makes them suitable for solving problems: speed-up and efficiency (agent can act asynchronous and in parallel, resulting in an overall increased speed-up), robustness and reliability (failure of one component does not make the entire system inoperable), scalability and flexibility (the system can be adapted to an increased problem size by easily adding agents), cost, development (due to computer standardization individual agents can be developed by different specialists) and reusability (possibility of reuse and reconfigure agents in different application scenarios) [107]. Role is a combination of certain responsibilities, functions and behaviors in the system and is responsible for one or more specific targets in the system. A group of agents have distinguishable nature, interfaces and behaviors through the role of agent. In the MAS, system objectives are undertaken by various role agents. Taking role as a base unit for modeling reflects the goal-driven idea during system modeling, and role plays a very important function from analysis to the whole development process [159].

Some applications of MAS are: dynamic tasks distribution implementation between spacecrafts (tasks are assigned to whole constellation of satellites, and their performers can adaptively change depending on emerging events) [138], MAS technologies application for adaptive planning of communication sessions establishment requests with nanosatellites in the ground stations network in response to the arising events, considering constraints [18], heterogeneous MAS for dynamic triage of victims in emergency scenarios [100] and cooperative control of UAV based on MAS

[68]. In agriculture and forest MAS has been applied to integrated pest management [66], simulation of prototypes for different agriculture robots that can be employed in the harvesting of a vineyard [6], coordination and control system for combine harvesters [5], simulating forest plantation co-management (simulations to explore scenarios of collaboration for plantations), multi-stakeholder management systems, such as common pool resources [123], simulation to investigate the impact of farm credit (an agricultural land-use change adaptation strategy) on farm household livelihood [148], and sensor networks that can be potentially applied in many areas including manufacturing, agriculture, construction, transportation and so on. In irrigation agents are able to model the stakeholders behaviors as well as their interactions (here the farmers individual and collective practices) [51], in the management of a basin river in a country air pollution control and management systems [133] and long-range monitoring system of irrigated area based on MAS and GSM [161]. Research on multi-agent systems can be classified into three categories: analysis (given the local rule of the agents, what is the collective behavior of the system?), Distributed control (given the desired collective behavior, how do we design the rules of the agents such that the system exhibit the desired behavior?), intervention (Given the desired behavior, how do we control or intervene in the system without destroying the local rule of the system?) [81].

A. Agents and Control

Multi-agent control systems are spatially distributed systems consisting of a number of interacting agents [81]. These networked multi-agent systems allow improve flexibility (decentralization, abstracting heterogeneous subsystem for integration, cooperative multiagent systems and high-level abstractions of system resources [94]), reliability (fault-tolerant, autonomy, responsiveness, scalability [34]), and cost efficiency in the process of sensing, communication, and control. In distributed control, each agent can be regarded as a control system, and the control law of each agent can be designed based on local information. In pinning control, we need to design the local feedback control law of some agents selected with some special properties. In fact, the pinning control can be regarded as a special case of distributed control. [81].

Soft control, is a novel method to intervene in the collective behavior of MAS. The central idea of soft control is to add one (or some) special agent(s) (called shill) into the original systems to guide the system to the desired behavior, but without changing the local rules of the existing agents. The special agent(s) can be controlled or designed by us, and cannot be identified by the existing agents. The existing agents take them as ordinary agents, so the shill agent(s) will not destroy the local rules of the ordinary agents, but can affect the behavior of other agents in its neighborhood. The property of local interactions between agents makes the influence of the shill spread out, so adding shill agent(s) may control the behavior of the whole system [81]. On the other hand SCADA systems encompasses the collecting of the information via a remote terminal unit (RTU), transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays. The integration of MAS an SCADA is developed in some works [70]. Also cooperative distributed Model Predictive Control algorithms are used to incorporate stability constraints [78].

Consensus problems for multi-agent systems in control applications have been studied because the variety of applications in engineering and science such as scheduling and planning [1, 2], automation [15] diagnostics [3], system restoration [11], distributed control [5, 7], hybrid control [8], market simulation [12, 13], congestion control [9, 10], network control [13, 14], condition monitoring [46], formation control, swarms, flocking and many more. Another active research area within networked control is event-based control. In practice, controllers are usually implemented on digital computers. Hence, the control law is only updated at discrete time instances. These can either be specified by a constant period, which is referred to as time-scheduled control, or be determined by certain events that are triggered depending on the plants behavior (event-based control) [135].

In the MAS-based collaborative decision system of crop production management, the external participants of the system include user, expert and administrator. Two major types of agents participate in the realization of system functions. The first type is resource agents, including data management agents and knowledge management agents; and the second type is decision-making support agents, including knowledge model agents, agents of growth simulation models, agents of management and control [159].

B. MAS design methodologies

Foundation for Intelligent Physical Agents (FIPA) is an IEEE Computer Society standards organization that promotes agent-based technology and the interoperability of its standards with other technologies. COIN (Coordination, Organization, Institutions, and Norms) is an internationally well-known community in multi-agent systems that focuses on the research on organizational structures in MAS and their coordination patterns [48].

Scenarios (stories about people and interactions, including agents, actors, sequences of actions and events) can describe different levels and details with multiple perspectives. The visual forms of scenario based specifications like Unified Modelling Language (UML) Sequence Diagrams (SD) [51] and Message Sequence Chart (MSC) can show the software behavior. Emergent behavior is defined as the unexpected behaviors of software components in the execution time, while it was not seen in their requirement and design specification. In this case Message Sequence Chart (MSC), Message Sequence Graph (MSG), and high-level Message Sequence Chart (hMSC) are used [50].

The Agent Modeling Language (AML) is a semiformal visual modeling language for specifying, modeling and documenting systems that incorporate concepts drawn from Multi-Agent Systems (MAS). The AML language allows the modeling of the roles and the attribution of roles and the definition of the behavioral aspect which allows the description of the interactions between agents and the individual behavior [17]. AML incorporates and unifies the most significant concepts from the broadest set of existing multi-agent theories and abstract models (e.g. DAI [24], BDI [17], SMART [9]), modeling and specification languages (e.g. AUML [1, 11, 12], TAO [18], OPM/MAS [20], AOR [23], UML [15], OCL [14], OWL [19], UMLbased ontology modeling [7]), methodologies (e.g. MESSAGE, Gaia, TROPOS, PASSI, Prometheus, MaSE), agent platforms (e.g. Jade, FIPA-OS, Jack, Cougaar) and multi-agent driven applications [150].

Agent-based computing introduces novel abstractions and programming structure. Classical methodologies are no more suited for such system. Thus, from software engineering point of view, novel and specific agent-oriented approaches are needed [70]. Different abstract models and methodologies are explained in the next section.

- **CoMoMas Methodology, 1996** [62].
- **Cassiopeia Methodology, 1996** [35].
- **MASB Methodology, 1996** [103] Multi-Agent Scenario Based Method.
- **AOMEM Methodology, 1996** [87] Agent Oriented Methodology for Enterprise Modelling.
- **CommonKADS Methodology, 1997** [77]
- **MaSE DeLoach Methodology, 1999** [41]. This methodology is based on the concepts of object-oriented programing, and in that sense the components of SMA are conceived and developed as objects. MaSE has a development tool named AgentTool in which the seven proposal design steps can be followed: goal capture, use cases application, role refining, agent classes creation, conversation construction, assembly of agent classes and system design. Each of these steps generates outputs, which can be class diagrams, models, tasks or sequences.
- **BDI Abstract Model, 1998** [59] (Belief Desire Intentions). This proposal has three basic components, as its name implies. It is part of an agent that has beliefs, which corresponds to a model or representation of the environment. The agent has desires, which correspond to a final state to be achieved, and this is achieved through the intentions, that are possible actions to modify the environment.
- **HIM Methodology, 1999** [47].
- **AUML Methodology, 2000** [110].
- **DESIRE Methodology, 2000** [83].
- **GAIA Methodology, 2000** [157]. In this methodology, objects are also taken into account, but as the last step in the design after obtaining some models of the multi-agent system (the design of these agents is not detailed). These models are low-level and are named agents, services and acquaintances model, that describe agents, their functions and their communication, respectively. In a high level are role and interaction models, which describe an organized system to which a measure of quality can be applied.
- **Adept Methodology, 2000** [80].
- **MESSAGE/UML Methodology, 2001** [49].
- **Tropos Methodology, 2001** [30]
- **Prometeus Methodology, 2002** [116].
- **PASSI Methodology, 2002** [25] [70]. Process for Agent Societies Specification and Implementation is a step-by-step requirement-to-code methodology for designing and developing multi-agent societies integrating design models and concepts from both Object Oriented software engineering and artificial intelligence approaches using UML notation. The models and phases of PASSI are: system requirements model, agent society model (roles), agent implementation model, code model, a deployment model.
- **ASPECS Methodology, 2010** [36] [70]. Is a software engineering process that describes steps for software development, starting with the requirements analysis to code implementation and deployment on a specific platform. It is a MAS methodology for the analysis and design of complex systems. ASPECS proposes to associate MAS to holonic system. Such systems are modeled as hierarchy of agents (agents composed by other agents). The main steps of the methodology are: Requirements analysis (ontology diagram), the design of an agent community, the implementation of the solution and the application deployment.

IV. INTELLIGENT ENVIRONMENTAL DECISION SUPPORT SYSTEMS AND AGENT BASED MODELLING

A. DSS

Computer systems that assist decision makers in choosing between alternative beliefs or actions by applying knowledge about the decision domain to arrive at recommendations for the various options, are named Decision Support Systems (DSS) [132]. It incorporates an explicit decision procedure based on a set of theoretical principles that justify the "rationality" of this procedure [9]. It can be used for both structured and unstructured decision. However, it cannot replace the decision maker itself because DSSs do not possess the human decision making abilities intuition, creativity or imagination. DSSs can be classified either as Data-Centric (information) or Model-Centric (simulations and optimization modeling). Other way how to classify DSSs is on the way it is used by its users: recurring decision making (formal) and ad-hoc decision making systems. DSSs can be also classified into directed (guidance to its users) and non-directed (not giving any guidance) systems. Last division is on individual and group DSSs [89].

B. EDSS

Environmental systems are stochastic and, very often, are multi scale, spatial and temporal dependent processes. They also tend to comprise complex interactions among social, cultural, physical, chemical and biological processes. These processes may not be known well and/ or may be difficult to represent, causing considerable uncertainty [132]. Therefore environmental problems are hard to model and understand. Environmental problems, as well as environmental systems, are dynamic in nature, and therefore deep models of their behavior are difficult to reproduce. Most environmental systems cannot be tackled only with the traditional tools of mathematical modelling. The effort to integrate new tools to deal with more complex systems has led to the development of so-called Environmental Decision Support Systems (EDSSs) [9].

C. IEDSS

Intelligent Environmental Decision Support Systems (IEDSSs) could be defined as systems using a combination of models, analytical techniques, and information retrieval to help develop and evaluate appropriate alternatives. Most developed IEDSS are based on traditional artificial intelligence approaches [9] as: expert models, neural networks, rule-based knowledge, evolutionary models, cellular models (cellular automata and Markov models), statistical techniques, hybrid models among others [117]. IEDSS integrate the expert knowledge/data stored by human experts through years of experience in the process operation and management [133]. Intelligent EDSSs or IEDSS can play a key role in the interaction of humans and ecosystems, as they are tools designed to cope with the multidisciplinary nature and high complexity of environmental problems [132].

Two kinds of IEDSS can be distinguished: the first category are those IEDSS aim to control or supervise a process in real-time, facing similar situations on a regular basis. They must guarantee robustness against noise, missing data, typos and any combination of input data. In general the end-user is responsible for accepting, refining or rejecting system solutions. In the second category are those that give punctual support to decision making, and are mainly used to justify multicriteria decisions of policy makers more than to make real decisions on a day-to-day basis [132].

The main advantages of using IEDSS to solve environmental problems are [9]:

- The ability to acquire, represent and structure the knowledge.
- The possibility to separate the data from the models.
- The ability to deal with spatial data (incorporating GIS tools, for example).
- The ability to provide expert knowledge (incorporating specific knowledge bases).
- The ability to be used effectively for diagnosis, planning, management and optimization.
- The ability to assist the user during problem formulation and selecting the solution methods.

D. AGENT-BASED MODELLING (ABM)

A model is a description of a system, usually a simplified description less complex than the actual system, designed to help an observer to understand how it works and to predict its behavior. Typically, models could be divided into mechanistic models and empirical models. Mechanistic models analyses the system from its first principles (set of mathematical formulas and equations). Empirical models are based on direct observation, measurement and extensive data records with mathematical/statistical models (Multiple Linear Regression (MLR), Principal Component Analysis (PCA), Discriminant Analysis (DA), Logistic Regression (LR) and Statistical Clustering, among others) and artificial intelligence models (Association Rules (AR), Classification Rules (CR), Decision Tree (DT), Artificial Neural Networks (ANN), Case-Based Reasoning (CBR), Fuzzy Logic (FL), Evolutionary Computation (EC), Bayesian Networks (BN) and Conceptual Clustering (CC), among others). Since the 80s, both the former mathematical/statistical empirical models and the later machine learning empirical models have been named as data mining methods, because the models constructed are the result of a mining process among the data [133].

Multi-Agent Simulation models follow the paradigm of Agent-Based Modelling (ABM). Agent-based modelling has the advantage to be able to: model an explicit connection between the micro and the macro level of the phenomenon [64], design and comments of model-based planting plan, inference and decision based on expert knowledge, statistical and predictive analysis and competitive decision of cooperation network [159]. In this approach, systems are represented as collections of autonomous decision-making entities, called agents [96]. ABM captures emergent phenomena, provides a natural description of the complex systems and is flexible. The ability of ABM to deal with emergent phenomena is the main driving force behind its success as a complex adaptive system modelling tool.

Agent-based modelling have introduced both a powerful metaphor and a group of technologies in the field of

IEDSS, giving support to the management of environmental problems, mainly of those concerning the management of renewable resources (modelling land, crops [159] and other resources (irrigation of a field, effective usage of fertilization, nutrition) [89] [86] [64], biodiversity management, forest management, erosion and soil management, environmental sensor networks in field (detection, localization, classification, identification and tracking) [96], integrated pest management or even integrated crop management [95], labor and capital in this model, modelling agent heterogeneity, especially risk preferences of farmers [86], and the impacts on decision making [95],[130]). These problems represent typical dynamic and unpredictable multi-agent domains, where flexible autonomous action is required to adapt to changing conditions. Briefly, for modular, decentralized, changeable, ill-structured and complex system, software intelligent agents are really appropriate [9]. There are a number of approaches to represent decision-making in MAS models in the land-based sector but they can be divided in two categories: behavior heuristics and optimization [86].

1) Agent Based Modeling Software: According to FIPA (http://www.fipa.org) in its Agent Management Reference model, the agent platform is the environment where an agent can live and perform its tasks. Each platform has two default agents: Agent Management System (AMS) and Directory Facilitator (DF). The AMS contains the identifier and states of all agents that exist in the platform. The DF is the agent that provides the default yellow page service in the platform. The Message Transport System is the part of the software that control message exchanges between different agents [70].

According to the level of abstraction exist some levels: at the lowest level there are systems that use some agent-alike entities, in the second level the systems are modeled using agents (a model), typically involving UML design, the third level involves agents for software specification, that is the use of BDI, LORA or similar techniques and in the fourth level the systems adopt a sophisticated agent-oriented software design process as Gaia or Tropos [9].

Although there are many systems available for developing agent-based models, in this section reviews eight; because to their ability of integrate Geographical Information System Tools, as an important requirement in spatial-temporal modelling in the researches related with precision agriculture:

- **AGENT ANALYST** Compatible with ArcGIS Desktop 10 software.

- **REPAST SIMPHONY** Suite of tools. Integrate open source GIS, specifically GeoTools, and WorldWind 3D visualizer, GRASS and QGIS. Repast Simphony models can be developed in several different forms including the ReLogo dialect of Logo, point-and-click statecharts, Groovy, or Java, all of which can be fluidly interleaved.

- **GAMA** GAMA is a modeling and simulation development environment for building spatially explicit agent-based simulations. Multiple application domains : Use GAMA for whatever application domain you want. High-level and Intuitive Agent-based language : Write your models easily using GAML, a high-level and intuitive agent-based language. GIS and Data-Driven models : Instantiate agents from any dataset, including GIS data, and execute large-scale simulations (up to millions of agents). Declarative user interface : Declare interfaces supporting deep inspections on agents, user-controlled action panels, multi-layer 2D/3D displays and agent aspects.

- **SWARM**

- **MASON**

- **NETLOGO**

- **MESA: An Agent-Based Modeling Framework in Python**

- **AGENTBASE**

For develop agent based modelling software, we can generalize three process. The first step consist in software development using software agents, typically dealing with FIPA standards; using available agent platforms such as JADE, ZEUS, JACK; or using an own platform. The second step is the system's implementation phase or stage. The third step is the validation where is determined the degree to which a model or simulation is an accurate representation of real world from the perspective of the intended uses of the model or simulation [9].

V. MAS-IDSS Water Management Models - Review

Some solutions to the irrigation control problem use a combination of feed-forward, feedback and mathematical models, considering relevant variables in every part of the soil, plant and atmosphere relations [128]. Exist mathematical models to test automatic irrigation controllers in computer simulations prior to their use in field experiments. On the other hand exist agent based models for simulation and control of complex systems. In the following lines we expose a review of these models. The review is done from both agent-oriented software modeling and implementation perspectives.

DSSAT- Decision Support System for Agrotechnology Transfer [73], [76]. Is a software application program that comprises crop simulation models for over 42 crops. For DSSAT to be functional it is supported by data base management programs for soil, weather, and crop management and experimental data, and by utilities and application programs. The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics. DSSAT and its crop simulation models have been used for many applications ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change. For applications, DSSAT combines crop, soil, and weather data bases with crop models and application programs to simulate multi-year outcomes of crop management strategies. DSSAT integrates the effects of soil, crop phenotype, weather and management options.

CROPGRO [22] Was developed to simulate growth, development and yield of a common bean crop. It considers the main physical and physiological processes of plants, such as photosynthesis, respiration, biomass accumulation and partition, phenology, soil water extraction, evapotranspiration and common bean growth and leaf area development as functions of daily climatological elements (rainfall, solar radiation, maximum and minimum temperature), for the specific conditions of soil. Water storage in the soil and its capacity to supply the plant roots are predicted based on the processes of superficial runoff, water percolation and redistribution in the profile. The model is sensitive to the characteristics of each cultivation, sowing dates, crop spacing and irrigation management options.

WAVE - Water and Agrochemicals in the soil, crop and Vadose Environment [156] The mathematical model describes the transport and transformations of matter and energy in the soil, crop and vadose environment. The model is deterministic, by which is meant that one set of input data always yields the same model output values. The mode is numerical, since finite difference techniques were used for the solution of the differential equations describing matter and energy transport in the soil-crop continuum, is holistic and one-dimensional.

SPASMO - Soil Plant Atmosphere System [65] Is a solute transport model developed by HortResearch, New Zealand. The SPASMO computer model considers water, solute (e.g. nitrogen and phosphorus), and microbial (e.g. viruses and bacteria) transport through a 1-dimensional soil profile. The soil water balance is calculated by considering the inputs (rainfall and irrigation) and losses (plant uptake, evaporation, runoff and drainage) of water from the soil profile. The model includes components to predict the carbon, nitrogen and phosphorus budget of the soil. These components allow for a calculation of plant growth and uptake of both N and P, various exchange and transformation processes that occur in the soil and aerial environment.

WOFOST (World Food Studies) [42] Is a simulation model for the quantitative analysis of the growth and production of annual field crops. It is a mechanistic model that explains crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions. WOFOST is implemented in the Crop Growth Monitoring System which is used operationally to monitor arable crops in Europe and to make crop yield forecasts for the current growing season.

MACRO [91]. Is a one-dimensional model that considers non-steady state fluxes of water, heat and solute for a variably-saturated layered soil profile. MACRO is a dual-permeability model, whereby the total soil porosity is partitioned into two separate flow regions (micropores and macropores), each characterized by a degree of saturation, conductivity, water flow rate, solute concentration, and solute flux density. A full water balance is simulated, including treatments of precipitation (rainfall, irrigation and snow), evapotranspiration and root water uptake, deep seepage and horizontal fluxes to tile drains.

GIM - Global Irrigation model [45]. Using this model compute how long-term average irrigation requirements might change under the climatic conditions of the 2020s and the 2070s, as provided by two climate models, and relate these changes to the variations in irrigation requirements caused by long-term and inter annual climate variability in the 20th century. The model computes net and gross irrigation water requirements in all 0.5 by 0.5 raster cells with irrigated areas. ”Gross irrigation requirement” is the total amount of water that must be applied by irrigation such that evapotranspiration may occur at the potential rate and optimal crop productivity may be achieved [44].

AdaptPumpa [119] is an agent based model that captures the essential features of the Pumpa irrigation system in Nepal to study the performance under different projections of climate change in the region. In the simulations include social dynamics simulated (farmers decisions) and social-ecological interactions come from the farmers decisions based on the availability of the resource. AdaptPumpa adds to [33] model (differential equations) five features: i) agents capacity to make decisions and adapt their irrigation strategy to the external conditions of water availability, ii) a greater range of climate change scenarios, iii) resource uncertainty, iv) farmers coordination challenges under climate change, and v) the interlinked effects of the temporal shift, water discharge change and water distribution scenarios irrigation in Nepal, http://www.openabm.org/model/3580/version/1. AdaptPumpa uses ODD (overview, design concepts, and details) protocol for describing individual and agent based models.

CATCHSCAPE [15], [9]. Deals with the irrigation of northern Thailand, using agents for representing all entities related with the hydrologic basin. Agents incorporate models for the determination of aquatic reservoirs with respect to future changes in drought conditions and changes in commodity prices, and farmer behavior.

SINUSE [55], [9] employs agents to model the Kairouan water basin. SINUSE agent-based system investigates the consequences of human behavior in the availability of aquatic resources by simulating physical and socioeconomic interactions on a free access water table. SINUSE is considered as a rst step in the use of MASs for groundwater studies, and it has proved the relevance of taking local and non-economic interaction into account in the case of the Kairouan water table.

FIRMABAR [98], [9] (FIRMA stands for Freshwater Integrated Resource Management with Agents and BAR for Barcelona) is an agent-based simulator, within the FIRMA project, aimed at simulating urban water management [42]. Such simulator provides the policy makers with an additional tool to evaluate alternative water policies in dierent scenarios. The simulator plays the life of a set of families (agents) on a grid that represents the territory. The global behavior of the simulation emerges as a result of the interaction of the individual agents through time (nothing in the model species the global-level behavior of the system). The step time in simulations is the month, and there are four central processes computed at each time step.

MANGA [93], [9] is a discrete event simulator (a sequential process of unrelated events) [39]. The objective of MANGA is to show, over a number of years (12-year period), the evolution of a group of farmer agents with a limited water resource. In MANGA the authors demonstrate that agent-based modeling could help negotiations by showing the consequences of water allocation rules with respect to dierent criteria (e.g. the climate of the year, the irrigated area and the level of irrigation).

Control-MWS [9], [60]. (Agent-Based Control of a Municipal Water System) implements a water pollution monitoring system of a simplied municipal water system (i.e. a single water reservoir, a single tank, a pump station with only one electrical pump, pipes and valves). It monitors the level and quality of water basically in the tanks and pumping stations, as strategic points to set up control strategies [28]. The authors use a distributed control architecture based on automation controllers with an extended rmware that supports intelligent agents. The intelligence of the system is distributed among multiple controllers by placing individual or multiple agents inside the controllers. After setting up some control strategies, simulations are done to predict the results in water quality under these control strategies.

GRENSMAAS [153], [9] is a project that started in the 1990s. Within the scope of this project the researchers [84] presented an agent-based model to evaluate different river management alternatives developed within the previous phases of the project. This agent-based model is coupled with an integrated river model that describes the impacts of river management, such as ood risk, nature development and costs (related to gravel extractions). Thus, the main use of the agent-based model is to investigate stakeholder environment interaction by simulating changing perspectives and behavior in response to environmental change. The agents are endowed with quantitative goal standards to evaluate their goals. The beliefs of the agents are related to their uncertainty perspectives for evaluating a river management strategy.

DSS MAS-GIS [152] [9] (Decision Support System coupling Multi-Agent System and Geographical Information System) is a framework developed to manage water in the Mediterranean islands. The MAS-GIS platform makes possible for users to better understand the current operation of the system and the evolution of the situation, while simulating dierent scenarios according to the selected water policies (i.e. best consumer water policies) and the climatic changes hypothesis [83].

PALM [99], [9] (People And Landscape Model) was used to simulate seven strategies of crop nutrient management used within a community of households (the model simulates resource ows in rural subsistence communities). PALM runs on a daily time step using daily weather data as driving variables. The model uses objectoriented concepts with multiple instances of various sub-models being possible. Consequently, as an example, dierent crop models (or even the same one) can be run simultaneously in dierent elds with dierent parameters (e.g. planting dates, etc.) for each instance. Its structure and the use of Object Oriented Programming (OOP) and agents allows a high degree of modularity, and hence exibility ([51], [50]).

DANUBIA [13], [9] is a decision support system embedded in GLOWA-Danube project aimed at evaluating the sustainability of future water resources management alternatives, and to evaluate consequences of IPCC (Intergovernmental Panel on Climate Change) derived climate scenarios for the period from 2000 to 2100 [32]. DANUBIA is a coupled simulation system comprising 16 individual models [11]. To integrate the dierent simulation models DANUBIA makes use of objectoriented framework approaches. The agent-based approach, within the overall system, is used to model demography, water consumption and supply infrastructure, thus, to assess and simulate the socio-economic aspects of the water cycle (not the physical processes concerned with the water cycle). For that purpose a simulator -DEEPACTOR- was built providing a common conceptual and architectural basis for the modeling and implementation of the socio-economic simulation models in GLOWA-Danube [10].

WPMS [112] [9] (Water Pollution Monitoring System) is aimed at monitoring water quality for regulatory compliance. The water pollution monitoring system is comprised of several sites/stations in which the water quality is monitored, and when the measurements of certain parameters are exceeded, a warning is sent to the supervisor system. As the sites are geographically distributed, they are modeled in a natural way as intelligent agents that communicate with a supervisor agent who receive corresponding messages from the sites. A prototype has been designed for future implementation [60]. The system can also be used to facilitate response to contamination incidents.

SIMULAIT WATER [121], [9] was used to analyze urban water trading and water saving incentives among households of differing demographic types. Each agent can mimic the behavior of individual elements (e.g. households) in a system, as well as their interactions (e.g. negotiations among households). In this case, agents model individual households and their purchasing and water consumption behaviors [64].

LUDAS citele2008land, [92],[9] (Land-Use Dynamic Simulator) is a multi-agent system to simulate spatio-temporal dynamics of coupled human-landscape system [38]. The system is aimed at explore alternative scenarios to improve livelihoods and mitigate negative impact of land-use changes, thereby supporting the negotiation process among various stakeholders in land-use planning. Human population and the landscape environment are all self-organized interactive agents that are called upon to perform tasks in parallel (i.e. synchronizing actions). The framework provides a platform where many techniques already developed in spatial modeling can be integrated. For instance, the authors nested the bounded-rational decision mechanism (e.g. the maximization of parameterized utility functions) with the reex mechanism (set of reex rules) to represent the decision making mechanisms of farming households about land use.

A comprehensive model [67] was developed for define distributed crop water requirements with surface and groundwater mass balance. The proposed modeling scheme combine hydrological, hydro-geological and management components, which control the conjunctive exploitation of surface and groundwater resources in intensively irrigated areas. It is composed by four modules that simulate at monthly scale: a) the inflow to the surface reservoir (SPI-Q regression model); b) the distributed soil water balance GMAT (Monthly Soil water balance); c) the reservoir water balance; and d) the ground- water balance.

BewUe (Bewässerung Uelzen. Irrigation Uelzen [125]. By linking soil water holding capacities, crop management data and calculations of evapotranspiration and precipitation from the climate change scenario RCP 8.5 irrigation requirements for maintaining crop productivity were estimated for the years 1991 to 2070. To assess the difference between evapotranspiration of grassland and the particular crop species, a comparison with a WASMOD (Water and Substance Simulation Model) simulation output for the particular crop species and grassland was conducted. The results show, that regional implications of global climate change will likely affect evapotranspiration as an important aspect in crop cultivation and as the most important influence for irrigation requirement.

SWAP (Soil - Water - Atmosphere - Plant system) [40]. A mechanistic model of the water flow in the Soil-Water-Atmosphere-Plant system was used to describe the soil hydrological conditions in response to climate and irrigation. The SWAP model applies daily crop potential evapotranspiration (ET_p), daily precipitation and irrigation to prescribe the upper boundary condition. ET_p is calculated from reference evapotranspiration (ET_o) and a crop factor. Reference evapotranspiration (ET_o) was estimated, for the reference and future climate case, from daily time series of air temperature by means of the Hargreaves and Samani method [69]. The HS model is a simplified method which requires solely air temperature data. Crop water use was simulated by the simple crop module option in SWAP which prescribes crop development. Numerical experiments were performed for an exemplary tomato cultivar and defined by a temporal profile of leaf area index (LAI), rooting depth and crop factor. Several experimental and literature data sets were examined in order to describe the phenology of the exemplary cultivar. In the study they simulated five different irrigation strategies given optimal irrigation water depths, timed and calculated on the basis of soil water deficit in the root zone.

AEZ (Agro-ecological Zoning) [57] The AEZ model uses detailed agronomic-based procedures to simulate land resources availability and use, farm-level management options, and crop production potentials as a function of climate, soil, and terrain conditions. At the same time, it employs detailed spatial biophysical and socio-economic datasets to distribute its computations at fine-grid intervals over the entire globe. The simulation results shows first, globally the impacts of climate change on increasing irrigation water requirements could be nearly as large as the changes projected from socio-economic development in this century. For this work, AEZ was used to compute water movement through the soil plant atmosphere continuum, to assess net crop irrigation water requirements (WRQ). The WRQ is defined herein as the amount of water in addition to available soil moisture from precipitation that crop plants on irrigated land must receive to grow without water stress.

MAPIS Multi-agent precision irrigation simulation [64] Presents possibilities of optimizing irrigation on the basis of two simulation approaches. In the first simulation approach a multi-agent-based tool calculates soil specific and corresponding water tensions by using pedotransfer functions. This makes possible a quantification of the need for irrigation and the control of the irrigation system. By integrating the physical concept of soil water potentials, temporal and spatial soil water fluxes are used to schedule dynamic and precision trickle-irrigation. The second simulation approach calculates a field-irrigation with simultaneous consideration of the horizontal variability of soil properties. The irrigation is carried out in a site-specific way with high precision. Both approaches show that precision and soil specific irrigation is accompanied by a significant reduction of irrigation water and an improvement of irrigation efficiency. Finally, the model calculates an irrigation plan to ensure a water application which is efficient and meets the demands. Thus the irrigation does not happen intermittently but in a continuous and dynamic way. This means that the amount of the water applied during the irrigation process is subject to controlled dynamic fluctuations.

Adaptive scheduling in deficit irrigation [72] A simple and practical real-time control system is proposed using a model-data fusion approach, which integrates information from soil water representation models and heterogeneous sensor data sources. The system uses real-time soil moisture measurements provided by an in situ sensor network to generate site-specific soil water retention curves. This information is then used to predict the rate of soil drying. The decision to irrigate is made when soil water content drops below a predefined threshold and when the probability of rainfall is low. A deficit strategy can be incorporated by lowering the irrigation refill point and setting the fill amount to a proportion of field capacity. Computer simulations show how significant water savings can be achieved through improved utilization of rainfall water by plants, spatially targeted irrigation application, and precision timing through adaptive control.

AMEIM - Agent-based Middleware for Environmental Information Management [8] Is an multi-agent application to manage environmental data for better accessibility as users. AMEIM uses four generic agent types: Contribution Agents, Data Management Agents, Distribution Agents and the Graphical User Interface Agent, which interacts with the platform administrator and orchestrates the platform agents. Direct users are the environmental scientists, the platform administrators and the computer scientists/developers. Indirect users include the government, the industry and the public. The designed MAS is able to capture data from several external sources and to validate the incoming data.

Multi-agent, Machine Learning for Soil Textural Composition [142] Is an approach to automating soil texture classification from in situ sensors in the field. This approach exploits the features of a soil water retention model using machine learning algorithms. Knowledge of the soil textures is then used to learn the composition of the field and its soil horizons. They discuss the role of soil texture classification within their multi-agent irrigation control system and then conduct a preliminary experiment with soil water retention data from the UNSODA database. The system is evaluated with respect to six classifiers. A maximum classification rate of 85.11% was achieved with a MLP neural network, although performance was relatively consistent across all classifiers. A multiagent platform has been proposed to control deficit irrigation using a wireless sensor network Within our proposed multiagent framework, the field was represented by three dimensional soil cube agents, each associated with a soil moisture potential sensor. Plant agents are also used to represent the water demand of crops by exploiting measurements of ET, crop stress status and the crop wilting point.

IEDSS - Interoperable Intelligent Environmental Decision Support Systems [133]. The framework is based upon the cognitive-oriented approach for the development of IEDSS, where three kind of tasks must be built: analysis tasks, synthesis tasks and prognosis tasks. Now, a fourth level will be proposed: the model construction layer, which is normally an off-line task. At each level, interoperability should be possible and inter-level interoperability must be also achieved. This interoperability is proposed to be obtained using data interchange protocols like Predictive Model Markup Language (PMML), which is a model interchange protocol based on XML language, using an ontology of data and AI models to characterize data types and AI models and to set-up a common terminology, and using workflows of the whole interoperation scheme. In the future, a Multi-Agent System will be used to implement the software components. An example of use of the proposed methodology applied to the supervision of a Wastewater Treatment Plant is provided. This Interoperable IEDSS framework will be the first step to an actual interoperability of AI models which will make IEDSS more reliable and accurate to solve complex environmental problems.

SHADOC [11], [12], [9]. Development of a multi-agent system model, a kind of virtual irrigated system, with a special focus on rules in use for access to credit, water allocation and cropping season assessment as well as organization and coordination of farmers. In Senegal River Valley, water first pumped in the river and then running by gravity, different actors acting on the environment. These actors, individuals or groups, are interconnected through membership and service relations. They are also, at their own level, in relation with other actors outside the system. This network of relations at different levels inside and across the boundary is the sign of a complex structure. This is hence a simulator of irrigated systems which specifically tackles the organization and coordination of farmers in a varying framework of collective rules. Neither individually based nor collectively constrained, both organization levels coexist and co-evolve. It is a good basis to explore different scenarios of individual behaviors and collective rules, thus allowing learning by simulating rather than learning by doing which has been over-practiced in the field of irrigation development. This model constitutes a virtual irrigated system which can already be used as a tool to test hypotheses of social organizations and institutions. This is still a theoretical simulator somewhat specific to the Senegal River Valley even though it has been designed to be able to deal with other contexts.

The SHADOC system (French acronym for Hydro-agricultural Simulator describing Organization and Coordination Modes) uses agents for simulating the behavior of the stakeholders and the farmers involved in the irrigation of Senegal valley. The model constitutes a virtual irrigated system which can already be used as a tool to test hypotheses of social organizations and institutions. This is still a theoretical simulator somewhat specic to the Senegal River Valley even though it has been designed to be able to deal with other contexts.

DSS-FS: A Decision Support System - Fertigation Simulator[10] Irrigation combined with fertigation has produced unquestionable results for the last few decades. It is a rather complicated process as many factors must be controlled in order to produce good and environmentally safe fertigation practices. The efficiency and uniformity of irrigation, as well as the balance of the nutritive solution used to irrigate are highly ruled by the complex and diverse information (weather, soil, water, and crop data). The DSS-FS system is intended to support design and optimization of irrigation and fertigation systems while increasing their environmental sustainability. The data set to be processed is stored in the DSS database and can be continuously updated according to new development results. Afterwards, the user might handle the input data through a basic and user-friendly interface while allowing the DSS-FS to retrieve default scenarios and thereby reducing the systems users need for advanced knowledge. An advanced mode of DSS-FS, which adds an increased level of precision in exchange for human support, includes soil sample analysis and other relevant information. The DSS-FS consists of three main modules available to the user: Irrimanager, Irrisystem and Fertigation.

MAS-CA multi-agent/cellular automata approach [19] MAS-CA is a spatial multi-agent programming model, which has been developed for assessing policy options in the diffusion of innovations and resource use changes. Unlike conventional simulation tools used in agricultural economics, the model class described here applies a multi-agent/cellular automata (CA) approach by using heterogeneous farm-household models and capturing their social and spatial interactions explicitly. The individual choice of the farm-household among available production, consumption, investment and marketing alternatives is represented in recursive linear programming models. Adoption constraints are introduced in form of network-threshold values that reflect the cumulative effects of experience and observation of experience of peers. The economic model and hydrologic components are tightly connected into a spatial framework. The integration of economic and hydrologic processes facilitates the consideration of feedback effects in the use of water for irrigation. The simulation runs of the model are carried out with an empirical data set, which has been derived from various data sources on an agricultural region in Chile. Simulation results show that agent-based spatial modeling constitutes a powerful approach to better understanding processes of innovation and resource use change.

MUSA - Multiagent Simulation for consequential LCA of Agrosystems [124] Is a ABM for simulation of incentives for maize to produce biofuels in Luxembourg with an aim to conduct life cycle assessment of the additional maize and the consequent displacement of other crops in Luxembourg. On the supply side they have farmers who are willing to sell their produce based on their actual incurred costs and an expected markup over costs. On the demand side, they have buyers or middlemen who are responsible for quoting prices and buying the output based on their expectation of the market price and quantity. They have N buyers who participate in the market over R rounds. Each buyer has a correct expectation of the total number of buyers in each market. At each round, the farmers are sorted by descending order of price quotes and the highest bidder gets buying priority. At the end of each round, the clearance prices are visible to all agents and the agents have an option of modifying their bids in the forthcoming rounds.

FIRMA - Freshwater Integrated Resource Management with Agents [102], [14],[9]. Prototype model integrating representations of both natural and social systems and developed in collaboration with stakeholders. The model integrates a hydrological model parameterized to represent the effects of precipitation and temperature on water availability in the Thames region of southern England (including Oxford, London and the Southeast) with a model of demand for water by households. This model integrate assessment and social simulation communities and it was developed as a key step in the demonstration of a new methodological approach. This approach rests on stakeholder participation in the model design and validation stages together with a compositional validation procedure. The participation of stakeholders is essential because the role of models in this methodological approach is to explicate and articulate presumptions of decision-makers in their formulation of expectations of the outcomes of their decisions. Applies agent-based modeling for the integration of natural, hydrologic, social and economic aspects of freshwater management. A variety of agent-based models has been developed for simulating consumers, suppliers, and government, and their interactions at dierent scale of aggregation. One of the FIRMA test cases has been applied on the Thames River to explore the eects of precipitation and temperature on water availability and household demand. In this case, water consumer agents communicate with each other, sharing perspectives in the form of endorsement.

ABM - GIM. Agent based modeling for the gravity irrigation management [17], [16]. Use agent technology in the field of gravity irrigation systems because the complexity to manage in real-time the water distribution operations those arrive asynchronously and dynamically and to be reactive and adaptive to the dynamic and unpredictable events that characterizes the field (mainly rainy advents). An important aim is the irrigations scheduling optimization using an evolutionary algorithm. Currently, the gravity irrigation systems networks have several limits and cause water loss. An efficient management of these irrigation systems is mainly characterized by a better water resources allocation among the various actors which therefore becomes necessary. However, this allocation is subject to several constraints: the fixed water resources, the crop, sewing, soil, climate data, and real needs of water. Uses (MSGIN) using multi-agent framework, particularly specialized agents by deploying the cooperation techniques, negotiation and planning, in order to allow the system managing and satisfying the requests for each culture and to react in real-time to the unpredictable events which can occur during the achievement of these requests.

MAS - Garden Irrigation [79] knowledge-based and distributed framework that simulates the behavior of an irrigation system and permits accurate determination of irrigation timing. Several agents, which represent the actors involved in this problem, coordinate their activities in order to evaluate different irrigation strategies. A common ontology shares the knowledge required in the agent-based framework, which can be tuned according to the particular circumstances of the field. The usefulness of the developed system is demonstrated in three case studies, in which the simulations performed by the system provide the answer to different questions (length of irrigation time, comparison of a fixed and a dynamic irrigation policy, and most efficient configuration of a garden). The system simulates the behavior of the irrigation system for the possible solutions and finds the most efficient one in terms of water consumption.

RMAS - Robot multi-agents system [118] This paper is monographic review of precision agriculture methods application with main direction of possible usage of multiagent systems. Multiagent systems usage in precision agriculture field offers many opportunities: it can decrease machinery weight and dimensions, can increase one type machinery count on the field etc. When multiagents are used it is possible to redistribute whole big agricultural task into smaller parts for it faster completion, upgrade precision agriculture machinery function from automatic to autonomous job performance. One main function of multiagent system is to monitor all agricultural fields by using subfield areas, where farmer can identify specific parameters of each area and implement management practices according to the area needs. These many agent systems are viewed like multirobot system with own decision making, real time planning and autonomous work performance. Additional feature is that each unit is independent, but it is collaborating with other units on the field to reach the total aim of the task. collaboration among units can be reached without human assistance.

ABSTRACT - Agent Based Simulation Tool for Resource Allocation in a Catchment [155], [154]. A multiagent simulation (MAS) approach is developed for representing the processes responsible for the distribution of water availability over space and time to spatial planning in a semi-arid river basin. A MAS model has been developed to represent local water use of farmers that both respond to and modify the spatial and temporal distribution of water resources in a river basin. The MAS approach is tested for the Jaguaribe basin in semi-arid Northeast Brazil. Model validity and required data for representing system dynamics are discussed. For the Jaguaribe basin both positive and negative correlations between water availability and water use have been encountered. It was found that increasing wet season water use in times of drought amplify water stress in the following dry season.

MAS - Water Pollution Monitoring Systems[113]. Design of a multi-agent system for water quality monitoring and control. The MAS paradigm solution has been found to be appropriate for this problem. The MAS architecture and methodology has been briefly described. The model is being developed and applied in a collaborative research and learning framework, which includes local water user organizations, state and local agencies, as well as research organizations. This system can be easily adapted to a different type of application or in conjunction with it, for example that of monitoring of water supply infrastructure system. In this case the parameters being monitored could include, lead concentration in water (or other chemical component of the pipe system being used), pressure, temperature, other dynamic parameters. The check monitoring at the tap compared to the monitoring at the source would produce data concerning the state of the water distribution lines and the eventual need for maintenance or upgrade of the water distribution system.

KatAWARE[51]. Multi-Agent system (MAS) developed and used following a participatory action research approach called Companion Modeling (ComMod). Participation in the decision-making process by all involved stakeholders is a crucial principle of Integrated Water Resource Management (IWRM). This methodology is composed of four steps: (1) the specification of the structure of the system, its dynamics and the indicators one wants to monitor, (2) the description of the initial state of the simulation, (3) the implementation of the model which can take the form of a computer program or of a role-playing game, (4) the reflection step to criticize the model and to propose further improvements. For the first two steps, they use a representation based on the Unified Modeling Language. An integral part of the participatory process was the development of a negotiation-support tool to enable the local water management institution, i.e., the Kat River Water User Association (KRWUA), to discuss future scenarios related to possible water allocations among the different sectors in the catchment, and the consequences of these scenarios in terms of economic, social and environmental outcomes.

ABM - Water Quality Control [107]. Describes an early stage of development of a multi agent system for water pollution monitoring and control. The multi-agent system can be used for real-time monitoring of water quality for regulatory compliance with national and European legislation regarding national drinking water quality. This is a first step in the implementation of a multi-agent system which takes itself decisions, not only provides advice to human decision-makers.

NED-2 [109], [9]. NED-2 is a robust, intelligent, goal - driven decision support system that integrates tools in each of these categories. NED-2 uses a blackboard architecture and a set of semi-autonomous agents to manage these tools for the user. The blackboard integrates a Microsoft Access database and Prolog clauses, and the agents are implemented in Prolog. A graphical user interface written in Visual C ++ provides powerful inventory analysis tools, dialogs for selecting timber, water, ecological, wildlife, and visual goals, and dialogs for defining treatments and building prescriptive management plans. Users can simulate management plans and perform goal analysis on different views of the management unit, where a view is determined by a management plan and a point in time. Prolog agents use growth and yield models to simulate management plans, perform goal analyses on user-specified views of the management unit, display results of plan simulation using GIS tools, and generate hypertext documents containing the results of such analysis. Individual agents use metaknowledge to set up and run external simulation models, to load rule-based models and perform inference, to set up and execute external GIS and visualization systems, and to generate hypertext reports as needed, relieving the user from performing all these tasks.

MAS-CHNs-WEB [75]. Watersheds are modeled as coupled human and natural systems (CHNSs) by coupling a multi-agent system (MAS) model and an environmental model. Multithreaded programming is used to improve the computational efficiency. As a result, the total running time of the coupled models is reduced by 80%, from one hour for a sequential run to twelve minutes with an eight-core desktop machine, running the model in parallel. To make the coupled models publicly accessible, a web-based application of the coupled models is implemented in the Hadoop-based cloud computing environment, which allows users to access and execute the model simultaneously without an increase in latency. This study presents a case of cyberinfrastructure design for complex watershed management problems, especially to parallelize computational models and provide model accessibility with user scalability.

CORMAS-OLYMPE [21]. Coupled between farming system modelling software (OLYMPE) and agent-based simulation platform (CORMAS) to better characterize and analyse farming systems identified as major centres of decision in agriculture. CORMAS enables representation of complex situations and takes into account interactions between different stakeholders. They describe the development process and they illustrate how the new platform can be used with a simple example developed for educational purposes. This model is used as a tool to support decision making processes and communication and provides an economic synopsis of the complexity of farming systems.

CARISMA [115]. The combination of certain technologies, leads to the integration of inference engines in the MultiAgent System. This combination is intended to provide the agents with the individual and collective intelligence necessary to resolve problems common to the entire system. The system has been developed within the so-called cARISMA Project: MultiAgent System for Remote Control of Solar Photovoltaic Power Plants. The objective is to control and monitor solar panel farms: in an automated way whenever possible and, the cases when it is not possible, to provide human telecontrol operators with control recommendations. To this end, small hardware devices are distributed with associated sensors and actuators in various areas of a solar farm in order to do this. This MultiAgent System employs the set of devices in order either to make decisions of automated control or to send recommendations to technicians of the solar plant based on the data and knowledge available.

DSS-PICO [120]. DSS to be used by technicians of the advisory service performing pest management according to an integrated production approach. Designing this type of system requires analyzing two main dimensions of complexity basically: the organizational dimension dealing with all the dependencies between the domain stakeholders, and the technical dimension concerning the study of natural plant protection techniques. The methodology, called Tropos, plays a central role in early requirement analysis and allows deriving a systems functional and non-functional requirements from a deep understanding of the domain stakeholders goals and of their dependencies. The architecture includes a set of software components (agents) that wrap existing information systems and interact with agents by providing.

DAWN [7], [9]. To support policy makers in their decisions, the authors have developed DAWN, a hybrid model for evaluating water-pricing policies. DAWN integrates an agent-based social model for the consumer with conventional econometric models and simulates the residential water demand-supply chain, enabling the evaluation of different scenarios for policy making. An agent community is assigned to behave as water consumers, while econometric and social models are incorporated into them for estimating water consumption. DAWNs main advantage is that it supports social interaction between consumers, through an influence diffusion mechanism, implemented via inter-agent communication. Parameters affecting water consumption and associated with consumers social behavior can be simulated with DAWN. Real-world results of DAWNs application for the evaluation of five water pricing policies in Thessaloniki, Greece. DAWN (Hybrid Agent-Based Model for Estimating Residential Water Demand) is a simulator that integrates an agent-based social model for the consumer with conventional econometric models. It simulates the residential water demandsupply chain and thus, enables the evaluation of dierent scenarios for policy making. It was used to evaluate ve dierent water-pricing policies for the period 2004-2010 in the metropolitan area of Thessaloniki [5]. Its main advantage is that it supports social interaction between consumers, through an inuence diffusion mechanism, implemented via inter-agent communication (JADE and FIPA specications).

Control Greenhouse - MAS [84]. The design of a multi-agent system for integrated management of greenhouse production is described. The model supports the integrated greenhouse production, with targets set to quality and quantity of produce with the minimum possible cost in resources and environmental consequences. Real time and robust system for monitoring and control of the greenhouse condition is proposed, which can automatically control of greenhouse temperature, lights, humidity, CO2 concentration, sunshine, pH, salinity, water available, soil temperature and soil nutrient for efficient production. In this regards wireless sensor networks play a vital role to monitor greenhouse and environment parameters. Each control process of the greenhouse environment is modeled as an autonomous agent with its own inputs, outputs and its own interactions with the other agents. Each agent acts autonomously, as it knows a priori the desired environmental set points. The developed system is simple, cost effective, and easily installable.

Mushroom Mechanization - MAS [38]. Presents a new methodology for mechanization of mushroom cultivation which can be applied to other agricultural products, The aim of this methodology is to increase efficiency, speed, accuracy and to decrease cost, the recent approaches in developing decision support systems for agriculture, and more generally for environmental problems management. They are using a multi-agent system to parallelize most of mechanization steps which can considerably increase the speed and efficiency of cultivation or production.

Irrigation System - MAS [131]. They present a smart irrigation system based on multi-agent architecture using fuzzy logic. The architecture incorporates different types of intelligent agents that an autonomous way monitor and are responsible for deciding if required enable / disable the irrigation system. This project proposes a real and innovative solution to the problem of inadequate water use with current irrigation systems employed in agricultural projects.

Irrinet- FDSS [61]. This study improves an existing irrigation web service, based on the IRRINET model, by describing a protocol for the eld implementation of a fully automated irrigation system. They demonstrate a Fuzzy Decision Support System to improve the irrigation, given the information on the crop and site characteristics. It combines a predictive model of soil moisture and an inference system computing the most appropriate irrigation action to keep this above a prescribed safe level. Three crops were used for testing the system: corn, kiwi, and potato. This Fuzzy Decision Support System (FDSS) favourably compared with an existing agricultural model and data-base (IRRINET). The sensitivity of the FDSS was tested with random rainfall and also in this extended case the water saving was confirmed.

Wide Area Monitoring - MAS [160]. Long-range monitoring system of irrigated area water that is operated very good, can improve the utilization efficiency of irrigating water resources, to economize irrigate water consumption greatly. They introduces Multi-Agent theories in the long-range monitoring system of irrigated area, has set up a kind of long-range monitoring system of irrigated area based on Multi-Agent, this system is formed by control center Multi-Agent subsystems, the communication layer that is formed by communication Agent and GSM communication network, and some monitoring station Multi-Agent subsystems. The control center Multi-Agent subsystems and monitoring station Multi-Agent subsystems realize the long-range control of the irrigated area through the information transmission of communication layer. Through emulation test, the system run well.

IMAS-GH [53]. The design of an intelligent multilayer multi-agent system for integrated management of greenhouse production is described. The model supports the integrated greenhouse production, with targets set to quality and quantity of produce with the minimum possible cost in resources and environmental consequences. The main goal is the Integrated Crop Management (ICM) of root-zone and aerial environment of the cultivated plants, through the cooperative actions of software agents, which bargain at the supervisory level. The conventional management systems have the drawbacks of being based on low level, static, user-defined goals, as they do not take into account the interactions between processes or they do it either in the LQG domain or in a non-systematic ad-hoc way. The poor performance when existing conditions lead to conflicting decisions of the control system, or irrational use of the resources can be drastically improved by the ability of the IMAS-GH system to allow humanwise perception and decision processes in an easily reconfigurable environment. The system evolves by means of accumulated knowledge as tools are endowed for agents experience or research results or growers experience.

ESAT-WMR [39], [9] (Expert System and Agent Technology to Water Mains Rehabilitation), the agent-based decision support tool reported intents to support a U.K. water company in its water mains rehabilitation decision making processes. A community of collaborative agents models the tasks and interactions of the water company and its associates, and, ultimately, assesses alternative strategies for the pipes network rehabilitation.

EDEN-IW [52],[9].(Environmental Data Exchange Network for Inland Water) is a system that aims to provide citizens, researchers and other users with existing inland water data, acting as a one-stopshop. EDEN-IW exploits the technological infrastructure of Infosleuth system, in which software agents execute data management activities and interpret user queries on a set of distributed and heterogeneous databases. Also, InfoSleuth agents collaborate for retrieving data and homogenizing queries, using a common ontology that describes the application eld. EDEN pilot demonstration enables integrated access via web browser to environmental information resources provided by oces of the connected agencies. The demonstration focuses on information relating to remediation of hazardous waste contamination.

WaWAT [31], [9]. WaWAT (WasteWater Agent Town) employs several co-operative agents who make use of case-base reasoning, rule-based reasoning and reactive planning, to support supervision and control of wastewater treatment plants [18]. It uses the WaWO ontology (Waste Water Ontology) [19] which provides a set of concepts that can be queried, advertised and used to control agent cooperation.

Adour, [147], [9]. Is a bargaining model to simulate negotiations between water users in a river basin [81]. A formal computable bargaining model of multilateral negotiations is applied to the Adour Basin case, in the South West of France, with seven agents (three farmers, two environmental lobbies, the water manager, the taxpayer) and seven negotiation variables (three individual irrigation quotas, the price of water, the sizes of three dams), in order to negotiate alternatives of water use. A sensibility analysis is conducted to quantify the impact of the negotiation structure (e.g. political weights of players, choice of players...) on simulations outcomes. The nal aim is to provide a better understanding of the complex interrelations between the various components of the modeled system: preferences of stakeholders over negotiated variables, the role of exogenous (i.e. hydraulic and budgetary) constraints in the bargaining game, the consequences of the structure of negotiation (e.g. decision rule, players weights, dimension of the issue space etc.) on the bargaining outcome etc.

TABLE I
SUMMARY OF REVIEW SYSTEM

Acronym	Main Task and Objectives	Application	Related Technologies	Agents (Types)
1. WOFOST (World Food Studies) - 1989 [42]	Simulation model for the quantitative analysis of the growth and production of annual field crops	Calculate attainable crop production, biomass, water use, etc. for a location given knowledge about soil type, crop type, weather data and crop management factors	dimensionless state variable development stage (DVS), PyWOFOST has been continued as part of the Python Crop Simulation Environment (PCSE) , CABO (weather format)	No Agent Based Model
2. WAVE - Water and Agrochemicals in the soil, crop and Vadose Environment - 1994 [156]	describes the transport and transformations of matter and energy in the soil, crop and vadose environment	Global	MS-FORTRAN 5.10, SWATRER model, SOILN-model (nitrogen model), LEACHN(solute transport model), SUCROS (Universal Crop Growth model)	No Agent Based Model
3. CROPGRO - 1998 [22]	simulate growth, development and yield of a common bean crop	It computes canopy photosynthesis at hourly time steps using leaf-level photosynthesis parameters and hedge-row light interception calculations	SOYGRO (soybean crop growth simulation model), PNUTGRO (Peanut Crop Growth Simulation Model), and BEANGRO (A Process-Oriented Dry Bean Model with a Versatile User Interface). FORTRAN	No Agent Based Model
4. SHADOC - 2000 [11], [12], [9]	A multi-agent model to tackle viability of irrigated systems	Simulate viability of irrigated systems in the Senegal River Valley	Gravity irrigated system, Object-modeling technique OMT, Implemented in SmallTalk language under VisualWorks environment, Petri Nets	Farmers with attributes: waterAllocation among farmer agents with their plot attribute along the same Watercourse instance, pumpStation management, creditAccess, production, food, land, waitingBetter.
5. ESAT-WMR - 2000 [39], [9]	Modeling and analysis of elective strategies for urban water supply pipe network rehabilitation	Water supply networks	KIF, KQML, Object-oriented programming	Interface agent, Heuristics agent, Information agent, Data mining agent, Database agent, Constraint Agent, Predictor Agent, HotSpot Agent.
6. FIRMA - Freshwater Integrated Resource Management with Agents - 2000 [102], [14],[9]	Agent Based Social Simulation Model of Water Demand Policy and Response	The model integrates a hydrological model parameterized to represent the effects of precipitation and temperature on water availability in the Thames region of southern England (including Oxford, London and the Southeast) with a model of demand for water by households	SDML: A Multi-Agent Language for Organizational Modelling, potential evapotranspiration (PET), decision-making process is the endorsements mechanism, ABSS.	thamesWorld agent, thamesGround agent and firmaModel agent, PolicyAgent, citoyen agents.
7. WaWAT - 2001 [31], [9]	A multi-agent cooperation infrastructure for supervision and decision-making in wastewater treatment plants	Wastewater treatment plants	Ontolingua KSL Server	Dynamic entities (monitoring, modeling, actuator, predictive agents, etc.)
8. Adour - 2001 [147], [9]	Stakeholder negotiation over water use	Water manage- ment	BDI	Farmers, environmental lobbies, water manager, taxpayer
9. MAS-CA multi-agent/cellular automata approach - 2001 [19]	Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis	The applicability of the model is tested on an empirical policy-related research question in Chile	Spatial cellular automata model, Geographic information systems (GIS), ASCII-text, C ++ object-oriented programming language	Farm-agents
10. SPASMO - Soil Plant Atmosphere System - 2002 [65]	Physically-based dynamic generic plant growth and nutrient leaching model	Soil-plant-animal. Estimation of irrigation requirements, leaching (N, pesticides) from paddocks	Fortran, Graphical Desktop Command Line, Output database used in CLUES	No Agent Based Model

TABLE II

SUMMARY OF REVIEW SYSTEM (CONTINUATION)

Acronym	Main Task and Objectives	Application	Related Technologies	Agents (Types)
11. GIM - Global Irrigation model - 2002 [45]	Impact of climate change on computed net irrigation	Global	General Circulation Models (GCMs) to compute the change of IR under doubled CO_2 conditions, Global Irrigation Model (GIM) that is a module of WaterGAP (Global modeling of water resources and water use), Crop coefficient k_c, USDA Soil Conservation Method, CROPWAT (Calculation of crop water requirements and irrigation requirements based on soil, climate and crop data), ECHAM (Atmospheric general circulation model), HadCM3 (Coupled atmosphere-ocean general circulation model)	No Agent Based Model
12. CATCH-SCAPE - 2003 [15], [9]	Simulation of the whole catchment features as well as farmers individual decisions	Water catchment management	UML, SmallTalk, Object-oriented programming, CORMAS	Crop, Farmer, Canal, Weir, Canal Manager, River
13. SINUSE - 2003 [55], [9]	physical and socio-economic interactions modelling for simulating demand management negotiations on a free access water table	Integrated management of a water table	UML, SmallTalk, Object-oriented programming	Plot, Water table, Farmer
14. EDEN-IW - 2003 [52],[9]	Data integration and homogeneous access provision services	Water resources data	JADE, FIPA-ACL, SQL, RDF, OKBC	DB resource agent, query decomposition agent, ontology agent, broker agent
15. MACRO [?]	a model of water flow and solute transport in macroporous soil	Synthesize current understanding of flow and transport processes in structured soils	Penman - Monteith combination equation, Crank-Nicholson difference scheme	No Agent Based Model
16. DSSAT-Decision Support System for Agrotechnology Transfer - 2004 [73], [76]	Models of 42 different crops with software that facilitates the evaluation and application of the crop models for different purposes	Simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics	CSM (cropping system model design), CERES models for maize and wheat), SOYGRO (soybean crop growth simulation model), PNUTGRO (Peanut Crop Growth Simulation Model), CROPGRO	No Agent Based Model
17. DSS-PICO - 2004 [120]	Decision support systems (DSS) based in MAS	DSS to be used by technicians of the advisory service performing pest management according to an integrated production approach.	Tropos, UML, GIS	Producer Agent, Advisor Agent, Local Government Agent, Plant Disease Agent, GISP agent (Geographic Information Service), BDL agent (Disease Behavior Learner), Wrapper agents, Interface agent. The PICO project [9] adopts agent-based requirement analysis for a decision support system in the eld of integrated production in agriculture. This work focuses on design issues, using Tropos methodology [29] and continuing their developments using software agents.
18. NED-2 - 2004 [109],[9]	Intelligent Information System designed to provide decision support for forest ecological system management in the eastern United States.	Powerful inventory, analysis tools, dialogs for selecting timber, water, ecological, wildlife, and visual goals, and dialogs for defining treatments and building prescriptive management plans	Backboard - Central organizing principle, Attribute Object Value (AOV), C ++, GIS display, Fuzzy rule set, HTML, metaknowledge,	Treatment definition agent, Simulation agent, Goal analysis planning agent, Timber goal analysis agent, Wildlife goal analysis agent, Water goal analysis agent, Visual goal analysis agent, Ecology goal analysis agent GIS agent, Report generation agents.
19. IMAS-GH - 2004 [53]	Intelligent multilayer multi-agent system (IMAS) for integrated management of greenhouse production	Integrated Crop Management (ICM) of root-zone and aerial environment of the cultivated plants, through the cooperative actions of software agents	Fuzzy expert rules, Goals and Beliefs, Greenhouse Abstraction Layer (GAL), Knowledge Representation Layer (KRL), Tropos	Mechanical Agent, Environmental Agent, User Interface Agent, Crop Agent, Greenhouse History Agent, Good Agricultural Practices Agent, Pest Diseases Deficiencies Agent

TABLE III
SUMMARY OF REVIEW SYSTEM (CONTINUATION)

Acronym	Main Task and Objectives	Application	Related Technologies	Agents (Types)
20. AMEIM - Agent-based Middleware for Environmental Information Management - 2005 [8]	Environmental data management tasks	Middleware to support the capturing of environmental information and to present the data in the desired way so that the direct user can implement all kind of transformations and use all kind of data through the function classes	Environmental Information Systems (EIS), Agent Object Relationship Modeling Language (AORML), Java Agent Development Environment (JADE), FIPA's Agent Communication Language, GAIA Methodology	Contribution Agents (CA), Data Management Agents (DMA), Distribution Agents (DA), Graphical User Interface Agent.
21. CORMAS-OLYMPE - 2005 [21]		tool to support decision making processes and communication and provides an economic synopsis of the complexity of farming systems. West Kalimantan (Borneo) in Indonesia, where rubber farmers have diversified with oil palm and other activities and also integrated new cropping methods and improved agroforestry practices	CORMAS, OLYMPE, XML files, UML classes	Farms, Towns
22. FIRMABAR - 2005 [98], [9]	Integrated freshwater assessment in a geographic area by means of water supply/demand simulations (in dierent scenarios)	Urban water management	SDML, Swarm libraries (Java), OOP	Families, companies, municipalities, government agents
23. DAWN - 2005 [7], [9]	Agent-based social model for the consumer with conventional econometric models and simulates the residential water demand-supply chain, enabling the evaluation of different scenarios for policy making	DAWN examines the propagation of water conservation signals in a simulation environment and can help water decision makers to understand the quantitative aspects of implementing an information and education policy toward controlling water demand	GAIA, Java Agent Development Environment (JADE), Physical Intelligent Agents (FIPA), Agent Object Relationship Modeling Language (AORML)	WAter supplier agent (WSA), consumer agents (CAs), Meteorologist agent (MOA), Simulator agent (SA)
24. MANGA - 2005 [93], [9]	Simulation of decision-making process and of the impact of water allocation on farmers collective behavior	Rural development, water resources management	UML	Farmers, water suppliers, crops, climate, information supplier agents
25. GRENS-MAAS - 2005 [153], [9]	Simulation of stakeholder support in under different policy strategies (nature development, gravel extraction, flood reduction)	Water catchment management	BDI (approach)	Policy makers, citizens, farmers, nature organizations, gravel extractors agents
26. DSS MAS-GIS - 2005 [152] [9]	Decision support system framework for water management in the Mediterranean islands coupling a Multi-Agents System with a Geographic Information System	Water management	CORMAS, ARCGIS, ODBC	Drillings, tanks, water companies, consumers (hotels and homes), and a water police agents.
27. DANUBIA - 2005 [13], [9]	Simulation of scenarios and strategies for the future of water in the upper Danube Basin (an integrative decision support system)	Water resources management (water supply and ground - water) under conditions of global change	UML, object- oriented programming (OOP)	Farmer agents (maize, Meat-Breed, etc.), WaterSuppliy-Company and Household agents

TABLE IV
SUMMARY OF REVIEW SYSTEM (CONTINUATION)

Acronym	**Main Task and Objectives**	**Application**	**Related Technologies**	**Agents (Types)**
28. PALM - 2006 [99], [9]	Simulation of management strategies in a community of households in Nepal (linking decision-making to underlying biological processes in soil nutrient dynamics)	Rural development	UML, OOP	Household, landscape, livestock agents
29. WPMS - 2006 [112] [9]	Water pollution monitoring for regulatory compliance (early stage of research; analysis phase)	Urban water management	FIPA-ACL, UML, GAIA	Monitor, supervisor and control agents
30. MAS - Water Pollution Monitoring Systems - 2006 [113]	Intelligent agent software technology to water quality monitoring	Regulatory compliance and Facilitate response to contamination incidents	FIPA standard, Gaia v.2 methodology, temperature, turbidity, conductivity, pH, free chloride, AUML notation	Monitor Agent, Supervisor Agent,
31. ABM - Water Quality Control - 2007 [107]	Development of a multiagent system for water pollution monitoring and control	Water quality control in the local water distribution system in the region Prahova - Romania. A community of agents is assigned to the task of monitoring a network of sensors in order to assess water quality in a distribution system, and to fire alarms in emergency situations	TROPOS methodology, design tool TAOM4E, GAIA methodology, FIPA, JADE, AUML notation, turbidity, organic carbon (TOC, DOC), nitrate, benzene, pH, electric conductivity, ORP, NH4, DO, redox, pressure, temperature and flow	Model Agent (MA), DataBase Management Agent (DMA), Reasoning Agent (RA)
32. AEZ (Agro-ecological Zoning) - 2007 [57]	compute water movement through the soil plant atmosphere continuum, to assess net crop irrigation water requirements (WRQ)	Global	FAO IIASA (International Institute of Applied Systems Analysis), BLS (Basic Linked System), CRU (climate database of the Climate Research Unit) , AQUASTAT (FAO's Information System on Water and Agriculture), EUROSTAT (European Statistics), WSI (water scarcity index) , (SRES) A2r (Special Report on Emissions Scenarios), GCMs (General Circulation Models), HadCM3 (Coupled atmosphere-ocean general circulation model) and CSIRO (Commonwealth Scientific and Industrial Research Organization)	No Agent Based Model
33. Adaptive scheduling in deficit irrigation - 2008 [72]	Real-time control system, which soil water representation models and heterogeneous sensor data sources	Simulation in deficit irrigation scheduling	WSN (Wireless Sensor Network), moisture soil sensors, decision tree (WEKA), NetLogo	3D cubic representation of soil
34. SIMULAIT WATER - 2008 [121], [9]	Simulation and analysis of various pricing and trading policies	Urban water management (supply and trading)	Scripting language	Household agents (low, medium and high)
35. LUDAS - 2008 citele2008land, [92],[9]	Spatio-temporal simulation of a coupled human landscape system.	Land-use and rural development	NetLogo 3.0	Household, landscape, agricultural agents
36. Control-MWS - 2009 [9], [60]	Water pollution monitoring system (water quality, energy costs and demand) of a simplified municipal water system	Urban water data management	Simulink tool	Pumping station, tank agents
37. Multi-agent, Machine Learning for Soil Textural Composition - 2009 [142]	Multi-agent, machine learning approach to classify the textural composition of soil within the field using only soil moisture observations	Exploits the features of a soil water retention model using machine learning algorithms and multiagents	UNSODA database, Soil Water Retention Curve (SWRC), Cone Penetration Testing, (CPT), inductive inference model,supervised classification, neural networks, Bayesian approaches, Support Vector Machine (SVM), simple Naïve Bayes classifier, Bayes network, Van Genutchen model, 70 sensors (soil water potential (15cm, 30cm and 45cm), humidity and temperature). Weather station (ET), wind and rainfall, NetLogo 3D	Soil Agent Cube, Plant agents.

TABLE V
SUMMARY OF REVIEW SYSTEM (CONTINUATION)

Acronym	Main Task and Objectives	Application	Related Technologies	Agents (Types)
38. KatAWARE - 2010 [51]	MAS model to represent water supply and demand dynamics at the catchment level	Development of a collective management plan (CMP) with the KRWUA (Kat River Water User Association (KRWUA)), the ambition to go beyond visioning and move towards the real negotiation process leading to the technical decision-making phase	Companion Modelling (ComMod), Participatory Modelling (PM), Unied Modelling Language (UML), Role-playing game (RPG), CORMAS simulation framework, AWARE (Action Research and Watershed Analyses for Resource and Economic sustainability) model,	Villages Agents, Farm Agents
39. ABSTRACT - Agent Based Simulation Tool for Resource Allocation in a Catchment - 2010 [155], [154]	MAS modeling, including agents equipped with simple decision-making heuristics based on empirical survey data to represent feedback processes between water availability and water use for irrigation, system components related to topography, hydrology, storage and water use for irrigation are included	Feedback mechanisms between water availability and water use in a semi-arid river basin	CORMAS platform under the VISUALWORKS environment, Semi-distributed hydrologic modeling approach, ClimWat-FAO, WAVES project (Soil characteristics), NashSutcliffe efficiency coefficient.	Farmer agents and Allocation Committee agents, Geographically located object classes are: Crop, River (branch) and Node.
40. RMAS - Robot multi-agents system - 2011 [118]	Application of multiagent systems in precision agriculture	Research in agent simulation tools, on decision making mechanisms creation with precision agriculture concepts	homogeneous robot multi-agents system (RMAS), heterogeneous software multi-agents system (SMAS), Behavior based architecture (BBA), Sense-Model-Plan-Act architecture (SMPAA), hybrid architecture (HA), Global Positioning System (GPS), Geographic Information System (GIS), remote sensing, intelligent devices, computers	Information agent, Environmental agent, Robotic agent.
41. Wide Area Monitoring - MAS - 2011 [160]	Long-range monitoring system of irrigated area water-use based on Multi-Agent	High-efficient long-range monitoring system of irrigated area water-use	Emulation Testing, JACK Intelligent Agents platform in JAVA, LAN	Monitoring center Multi-Agent subsystem (Monitoring center management Agent (MCM-Agent), Water-need measurement Agent (WNM-Agent), Optimized calculate Agent (OC-Agent), Water-allocate control Agent(WAC-Agent), Water-use measure Agent (WUM-Agent), Water fees manage Agent (WFM-Agent), Statistical report form Agent (SRF-Agent), Information inquiry Agent(II-Agent)), GSM communication layer Multi-Agent system(monitoring center communication Agent(MCC-Agent), monitoring station communication Agent(MSC-Agent) and GSM public communication network), the monitoring station Multi-Agent subsystems (monitoring station management Agent (MSM-Agent), data-gather Agent (DG-Agent), data-inquire Agent (DI-Agent), data-store Agent (DS-Agent), data-exhibit Agent (DE-Agent), fault-alarm Agent (FA-Agent), implement control Agent(IC-Agent))
42. Control Greenhouse - MAS - 2011 [84]	Design and Development a Control and Monitoring System for Greenhouse Conditions Based-On Multi Agent System	Automatically control of greenhouse temperature, lights, humidity, CO2 concentration, sunshine, pH, salinity, water available, soil temperature and soil nutrient for efficient production	JADE (Java Agent Development Framework), MIND (condition - action rules)	Environmental agents (temperature, humidity, CO2 concentration, sunshine), soil condition agents(pH, electrical conductivity, salinity, water available, soil temperature, soil nutrient).

TABLE VI
SUMMARY OF REVIEW SYSTEM (CONTINUATION)

Acronym	Main Task and Objectives	Application	Related Technologies	Agents (Types)
43. ABM - GIM. Agent based modeling for the gravity irrigation management - 2011 [17], [16]	Gravity irrigation modeling by a multi-agent technology and irrigations scheduling optimization using an evolutionary algorithm	Simulation in the irrigated sector R3 is located in the eastern part of the semi-arid Tensift plain, at 40km from the city of Marrakech (Morocco)	SAMIR (Satellite Monitoring off Irrigation),NDVI (Normalized Difference Vegetation Index), Crop Water stress (K_s) FAO-56 method, AML language (Agent Modeling Language),StarUML tool, UML (Unified Modeling Language), JADE platform (Java Agent Development Framework), FIPA specifications (Foundation for Intelligent Physical Agent), Irrigation Priority Index (IPI), Covariance Matrix Adaptation Evolution Strategy (CMA-ES), Business Process Model and Notation (BPMN).	Supervisor agent, scheduler agent, operator agent, source agent, AUAW agent.
44. DSS-FS: A Decision Support System - Fertigation Simulator -2012[10]	Fertigation Simulator Software. Decision Support System to Fertigation	Design and optimization of sprinkler and drip irrigation systems	Drip and sprinkler Irrigation, FAO-evapotranspiration, Shape of the wet bulb, Electro-conductivity, pH, Sodicity index (SAR),Fertigation Efficiency Index (FEI), Visual Basic	No Agent Based Modeling
45. MAS Garden Irrigation - 2012 [79]	multi-agent system (MAS) to simulate the irrigation policy of a green area	Simulates the behavior of an irrigation system and permits accurate determination of irrigation timing (scheduling) with case studies for garden irrigation	sprinkler irrigation, MESSAGE methodology, Unified Modeling Language (UML), Java Agent Development Framework (JADE), FIPA standards, XML-based notation	Controller agent, Zone Agent, Sprinkler Agent, Species Agent, Fertilization Agent, Forze Fertilization Agent, Irrigation Agent.
46. Irrigation System - MAS - 2013 [131]	Smart irrigation system based on multi-agent architecture using fuzzy logic	Solution to the problem of inadequate water use with current irrigation systems employed in agricultural projects	JADE, FIPA, Arduino, MISO (multiple input, single output), Fuzzy Associative Memory (FAM), NetBeans, Visual Studio, Microsoft Access	Master Agent, Field Agent, Control Agent
47. CARISMA - 2014 [115]	MultiAgent System for Remote Control of Solar Photovoltaic Power Plants	control and monitor solar panel farms	JADE, Desires, Beliefs and Intentions, temperature, humidity, CO_2, and radiation sensors, Expert System, Neural Networks, Bayesian Networks,platform called PeMMAS, SquidBee, inference systems	Teleoperator Agent, Coordinator agents, Operator Agents, Sensor-Device Agents, Remote Agent.
48. Mushroom Mechanization - MAS - 2014 [38]	Mushroom Cultivation Mechanization Architecture by Using Multi-Agent and parallelism Systems	To increase efficiency, speed, accuracy and to decrease cost in Mushroom Cultivation	Beliefs, desires and intentions (BDI) architecture, Time division multiple access (TDMA) protocol, C#	Monitoring of environmental conditions agents, preparation of compost agent, day counter agent, temperature regulator agent, splinker agent, harvest agent.
49. IEDSS - Interoperable Intelligent Environmental Decision Support Systems -2014 [133]	development of Interoperable Intelligent Environmental Decision Support Systems (IEDSS)	Supervision of a Wastewater Treatment Plant	Predictive Model Markup Language (PMML), XML (Extensible Markup Language), language, Environmental Decision Support Systems (EDSS), JADEX Multiagent platform, BDI architecture, Biological Wastewater Treatment Plant (WWTP), GESCONDA tool	Diagnostic Model Executors Agent, Predictive Model Executor Agent.
50. MAPIS Multi-agent precision irrigation simulation - 2014 [64]	Calculates soil specific and corresponding water tensions by using pedotransfer functions	Quantification of the need for irrigation and the control of the irrigation system	SeSAm (Shell for Simulated Agent Systems), pedotransfer functions (PTFs), reference soil groups (RSGs), World Reference Base for Soil Resources (WRB), GRIRIS Grid-based irrigation simulation	Moisture sensors and Dripping units

TABLE VII
SUMMARY OF REVIEW SYSTEM (CONTINUATION)

Acronym	Main Task and Objectives	Application	Related Technologies	Agents (Types)
51. Irrinet-FDSS - 2015 [61]	Fuzzy Decision Support System for irrigation and water conservation in agriculture	To enhance the performance of an existing web-based irrigation advisory system, in view of an independent automation with dedicated field hardware.	Fuzzy Decision Support System (FDSS), IRRINET (Motorola Irrigation), IRRISAVE, Irrigation inference system, Irrigation performance index (IPI)	No Agent Based Model
52. MUSA - Multiagent Simulation for consequential LCA of Agrosystems - 2015 [124]	Modelling Price Discovery in an Agent Based Model for Agriculture in Luxembourg	Aims to simulate the future possible evolution of the Luxembourgish farming system, accounting for more factors than just the economy oriented drivers in farmers decision making processes	LCA (Life cycle assessment), STATEC (Institut national de la statistique et des tudes conomiques du Grand-Duch de Luxembourg), Java	Entities: farmers agents, farms, product buyers, crop, description values, time, space.
53. MAS-CHNs-WEB - 2015 [75]	Watersheds are modeled as coupled human and natural systems (CHNSs) by coupling a multi-agent system (MAS) model and an environmental model	Irrigation Study and its environmental impacts in the Republican River basin. A multi-agent system model is designed to simulate the agents' pumping behaviors, and it is coupled with the physically-based RRCA groundwater model. The MAS model, which incorporates self-learning and utility	Hadoop (cloud computing environment), CHNSs (coupled human and natural systems), BMP (Best management Practice), OPL (Our Pattern Language), RDBMS (relational database management systems), ACID-compliant (A: atomicity; C: Consistency; I: Isolation; D: Durability), RRCA Republican River Compact groundwater model, MODFLOW-2000, Fortran, Robust Optimization (RO) framework, Bayesian statistics, Object - oriented language, Java, Unied modeling language (UML), MATLAB nonlinear optimization solver, Asynchronous JavaScript and XML (AJAX)	pumping Agents
54. comprehensive model.Distributed crop water requirements with surface and groundwater mass balance - 2016 [119]	Integrated water supply system Model	Fortore water supply system (Apulia region, South Italy)	Reservoir and groundwater, SPi-Q regression model (inflow to reservoir), GMAT(Monthly Soil water balance), Reservoir Water balance model (change in time), Aquifer water balance model	No Agent Based Model
55. Adapt-Pumpa: Pumpa Irrigation System model - 2016 [67]	Water management simulation	Pumpa irrigation system, a small-scale irrigation system in Nepal	Flood irrigation, ODD(Overview, design concepts, and details),Gini coefficient of yield, Netlogo 5.0	Six Irrigator sectors
56. BewUe (Bewässerung Uelzen. Irrigation Uelzen - 2016 [125]	Plant water availability and irrigation requirements	model influence by regional climatic alterations and the regional variability on Germany (Diepholz, Uelzen, Fläming and Oder-Spree)	RCP8.5 (Representative Concentration Pathway - high greenhouse gas emission), INM-CM4 (coupled model of the atmospheric and oceanic general circulations), ECHAM6 (Atmospheric general circulation model), Tmax (Based in general circulation climate model ACCESS1.0, WASMOD (Water and Substance Simulation Model	No Agent Based Model
57. SWAP (Soil - Water - Atmosphere - Plant system) - 2017 [40]	identify crop adaptation options to face the expected changes in water availability by exploiting the existing intra-specific biodiversity of the tomato crop and accounting for irrigation management and the hydrological properties of soils	Irrigated district in southern Italy - Tomato crop	Pressurized pipeline network, and delivered on-demand, HYPRES (hydraulic properties of European soils), RSWD (Relative Soil Water Deficit)	No Agent Based Model

VI. DISCUSION

Analysis and Discussion of fifty-seven applications using agent-based technology in the water management domain, have been briefly explained. In $9-17$ pages and Tables I-VII (see pp.$19-25$) a summary is given, with some important characteristics used to analyze the systems reviewed. These characteristics are related with acronym, main task and objectives, application, related technologies and agents types used in each research.

In this review also we find some important challenges and research topics in the development of Multiagent systems related with:

- Time Scheduling of Data Transmission Sessions multi-agents. Demand-Supply Networks (DSN) [140], [139].
- Distributed estimation and cooperative filtering, soft control and informed agent intervention, nonlinear interaction dynamics, constrained communication, optimal consensus control, competition and cooperation [81].
- Platforms: A number of multi-agent system platforms exist. The necessity to develop agents that can interact with each other is fundamental to the development of flexible, extensible, open architectures [37].
- Intelligent agent design: A number of different architectures for intelligent agents can be found in the literature. Each of these implementation strategies will produce agents with different degrees of reactivity, proactiveness and social abilities. What is not easily understood is how autonomy varies across these implementation strategies and their suitability for different kind of control engineering applications [37].
- Agent communication languages and ontologies: International standards are set by the Foundation for Intelligent Physical Agents (FIPAs). An important point of using agent-based technology is that all agents within control engineering applications should be able to cooperate and interoperate. Therefore, the community must agree on appropriate agent communication language standards [37].
- Security: Due to the peer-to-peer communication between agents, security can be a key problem. Here must be measures to determine the level of trust between agents and the security of messaging. Similarly, communication between two agents is open to attacks such as sender spoong (the message claims that be from a more trusted agent) and message modification (a message is changed while traveling between agents, particularly in negotiation situations) [37].
- Mobility: a number of researchers are interested in mobile agents, which move completely (source code and data) from machine to machine. While this has been suggested within a few control engineering applications, no credible reason for using this approach is clear [37].
- The way in which a MAS provides flexibility, extensibility and fault tolerance needs to be understood. e properties of agents that produce these qualities are: autonomy, open MAS architectures, platform for Distributed systems, Fault Tolerance [37].
- The research on NMAS is still confronted with many challenges and difficulties especially for design and analysis. For example, how to formulate or decompose the relevant tasks and objectives; how to design efficient and effective control protocols to compensate for communication constraints; how to guarantee the stability and achieve the consensus simultaneously. There exist many challenges, including capturing, storage, visualization, sharing, transfer, search and analysis of the data, allocation, coordination of the computing tasks. It is hard to handle this kind of real-time big data and computing using traditional database management and processing tools. Challenging issues, particularly real-time big data, communication delays, heavy computing, and coordination of multiple tasks [97].
- The distributed nature of networked systems and their need to adapt to varying conditions, however, also has great challenges in terms of emergence and scalability. For networked mobile systems, it is clear that emergent behavior is a very promising direction, given that the capability of a single agent is quite limited so far. However, this leads also to the challenging issue of how to prevent undesired emergent behaviors from undermining the reliability of the system [81].
- One of the problems that arise in DSS and Multi Agent Systems (MAS), is the lack of a central controller that may cause the components/agents a new behavior to emerge at run time, which was not seen in the system specifications. This unexpected behavior, which is known as emergent behavior at the component level (i.e. considering behavior of agents individually) and implied scenario at the system level (i.e. considering the system behavior), may cause critical damage [50].

Three related aspects to the development of MAS in recent years that we consider could be used in an irrigation system are Holonic Multi-Agent Systems (HMAS), Cooperative coevolution (CCEA) and Networked MAS (NMAS), as adaptation and mitigation strategies against the effects of climate change.

- **Holonic Multi-Agent System (HMAS)** [48]. An organization consists of the definition of roles, relationships, and control/authority structures, in this case Agents that interact with each other over a long term goal, and how these interactions affect resource allocation, data flow, authority levels, and coordination patterns, among many other system characteristics. The contributions of organizational approaches to MAS domains include modularity, security of applications, limiting the scope of interactions, management of uncertainty and redundancies, and formalizing high-level goals.

  Several organization models, with different characteristics, have been proposed in the literature, such as hierarchies, holarchies, coalitions, teams, congregation, societies, federations, markets, matrix, and compound organizations, among others; some examples of them are named in literature AGR (Agent, Group, Role), MOISE, MOISE+, Electronic Institutions and MaSE, explained in next sections. Holonic organizations are among the successful organizational models that have been introduced in multi-agent systems recently, and resulted in the concept of Holonic Multi-Agent System (HMAS). HMAS is a multi-level structure composed of holons. Holon word is derived from the Greek word holos, meaning whole, and the suffix on, meaning part; concept with roots in biology and sociology, as it was introduced for the first time by a Hungarian philosopher Arthur Koestler, to describe the recursive and self-similar structures in biological and sociological entities [88]. The holonic concept allows the modeling of a MAS at several granularity levels. Based on its unique structure, a holonic model brings several significant attributes to multi-agent systems, such as self-similarity, reliability, stability, and dynamism, to name a few.

According to the previously mentioned rules, a holonic multi-agent system needs to have a flexible hierarchical structure. The flexibility of the structure is derived from the flexible autonomy of the holons and their ability to change the intra-holon arrangements. According to flexible autonomy, a manager, called head, sets the goals of its holon, while the members themselves choose the strategy to use, based on their local knowledge. The lowest level holons are responsible for the real actions in the environment.

In general, the organization of a holonic multi-agent system consists of two primary stages: building the initial holarchy; and controlling its structure against internal and external stimuli during its lifetime. The algorithms proposed for this purpose, can be classified into two main categories: centralized methods, in which a central system is responsible for the whole process and decentralized algorithms, in which the holonfication process is managed distributively by the agents themselves. In centralized algorithms, the system needs to have all the information about the members at any given time. Although such an assumption may ease the holonification process to a large extend, it limits the application of the holonic multi-agent systems in large and open systems, and also makes them suffer from single point of failure problem. In distributed holonification methods, on the other hand, extendibility and suitability for large-scale open multi-agent system problems are achieved with an expense of high coordination needs, resulting from the local and limited domain of information that is available for the agents. In other words, in our model, there is no central unit for building and controlling the holarchy, and the whole process is controlled by the member agents, according to their local information about themselves and their neighbors in a multi-agent network.

- **Cooperative coevolution (CCEA)** [63]. This is a valuable approach for the evolution of heterogeneous multiagent systems and some works focus on the evolution of controllers for behaviorally heterogeneous, but morphologically homogeneous. In the classic CCEA architecture, each agent evolves in an isolated population, and the individuals are evaluated by forming collaborations with individuals from the other populations. The key advantage of CCEAs is that since populations are isolated, it is possible for different populations to evolve radically different agents, with genomes of different lengths, and even to use different evolutionary algorithms. The cooperation between morphologically heterogeneous robots can, for instance, augment the capabilities of the group, allowing the achievement of tasks that are beyond the reach of a single type of robot. A key element in the evolution of cooperative behaviors is synchronized learning, populations should exhibit a mutual development of skills, in order to avoid loss of fitness gradients and convergence to mediocre stable states. A number of papers have recently appeared on the modeling of coevolutinary networks, such as coevolution of behavior and structure in Web [59], influence of behavior on the spread of diseases [60], co-emergence of cooperation and hierarchical structure in games [61], evolution of opinion formation on adaptive network [62], see [63 64] and http://adaptivenetworks.wikidot.com/publications for more references [81].
- **Networked MAS (NMAS)** [97]. In recent years, further development of communication technology, particularly Internet technology, has led to a number of MASs that employ communication networks to exchange information mutually. These result in a new system named networked MAS (NMAS) as the most important NMAS application is the Internet of Things (IoT), which is one of the hottest growth sectors in the global economy. Various NMAS are widely used in the fields of sciences and engineering, such as smart grid, satellite communications, GPS, robot networks, biological networks, sensor networks, unmanned vehicles, power systems, etc. The main research on NMAS can be classified into two directions: 1) the development of distributed estimation techniques for sensor networks and 2) the control of mobile autonomous agents using information obtained over networks. In NMAS, there are multiple controllers rather than a single controller and also there exist interactions among the agents that the individual agent controllers must consider. In NMAS, as the scale of the system increases, the captured real-time data and required real-time computing will grow in size dramatically.

VII. CONCLUSIONS

The state of the art in agent-based approaches applied to irrigation issues shows the utility of agents as solvers of environmental problems. Each agent has incomplete information or capabilities for solving the problem. Thus, the importance of MASs is concerned with the behavior of a collection of agents designed at solving a given problem together. There is no global system control. Data is decentralized, and Computation is asynchronous. The design of the systems studied is mainly done using agent-based concepts whereas for their implementation the use of object-oriented technologies prevails.

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