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SIZE AND STRUCTURE OF THE IRRIGATION AND WATER INFORMATION SYSTEM: ABHM, ORMVAM AND ORMVAD

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MOROCCO ECONOMIC COMPETITIVENESS

SIZE AND STRUCTURE OF THE IRRIGATION AND WATER INFORMATION SYSTEM: ABHM, ORMVAM AND ORMVAD

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By DAI

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MEC PROGRAM

The Morocco Economic Competitiveness Program (MEC) funded by USAID for a four-year period has the objective of economic growth, and has adopted a multi-sectorial approach to reduce obstacles to productivity, trade and investment in Morocco. The program has three components: (i) improving the economic environment, (ii) rational use and recovery of agricultural water, and (iii) development and strengthening of professional capacities.

The general objective of component 2 is rational use of water and its recovery in agriculture, withinclusion in national strategic plans, i.e. the PMV (Green Morocco Plan) and PNEEI (national irrigation water saving program). In terms of management of the demand, MEC will contribute to the implementation of political and institutional reforms, notably, setting prices for irrigation water, adoption of water-saving technologies for irrigation water and financing tools for farmers, as well as enhancing the connections between farmers and markets.

INTRODUCTION/CONTEXT

Integrated Management of Water Resources (GIRE) is currently considered the solution for water resources problems.

GIRE is a systemic method (which considers all hydraulic systems) for sustainableusage, distribution and monitoring the use of water resources based on the social and economic context and environmental objectives.

GIRE must outline the different types of water resources, i.e. surface water, groundwater and unconventional water.

GIRE must define all water services, i.e. mobilization, production, transfer, distribution, consumption, drainage and treatment, as well as reuse of waste water.

The DRPE (water planning and research directorate),which conducts national-level research and water planning, has usedthe GIRE strategy for several decades, with the crowning achievement of establishingDrainage Basin Agencies.

Water planning remains an obstacle to management of the limited water resources in Morocco. Drainage Basin Agencies (ABH in French) throughout Morocco are the primary sites with complete data on the status of water resources. This information can be accessed through a series of government organizations and other parties involved and provides information for decision makersfor the allocation and management of water. Since ORMVAs [regional agricultural development authorities]account for 80% of the irrigation water used, they are major stakeholders.

Morocco has undertaken an in-depth reform of the water sector through the creation of Drainage Basin Agencies. In addition, the establishment of various basin councils, commissions and committees at the principal basins, sub-basins and regional aquifers enables coordination meetings on water and its various uses. These organizations, which include Drainage Basin Agencies (ABH), regional agricultural development authorities (ORMVA), other organizations involved in the distribution of water (ONEP, state-controlled organizations), as well as representatives of the various water usersprovide opportunities to coordinate and plan actions to handle the issues of management and distribution of the resources among the various users.

The prerequisites for efficient water management follow:

- Use of scalar and spatial dataat a certain resolution;
- In-depth knowledge of the processes: time and space scales
- Group/set of mathematical models
- Other tools to support decision making (data analysis, data mining, etc.)
- IS: Data Integration–GIS [geographic information system] -Models- Knowledge

TARGETED OBJECTIVES AND CONTRIBUTION OF IS

The overall objective of the IS is to help the ABHM and Moulouya and Doukkala ORMVAs prepare for the development of an irrigation and water information system that enables better governance of water on the regional scale. The three principal areas where the display and presentation of information are fundamental to the Water Agency, the ORMVAs, are the discovery, representation and analysis of information. The discovery of information consists of facilitating users' identification of information of interest. The purpose of representing the information is to present the information in a way that enhances understanding. Analysis of the information will enable users to examine the data, relationships and trends. These cases of high-level use can each be broken down into more specific display and reportingtasks. The discovery of information enables users to identify information of interest from the body of information on water that will be available to them. Interfaces that permit efficient discovery of pertinent information require understanding the types of responses users want for the questions. This understanding can then be used to develop search query interfaces adapted to users' needs. Presentation of information refers to the representation of data in a way that provides information and enhancesunderstanding. The information presentation method varies based on the type of data and questions posed by the user. In the case of information on water, the presentation methods will first need to be focused on the display of spatial-time data. Information analysis refers to the provision of data investigation tools –in graph form, for example, to identify relationships and trends or perform statistical analyses.

Understanding why users will use the system, and what they will use it for, will be essential to determining how the system should be developed. This understanding will support all the components – the query interface, how the map displays can be best used, what time information should be represented and how to best use technologies such as data mining to optimize the recovery of data. In addition, information on water resources is intrinsically spatial in nature, with a closely associated time component.

Observation data is a large part of the data archives, and the interfaces and displays must be developed in the space-time context. Finally, further to user requirements, an in-depth survey of presentation techniques must be conducted based on key questions and types of data. This includes evaluation and prototyping of various ways of representing the information selected to answer specific questions. This targeted approach for information specific to the water scenarios will enable more effective design of the system over the long term. It should also be recognized that the various users' needs may differ, which results in different levels of requirements, simple services to bring to light data appropriate for data analysis. The system launched should be stratified in layers that satisfy the different user communities.

Solutions to the complex problems of water resources depend upon precise and effective evaluation of the information. Information that can be drawn from the collection of numerous data and modeling in disciplines as disparate as geography, geology, engineering, meteorology and sociology requires tools for interpretation. GIS has emerged as a popular spatial tool for the analysis, interpretation and visualization of various scientific and technical disciplines. It is recognized as an emerging technology beneficial to water resources professionals. The development of tools to support decision making (DSS) using GIS, predictive models and databases to help solve complex engineering and scientific problems is ever-changing.

The continuous decline in the cost of computing technologies and simultaneous increase in processor speeds have permitted the dissemination of GIS technology for a larger number of modelers. In the area of water resources, applications include planning, design, analysis, operation and maintenance, multi-use aspects including irrigation, evaluation of contamination with nitrates in groundwater and the incorporation of sophisticated hydrodynamic and water quality models in one GIS to examine hydrodynamic aspects and discharge of contaminants.

WHICH INFORMATION SYSTEMS?

An information system (IS) collects, processes, stores, analyzes and disseminates information for a specific goal or “Application”.

The components of an IS are:

- ✓ Equipment
- ✓ Software
- ✓ Data
- ✓ Network
- ✓ Procedures
- ✓ Human resources

IS are distinguished by the intended functionalities:

- ✓ IS: - Information System
- ✓ DSS: - Decision Support System
- ✓ SDSS: - Spatial Decision Support System
- ✓ ISDSS: Intelligent Spatial Decision Support System

DSS have the following characteristics:

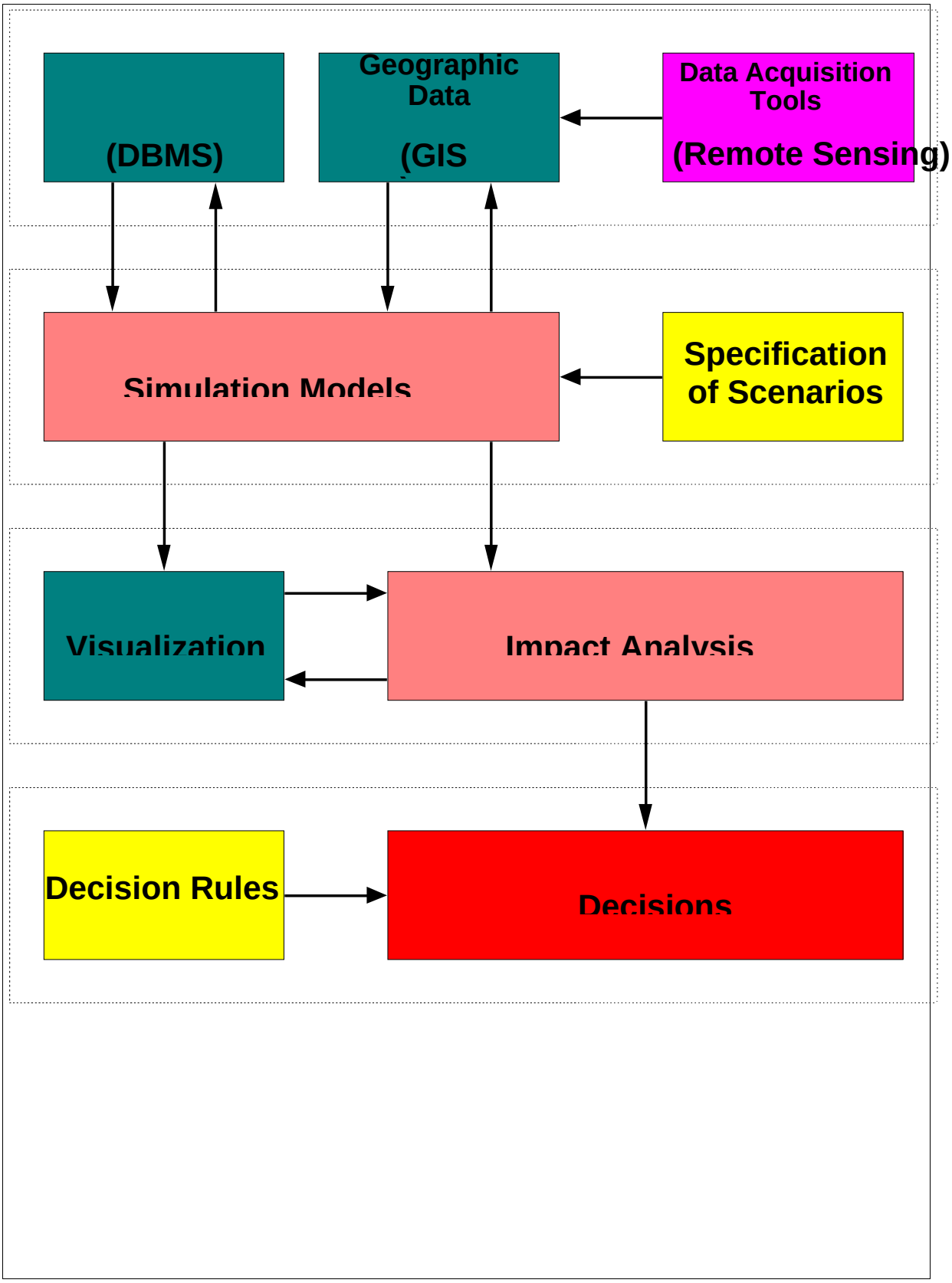
- ✓ Systems to support complex, non-routine decisions
- ✓ Principal objective: convert data into information
- ✓ Generally used by management on the tactical level for decisions and analysis
- ✓ This information system not only presents results, but also expands information with alternative solutions.

Additional components of a DSS provide the possibility of:

- ✓ Mathematical modeling
- ✓ Simulation
- ✓ Queries
- ✓ Data mining

Figure 1illustrates the functionalities of an SDSS (most appropriate system for water issues):

Figure 1: Spatial Decision Support System



An operational IS for ABHM/ORMVAM has the following requirements:

- Handles Data
  - ✓ Observed
  - ✓ Meshed (Models)
  - ✓ Rules, Levels and Standards for information exchanges
  - ✓ Presentation of data
  - ✓ Distribution/dissemination level
- Handles Decision Support Tools
  - ✓ Models (surface water, groundwater, quality, allocation management)
  - ✓ Data analysis
  - ✓ Optimized management

A water information system (WIS) is necessary so that these organizations have the information necessary to decision making and the public is informed.

The principal areas of competency of an ABH include centralization of quantitative and qualitative data on water and its use, mediation between users, planning and scheduling large-scale interventions, equipping and building structures and their funding. ABHs provide information on water for its production or pertaining to a flood risk or poor water quality. They also ensure hydrological forecasting and the consistency of data.

ORMVAM manages its share of water (on the order of 80%), which is received from the ABH upon request, for distribution in irrigated areas.

ABHsare unique compared with ORMVAs in the sense that they manage data and processes that are continuous over space and time. This aspect somewhat complicates the vision to be adopted for ABHs and will have to be considered in order to offer a different solution than the one suggested for ORMVAs.

DATA/INFORMATION/DECISION

Data alone have no value unlessconverted into information. When data are organized, presented, analyzed, interpreted and considered useful to support decision making, they become very useful information. Similarly, geographic information may be defined as geo-referenced data, which was processed in a meaningful way for the decision maker and perceived as a real value in the decision making process. Information is produced via data for the decision maker.

SPATIAL ASPECTS –GIS IN THE AREA OF WATER

GIS offers a spatial cognitive representation of complex hydraulic and hydrologic systems in order to resolve engineering issues with water resources. GIS can incorporate associated relational spatial data in traditional water resource databases to present an overview of the target region. This integration is achieved by combining sociological, geographic, geological and environmental factors related to the spatial entities of the water resources issue, receiving priority use in decision making.

For an area of specific interest to decision makers, GIS has the capacity to display information in order to interpret data and the output of water resources models, which enables users to adopt a more dynamic approach with the input of data, modification and establishment of scenarios and evaluation. Based on the range of GIS applications and users, major advantages may result from combining GIS with predictive models. In fact, GIS offers a virtual environment where decision makers can analyze theory and evaluate competing management strategies.

Sound decision making depends on the quality and quantity of information available. The quality of the data is an important factor and the accuracy of a GIS will depend greatly on the scale, resolution of maps, satellite images and other sources and techniques used to create the sets of GIS data.

ANALYSIS OF THE EXISTING SYSTEM

The first diagnostic/audit phase of the IS showed the existing system as precisely as possible in terms of the IS data, as well as the associated decision support tools. The technical, organizational and human aspects related to the existing IS were analyzed during this phase.

This general mapping of the IS involved the number of workstations, servers, network typology, geographic distribution, various DBMS and GIS used, models and tools, quality of the data, backup procedures, integrity of the data, quality of the DBMS and GIS, logical/physical structure to a lesser degree, constraints, etc. As indicated in the following tables, which were updated in the scope of recent inspections of the ABH and ORMVA, specific attention was paid to human skills in terms of knowhow, expertise, the number of technicians and decision makers, the lack of skills, etc.

Table 1: Know How/ABHM-ORMVAM Expertise

Subject	Existing Skills	Skills that are Lacking
Basic Information Technology	Use: Yes; Administration: No	
DBMS	Use: Yes; Administration: No	Use; Administration
GIS	Use: Yes; Mixture of tools, administration: No	Geomatic project manager; Training manager; Technicians
Cartographic Summary	GPS: No; Digitization: Mediocre; Scanning: Yes	GPS; Digitization
Image Processing	Orthorectification: No; Mosaicing: No; DTM (digital terrain model): No; Signal Processing: No	Orthorectification; Mosaicing; DTM; Signal processing
Acquisition of Field Data	Low level	Use and practice of the GPS
ABHM- Specific Skills		
Modeling/ Systems Simulation	Miscellaneous knowledge	In-depth and complete knowledge
Groundwater	GMS, Modflow, Groundwater Vista	Software purchase or update

Subject	Existing Skills	Skills that are Lacking
Surface Water	GMS; HEC-HMS, HEC-RAS	GMS Full Package: SMS Full Package
Quality Management	Miscellaneous knowledge, engineering firm work	To be purchased
Reservoir Management	Miscellaneous knowledge, engineering firm work	To be purchased
ORMVAM – Specific Skills		
Monitoring crops	No use of satellite imaging	In-depth and complete knowledge,
Parcel Information System	Sector level, some parcels	To be designed
Management of water towers	Canal de Provence endeavor	To be purchased or preferably designed
Verification of drip irrigation	Manual	To be purchased
Management of hydro-agricultural equipment maintenance	Partner software, good command, but dated from 1992	Update or purchase

Table 2: Acquisition of maps and satellite images (ABHM-ORMVAM)

Maps Section	Existing	Required
Reference Data	No fees: acquired from the central administration Fees charged: no	Basic georeferenced maps
Data Produced	Professional applications	Maps covering the basin/areas irrigated over time

ABHM

In February-March 2010, an initial assessment of the existing data and information systems was made and concisely revealed the existing database modules, the process for acquisition, control, storage, processing and use of hydrological, meteorological and hydrogeological data, aspects related to their management and the existing tools for data storage, processing, modeling and management. In addition to the inventory of water resources, the DRPE (water planning and research directorate) measures the quality of the water. Other information relative to the development and use of water resources is collected by partners who use the resource, i.e. the ONEP, state-controlled organizations, drinking and industrial water distribution concessionaires, ORMVAs and other agriculture departments for irrigation water. The varied information is stored in the Badre21 national database system and published in bulletins on the hydrologic situation or in bulletins on the water quality status in hydraulic regions. Part of this information is disseminated over the Internet (status of storage damsand hydrologic situation at hydrometric stations). A data collection system relative to the daily hydraulic reports from storage dams was also deployedat ABHs by the DRPE.

Multiple applications are linked to information technologies or the existing water information system. The current water database is in fact composed of several independent satellite databases developed on very different environments in the scope of various previous studies, and varied by the consulting engineers or in the framework of international cooperation. The following may be cited specifically:

- A hydrometeorological model on BADRE21- developed by the DRPE in Rabat
- A hydrogeological model on ACCESS
- A water quality module in EXCEL
- A module for water fees and sampling authorization in ORACLE
- A module listing sampling points in EXCEL
- A module of data on water storage dams in EXCEL

Various GIS tools are used: Arc GIS 9.2 and MapInfo

The Badre21 system is theoretically the central core of the national water information system. However, certain difficulties relative to the daily management and status of the ABHs hinder its proper implementation. Data are not entered into the system regularly. Administration and use of the BADRE21 system requires qualified staff trained for this purpose. Redeployment on an Intranet/Internet platform could simplify the usage procedures and sort out these issues in terms of software & hardware. The Badre21 database can be configured. Its two basic concepts rely on measurement sites and measurements. Management of the various water points, sources, discharges, etc. in a single database accessible to several departments led to standard IRE identification and adoption of the concept of measurement sites at the water point location. In parallel to these two basic concepts, Badre21 also manages the administrative zoning (with levels that can be configured) and hydraulic zoning (with three levels).

- **In terms of modeling, ABHM has the following tools:**
  - ✓ The hydrogeological model Modflow 2000 version 6 for groundwatersimulation
  - ✓ Moulouya flood forecasting modelbased on HEC-HMS
  - ✓ Software to calculate dam water levels
  - ✓ DPH module for management of public water
- **Maps:**
  - ✓ Georeferenced map of the region,

- ✓ Themed maps developed in the framework of the Integrated Water Resources Management Plan (PDAIRE): (hydrometric network, conditions of piezometric networks, rainfall network, dams, etc.)

- **Telemetry Network:** Six automated hydrometric measurement stations (water height & rainfall) enable data transmission through telemetry. This telemetry network was established in the scope of a Moroccan/Spanish cooperation program.

- PDAIRE is in its final phase and will deliver an analysis that includes various layers of cartographic data in GIS form.
- The Water Planning and Research Directorate just issued a contract to provide the entire Moulouya basin with a network for transmitting hydrologic data via radio.
- The agency has a Web site.

The following table groups the various GIS and recent studies at ABHM.

Table 3: GIS or Other ABHMStudies

SIG et Base de Données élaborés dans le cadre des marchés ABHM

	Année	Intitulé	Zone concernée	BD & Enregistrements	SIG	Utilisateur
inventaires des points de prélèvements	2004	**Inventaire** des prélèvements d'eau souterraine à partir des nappes de la Haute Moulouya et du sillon Itzer Enjil et détérmination des **assiettes des redevances**	Haute Moulouya et partie amont de la Moyenne Moulouya	Access / 5286	MapInfo	DDRE
	2005	**Inventaire** des prélèvements d'eau souterraine à partir des nappes de la Moyenne Moulouya du Bassin de Guercif et de la plaine de Kerte et détérmination des **assiettes des redevances**	Moyenne Moulouya (parties médiane et avale), Bassin de Guercif et plaine de Kerte	Access / 5067	ArcView 3.2	DDRE
	2005	**Inventaire** des prélèvements d'eau souterraine à partir des nappes des plaines de Angad et Bouhria et détérmination des **assiettes des redevances**	Plaines des Angad et Bouhria	Access / 2100	MapInfo	DDRE
	2006	**Inventaire** des prélèvements d'eau souterraine dans la chaîne des Beni Bouyahi	Chaîne des Beni BouYahi et plaine d'Azlef	Access / 425	ArcView 3.2	DDRE
	2007	**Inventaire** des prélèvements d'eau souterraine des nappes du Couloir Taourirt - Naima et détérmination des **assiettes des redevances**	Couloir Taourirt - Naima et CR de Guenfouda	Access / 890 + dBASE	ArcMap	DDRE
Inventaire Gravières		**Inventaire** des sites d'excavation de materiaux de construction du **DPH** dans la zone d'action de Bassin Hydraulique de la Moulouya	Zone d'Action ABHM	Access / 159	ArcView 3.2	DP
Inventaire fil eau	2007	**Inventaire des prélèvements au fil de l'eau** au niveau des périmètres de la PMH et détermination des assiettes de redevance	Zone d'Action ABHM	Access / 787	MapInfo	DAQ
inventaires + études hydrogéol	2005	**Inventaire** des prélèvements d'eau souterraine à partir des nappes de la plaine de Figuig et élaboration des **cartes hydrogéologiques** de gestion des nappes	Plaines de Figuig	Access / 213 + dBASE	ArcView 3.2	DDRE
	2007	Etude de **synthèse hydrogéologique** dans la Chaîne de Beni Snassen avec **enquête de points d'eau**	Chaîne des Beni Snassen - Beni BouYahi	Access / 1198 + dBASE	MapInfo	DDRE
	2009	Etude hydrogéologique de l'Oued Sefrou - Ain Sfa / Préfecture Oujda Angad	Bassin Oued Sefrou (Beni Snassen Sud)	Access / 143	MapInfo	DDRE
	2005	**Etude Hydrogéologique** de l'aquifère de la plaine des Triffa + **inventaire** des points d'eau (Mission 1 & 2 de l'étude de modélisation hydrogéologique de la nappe des Triffa)	Triffa	Access / 2773	ArcView 8.0	DDRE
études hydrogéol	2005	Elaboration des **cartes hydrogéologiques** de gestion des nappes du Kert, Gareb, Bouareg, Bouhria et Angad (SIG)	Plaines de Kert, Gareb, Bouarg, Angad et Bouhria, et Jbel Hamra	Access / 2930	ArcGIS 8.3	DDRE
	2005	Elaboration des **cartes hydrogéologiques** de gestion des nappes de la Haute Moulouya,de la Moyenne Moulouya et du Bassin de Guercif	Haute Moulouya, Moyenne Moulouya et Bassin de Guercif	dBASE	ArcView 3.2	DDRE
tudes géophys	2005	Etude **géophysique** par sondages électriques dans les Hauts Plateaux et la plaine de Tafrata	Nord Ain Beni Mathar et Nord Tafrata		MapInfo	DDRE
	2008	Etude **géophysique,** éléctrique et synthèse dans la Haute Moulouya et le Haut Kert	zones de Ksabi - Midar et Azlef		ArcGIS 9.1	DDRE
	n cour	Etude **géophysique,** éléctrique dans le Couloir Taourirt - Naima	Zone Layoun - Naima		Arc GIS 9.1	DDRE
	n cour	Atlas des sources	Tout le bassin		Arc Gis 9.3	DDRE
	n cour	Etude **hydrogéologique** des nappes semi-profondes du Couloir Taourirt-Naima	Couloir Taourirt-Naima		Arc GIS 9.1	DDRE
	n cour	Etude **Hydraulique** des panneaux de Zaida	Zaida (Haute Moulouya)		Arc GIS 9.2	DDRE
	n cour	**Inventaire** des points de prélèvements d'eau souterraine à partir des nappes de la Chaîne des Horsts, Hauts Plateaux, B.Guercif et Tamellalt	Chaîne des Horsts, Hauts Plateaux, B.Guercif et Tamellalt		Arc GIS 9.2	DDRE

Division Développement des Ressources en Eau
Division Planification
Division Aménagements et Qualité

ABHM has a few themed layers of hydrographic networks and groundwater, but made in a very comprehensive manner.

It should be noted that the acquisition, control and entry of data (hydrologic, meteorological, hydrogeologic, water quality, dams, etc.) is performed manually.

Therefore, the objectives targeted for the ABH IS are:

- To define the content and function of an information system on water in Oriental that would be managed by ABH to meet the water requirements of the Moulouya region, and the entire community.
- To provide specifications for each group of data and recommendations on how to develop, implement and disseminate it to various levels.

ORMVAM

ORMVAM also has numerous data/themed layers:

- ✓ IGN (National Geographic Institute)action zone of the Moulouya Drainage Basin Agency/region/Office action zone
- ✓ Watershed hydrographic network with location of dams
- ✓ Condition of the office action zone
- ✓ Administrative zoning: region/villages
- ✓ Irrigated area
- ✓ Pedology of the irrigated area
- ✓ Hydrogeology of the office action area
- ✓ Irrigation water distribution and transportation network, including the location of structures, equipment and pumping stations
- ✓ Agricultural drainage network (surface drainage) including reservoirs, *exécutoires* and*dayas*
- ✓ Parcel status of the farms
- ✓ Demarcation of the sectors and irrigation segments, including location of the supervision centers (CGR and AGR, etc.)
- ✓ Network of traffic lanes inside the irrigated area
- ✓ Hydraulic framework (expropriated and parcels)
- ✓ Wells and drilling, including hydraulic and physical-chemical characteristics (piezometry, salinity, nitrates, etc.)
- ✓ Identification of the sectors by irrigation mode
- ✓ Private irrigation in the office action area (bours [rainfed] zones)
- ✓ Supplies
- ✓ Monitoring of hydraulic stress
- ✓ Monitoring of output
- ✓ Monitoring of soil use

- ✓ Data on livestock farming
- ✓ Lists of the office's hydroagricultural equipment by segment and sector, possibly up to the parcel level
- ✓ List of studies and documents in general
- ✓ Management of the subsidy files granted by the FDA by component
- ✓ Management of the billing for irrigation water and recovery
- ✓ Crop and irrigation programs
- ✓ Irrigation water orders by sector and by segment
- ✓ Water resources at the hydraulic complex level (change in reserves and filling rates, etc.)
- ✓ Change in water allocations by farming year
- ✓ Volumes released at the foot of the dam, distributed at the top of the networks and consumed at the top of the parcels and monitoring of irrigation water towers by zone, sector and segment
- ✓ Change in water and power rates by rate sector
- ✓ Monitoring of consumption indicators and water and power costs and operation of the networks and pumping stations
- ✓ Monitoring of maintenance interventions by type of structure and equipment, and by sector (maintenance performed through one's own means and through subcontracting)
- ✓ Staff and farmer training programs
- ✓ Accounting indicators resulting from analytical accounting by position, service or department (income and expenses, and specifically linked to the water service)
- ✓ Identification of water users/farmers by type of customer and by parcel attached to the hydraulic sector (canal, branch, hydrant, hydrant [*sic*], etc.) and by sector and segment
- ✓ Monitoring of water theft, destruction of public property violations, etc.
- ✓ Status of Agricultural Water User Associations and Land Reform Cooperatives
- ✓ Monitoring of water fees
- ✓ Agro-meteorological parameters and environmental watchdog (quality of irrigation surface and groundwater and soil)
- ✓ Requests and complaints of farmers who use irrigation water
- ✓ Authorizations to remove water for agricultural use in the ORMVA action area

The required models concern:

- ✓ Water savings and recovery
- ✓ Modeling crop water requirements
- ✓ Modeling irrigation networks
- ✓ Agroclimatic models
- ✓ Econometric models

The applications must be specific to the office's needs and sufficiently user-friendly, consisting of the following types of tools:

- ✓ Project/contract management
- ✓ Drip irrigation verification
- ✓ Management
- ✓ Water tower management
- ✓ Maintenance of networks of equipment
- ✓ GIS: integrating all layers useful to the office such as hydro-agricultural infrastructure, map of soil and use of the soil, groundwater, parcels, networks, pollution, etc.

ORMVAM has indicated the following priorities:

- ✓ Use of satellite images to support the management of agricultural production
- ✓ Parcel Information System (Sector developed by DIAEA [Department of Irrigation and Agricultural Space Development])
- ✓ Management of hydro-agricultural equipment maintenance
- ✓ Management of water towers
- ✓ Drip irrigation verification

PRELIMINARY OBSERVATIONS

This assessment provided an idea of the ABHM and ORMVA information systems [and] confirmed that they are at the heart of all activities. This often presents the following problems for these organizations:

- ✓ Knowledge ofand training on IS and GIS in particular
- ✓ Maintenance
- ✓ Updates
- ✓ Costs that are difficult to quantify
- ✓ Developments that are often archaic and difficult to put into general use

Archiving of plans, basic topographic maps, information on the specialty areas (water, agriculture, irrigation) and conversion of data are extremely important elements to be considered for the progressive launch of good knowledge of the various data-information-specialty areas-use-dissemination systems for coherent development in the scope of the IS design process.

Other constraints are summarized in the following sections.

PARTNER CONSTRAINTS

- ✓ Data
- ✓ Technological [constraints]
- ✓ Cultures and customs
- ✓ Human and organizational resources

DATA CONSTRAINTS

- ✓ Availability
- ✓ Representativeness
- ✓ Quality
- ✓ Absence of metadata
- ✓ All maps are not georeferenced
- ✓ Uncontrolled archiving
- ✓ Decentralization
- ✓ Purchase cost

TECHNOLOGICAL CONSTRAINTS

- ✓ Material and equipment available
- ✓ Work platforms
- ✓ Lack of technical support
- ✓ Extremely large amount of data
- ✓ Varieties of data required by the models
- ✓ Lack of integration of new functionalities

HUMAN RESOURCES AND ORGANIZATIONAL CONSTRAINTS

- ✓ Decision maker and IT
- ✓ Allocation of resources
- ✓ Excessive workload, thus expertise not developed
- ✓ Glossary
- ✓ Apathetic toward change
- ✓ Rigid decision-making procedures
- ✓ Little or nodecision-maker/user/designer feedback

A data warehouse is essential for both entities examined in parallel with the examination of the other aspects that permit its proper implementation vis-à-vis the services rendered, specialty areas and various customers. Recommendations for future changes will be the subject of the following sections.

METHODOLOGICAL APPROACH FOR CONCEPTUALIZATION OF THE IS

An important element of a water resources information system is knowledge of the characteristics of the hydraulic system, notably:

- ✓ Basins and sub-basins
- ✓ Streams and hydrographic network
- ✓ Aquifers
- ✓ Flood plains
- ✓ Warehouses/quarries
- ✓ Wetlands
- ✓ Various uses of the water
- ✓ Other ecosystems (sites of biological and ecological interest (SIBE), etc.)

Further to various work meetings with ABHM and ORMVAM technical departments, a detailed structure/architecture of the “water” IS, which best responds to the needs expressed separately by ABHM and ORMVAM, was established. This architecture identifies the tools (hardware & software) to be acquired as well as the other computer applications that need to be acquired/developed in order to make the proposed IS operational in terms of its informative, applicative, collaborative and decision support components.

The best ways to implement the management of water information systems for ABH and ORMVA were examined, with the possibility of exchanging certain types of data to enhance the handling of information, and easy access in a timely manner. The first step involves handling theconversion of data into information that is useful and canpossibly support decision making. Then, a series of applications and tools will be added to aid in decision making.

STRUCTURE/ARCHITECTURE OF THE PROPOSED SYSTEM

The following elements are considered for the design of a standard architecture:

- Analysis of the needs: This step identifies the objectives of the GIS related to the institution's needs (February 2010 report).
- Detailed inventory of resources: This step requires an inventory of the resources related to GIS such as maps, plans, drawings, spatial and tabular data, databases, computer resources (equipment, software and network), and the skills and interests of the staff. This step describes the current status of the organization.
- Needs (priorities): It is not possible to implement a large number of applications simultaneously; the needs identified must be prioritized. This can be achieved by assigning a priority level to the needs, such as: critical, more urgent, very high, top, average and low. Applications that can be developed rapidly should be the highest priority to help see rapid progress during the implementation phase.
- Design of the system: This step recommends a GIS to support the applications identified in the preceding steps. It is a good idea to assess the current status of the organization in terms of the key functions and identify the required elements that are necessary to create the desired improvements. The design of the system consists of determining the specifications for the following components:
    - Conversion of data (mapping): About 75% of typical GIS costs are related to the conversion and creation of data. This component includes data conversion methods (scanning, digitization, etc.) and the source, resolution and scale of the maps or cartographic layers. Needs-based design is particularly critical for the conversion of data and database components. The design and content of the mapping elements and database determine the fundamental capacity of the entire GIS. These components can be considered the foundation of the system. Once the effective implementation has begun, major modifications to the mapping or design of the database can be very costly.
    - Database: A GIS database stores descriptive information on the functionalities of the maps in the form of characteristics. The creation of a GIS database is the most difficult and expensive part of the development of GIS applications. The success of the GIS applications resides in a well-designed database that provides appropriate information in a useful and accessible manner. Therefore, the design of the database is determined by the applications requirements. The design of the database is presented using a data dictionary, which documents the logical and physical structure of the layers of the GIS.
    - Software: GIS software represents less than 10% of the total cost of GIS in most cases. GIS software must be "open" in terms of architecture. An open GIS enables sharing geographic information and integration among different GIS, or related tools (remote sensing, for example), and applications such as hydraulic modeling. An open GIS can function on different operating systems, platforms and database management systems. It can be sized to support a wide range of applications requirements, from an engineer in the office using the GIS to a mobile field technician using a pocket PDA, to other users working on the system from other departments.

- Choice of equipment:Selection of the appropriate equipment depends on the scope of the GIS application project and available resources. GIS equipment can be set up as an autonomous workstation or in a network configuration. A configuration includes:
    - ✓ Computer with a fast processor, large memory and significant disk space
    - ✓ DVD reader
    - ✓ Large, high resolution (21 inchminimum) color screen
    - ✓ Backup and storage device such as a CD or DVD burner
    - ✓ Color printer
    - ✓ Large format color tracer
    - ✓ Large format scanner (if possible, otherwise A3)
    - ✓ High speed Internet connection (cable or ADSL)
    - ✓ GPS receiver (Mobile GIS)
    - ✓ Server computer (for network configurations)

Like GIS software, equipment accounts for less than 10% of the total GIS investment. Therefore, the cost factor alone should not be used to select the equipment. The following factors should also be taken into account: service and support, capacity for growth (storage and memory), connectivity with peripheral devices (printers, scanners, digitizers, GPS equipment, and field computers), and connectivity to the Internet and networks (intranet and extranet).

- User interface

DATA

As noted previously, the data warehouse should contain, among other things, all data characterizing the study region (watershed), as well as other layers specific to ABHM and ORMVAM.

The set of data includes the characteristics of the watersheds, including geographic, hydroclimatic, socioeconomic and environmental data, digital terrain elevation models, soil properties and use, and satellite images.

The GIS database includes the set of data necessary to execute the models and assess the impact.

Geographic layers include:

Physical Data:

- ✓ Geology (surface, hydrogeological characteristics)
- ✓ Soil (surface roughness, area, depth of the soil, texture grade, wilting point, porosity, field capacity, drainage properties)
- ✓ Soil coverage (area, harvest loss, interception coefficient, distribution of roots, etc.)
- ✓ Zones of ecological or cultural interest

Topographic and Geometric Information:

- ✓ Reference points (geodesic location and other fixed reference)
  Scope and boundaries of the basin

- ✓ Altitude information from which a digital terrain model (DTM), grid and TIN (triangulated irregular network) are derived, unless remote sensing images are used
- ✓ Hydrographic network (rivers, streams, lakes, name, length, hydraulic properties)

Social Data:

- ✓ Administrative boundaries and human organizations
- ✓ Location and intensity of the economic activities

Infrastructure:

Road network, paths, drinking water network, irrigation network, electrical network, telecommunications network, water distribution, dams and reservoirs, pumping stations, river regulation, treatment plants, industries, wastewater output, hydroagricultural equipment, etc.

Observation Networks:

- ✓ Meteorological network (hydrologic parameters such as precipitation, evaporation, temperature, wind parameters, moisture, exposure to the sun, pressure, radiation)
- ✓ Network measurement stations (flow, water level, discharge measurements, relationships of the water discharge level, transport of sediments (name, position, time, value)
- ✓ Quality control system (pH, water temperature, water turbidity, BOD-5, COD, N, heavy metals, etc.)

Some of these data may not be available at all, either when requested or at the desired spatial scale/resolution. Moreover, it should be noted that GPS is a revolutionary space age technology for the collection of GIS data. It is an effective and increasingly popular means of collection, at the same time asthe placement (coordinates) and characterization of data in the area. Most GPS receivers record their data in ASCI code (American Standard Code for International Interchange), which can be imported to a GIS with no need to retype the coordinates of the values. The latest GPS equipment can provide data in a GIS-compatible format, such as the ESRI Shapefile.

Statistical tools and the implementation of specific knowledge bases, in addition to remote sensing images to be acquired, will help fill the void/inadequacy of information.

Specific ABHM and ORMVAM data will be differentiated.

ABHM MODELS

Table 4summarizes the types of models that ABH uses or could use (Annex2).

Table 4: Standard Models for ABHM

Type of Models	**Use**	**Types of Public or Commercial Software**
Hydrologic	Predetermination, flood forecasting, rainfall-runoff model (calculation of a given recurrence interval flow in order to determine the size of a hydraulic structure, determination of a design	HEC-HMS, SWMMH, SPF, PRMS, SHE, etc.

	flood, real-time prediction of flows on bodies of water, etc.) Global, semi-distributed and distributed models Conceptual models, black-box	
Groundwater	Modeling, simulation and management of aquifers Demarcation of [water] supply areas and protected areas Demarcation of groundwater contamination Design and management of "on-site" contamination Excavation (quarries, sandpits, mines, etc.) impact assessments Environmental risk assessment associated with the presence of contaminants in the soil	ASMWIN, GMS, MODFLOW, FEMWATER, PEST, SEAWAT, FEFLOW, etc.)
Hydraulic	Rivers, Lakes, Bays, Drainage Channels, Estuaries	HEC-RAS, HEC, DYNHD, MIKE 11, SMS, TELEMAC, etc.
Water Quality	Rivers, Lakes, Bays, Drainage Channels, Coasts and Estuaries	BASINS, WASP, SWAT, QUAL2E, HEC, DYNHD, MIKE 11, SMS, TELEMAC, etc.
River/Reservoir/Use Management	Management, Simulation of Scenarios, Regulation	RIVERWARE, MODSIM, OASIS, DELFT-TOOLS (RIBASIM, HYMOS, SOBEK), MIKE-BASIN, HEC-ResSIM, etc.

Models appropriate for ABHM will be selected from these models.

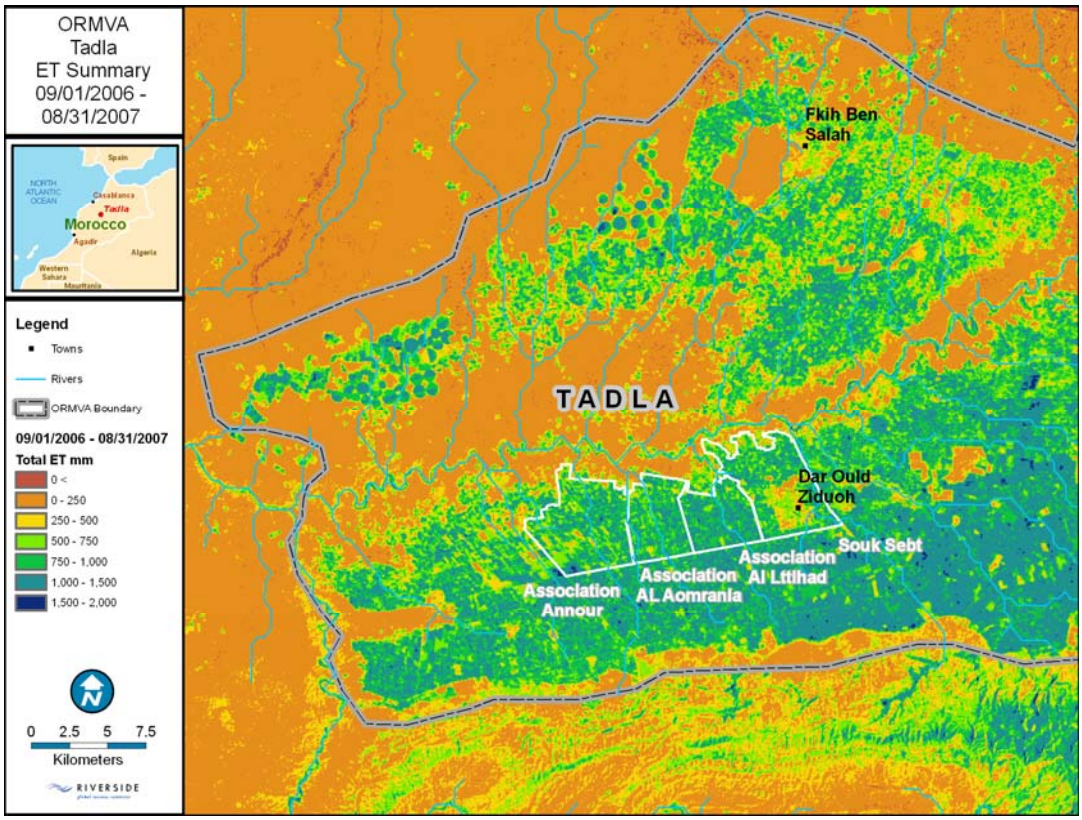
ORMVAM MODELS

A few existing tools for irrigation planning and water management are presented for illustration purposes.

We are presenting two specific types of software to help managers of water and irrigants allocate water and sequence the delivery, with the objective being to help ORMVA estimate the productivity of water, and with the monitoring and effectiveness of the modeling system for the current irrigation systems and for the conversion to drip or other types of irrigation.

- CropWat 8.0 is a Windows program for estimating the crop water requirements and irrigation. The calculations are based on FAO Publication No. 56 "Crop evapotranspiration –Guidelines for computing crop water requirements" and No. 33 "Yield response to water," including application of the Penman-Monteith Method. The program facilitates the development of irrigation schedules and evaluation of irrigation practices with irrigation and rain conditions. CropWat includes interfaces in French and online help.
- The CLIMWAT database provides the climate by default, crops and soil to meet the CropWat requirements. Real time, on-siteuse and historic data enable CropWat to examine the issues of managing planning, productivity of water and crop yields. This software is available free of charge from the FAO site.
- TrueISM (water tower management) is software that manages irrigation scheduling efforts, evapotranspiration and soil moisture calculations, when taking an inventory and maintaining irrigation systems. The software uses historic data to analyze trends and automatically interfaces with data acquisition networks in real time. Its functionalities allow the creation of Web and hard copy reports for individual water users and interested parties (commercial).
- Use of satellite images to map and monitor evapotranspiration: Quantifying the consumption of water over large surfaces and in irrigation projects is essential to predicting water requirements, managing water rights, planning water resources and regulating water. Due to the difficulty of obtaining this information, however, it is often poorly understood and represented as a component of the analysis of the hydrological balance and decision-making tools for water resources. With images available free of charge from NASA USGS/(Landsat) satellites, ORMVAM can use new satellite image processing algorithms to estimate accurately the evapotranspiration of irrigated land in order to manage and monitor the use of irrigation water and efficacy.
- Metric is an image processing model composed of several sub-models for the calculation of evapotranspiration as a remnant of the surface energy balance. Metric has been widely used with Landsat images in many regions throughout the world, including a study conducted recently by Riverside, funded by the World Bank (the document on evapotranspiration in the pilot areas of Doukhala, Haouz, Tadla and in the Oum Er Rbiaa basin in Morocco, Riverside 2010). Therefore, we propose assisting ORMVAs with the acquisition of Landsat images and their processing using the Metric approach to determine evapotranspiration over the entire irrigated surface. Evapotranspiration data are spatial, and can therefore be incorporated in the area or sector for evaluation, analysis of the hydrological balance and monitoring. In addition, if applicable, a hybrid approach using vegetation indices (NDVI) can be used to estimate evapotranspiration with significantly less processing and analysis. The figure below illustrates a typical result of calculations used for the Oum Er Rbiaa basin.

Figure 2: Example of Cumulative Annual Evapotranspiration Map derived from satellite images for ORMVAT (Riverside, 2010)



Moreover, various other tools described below are desired:

- ✓ Processing and analysis procedures for sustainable and rational management of water (development of specific applications)
- ✓ Management and monitoring of care and maintenance operations for the irrigation and drainage networks and tracks
- ✓ Management and monitoring of the use of the soil with the objective of meeting the demand for water
- ✓ Management of water towers and billing
- ✓ Management of distribution personnel
- ✓ Management of agricultural production
- ✓ Utilities and database to monitor water users, livestock farming, etc.

COMMON STRUCTURE

The common structure of the IS must take into account the possibility of exchanges between ABH and ORMVA as well as all other potential customers or partners, and should include the following modules:

- ➢ ***Partners*** responsible for a set of measurement points or structures
- ➢ ***Removal points/structures***relating to the following water resources:

- ✓ Surface water
- ✓ Groundwater
- ✓ Unconventional water
- ✓ Mixed waters
- ✓ Wastewater

Structures must be identified by their IRE No. and/or name.

- **Uses of water, including**:
  - ✓ Supply of drinking water
  - ✓ Irrigation
  - ✓ Power production
  - ✓ Recharge of aquifers
  - ✓ Other
- ***Parameters***can be measured at each structure/removal point belonging to the following categories:
  - ✓ Quality
  - ✓ Quantity
  - ✓ Other
- ***Geographic location***of theremoval points/structures through their Lambert coordinates and affiliation with a province, *cercle*and village.
- ***Chronological series of the parameters and measurement frequency***

Information related to each module must be grouped into clear and explicit tables. The database must be usable through a search engine, which will enable the execution of pre-established queries relative to the:

- ✓ Partners and structures they handle
- ✓ Resources available in the basin
- ✓ Parameters measured by the partners
- ✓ Uses of the water
- ✓ Pollution able to threaten the basin
- ✓ Locations subject to measurement
- ✓ Timeline of measurement monitoring

The reasoning is to develop a water governance (ABH) or irrigation governance (ORMVA) database as developed in Figure 3 (Concept of Governance), Figure 4 (ABHM Characteristics) and Figure 5 (ORMVM Characteristics), which group as well the specialty area, data, services, customers, etc. aspects, which would be combined with various specialty areaapplications to analyze usage scenariosand support decision making.

Figure 3: WGDB at the Core of the Water Governance Process

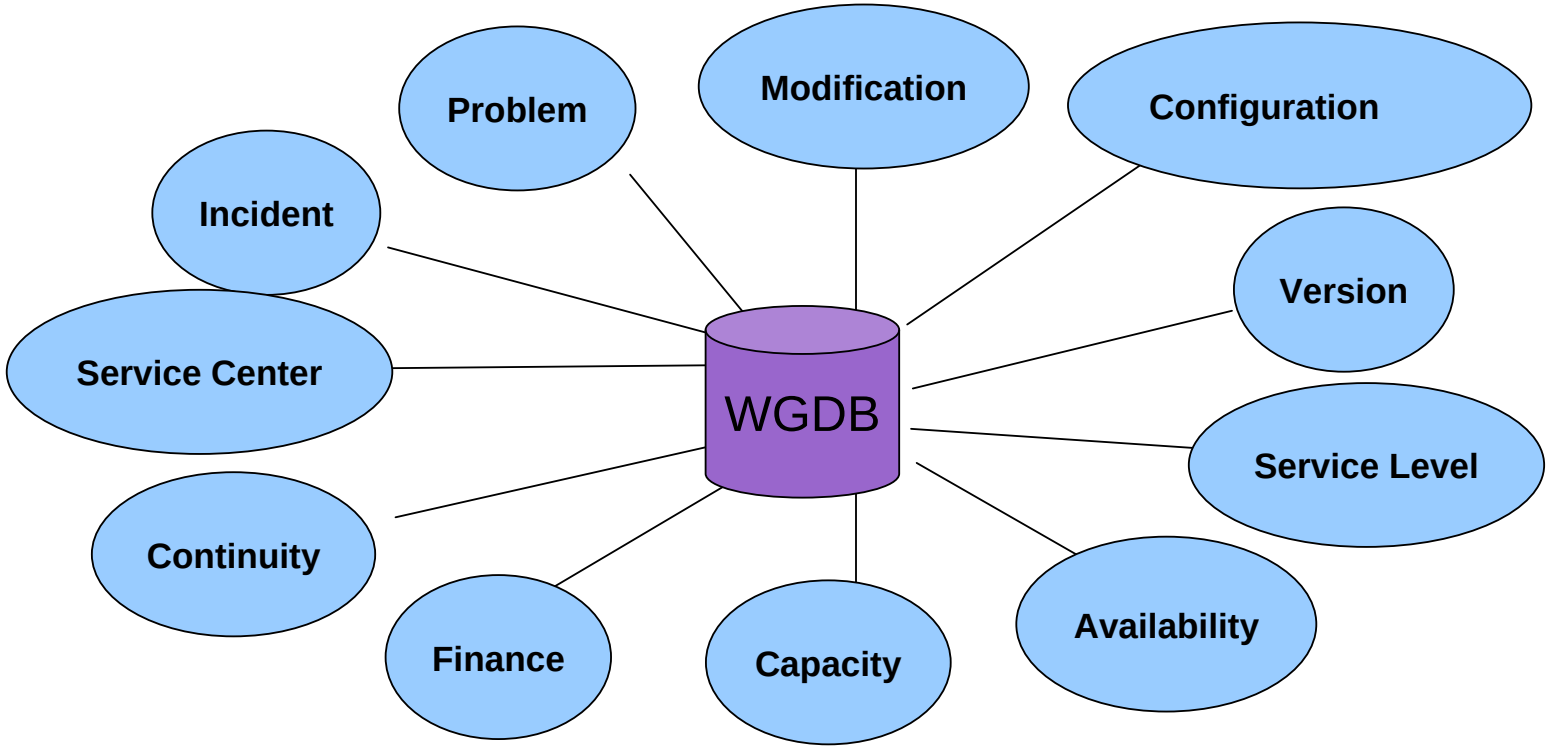


Figure 4: Proposed Architecture– ABHM

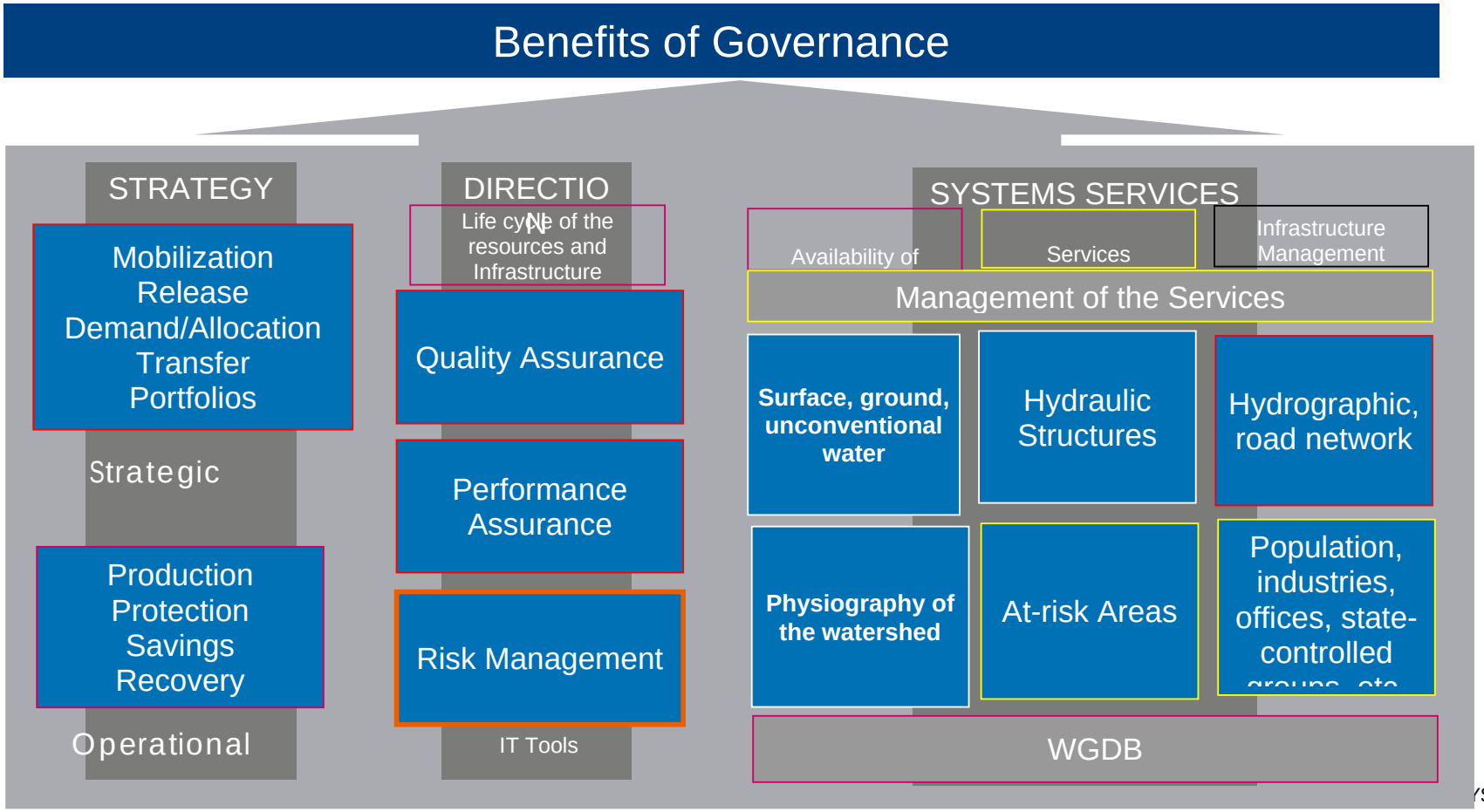
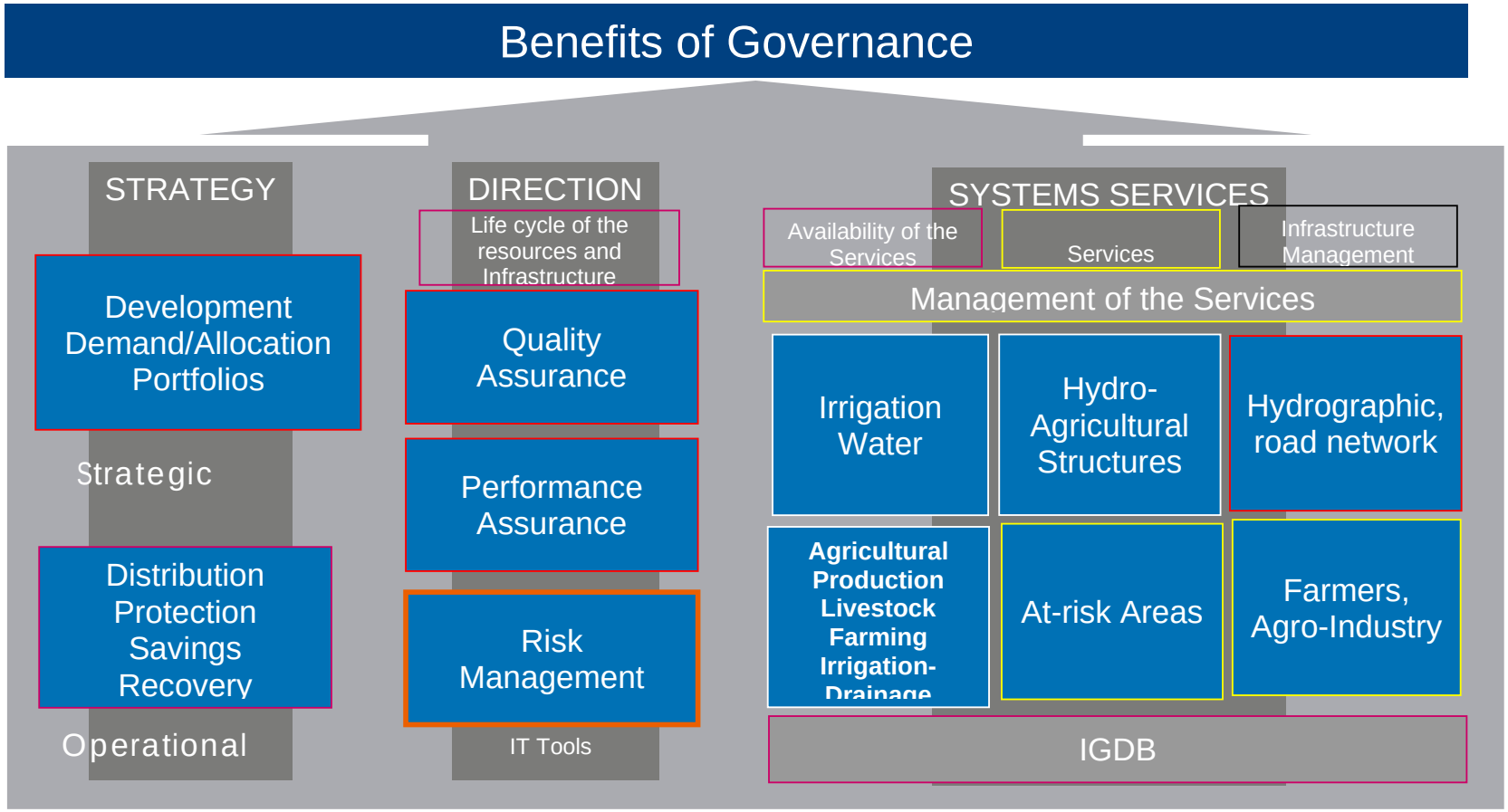


Figure 5: Proposed Architecture – ORMVAM/ORMVAD



STRUCTURE AND INSTALLATION OF THE ABHM IS

The GIS architecture proposed for ABHMis ArcGIS, for the following reasons:

- ✓ All users will work via the Internet with the same interface.
- ✓ All users will add data to the same central database (Oracle or other).
- ✓ All users see the data in real time.
- ✓ All users have access to the same set of thematic data.
- ✓ All users have access to the model reports/statistics/maps.
- ✓ Ease of central administration of users, data and the application.
- ✓ It is easy to add new data and models/forms via the application.
- ✓ Possible to connect with other GIS applications to recover data in real time

However, this solution requires immediately hiring a computer engineer to deal with it and a certain degree of computer literacy, in GIS specifically. While waiting to achieve these capacities through training, practice and familiarization with spatial data and GIS applications, we suggest the first step of creating and developing a cross GIS unit at ABHM (transitional phase) for a one-year period. Once operational, and a computer engineer is hired, focus will be shifted toward the ArcGIS Server solution.

Proposed Configuration

The following configuration is proposed for the first step:

Hardware/Software:

- ✓ 1 cartographic server
- ✓ 3 PCs
- ✓ 1 A0 plotting board
- ✓ 1 A0 Scanner
- ✓ 1 A3 Scanner
- ✓ 1 ARC GIS license and multi-user (3 users) spatial analysis tools (ORACLE DBMS available)
- ✓ 1 Erdas Imagine license/or ER Mapper/or ENVI for analysis and processing of satellite images
- ✓ 2 Mobile GIS ArcPad GPS

Specialty area software/modeling and simulation (Annex 2):

- ✓ Spatial hydrology
- ✓ Surface water
- ✓ Groundwater
- ✓ Quality
- ✓ Reservoirs/Rivers

Training on Products:

(DBMS, GIS, GPS, Remote Sensing, Specialty Area Software, Modeling, Simulation, Optimization)

Support/Supervision of certain developments:

- ✓ Database, applications related to hydrologic spatialization and rainfall-runoff models, hydrogeology, quality and storage dam management models, etc.
- ✓ Monitoring certain aspects related to the various customers and partners, etc.

STRUCTURE AND INSTALLATION OF AN IRRIGATION IS AT ORMVAM/ORMVAD

This will involve the development and installation of a Geographic Information System at the Regional Agricultural Development Authority to manage and use irrigation systems, which will cover:

- ✓ The activities areas covered by the system to be set up follow:
- ✓ Management of irrigation water customers
- ✓ Management of water distribution
- ✓ Management of consumption
- ✓ Management of irrigation water billing
- ✓ Management of recovery monitoring

The system will include a:

- ✓ Database
- ✓ Set of applications to be planned for analysis, management and decision making, as well as dissemination of information

From the operational perspective, the system must permit:

- ✓ Determining the size and installation of spatial databases with clear, pertinent and reliable information on the Moulouya area (ORMVAM)
- ✓ Strengthening through training activities the technical skills of ORMVAM managers and technicians in GIS and remote sensing to ensure sustainability
- ✓ Establishment of processing and analysis procedures for sustainable and rational management of water (development of specific applications)
- ✓ Management and monitoring care and maintenance operations for irrigation and drainage networks and tracks
- ✓ Management and monitoring of the use of soil with a view to satisfy the demand for water

The execution of this project is structured in three phases (see planning of the information system installation process):

Phase 1:

This phase has been completed. The following activities were carried out during this phase:

- ✓ Diagnostic analysis of the information system existing at the ABHs and ORMVAs
- ✓ General design of the functional architecture of the IS
- ✓ Basic identification of the computer tools to be purchased, and
- ✓ Organization of workshops to present the findings of the assessment

Phase 2:

- Exhaustive inventory and detailed analysis of all existing data files (format, reliability, etc.) at the ABHs and ORMVAs. Missing data will be identified and the training requirements will be assessed.
- Analysis and determination of the size of the GIS

- Establishment of the GIS unit at the office (engineers and technicians)
- Data collection and development of the spatial database
- Training and technology transfer

The second phase of the project will also consist of analyzing ORMVA requirements more precisely and understanding the "specialty" characteristics of the management of irrigated areas. This is an essential phase, which guarantees optimal operation of the system, its viability and permanence. These specific requirements at the ORMAs concern specifically:

- ✓ Locating the action area of the ORMVAs (parcels, sectors, etc.)
- ✓ Locating the irrigation networks, pumping stations and other structures
- ✓ Their hydraulic and/or technical characteristics
- ✓ Monitoring the condition of their functionality and maintenance
- ✓ Management of water towers and billing
- ✓ Management of distribution personnel
- ✓ Management of agricultural production
- ✓ Utilities and DB to monitor water users, livestock farming, etc.

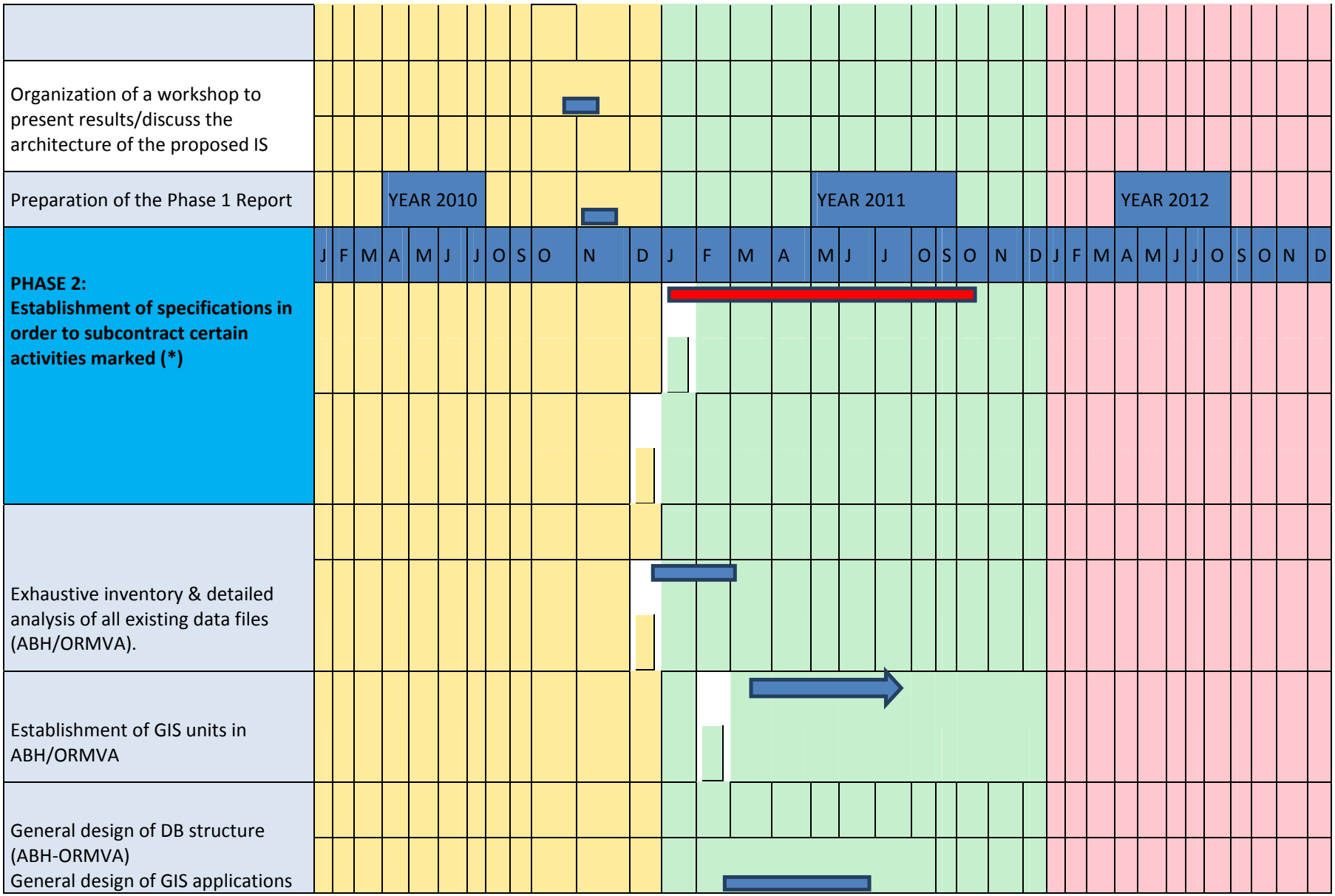
Phase 3:

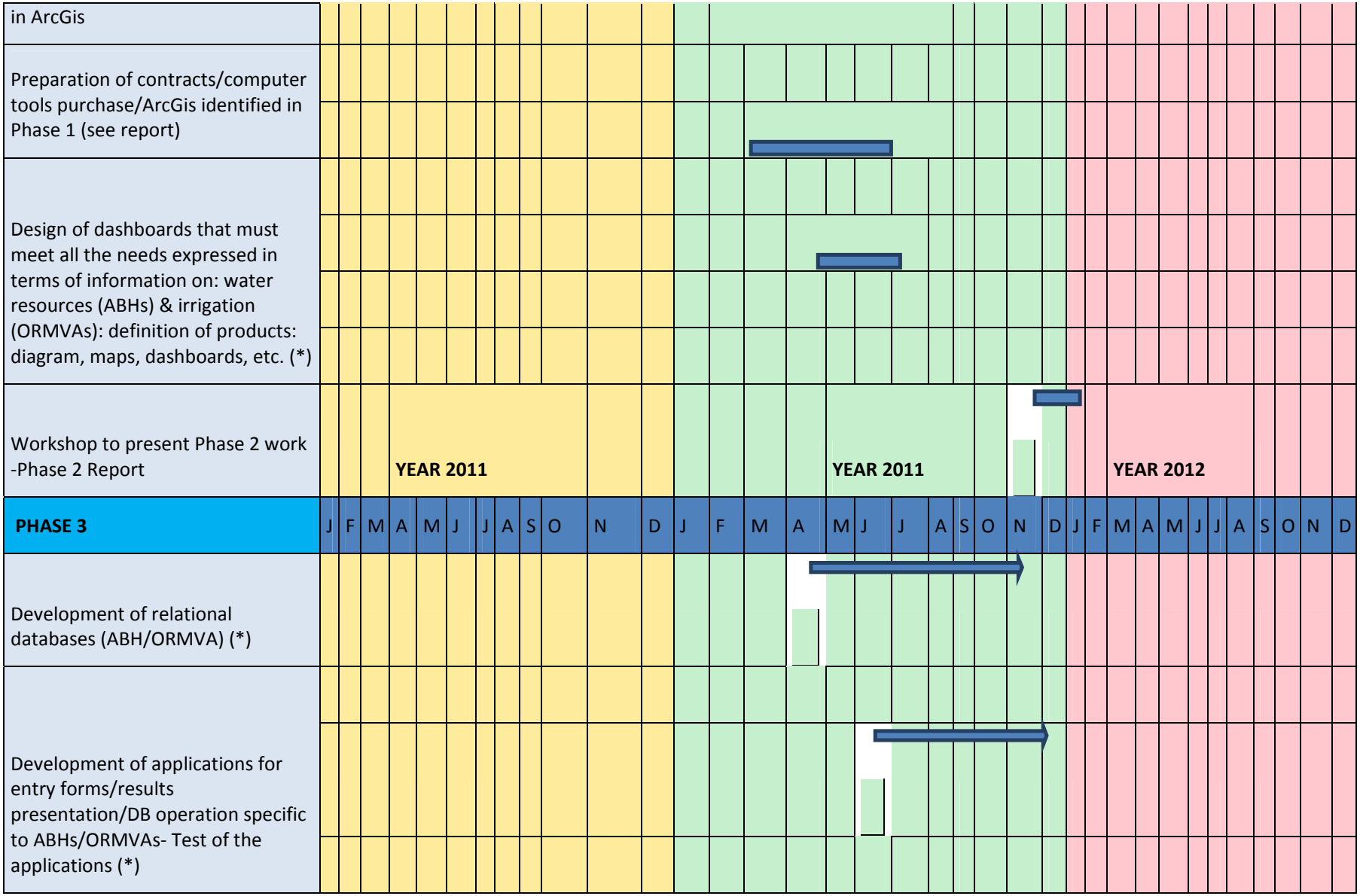
- ✓ Creation of the spatial database
- ✓ Development of applications specific to ABHs and ORMVAs
- ✓ Test and installation of the IS
- ✓ Training the team responsible for managing the IS

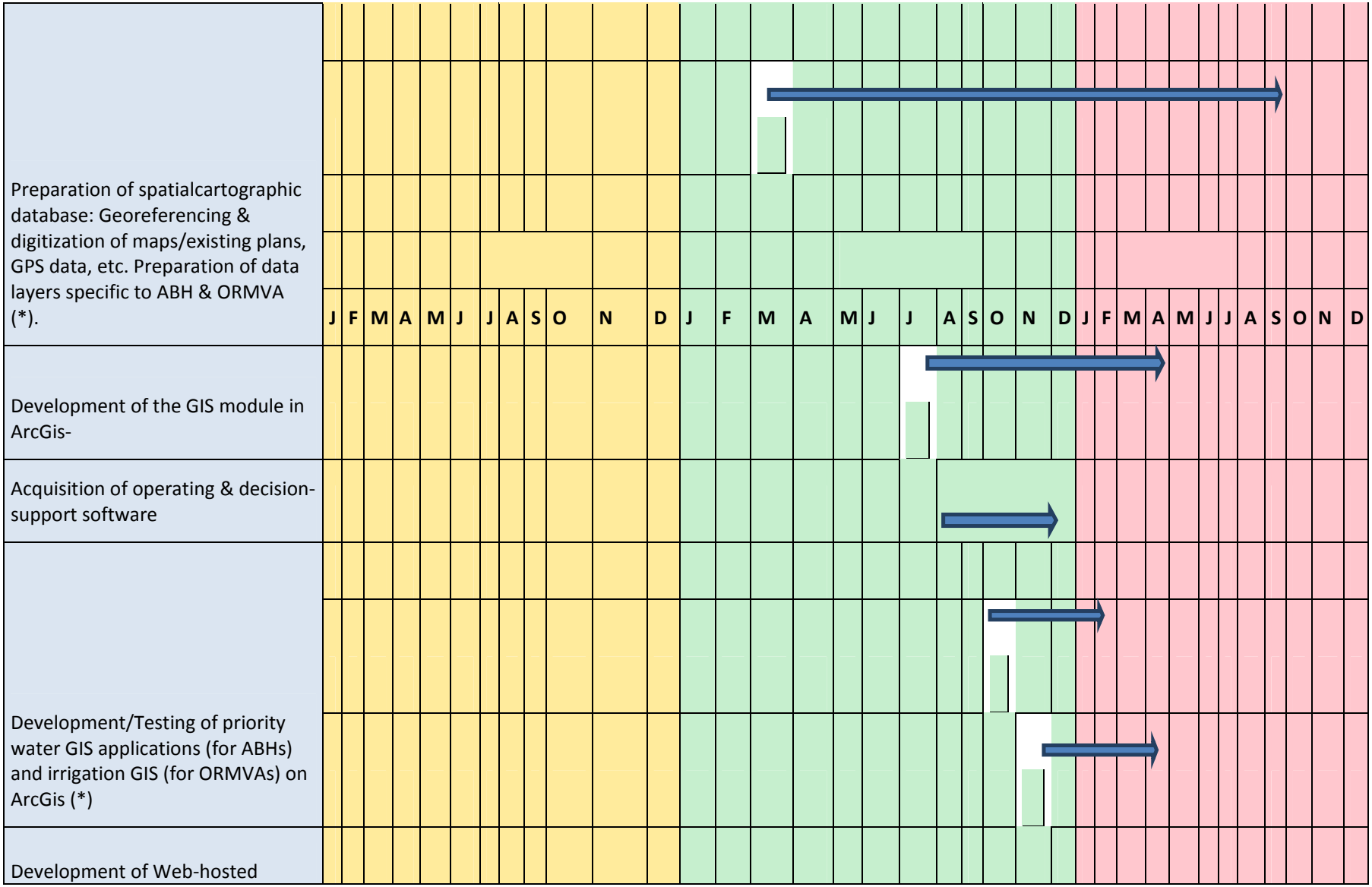
It should be noted that an important prerequisite to this phase is the development of electronic document management, which would enable in the first step archiving all plans, maps, drawings and other ORMVAM documents. Once the principal data have been acquired, the project will go on to the next step, which consists of processing the information for analysis and decision-making purposes. It involves developing GIS applications that enable the use of databases and satisfying specific needs related to the management of irrigation water. These applications must be simple and concrete, meeting the needs expressed by the managers.

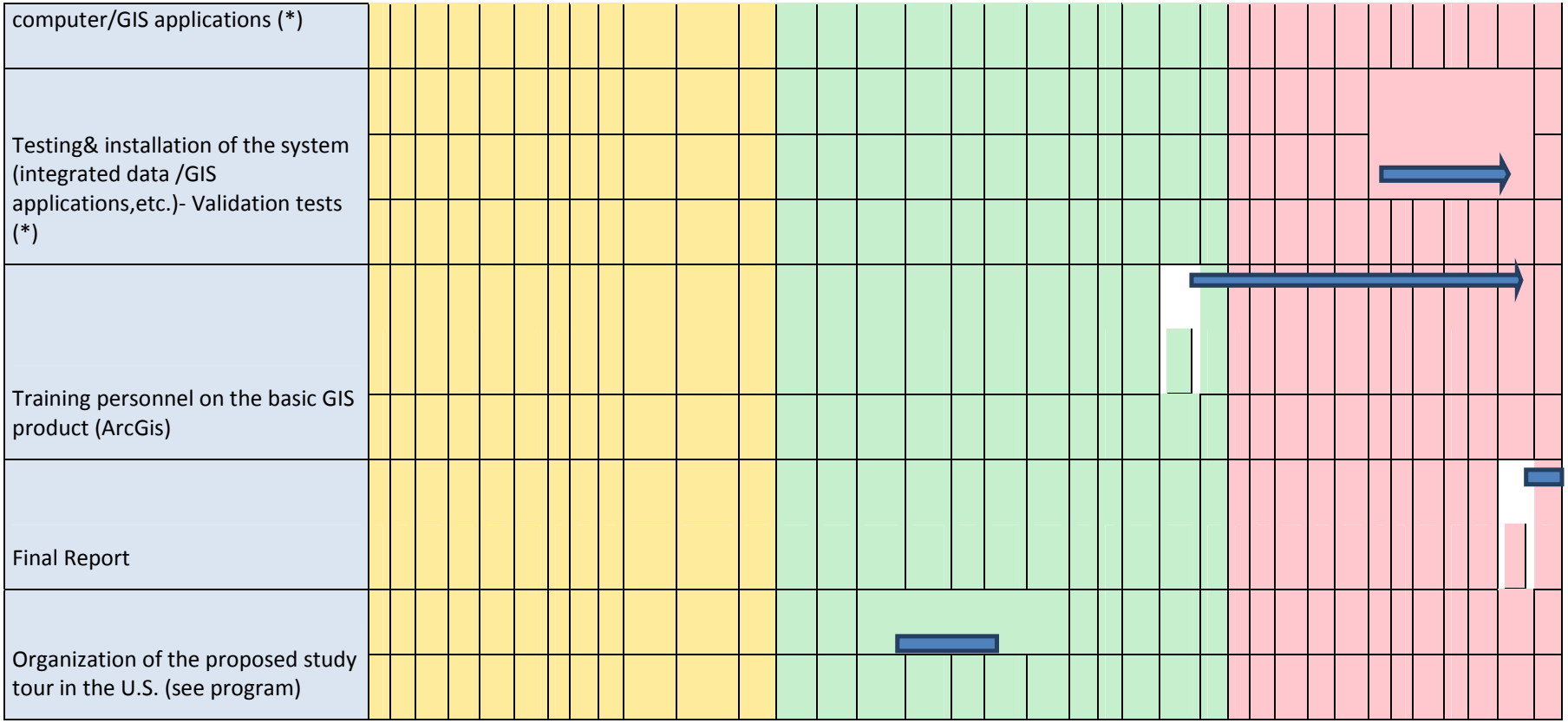
PLANNING THE IRRIGATION/ WATER INFORMATION SYSTEM DEVELOPMENT PROCESS IN ABHs AND ORMVAs

DESCRIPTION OF THE ACTIVITIES	YEAR 2010												YEAR 2011												YEAR 2012											
PHASE 1:	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Assessment of the existing information system at ABHM-ORMVAM- ABHER-ORMVAD-Survey of Needs																																				
Organization of workshops with ABHM, ORMVAM and ABHOER to present/discuss results of the assessment																																				
General design of the functional architecture of the IS																																				
Basic identification of the computer tools/ArcGis (hardware/software), to be purchased/installed for ABH/ORMVA- Estimate of the costs.																																				


Organization of a workshop to present results/discuss the architecture of the proposed IS
Preparation of the Phase 1 Report
YEAR 2010
YEAR 2011
YEAR 2012
J F M A M J J O S O N D J F M A M J J O S O N D J F M A M J J O S O N D
PHASE 2:
Establishment of specifications in order to subcontract certain activities marked (*)
Exhaustive inventory & detailed analysis of all existing data files (ABH/ORMVA).
Establishment of GIS units in ABH/ORMVA
General design of DB structure (ABH-ORMVA)
General design of GIS applications


in ArcGis
Preparation of contracts/computer tools purchase/ArcGis identified in Phase 1 (see report)
Design of dashboards that must meet all the needs expressed in terms of information on: water resources (ABHs) & irrigation (ORMVAs): definition of products: diagram, maps, dashboards, etc. (*)
Workshop to present Phase 2 work -Phase 2 Report
YEAR 2011
YEAR 2011
YEAR 2012
PHASE 3
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
Development of relational databases (ABH/ORMVA) (*)
Development of applications for entry forms/results presentation/DB operation specific to ABHs/ORMVAs- Test of the applications (*)


Preparation of spatialcartographic database: Georeferencing & digitization of maps/existing plans, GPS data, etc. Preparation of data layers specific to ABH & ORMVA (*).
Development of the GIS module in ArcGis-
Acquisition of operating & decision-support software
Development/Testing of priority water GIS applications (for ABHs) and irrigation GIS (for ORMVAs) on ArcGis (*)
Development of Web-hosted
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D


computer/GIS applications (*)
Testing& installation of the system (integrated data /GIS applications,etc.)- Validation tests (*)
Training personnel on the basic GIS product (ArcGis)
Final Report
Organization of the proposed study tour in the U.S. (see program)

Proposed Configuration

Hardware/Software:

- ✓ 1 cartographic server
- ✓ 3 PCs
- ✓ 1 A0 plotting board
- ✓ 1 A0 Scanner
- ✓ 1 A3 Scanner
- ✓ 1 ARC GIS license and multi-user (3 users) spatial analysis tools (ORACLE DBMS available)
- ✓ 1 Erdas Imagine license/or ER Mapper/or ENVI for analysis and processing of satellite images
- ✓ 2 Mobile GIS ArcPad GPS

Software and Specialty Area Tools

Tools to monitor irrigation, production and recovery

Training on Products:

(DBMS, GIS, GPS, Remote Sensing, SpecialtyArea Software, Modeling,)

Support/Supervision of certain developments (parcel information system, water towers, monitoring certain aspects related to irrigation efficiency, etc.)

IMPLEMENTATION SCHEDULE AND ESTIMATED BUDGET

An execution plan determines the actions and resources necessary to implement a GIS. It provides information on the phasing, costs, staff, training, operation and maintenance. Progressive implementation is preferable.

The phases must be designed to distribute the costs equally and allow a comfortable rhythm over the course of the project. For success, rapid implementation of high-impact applications, which can be used immediately, should be put first. Integration of the GIS in the information systems and other applications is beneficial, but technically complex. It will require a great deal of care.

Key factors to success such as acquisition of equipment, software installation and testing, training and workshops, feeding the database, testing the database and development of applications - as milestones- will make it possible to measure success in small steps throughout the execution process. The milestones must specify the set of data, applications and users' access.

User participation is a key factor to the success of a GIS project and the modeling and decision support applications related to it. They [users] should be included in all stages of the development of a GIS, preparation of data and execution of models on practice cases, rather than needs analysis interviews alone.

Estimated Budget

The estimated budget basically includes the following items:

1. GIS requirements, DBMS Software/Hardware

Purchase of GIS, DBMS equipment and software

2. DBMS, GIS and remote sensing training.

3. Exhaustive inventory of data (ABH and ORMVA level)and their conversion, and models to refine the needs in terms of conceptual models of the data and development of spatial databases and focused specialty models.

4. Specialty Models

Annex 2 presents all types of models from which a useful priority set will be extracted for ABHM, with those of the ORMVAs being relatively well defined.

5. Training on Specialty Models

6. Subcontracting of specific applications to engineering firms:

(Topography, consulting, metrology, data conversion, archiving, databases, etc.).

7. Establishment of agro-meteorological measurement stations for ORMVAM/ORMVAD.

8. Acquisition and installation of hydrometeorological telemetry stations for ABHM.

It should also be noted that the institutions are responsible for the basic equipment for the room housing the tools (stable supply of electricity, uninterruptable power supply and protective devices, air conditioning, high-speed Internet connection). Operating systems (generally Windows for partners) are also required.

The estimated partial budget including essentially the basic GIS equipment and software, basic training on DBMS, GIS and the related development is estimated at nearly US$1 million, to which a supplemental budget must be added for subcontracting certain applications to engineering firms, the purchase and installation of agro-meteorological measurement stations and hydrometeorological telemetry stations, as well as the budget necessary for the proposed study tour.

RECOMMENDED IMMEDIATE ACTIONS – NEXT STEPS

- Establish an exhaustive inventory of the data and models existing at the ABHM and ORMVAs for a better grasp and clearer understanding of the data requirements of the models in order to finalize the conceptualization phase and acquisition of the equipment/software/models/other tools.
- Schedule a 7 to 10 day study tourof the U.S. (Annex 1) for Moroccan RBA and ORMVAofficials. The objective of this tour is to show these officials the results of operational IS at American organizations, results used in applications that can be adapted to the ABH and ORMVA context. American federal agencies include government workers in the field of water management, water districts (management based on multiple uses of irrigation, municipal, industrial and environmental uses) and irrigation companies. This would give them a better idea of the contribution information systems can make, the human resources involved, organization and potentially improved productivity.

ANNEX 1: POTENTIAL STUDY TOUR FOR MOROCCAN RBA AND ORMVA OFFICIALS

Objective: Expose RBA and ORMVA officials to U.S. agencies involved with research, operations, international programs relevant to Morocco. Focus on successful IMS that are used in applications similar to the Morocco context. This could be a stimulating dialogue for both sides. Agencies would include U.S. federal, state water management officials, water districts (managing for multiple uses including irrigation, municipal, industrial, environmental) and irrigation companies.

LOCATION	OFFICES TO VISIT	SUBJECT MATTER
• Washing-ton, D.C.	• United States Bureau of Reclamation (USBR); International Office	• Databases; Information Management Systems (IMS) • Irrigation Water Management • Reservoir Operations • Water Quality • Multiple Use & Water Resources Allocation
	• United States Army Corps of Engineers (USACOE); International Office	• IMS and Database Management • River Basin Modeling Management • Reservoir Operations • Geographic Information Systems
	• United States Geological Survey (USGS); International Office	• IMS • Real Time Monitoring International River Basins • Water Quality Modeling
	• National Oceanic and Atmospheric Administration (NOAA);	• Hydrology and Meteorology • Flood Forecasting • Climate Change, Adaptation and Water

LOCATION	OFFICES TO VISIT	SUBJECT MATTER
	o U.S. National Weather Service (US NWS) International Activities Office	Management • Flood Forecasting
	• National Aeronautic and Space Administration (NASA)	• IMS • Remote Sensing for Water Management • Geospatial Modeling • Satellite Missions for Monitoring Earth Processing and Water Resources
• Colorado	• USBR/Denver; Technical Services Center	• Water Resources Management • Water Resources Lab • International Water Management • Salinity and Water Quality
	• State of Colorado o Colorado Water Conservation Board o State Engineers Office	• Water Allocation • Water Laws • Decision Support Systems for Water Resources Management
	• Northern Colorado Water Conservancy District	• Irrigation Scheduling • Groundwater Monitoring and Management • Water Supply Forecasting and Management • Transboundary Diversions and Monitoring • Water Rights and Allocation
	• North Poudre Irrigation Company	• Irrigation Management • Water Supply • Monitoring and Efficiency of Irrigation Methods

LOCATION	OFFICES TO VISIT	SUBJECT MATTER
	• Colorado State University; International Programs	• Water Resources Management • Research and Applications for Water Management • International Center for Modeling and Climate Change Analysis
	• EPA, USGS	
	• Environmental Systems Research Institute	• GIS and Data Modeling • Spatial Data Visualization •
	• Riverside Technology, inc	• Decision Support for Water Management • Real Time Hydrometeorological Data Collection Networks • Time Series Data Management and Analyses • Flood Forecasting; Reservoir Operations • Evapotranspiration and Consumptive Use Modeling • GIS and Remote Sensing • Climate Change Modeling

ANNEX II: ALTERNATIVE MODELS FOR CONSIDERATION

INTRODUCTION

The following tools (Chemtronics, 2004; Riverside 2005) are potentially available for use by the MEC, subject to possible licensing requirements. The models are presented under six general categories:

- Hydrologic Models
- Groundwater Models
- Hydraulic Models
- Water Quality Models
- River / Reservoir / Use Management Models
- Other DSS / IMS Areas Not Summarized herein

HYDROLOGIC MODELS

Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS; HEC, 2001)

The USACE Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) is an event based precipitation-runoff model. In addition to the basic watershed modeling capabilities, HMS includes several other optional features involving: partially automated parameter calibration, multiplan/multiflood analysis, dam safety analysis, economic flood damage analysis, and flood control system optimization.

An HMS precipitation-runoff modeling application typically involves dividing a watershed into a number of sub-watersheds for analysis. HMS provides flexible options for developing and/or inputting precipitation data, which may reflect snowfall and snowmelt as well as rainfall. Precipitation volumes are converted to direct runoff volumes using one of the following optional methods: Soil Conservation Service curve number method; initial and uniform loss rate; exponential loss rate function; Holtan loss rate function; or Green and Ampt relationship. Runoff hydrographs are computed from the incremental runoff volumes using either the unit hydrograph or kinematic routing options. A unit hydrograph may be input to HMS. Watershed modeling also involves routing hydrographs through stream reaches and reservoirs. HMS uses hydrologic storage routing for reservoirs. The following channel routing options are provided: Muskingum, Muskingum-Cunge, modified Puls, working R and D, average lag, and kinematic wave. HMS includes modeling capabilities such as snowmelt rather than just rainfall; flood control economic analyses; and partially automating parameter calibration.

HEC-HMS is available free of charge from HEC with no support available for non-Corps users.

Stanford Watershed Model (SWM; Crawford and Linsley, 1966)

SWM and its variations are composed of a set of water budget accounting procedures that incorporate computational routines for the various hydrologic processes such as interception,

infiltration, evapotranspiration, overland flow, channel routing, and so forth. Time series input data include precipitation, potential evapotranspiration, and, if snowmelt is modeled, additional meteorological data. In the model, precipitation is stored in the snowpack and in three soil-moisture zones (upper, lower, groundwater). The upper and lower storage zones account for overland flow, infiltration, interflow, and inflow to groundwater storage. Groundwater storage supplies baseflow to stream channels. Evaporation and transpiration may occur from any of the three storage zones. The runoff from overland flow, interflow, and base flow enters the channel system and is routed downstream. Model output includes continuous outflow hydrographs.

Derivatives of the Stanford Watershed Model include (Viessman et al., 1989; Ponce 1989) the **Kentucky Watershed Model**, **Texas Watershed Model**, **Ohio Watershed Model**, **U.S. Department of Agriculture Hydrograph Laboratory (USDAHL) Model**, **Sacramento Model** including its implementation in the National Weather Service River Forecast System (NWS-RFS), **Hydrocomp Simulation Program**, and **Hydrological Simulation Program-Fortran (HSPF)**.

Several implementations of SWM are available free of charge. Others come as part of licensed software packages; pricing varies.

Hydrological Simulation Program-Fortran (HSPF; Johanson et al., 1980, 1984)

The current successor model to SWM provides relatively sophisticated capabilities for continuous simulation of a broad range of hydrologic and water quality processes. HSPF is "a comprehensive package for simulation of watershed hydrological and associated water quality processes on pervious and impervious land surface, in the soil profile, and in streams and well-mixed impoundments" (Donigian et al., 1984). HSPF consists of a set of modules arranged in a hierarchical framework, built around a time series management system. The various simulation and utility modules can be invoked individually or in various combinations. The structured design of the model facilitates users adding their own modules, if they so desire. HSPF simulates watershed hydrology and water quality for both conventional and toxic organic pollutants. Input data include time histories of rainfall, temperature, and solar radiation; and information regarding land-surface characteristics, such as land-use patterns and soil properties, and land-management practices. The model predicts flow rates, sediment loads, and nutrient and pesticide concentrations. HSPF allows integrated simulation of land and soil contaminant runoff processes with instream hydraulic and sediment-chemical interactions. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical. The transfer and reaction processes modeled are hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption. Sorption is modeled as a first-order kinetic process in which the user must specify a desorption rate and an equilibrium partition coefficient for each of the three solid types. Benthic exchange is modeled as sorption/desorption and desorption/scour with surficial benthic sediments.

There are three main modules in HSPF (PERLND, IMPLND, and RECHRES) that simulate hydrological and chemical processes in pervious land cover, in impervious land cover, and in reaches. PERLND treats the land surface and the underlying soil profile as a series of connected storage reservoirs, each of which receives either inputs, spills output, or both. IMPLND is much simpler than the PERLND due to the absence of the soil profile, since no water is considered to move beyond the land surface. RESCRES routes both water and chemicals entering a reach from the land segment to the downstream point. HSPF simulates sediment transport processes at the hill slope and reach levels. The model assumes that the transported sediment material consists of sand, silt, and clay. Several options are available for the model user to estimate the sediment load from the land to the reach and the final load at the outlet.

Various chemical constituents can be modeled in HSPF. It is assumed in the model that constituents undergo various chemical processes in the pervious land segment (this is not the case for the impervious land). The model considers adsorption and desorption of constituents to material in the

soil and sediments, mineralization/immobilization processes, and plant uptake. Constituents removed from the land in either dissolved form or associated with sediment are delivered with runoff to the main river channel where chemical stream processes occur until the outlet is reached.

HSPF is available free of charge from the USGS. A high quality graphical user interface to HSPF is available in the Watershed Modeling System (WMS; EMRL, 2004) licensed at $4,600 for a single user.

Precipitation-Runoff Modeling System (PRMS; Leavesly et al., 1983)

The U.S. Geological Survey (USGS) Precipitation-Runoff Modeling System (PRMS) performs computations on both a daily and smaller time-interval storm scale using variable time steps (DeVries and Hromadka, 1993). During a storm event, time intervals as small as a minute may be used to compute runoff using kinematic flood routing for a watershed represented by interconnected flow planes and channels. A daily interval is used between storm events. Streamflow is computed as mean daily flow. In PRMS, a watershed is represented by a number of hydrologic response units (HRUs) each of which is assumed to have homogeneous hydrologic characteristics. Hortoninan infiltration is modeled with the Green-Ampt infiltration method. HRU parameters include surface slope, aspect, elevation, soil type, vegetation type, and distribution of precipitation. PRMS performs water and energy balances for each HRU, and the watershed response is the sum of all pertinent HRU responses. PRMS can be used in combination with the USGS ANNIE data management program, and a modified version of the National Weather Service (NWS) Extended Streamflow Prediction (ESP) model to provide a comprehensive watershed modeling system.

The Modular Modeling System (MMS), an outgrowth of the development of PRMS, is an integrated system of computer software that is being developed to provide the research and operational framework needed to support development, testing, and evaluation of physical process algorithms and to facilitate integration of user-selected sets of algorithms into operational environmental-process models (Leavesley et al., 1996; Leavesley et al., 2004). MMS includes PRMS. A geographic information system (GIS) interface, the GIS Weasel, has been developed to support MMS in model development, application, and analysis. The GIS Weasel permits application of a variety of GIS tools to delineate, characterize, and parameterize the topographic, hydrologic, and biologic features of a physical system for use in a variety of lumped and distributed parameter modeling approaches. The integration of the GIS Weasel and MMS provide a flexible framework in which to integrate and apply environmental models and analytical tools. MMS was integrated with the Object Modeling System and is available free of charge (Javaforge, 2010).

Systémè Hydrologique Europeen (SHE; Abbot et al., 1986a, b)

SHE was developed jointly by the Danish Hydraulic Institute, United Kingdom Institute of Hydrology, and SOGREAH in France with financial support from the Commission of European Communities (Abbott et al., 1986; DeVries and Hromadka 1993). SHE is a physically based, distributed parameter watershed modeling system which incorporates the major hydrologic processes including precipitation, snowmelt, canopy interception, evapotranspiration, overland flow, saturated and unsaturated subsurface flow, and channel flow. Spatial variability of the hydrologic processes is represented by a rectangular grid in the horizontal plane and vertically by a series of horizontal planes at various depths. SHE may be applied in analyzing irrigation schemes, land-use changes, water development projects, groundwater contamination, erosion and sediment transport, and floods. The SHE model and its derivatives (e.g., MIKE SHE) are proprietary, with source code not available. License fees are not available online.

GROUNDWATER MODELS

Aquifer Simulation Model for WINdows (ASMWIN; Kinzelbach and Rausch 1995; Kinzelbach, 1986; Swiss Federal Institute of Technology, 2004)

Developed by the Swiss Federal Institute of Technology (ETH), ASMWIN is a horizontally or vertically, two-dimensional groundwater flow and transport model. The solution of the flow equation uses a finite difference method solved with the method of preconditioned conjugate gradients (PCG) or the IADI-method (Iterative alternative direction implicit procedure). An automatic model calibration procedure using the Marquardt-Levenberg algorithm is available in ASMWIN. The interpolation of the velocity uses the methods by Prickett or Pollock. Two transport simulation modules are available: a finite-difference scheme; or a random-walk method based on Ito-Fokker-Planck theory. Pathline and isochrone computed by Euler-integration as well as transport simulation are possible for steady state flow fields only. It appears that this software is available for free, though certain versions that appear to be advanced are licensed and sold by third parties.

Groundwater Modeling System (GMS; EMRL, 2004)

GMS has been developed by the Environmental Modeling Research Laboratory (EMRL) at Brigham Young University. GMS provides tools for groundwater simulation including site characterization, model development, calibration, post-processing, and visualization. GMS supports **MODFLOW**, **MODPATH**, MT3DMS/RT3D, **SEAM3D**, **ART3D** (Simple analytical transport model), **UTCHEM** (multi-phase reactive transport), **FEMWATER** (3D finite-element model for saturated and unsaturated zone), **PEST**, and **SEEP2D** (2D finite-element seepage model). GMS costs $7,600 including all modules and interfaces.

MODFLOW (Harbaugh et al., 2000)

Several versions of MODFLOW have been released: MODFLOW-88 (McDonald and Harbaugh, 1988); an enhanced version MODFLOW-96 (Harbaugh and McDonald, 1996); and MODFLOW-2000 (Harbaugh et al., 2000) that fully integrates parameter estimation. MODFLOW is a three-dimensional finite-difference groundwater model with a modular structure that allows it to be easily modified to adapt the code for a particular application. MODFLOW simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block. MODFLOW is currently the most used numerical model in the U.S. Geological Survey for groundwater flow problems.

In addition to simulating ground-water flow, the scope of MODFLOW-2000 has been expanded to incorporate related capabilities such as solute transport and parameter estimation.

Several versions of Modflow are available free of charge from the USGS.

HYDRAULIC MODELS

Hydrologic Engineering Center – River Analysis System (HEC-RAS; HEC, 2002)

HEC-RAS is an accepted U.S. standard for calculating river hydraulics. The model was originally developed in the 1960s and has evolved through numerous modifications and expansions. Originally, RAS was intended for computing water surface profiles for steady gradually varied flow in natural or man-made channels. The computational procedure is based on the standard step method of solution. The computations proceed by reach, with known values at one cross-section being used to compute the water surface elevation, mean velocity, and other flow characteristics at the next cross-section. Both sub critical and supercritical flow regimes can be modeled. The effects of obstructions to flow such as bridges, culverts, weirs, and buildings located in the floodplain may be reflected in the model.

RAS can be used for simulating one-dimensional steady or unsteady flow, sediment transport and movable boundary open channel flow. The RAS system contains three components for: (1) steady flow water surface profile computations; (2) unsteady flow computations; and (3) movable boundary hydraulic computations. All three components use a common geometric data representation, and common geometric and hydraulic computation routines. RAS is comprised of a graphical user interface, separate computational engines, data storage/management components, graphics, and reporting capabilities.

Although RAS is a stand-alone model, it is often used in combination with HMS. A typical HMS/ RAS application involves predicting the water surface profiles that would result from actual or hypothetical precipitation events. Precipitation associated with an actual storm, design storm of specified exceedance frequency, or design storm such as the probable maximum storm, is provided as input to the HMS model. HMS performs the rainfall-runoff and routing computations required to develop hydrographs at pertinent locations in the stream system. Peak discharges from the HMS hydrographs are provided as input to RAS, which computes the corresponding water surface elevations at specified locations. RAS is also sometimes used to develop discharge versus storage volume relationships for stream reaches which are used in HMS for the modified Puls routing option.

HEC-RAS is available free of charge from HEC with no support available for non-Corps users.

Dynamic Hydraulics (DYNHYD; Ambrose et al., 1993a)

The DYNHYD model is a link-node hydrodynamic model simulating velocity, volume, and water depth under river flow phenomena. The equations of conservation of mass and energy are solved by the method of finite-differences to predict water velocities, flows, water heights, and volumes. The model is driven by variable upstream flows and downstream heads, and assumes that flow is predominantly one-dimensional. Bed characteristics are parameterized using Manning's n. Wind that can either oppose or concur with flow can also be accounted for within the model. DYNHYD is a one-dimensional model, simulating velocity in the direction of the channel, but is applied to two-dimensional (vertically integrated) systems by approximating the system by a network of nodes with interconnected one-dimensional channels. It is generally operated in conjunction with a transport (i.e., water quality) model lacking a hydrodynamic capability, e.g., WASP. The model assumes a simple channel geometry; rectangular in cross section with cross sectional area is proportional to depth. Thus, this sort of model would not be appropriate for applications to rivers with floodplain areas or gentle lateral side slopes. Generally, DYNHYD5 cannot be applied to stratified water bodies or water bodies without well-defined primary flow directions. The more usual configuration for DYNHYD is a steady or slowly varying inflow regime, for evaluation of critical-condition or normal-condition water quality. Since DYNHYD is a time-advancing model, in principle it can handle dynamic events, such as flood hydrographs. However, its limited accuracy would probably result in poor accuracy for a "fully dynamic event" such as a flood event in a flashy stream (Ward and Benneman, 1999a). The software is available in the public domain (executable and source code) from Scientific Software at http://www.scientificsoftwaregroup.com/.

MIKE-11 (DHI, 2010)

A piece of the suite of MIKE tools built by DHI, this software provides 1-D hydraulic analysis with several modules to extend its capabilities into hydrology, sediment transport, water quality and eutrophication, and coastal modeling. Limited information is available online, with DHI preferring that you contact a representative for details.

Surface Water Modeling System (SMS; EMRL, 2004)

SMS has been developed by the Environmental Modeling Research Laboratory (EMRL) at Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station (WES), and the US Federal Highway Administration (USFHWA). SMS is an interface providing access to one-, two-, and three-dimensional hydrodynamic modeling software, including pre- and post-processor software for surface water modeling. SMS models allow calculation of water surface elevations and flow velocities for shallow water flow problems, for both steady state and dynamic conditions. Additional applications include the modeling of contaminant migration, salinity intrusion, and sediment transport (scour and deposition). SMS license fees are $9,250 for a single user including all modules and interfaces.

WATER QUALITY MODELS

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS; USEPA, 2004)

BASINS is a DSS that brings together large amounts of environmental data and modeling capabilities in a single package with a GIS serving as the integrative platform. BASINS has three objectives: to facilitate the examination of environmental information, to support analysis of environmental systems, and to provide a framework for examining management alternatives. The system runs on PCs in the Windows environment and allows users to assess water quality at selected stream sites or throughout an entire watershed. It integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to environmental protection. BASINS is comprised of a suite of components for performing watershed and water quality analysis, including:

- Environmental and GIS databases (mainly U.S. based, but there are several applications in Europe);
- Assessment tools for evaluating water quality and point source loadings;
- Utilities, including data import and management of water quality observation data;
- Watershed delineation tools;
- Utilities for classifying digital elevation models (DEM), land use, soils, and water quality data;
- In-stream water quality and eutrophication model (QUAL2E ver. 3.2);
- Simplified GIS-based non-point source annual loading model (PLOAD);
- Watershed loading and transport models:
    - HSPF, a watershed scale model for estimating instream concentrations resulting from loadings from point and nonpoint sources. WinHSPF is included which is an interface to the Hydrological Simulation Program Fortran (HSPF), version 12 and
    - Soil and Water Assessment Tool (SWAT), a physically-based, watershed scale model for predicting the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time.

- Model results postprocessor (GenScn) for scenario generation to display, analyze, and compare results from HSPF and SWAT

BASINS' databases and assessment tools are directly integrated within an ArcView GIS environment (EPA will release a version of BASINS for the ArcGIS platform sometime in 2004).

BASINS is available free of charge from the EPA.

Water Quality Analysis Simulation Program (WASP; Ambrose et al., 1993b; Wool et al., 2003)

Maintained by the Environmental Protection Agency, WASP is a generalized modeling framework for simulating aquatic systems including rivers, reservoirs, estuaries, and coastal waters. WASP is designed to provide a flexible modeling system. WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types. The time varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the model. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity, and sediment fluxes. Water quality processes are modeled in special kinetic subroutines that are either selected from a library or supplied by the user. EUTRO and TOXI are sub-models which can be incorporated into WASP to analyze conventional pollution involving dissolved oxygen, biochemical oxygen demand, nutrients and eutrophication and toxic pollution involving organic chemicals, metals, and sediment. WASP has no hydrodynamic capability and must be linked with another model for this purpose; the most common linkage is to DYNHYD that comes as part of the WASP software. Other hydrodynamic programs have also been linked with WASP RIVMOD handles unsteady flow in one-dimensional rivers, while SED3D handles unsteady, three-dimensional flow in lakes and estuaries.

WASP has been used to examine eutrophication of Tampa Bay, FL; phosphorus loading to Lake Okeechobee, FL; eutrophication of the Neuse River Estuary, NC; eutrophication Coosa River and Reservoirs, AL; PCB pollution of the Great Lakes, eutrophication of the Potomac Estuary, kepone pollution of the James River Estuary, volatile organic pollution of the Delaware Estuary, and heavy metal pollution of the Deep River, North Carolina, mercury in the Savannah River, GA.

WASP6 comes with a data preprocessor that allows for the rapid development of input datasets, by either cut-and-paste or queried from a database. A Post-Processor provides an efficient method for reviewing model predictions and comparing them with field data for calibration. WASP has been used for about twenty years and is a well-established water quality model, supported by the USEPA. The current version is WASP6.2, released in November 2003 to the Windows operating system. WASP is written in FORTRAN and executables and source code are in the public domain and can be downloaded from http://www.epa.gov/athens/wwqtsc/html/wasp.html.

WASP is available free of charge from the EPA.

Soil and Water Assessment Tool (SWAT; Neitsch, 2002)

SWAT is a continuous hydrologic simulation of water, sediment, and chemical movement created by Texas A&M University, for the USDA Agricultural Research Service. SWAT is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. Given values for basic climatic variables, the model calculates canopy storage, infiltration (using SCS Curve number method), surface runoff, ponds, evapotranspiration, lateral subsurface flow, tributary channels, and return flow. The model also calculates land cover/plant growth, erosion, nutrients, pesticides, and management. Water management options in the model include water use (domestic or agricultural) water transfer between reservoirs, reaches or sub-basins or exportation from the

basin. SWAT is coded in FORTRAN-90 and is transportable to a variety of platforms, including PC compatibles.

SWAT is a continuous model working at the basin scale to look at the long-term impacts of management and timing of agricultural practices (Neitsch et al., 2000). The model was created by merging SWRRB (Simulator for Water Resources in Rural Basins), and ROTO (Routing Outputs To the Outlet). The goal of developing the SWRRB model was to predict the effects of management decisions on water and sediment yields for ungaged rural basins throughout the United States.

The hydrological phase in SWAT provides the required parameters for the chemical constituent calculations in the watershed. The most important parameter is the runoff volume computed by the modified SCS curve number method. Another significant flow parameter is the lateral subsurface flow or interflow that represents a stream flow contribution originating below the soil surface but above the zone of saturation. The model applies the kinematic storage method to estimate this stream flow component. The model solves the water mass balance equation in shallow aquifers to estimate base flow contribution. Sediment removal from the land surface is calculated by the Modified Universal Soil Loss Equation (MUSLE).

SWAT and several associated modules and interfaces are available free of charge from Texas A&M University which provides this service for the USDA.

Enhanced Stream Water Quality Model (QUAL2E; Brown and Barnwell 1987)

The QUAL2E is a one-dimensional (longitudinal) model for simulating well-mixed streams and lakes. A watercourse is represented as a series of piece-wise segments or reaches of steady, non-uniform flow. Flows are constant with time and uniform in each reach, but can vary from reach to reach. QUAL2E allows simulation of point and non-point loadings, withdrawals, branching tributaries, and in-stream hydraulic structures. The model allows simulation of 15 water quality constituents including: dissolved oxygen, biochemical oxygen demand, temperature, algae as chlorophyll, organic nitrogen, ammonia nitrogen, nitrate nitrogen, organic phosphorus, inorganic phosphorus, coliforms, an arbitrary non-conservative constituent, and three arbitrary conservative constituents. QUAL2E has optional features for analyzing the effects on water quality, primarily dissolved oxygen, and temperature, caused by diurnal variations in meteorological data. Diurnal dissolved oxygen variations caused by algal growth and respiration can also be modeled. QUAL2E also has an option for determining flow augmentation required to meet any pre-specified dissolved oxygen level. QUAL2E and its variations stem from early models, including DOSAG model which solves the steady-state oxygen sag problem for a multi-segment river reach, and QUAL (TWDB 1971) which was developed by expanding DOSAG. QUAL II (Roesner et al., 1973) was developed for the Environmental Protection Agency by expanding and improving QUAL. Qual2E is in the public domain and can be downloaded from: http://www.epa.gov/docs/QUAL2E_WINDOWS/#files.

The Qual2E User's manuals are available at:
http://www.epa.gov/waterscience/basins/bsnsdocs.html#qual2e

RIVER / RESERVOIR / USE MANAGEMENT MODELS

RiverWare™ (Zagona et al., 2001; Boroughs and Zagona, 2002; CADSWES, 2004)

The Tennessee Valley Authority (TVA), the United States Bureau of Reclamation (USBR), and the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems (CADWES) collaborated to create a general purpose river basin modeling tool - RiverWare™. RiverWare™ is a reservoir and river system operation and planning model. The software system is comprised of an object-oriented set of modeling algorithms, numerical solvers, and language components.

Site-specific models can be created in RiverWare™ using a graphical user interface (GUI) by selecting reservoir, reach confluence, and other objects. Data for each object is either imported from files or input by the user. RiverWare™ is capable of modeling short-term (hourly to daily) operations and scheduling, mid-term (weekly) operations and planning, and long-term (monthly) policy and planning. Three different solution methods are available in the model: simulation (the model solves a fully specified problem); rule-based simulation (the model is driven by rules entered by the user into a rule processor); and optimization (the model uses Linear Goal-Programming Optimization).

Operating policies are created using a constraint editor or a rule-based editor depending on the solution method used. The user constructs an operating policy for a river network and supplies it to the model as "data" (i.e., the policies are visible, capable of being explained to stakeholders; and able to be modified for policy analysis). Rules are prioritized and provide additional information to the simulator based on the state of the system at any time. RiverWare™ has the capability of modeling multipurpose reservoir uses consumptive use for water users, and simple groundwater and surface water return flows.

Reservoir routing (level pool and wedge storage methods) and river reach routing (Muskingum-Cunge method) are options in RiverWare™. Water quality parameters including temperature, total dissolved solids and dissolved oxygen can be modeled in reservoirs and reaches. Reservoirs can be modeled as simple, well mixed or as a two-layer model. Additionally, water quality routing methods are available with or without dispersion.

RiverWare™ does not have a connection to any GIS software; however, a hydrologic database (HDB) may be available (Frevert, et al., 2003; and Davidson et al., 2002). HDB is a relational database used by the USBR and developed by CADWES to be used in conjunction with RiverWare™. HDB is an Oracle-based SQL database and includes streamflow, reservoir operations, snowpack, and weather data.

RiverWare™ is currently being used by the Tennessee Valley Authority for daily scheduling of more than 40 reservoirs and hydropower plants. The U.S. Bureau of Reclamation uses RiverWare's rule-based simulation models on the Colorado River for policy negotiations, to estimate salinity and set monthly target operations for the entire river basin. The U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and the U.S. Geological Survey have applied RiverWare's rule-based simulation and water accounting to the Upper Rio Grande to track native water and diversions.

RiverWare™ runs on Sun Solaris (UNIX) workstations or Windows based PCs. First year license fees for are $6,500 / $11,500 (Single Node/Floating License) and the annual renewal fee is $2,500 / $5,000.

ModSim (Labadie et al., 2000; Shannon, et al., 2000; Dai and Labadie, 2001; Labadie, 2004)

ModSim is a generalized river basin DSS and network flow model developed at Colorado State University with capability of incorporating physical, hydrological, and institutional/administrative aspects of river basin management, including water rights. ModSim is structured as a DSS, with a graphical user interface (GUI) allowing users to create a river basin modeling networks by clicking on icons and placing system objects in a desired configuration on the display. Through the GUI, the user represents components of a water resources system as a capacitated flow network of nodes (diversions points, reservoirs, points of inflow/outflow, demand locations, stream gages, etc.) and arcs (canals, pipelines, and natural river reaches). ModSim can perform daily scheduling, weekly, operational forecasting and monthly, long-range planning. User-defined priorities are assigned for meeting diversion, instream flow, and storage targets. ModSim employs an optimization algorithm at each time step to solve for flow in the entire network to achieve minimum cost while satisfying mass balance at the nodes and maintaining flows through the arcs within required limits. Conjunctive use of surface and ground water can be modeled with a stream-aquifer component linked to response

coefficients generated with the MODFLOW groundwater simulation model (Fredrick et al., 1998). ModSim can be run for daily, weekly, and monthly time steps. Muskingum-Cunge hydrologic routing is implemented in the model.

ModSim can also be used with geographic information systems (ArcGIS) (1) to generate input data for the model based on spatial databases, (2) to provide an interface for the user to modify input parameters, and (3) to display the results of the model in a way that decision makers can view the results in an easy to understand format (Gibbens and Goodman, 2000)

ModSim has been extended to treat water quality issues in stream-aquifer systems through an interactive connection to the EPA QUAL2E model for surface water quality routing, along with a groundwater quality model for predicting salinity loading in irrigation return flows (Dai and Labadie, 2001).

ModSim is well documented in both user manuals and source code comments. Model data requirements and input formatting are presented along with sample test applications useful in understanding model setup and operation. Currently, ModSim is being upgraded to use the ".NET Framework" with all interface functions handled in Visual Basic and C#. This will greatly enhance the ability of the model to interact with relational databases and all variables in the model will be available for reading or writing to a database.

ModSim is in the public domain, and executable versions of the model are available free of charge for use by private, governmental, and non-governmental users. Generally, the source code for the model is not available. However, some government agencies have negotiated agreements with the developer in which the source code is made available to the agency and the agency is allowed to change or modify the source code as necessary for agency-related projects.

Current users of the ModSim include the U.S. Bureau of Reclamation, the City of Ft. Collins, Colorado, the City of Greeley, Colorado, the City of Colorado Springs, Colorado, and the Imperial Irrigation District in California. Many additional applications of ModSim exist.

Operational Analysis and Simulation of Integrated Systems (OASIS; HydroLogics, 2001; Randall et al, 1997)

(OASIS), developed by HydroLogics, Inc., is a general-purpose water simulation model. Simulation is accomplished by solving a linear optimization model subject to a set of goals and constraints for every time step within a planning period. OASIS uses an object-oriented graphical user interface to set up a model, similar to ModSim. A river basin is defined as a network of nodes and arcs using an object-oriented graphical user interface. Oasis uses Microsoft Access for static data storage, and HEC-DSS for time series data. The Operational Control Language (OCL) within the OASIS model allows the user to create rules that are used in the optimization and allows the exchange of data between OASIS and external modules while OASIS is running. OASIS does not handle groundwater or water quality, but external modules can be integrated into OASIS. Oasis does not have any link to GIS software or databases.

OASIS has been used to model parts of the South Florida Water Management District (SFWMD), the Delaware River (Delaware River Basin Commission), the Roanoke River (U.S. Bureau of Reclamation, The Nature Conservancy), the Kansas River (Kansas Water Office), the Rio Grande (University of Texas at Austin), the South Fork of the American River in California, and for long term planning in the Alameda Water District in California.

HydroLogics states that OASIS "is the centerpiece of [their] consulting work" without offering a licensing cost on their website, suggesting that selection of OASIS may require that HydroLogics perform the model implementation work.

DELFT-TOOLS (Delft Hydraulics, 2004)

Delft-Tools is a framework for decision support developed by Delft Hydraulics for the integrating water resources simulation programs. Functions of the system include scenario management, data entry, and interactive network design from map data, object-oriented database set-up, presentation, analysis, and animation of results on maps. DELFT-TOOLS integrates the Delft Hydraulics models: SOBEK, RIBASIM, and HYMOS. SOBEK is a one-dimensional river simulation model that can be used for flood forecasting, optimization of drainage systems, control of irrigation systems, sewer overflow design, ground-water level control, river morphology, salt water intrusion, and surface water quality. The River Basin Simulation Model (RIBASIM) is a river basin simulation model for linking water inputs to water-uses in a basin. It can be used to model infrastructure design and operation and demand management in terms of water quantity and water quality. HYMOS is a time series information management system linked to the Delft Hydraulics models.

Deltares now handles Delft software and licenses the models separately. Approximate costs (estimated using exchange rates for Euros to US dollars) are HYMOS, $20500; SOBEK, $16500; RIBASIM, $13800.

MIKE-BASIN (DHI, 2004)

MIKE-BASIN couples ArcView GIS with hydrologic modeling to address water availability, water demands, multi-purpose reservoir operation, transfer/diversion schemes, and possible environmental constraints in a river basin. MIKE-BASIN uses a quasi-steady-state mass balance model with a network representation for hydrologic simulations and routing river flows in which the network arcs represent stream sections and nodes represent confluences, diversions, reservoirs, or water users. ArcView is used to display and edit network elements. Water quality simulation assuming advective transport and decay can be modeled. Groundwater aquifers can be represented as linear reservoirs. Current developments are underway to utilize the functionality of ArcGIS-9 in MIKE-BASIN.

Basic input to MIKE-BASIN consists of time series data of catchment run-off for each tributary, reservoir characteristics and operation rules of each reservoir, meteorological time series, and data pertinent to water demands and rights (for irrigation, municipal and industrial water supply, and hydropower generation), and information describing return flows. The user can define priorities for diversions and extractions from multiple reservoirs as well as priorities for water allocation to multiple users. Reservoir operating policies can be specified by rule curves defining the desired storage volumes, water levels, and releases at any time as a function of existing storage volumes, the time of the year, demand for water and possible expected inflows.

Water quality modeling in MIKE-BASIN is based on steady, uniform flow within each river reach and a mass balance accounting for inputs of constituents, advective transport, and reaction within the reach. Complete mixing downstream of each source and at tributary confluences is assumed. Non-point pollution sources are handled in the model as well as direct loading from point sources. The model accounts for the following water quality parameters: biochemical oxygen demand, dissolved oxygen, ammonia, nitrate, total nitrogen, and total phosphorus. Non-point loads are represented using an area loading method accounting for the nitrogen and phosphorous loads originating from small settlements, livestock and arable lands assuming certain unit loads from each category.

MIKE-BASIN runs on Windows based PCs. First year license fees for are $3,200 / $10,000 (Single Node/Floating License) and the annual renewal fee is $800 / $2,500 (A Single Node license is restricted to running on one machine. A Floating License allows up to five concurrent sessions running on different nodes on a network). The software is sold by a U.S. subsidiary in Pennsylvania.

MIKE-BASIN is currently being used by the Idaho Department of Water Resources (IDWR) and the Bureau of Reclamation surface water budget models for various river basins in Idaho, ElectroPeru for real-time decision support system for reservoir operation and optimization, the government of Sabah, Malaysia for Environmental Planning, the Gold Coast, Australia government for the Gold

Coast Drought Management Strategy, the Italian government for developing the Piedmonte Water Resources Action Plan, the Vietnamese government for support to Capacity Building of Water Resources Sector Institutes, the Honduran government for a Decision Support System for Water Resources, and the Chinese government for the Yangtze River and Estuary Study.

Hydrologic Engineering Center – Reservoir Simulation System (HEC-ResSim; HEC, 2003)

Reservoir System Simulation created by the U.S. Army Corp of Engineers – Hydrologic Engineering Center as the successor to HEC-5. Rossi has a graphical user interface (GUI) and utilizes the HEC Data Storage System (HEC-DSS) for storage and retrieval of input and output time-series data. ResSim is included in CWMS. ResSim is used to simulate reservoir operations including all characteristics of a reservoir and channel routing downstream. The model allows the user to define alternatives and run their simulations simultaneously to compare results. Network elements include reservoirs, routing reaches, diversions, and junctions. In ResSim, watersheds include streams, projects (i.e. reservoir, levees), gage locations, impact areas, time-series locations, and hydrologic and hydraulic data for that specific area. Schematic elements in ResSim allow you to represent watershed, reservoir network and simulation data visually in a geo-referenced context that interacts with associated data. ResSim can access an Oracle Database to read and write time series data. Reservoirs are complex elements that are made up of the pool, the dam, and one or more outlets. The criteria for reservoir release decisions, an operation set, are drawn from a set of discrete zones and rules. The zones divide the reservoir by elevation and contain a set of rules that describe the goals and constraints that should be followed when the reservoir's pool elevation is within the zone. Alternatives are developed to compare results using different model schematics (physical properties), operation sets, inflows, and/or initial conditions. To assist in analyzing simulation results, included within ResSim are default plots, a variety of summary reports, and HEC-DSSVue. ResSim does not deal with water quality, environmental in-stream flows, recreation, etc. The only aspect it does deal with is power generation as a characteristic of the reservoir.

HEC-ResSim is available free of charge from HEC with no support available for non-Corps users.

OTHER DSS / IMS AREAS NOT SUMMARIZED HEREIN

The following components of a DSS/IMS are not discussed at any length in this document but are worth noting here:

- Database
- Realtime Data Collection
- Meteorological and Climate Models
- Data Analysis and Display
- Consumptive Use Models
- Dissemination of Information (to Operators, Management, Government, Public)

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