HIDROGEST, a GIS framework for integration of decision support tools for improved water use and participatory management in pressurized on-demand irrigation systems

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HIDROGEST, A GIS FRAMEWORK FOR INTEGRATION OF DECISION SUPPORT TOOLS FOR IMPROVED WATER USE AND PARTICIPATORY MANAGEMENT IN PRESSURIZED ON-DEMAND IRRIGATION SYSTEMS.

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SUMMARY – Decision Support Systems (DSS) are important tools for both producing and processing information and to make it available in such a format that help decision makers and users to make the best decisions. To cope with the variety of DSS and models, it was developed a concept of a GIS framework – HIDROGEST – to integrate such tools, thus creating a unified database, extending it with GIS functionalities, and reusing the output data of given models as input data for other models. Thus, HIDROGEST provides an integrated approach to the decision-making process aiming improved water use and participatory management in irrigation. One of the models included in HIDROGEST is AKLA, a model for performance analysis of pressurized networks operating on-demand that simulates its hydraulic behavior for several flow regimes and computes appropriate performance indicators. When integrated in a visual framework, the model allows the manager and technical staff of water users associations (WUA) to analyze alternative demand scenarios relative to cropping patterns and water availability, as well as changes in the infrastructure network, which results may be analyzed with farmers in participative sessions prior to or during the irrigation season to assess the most probable constraints in water delivery. Results may also be used to define outlet discharges and pressure available for farm irrigation systems design, thus to establish broad scenarios of water use inside an irrigation project aimed at improving water use in irrigation.

Key words: GIS, pressurized systems, performance analysis, model integration, farmers' participation

INTRODUCTION: MODELLING TO FACILITATE PARTICIPATORY IRRIGATION MANAGEMENT

By definition, participatory management is the practice of empowering employees to participate in organizational decision making. This practice grew out of the human relations movement in the 1920s, and is based on some of the principles discovered by scholars doing research in management and organization studies (Bartle, 2006). When related to the irrigation subject, this conceptual framework is often referred to as Participatory Irrigation Management (PIM). According to the International Network on Participatory Irrigation Management (INPIM, 2004), PIM goes beyond merely involving farmers in irrigation management but more as a change in the traditional forms of Governance by Irrigation Agencies and Governments (INPIM, 2004). In fact, large investments have been made in upgrading (and building) irrigation systems to ease their management, such as lining of canals, adding more control structures and measuring devices and, as for this case study, installing on-demand pressurized networks.

The Food and Agriculture Organization (FAO) defines a complementary concept, that of Farmers' Water Management (FWM): the process in which individual farmers and farmers' institutions set objectives for the management of their water resources; establish appropriate conditions for their implementation, and identify, mobilize and use the water resources. The FWM's main objective is to guaranty a sustainable agricultural production through improved water control by farmers, in order to improve both food security and farm income, in particular for the small-holder (FAO, 2001). This concept assumes a greater importance in water scarcity conditions, such as for irrigation systems (IS) where drought water scarcity occurs and farmers are obliged to cope with strict water restrictions.

The role of the staff of water users associations (WUA) is quite important as they act as the main interface between the farmers and their needs and the external entities that either impose management rules or make available innovation, including the extension services and Universities. The network of contacts among the WUA leadership and external agencies can bring the farming community into closer contact with related services, e.g., credit, training opportunities. Farmers learn through their experience of involvement with their WUAs, mainly accounting, budgeting, planning, and organization, which constitutes a set of knowledge that can later be used in many other productive endeavors (Fujisaka and Jones, 1999). Local knowledge helps to better identify and prioritize problems, and finding good solutions to problems. When irrigators' organizations are empowered to control investments in irrigation infrastructure they typically find many ways to reduce waste, and spend money more wisely.

The type of problems and possible solutions that occur more frequently in irrigated areas regarding the improvement of the irrigation system are often related to the agreement with the WUA managers about upgrading the infrastructures, mainly increasing pipe diameters in critical areas of the network, setting constraints for hydrants in problem locations, planning adequate tariff rules, and planning different types of delivery schedules. These processes should involve public stakeholders (farmers and WUA staff) through meetings in which the aforementioned solutions should be presented and discussed, or where alternative techniques may be considered, thus enabling a greater involvement of users in planning irrigation improvements or contributing to more adequate designs and rehabilitation solutions considering the ways in which users actually operate, thus helping to avoid inappropriate and unworkable designs.

One of the most important challenges for irrigation reform is to avoid the self-feeding cycle of, poor maintenance and performance and waste of natural resources as well as waste of funds due to premature rehabilitation when a lack of knowledge and incentives may induce water users and irrigation managers to neglect preventive maintenance and to seek for rehabilitation through externally subsidized projects. Irrigation management transfer has been seen as a way to reduce government irrigation budgets by shifting the costs of irrigation operation and maintenance to users (INPIM, 2004). Reforms have shown that when users contribute to irrigation costs this happens because they are involved and confident that their money and labor will be spent more efficiently. However, feasible participatory irrigation management can only be sustainable if irrigation can be competitive. To escape the trap of deferred maintenance and dependence on externally subsidized rehabilitation it is required that those responsible for managing irrigation systems have the incentives, skills and capacity to carry out preventive maintenance and invest in major repairs and improvements to infrastructure, as well as in training of both WUA staff and farmers. The creation of such knowledge and capabilities needs bridging the gap between WUA, researchers, extensionists, farmers and other relevant actors. The use of information technologies takes then an important role, namely to create databases, support maintenance and accounting, and assessing the performance of the irrigation systems (Lamaddalena and Sagardoy, 2000).

For pressurized irrigation networks, in order to solve problems of less good performance, solutions at irrigation project-level requiring conciliatory WUA and farmers decisions may involve:

- Reinforcement of pipe sizes where head losses are excessive, i.e. critical network sections;
- Install additional in-line pumping station along critical sections of the network;
- establishment of rules limiting the farmers' freedom to withdrawal water in critical zones and during periods of peak demand or, alternatively, installing shut-off valves upstream of these areas;
- Installing flow and pressure regulators in selected nodes of the network;
- adapting management rules to farmers needs;
- adjusting the hydraulic head by further regulation of the pumping station.

At farm-level, participatory management may help to create an irrigation-specific knowledge-base to gather and exchange information with other farmers and WUA in order to cope with limitations due to system characteristics; possible solutions include:

- installing additional lifting units (booster pumps) downstream of critical hydrants;
- optimizing the design of the on-farm systems to reduce head losses and improve operation;
- improving the irrigation schedules, including to avoid irrigating during peak hours in critical areas;
- adapting the farmers irrigation method and cropping pattern to network constraints, e.g., choose low pressure irrigation.

Participatory design processes can help users to better understand and benefit from technical expertise that is needed to successfully formulate better solutions to the problems they face, to improve their technical knowledge and capabilities, or to calibrate and validate models, mainly performance analysis models such as AKLA (Lamaddalena, 1998; Lamaddalena and Sagardoy, 2000). The use of information tools such as HIDROGEST, described below, are likely to increasfacilitate the process of technology and experience transfer between the WUA and the farmers and simultaneously build a social capital with the whole rural community. Moreover, intelligent information tools may also contribute to introduce innovation, support farmers advising as for irrigation scheduling (Branco et al., 2005), and to create information that eases the decision process.

In the past years, several scientific models were developed to provide researchers and practitioners with tools that model the reality, build scenarios, and support decisions. Earlier models were developed as stand-alone software requiring large amount of data from users and with complex graphical interfaces. At present, the information and communication technologies (ICT), such as GIS, WEB and Database technologies brought a new paradigm in the development of new scientific models and software (Fordham and Malafant, 1997; Munack, 2006). Integration is a core concept that is essential to the acceptance of software by the users, including models for water resource management (McKinney and Cai, 2002; Letcher *et al*, 2006).

This paper reports on developments along these lines aimed at creating a software tool for supporting managerial activities in a pressurized irrigation system and to ease links between WUA managers and farmers on decision making, including through the use of various models. In this application to the irrigation system of Lucefecit, South Portugal, the integration with the performance analysis model AKLA is focused showing how the AKLA model is integrated in the HIDROGEST framework for creation and comparison of water delivery scenarios based on water saving criteria. The importance of database integration and map representation of results is discussed.

HIDROGEST PLATAFORM

The HIDROGEST application (Mateus et al., 2005) aims at providing an intelligible link between modern technologies and users in the perspective of management of an irrigation project (IP). This application is a management system composed of several databases, spatially and non-spatially referenced, and tools to analyse and access them in a friendly fashion, mainly with GIS. HIDROGEST can behave as a cross-platform interface that uses several mathematical models and simultaneously manages the needed data for use within the models (input data) and the storage and handling its results for later usage (output data). This concept was already proved to be efficient with several applications: with the SEDAM model, a DSS for demand and distribution simulation and scenarios evaluation in a surface irrigation district (Gonçalves *et al*, 2003), including when SEDAM is integrated in a GIS framework (Gonçalves *et al*, 2005); for using SADREG (described by Darouich *et al*, 2007), a DSS for surface irrigation design when integrated in a GIS (Gonçalves *et al*, 2006); finally, for operation of an irrigation scheduling model with a GIS database and integration in the WEB (Branco *et al*, 2005).

Mathematical models need data to operate and produce new information. Besides almost all models allow manual input data, they are developed over a unique internal database. These internal databases have large variability of formats (.mdb, .txt, .dbf, etc.) specifically adapted to the model where they are integrated. However, a large amount of data in these databases is or should be the same for several models, such as soil, crop, climatic, and other data. AKLA model is no exception, where text files with different extensions compose the internal database of the model. Applying a single database structure will increase data stability and ease validation using diverse models and by comparing and reusing output data between models. Thus, if data should be the same for various models it becomes difficult to maintain and synchronize all different databases of all existing models. The centralization of all data in a single database has thus the following advantages:

- Maintenance – it is no longer necessary to synchronize several databases, including with different formats. Data are updated only in one database;
- Accessibility – data can be accessed in only one physical location;
- Integration – standard data types and structured data allow to cross information between models;
- Technological evolution – allows modification of data type formats without changing the models.

The main purpose of HIDROGEST is to play a role of workbench for usage of various models, integrating them with a unique database (Fig. 1). A single database it is not composed by only one file, but by a combination of several files with one or more formats. The linkage between the user-model-database is accomplished in HIDROGEST by means of interfaces, one for the database and another for each model. The model interface presents forms for users to input data and other kind of information relevant to the model, and to present results in both graphic and table formats. The database interface manages the data that is used by the models, allowing to store input model data for each model run, querying the database for common data and storing the results. For presentation of the results in GIS extension, the data is collected directly on the database without needing to use the model. Since there is an interface to link the models to the database, changing database formats will only take effect on the interfaces and not on the models (Fig. 2).

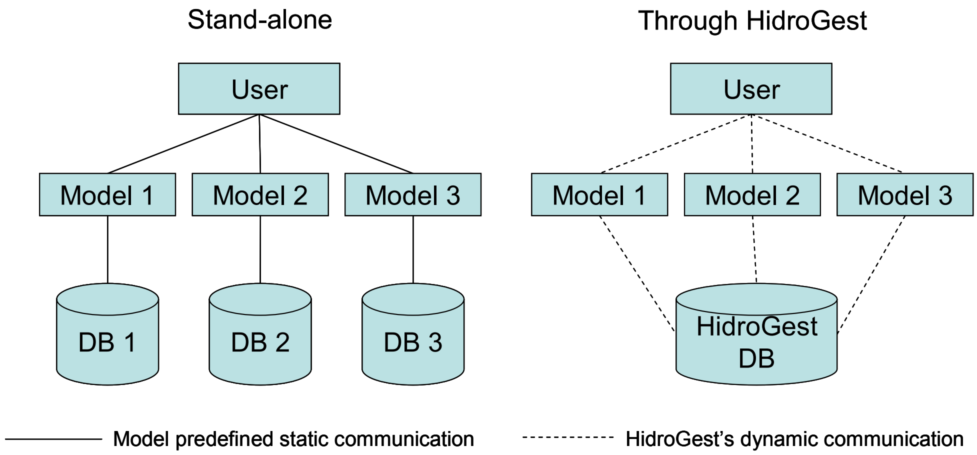

Fig.1. Scheme of user-model-database link in stand-alone models and HIDROGEST

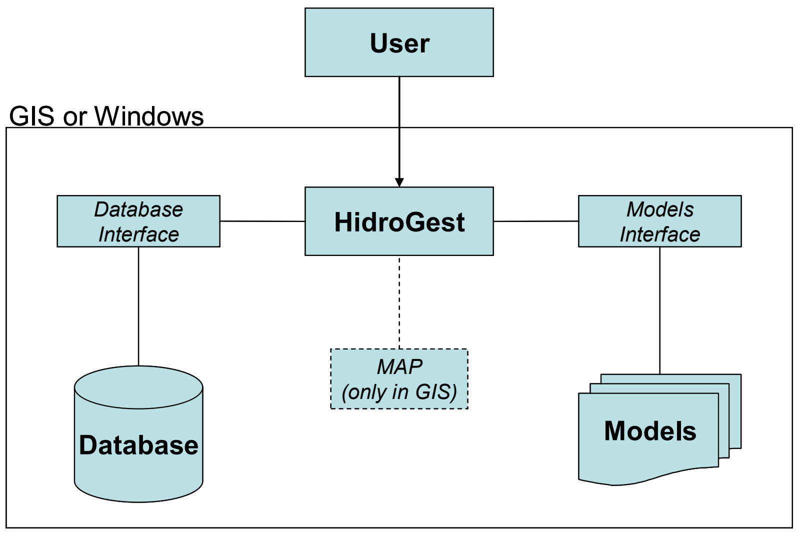

Fig. 2. HIDROGEST database and models interfaces

In previous work (Branco *et al*, 2005; Mateus *et al*, 2005), proprietary software was used in the development of HIDROGEST and model integration, namely MS Access, Visual Basic 6 and ArcGIS 8.x. Although these applications are compatible between each other, the costs of licenses are an issue to bear in mind. In contrast, open source software is gaining ground towards proprietary software with clear cost benefits and more integration flexibility. According to this, HIDROGEST database was migrated to PostgreSQL (database) and the scripts of database and model interface were developed in Ruby.

THE AKLA MODEL FOR PERFORMANCE ANALYSIS

Pressurized irrigation networks operating on-demand, offer an opportunity to reduce some of the problems that usually characterize irrigated agriculture relative to impacts of water conveyance, distribution and delivery, so this technology is often related to the modernization of irrigated agriculture itself (Lamaddalena and Sagardoy, 2000). The use of models such as AKLA can aid this modernization process as they can be used to diagnose the performance of pressurized networks operating on-demand, hence helping the actors that are involved in water management both at farm or irrigation-project level.

In on-demand irrigation networks there is a very small probability of having all the hydrants working simultaneously; therefore the discharge for which the networks are sized is much smaller than the sum of all hydrants' discharges. Various approaches for defining the discharges to be used at design have been developed aiming at allowing adequate performances with reduced costs (Calejo, 2004; Calejo et al., 2005b). The current work aims at the integration of simulation models, such as the IRDEMAND model (Calejo et al., 2005b), in a GIS framework so that its results can be easily processed, viewed, discussed and disseminated among the water users association (WUA) actors.

The AKLA model is thoroughly explained by Lamaddalena and Sagardoy (2000) and its flowchart is presented in Fig. 4. The model has been used in several field situations in the Mediterranean basin including in the Lucefecit system (Calejo et al., 2005a) and is applied for design in Portuguese consultancy companies (COBA, 2005). One of main advantages is that it adopts both for design and performance analysis a Several Flow Regime Model (SFRM). This is of particular relevance in on-demand irrigation networks because in these systems several flow regimes occur depending of the hydrants that are simultaneously in operation (Lamaddalena and Sagardoy, 2000). The flow regimes are randomly generated by a specific module and each regime comprises a series of hydrants simultaneously open, which constitute a discharge configuration, where the sum of the nominal discharge of the opened hydrants is equal to the network upstream discharge at that time. This one may be measured, as for the Lucefecit application (Calejo et al., 2005a) or is derived from the design upstream discharge.

A hydrant (j) of a configuration (r) is considered satisfied when the following relationship is verified:

$$H_{j,r} = H_{min} \quad (1)$$

where H j,r [m] is the head of the hydrant, j, within the configuration r, and Hmin [m] is the minimum required head for the appropriate operation at farm level. The relative pressure deficit $\Delta H_{j,r}$ at each hydrant is then defined as:

$$\Delta H_{j,r} = (H_{j,r} - H_{min})/H_{min} \quad (2)$$

To evaluate the performance of the network, also a reliability indicator is used referring to each hydrant an time step of the analysis (Lamaddalena and Sagardoy, 2000). This indicator bases on the assumption that a failure occurs when the hydrant is not delivering the respective discharge with the required pressure. The indicator describes how often the irrigation system fails. It allows an easy perception of the operation conditions and constraints of the whole network maintaining the scope narrow enough so that each hydrant can be individually analyzed.

This analysis, using both the reliability and the relative pressure deficit as indicators, assesses the adequacy of an irrigation systems both at the design phase and under operation, which allows to identify deficiencies and respective causes and to gather relevant information in order to develop the most customized and cost-effective improvements. This model is able of performing a hydraulic analysis for each hydrant, making it easy for the WUA manager to assess less favored hydrants or areas of the network where insufficient pressure may occur due to head losses in the pipes or to the piezometric elevation, so needing interventions as analyzed earlier. The simulation capabilities of the model allow to simulate such solutions and therefore to support decisions for improvement. The AKLA model, when integrated in a visual environment, the model allows the manager and technical staff of water users associations (WUA) to analyze impacts on the system performance of alternative demand scenarios relative to cropping patterns and water availability, as well as changes in the infrastructure network, which results may be analyzed with farmers in participative sessions prior to or during the irrigation season to assess the most probable constraints in water delivery. Results may also be used to inform farmers about discharges and pressure available at the hydrants, so providing base information for selection of farm irrigation systems and respective management, thus to establish broad scenarios of water use inside an irrigation project aimed at improving water use in irrigation. Under these circumstances, the model works as a base decision support tool.

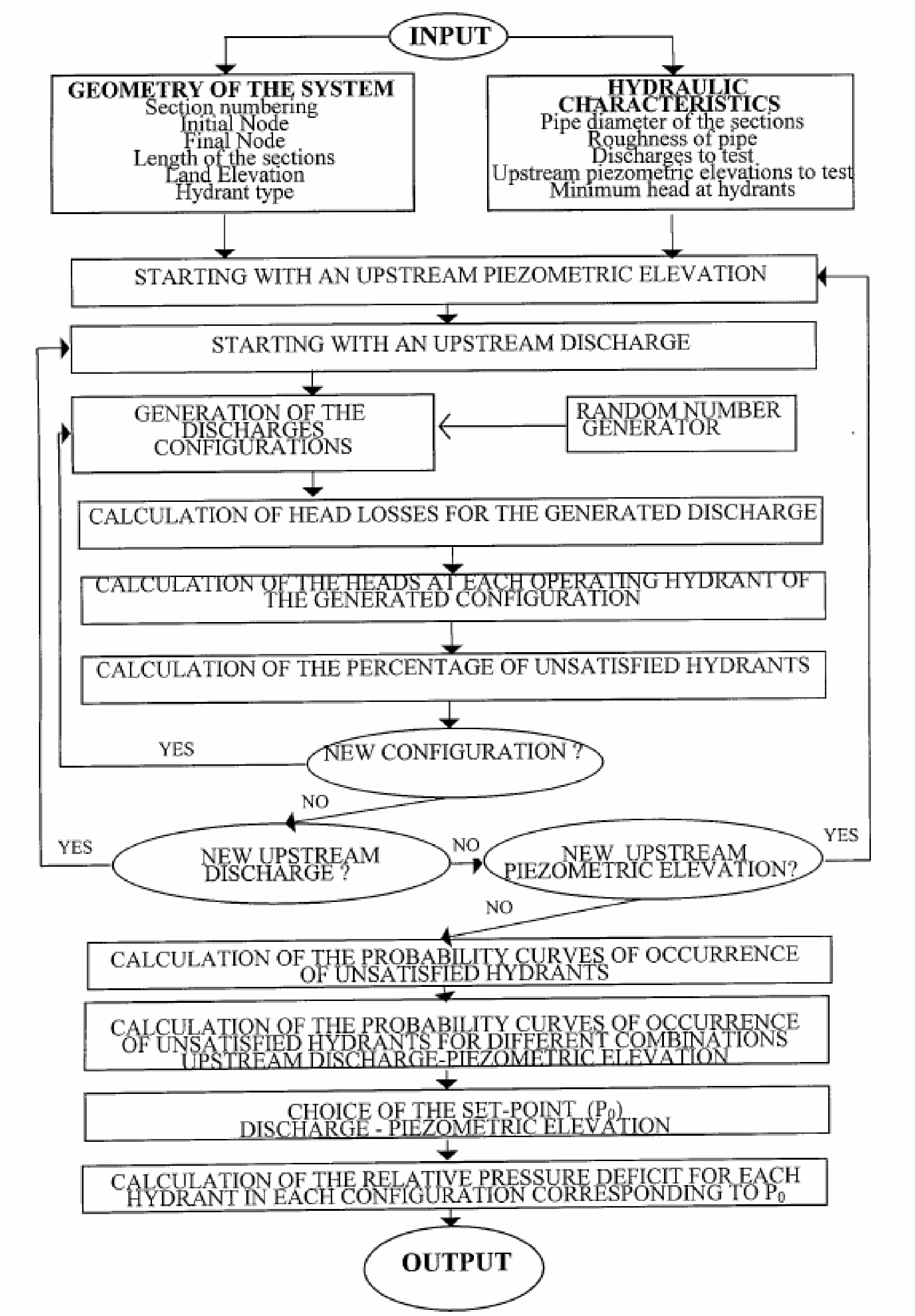

Fig. 3. Flow diagram of the AKLA model (Lamaddalena and Sagardoy, 2000)

AKLA MODEL INTEGRATION

Integration of softwares always depend on the strucuture and the workflow of the softwares. In this case, the AKLA model is a component of a broader application, COPAM, wich is composed by several executable files build in TURBO PASCAL and stores both input and output data in text files (Lamaddalena and Sagardoy, 2000; Calejo et al., 2005a). Differently, the HIDROGEST application is based on model/database interaction with a GIS extension. Since the AKLA model software is closed, the integration is established majorly over the databases. The information on the IP irrigation network that AKLA uses is stored in HIDROGEST database. Scripts were built to query HIDROGEST database for necessary data and create the text files in the AKLA format. A scenario schema was created for the database to store input and output data and allow user to analyse and compare each AKLA run. Fig. 3 presents the flowchart of AKLA integration in the HIDROGEST framework.

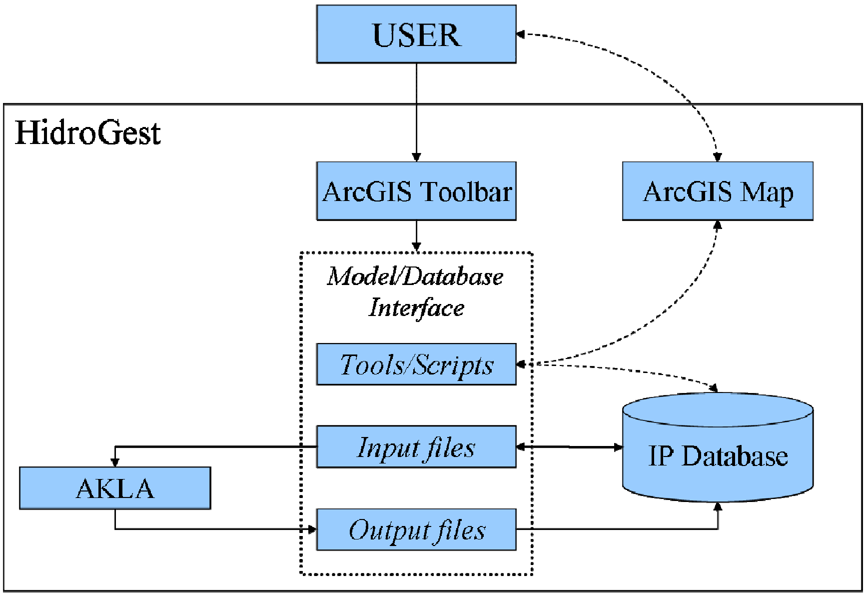

Fig. 4. Schema of AKLA integration in HIDROGEST

Four major components exists in this integration of AKLA in the HIDROGEST framework:

- ArcGIS interface and links – specific toolbar for HIDROGEST with command buttons for each functionality. Each command button triggers the respective tool that can be a graphical interface to input data, graphical interface to view output data or to visualize output data in the map. Map layers are linked with output tables of the IP database in order the allow this data to be easily visualized in the map.

- Model/Database interface - this interface is the core of the integration:

    - run AKLA - to run AKLA model, it is displayed to the user graphical interfaces were he inputs scenario specific data (upstream discharge, upstream piezometric elevation, etc.). The remaining data is queried to the database (such as network structure). All data is then compiled and transcribed to input text files and AKLA model is triggered and also stored into IP database according to respective scenario;
    - read AKLA output – data in output files are collected and stored into IP database according to respective scenario;
    - view data – for each tool, a script was developed to query the database, retrieve data and link data to map layers. According to each case, these tools provide interaction with map, graphical interfaces to support user or graphics are presented;

- AKLA model – executable files of AKLA model;
- IP Database – this database stores geographic and non-geographic data of Irrigation Project. All data represented in the maps is stored in this database identified by scenarios.

The following Figs (5 to 10) show how the AKLA model runs when integrated in the HIDROGEST framework (ArcGIS 9.x) and its application to the Irrigation Project of Lucefecit. When started (Fig. 5), the HIDROGEST toolbar shows the current avaliable models, in which the AKLA model is listed. The selcetion of the AKLA model introduces the user to the model's graphical interface (Fig. 6) where the user can select the desired options such as the scenario to be simulated.

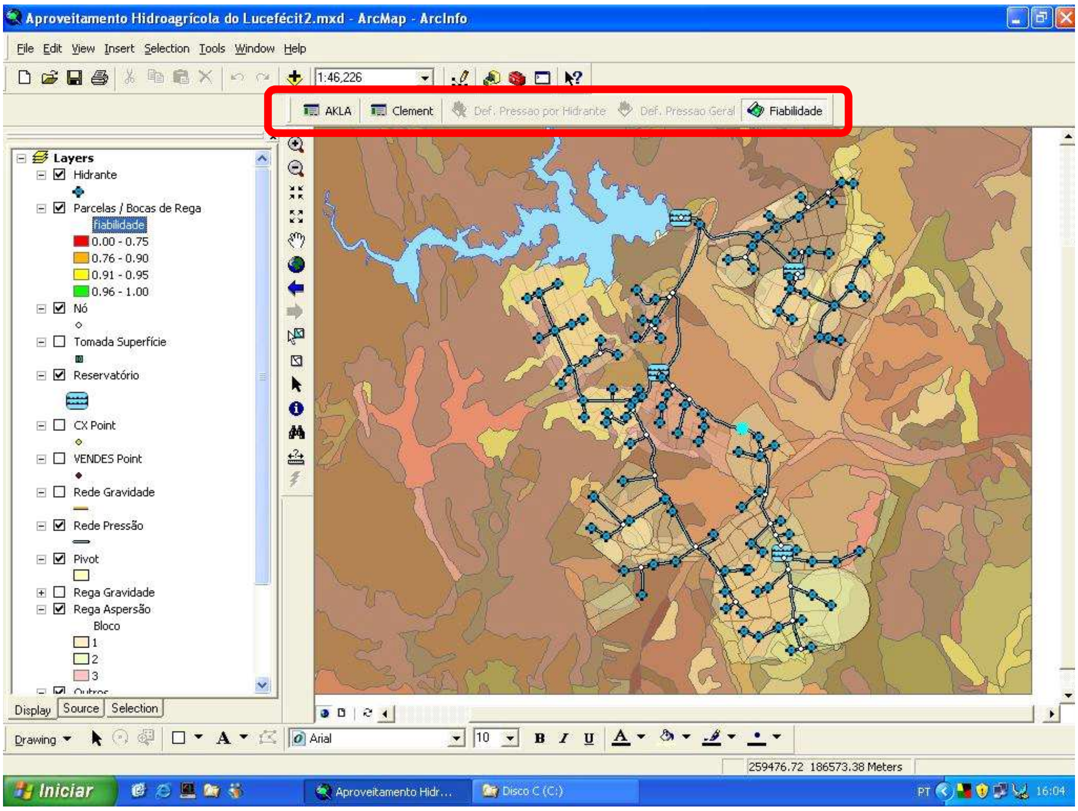

Fig. 5. ArcGIS environment (irrigation network overlaying the soil map) with HIDROGEST toolbar applied to the Lucefecit irrigation system

Each scenario refers to a single irrigation season (IS), that is associated to a given year, which has its particular network and active hydrant structure defined in the IP Database. So, when the WUA Manager selects an IS, the corresponding topological description of the network for that irrigation season is loaded from the IP Database at run-time.

The information that is contained in the database that characterizes the network consists basically in pipe sections and branches connected by nodes. Each section is defined by the respective up-and downstream nodes; the latter corresponds to a junction node if it branches again or to a hydrant if it is the terminal node of a given section. A junction node cannot support more than three connections, one referring to the upstream pipe section. In certain situations a unit length section can be added to simulate a 4 connection node. The hydrants nominal discharges and the pipes roughness coefficient used to calculate head losses are included in the database.

Every node has information on the site elevation and if it has a hydrant it contains information relative to:

- The operation status of the hydrant, i.e. if it is active or not; in the last case, the immediate upstream branch isn't considered in the network's structure;
- Nominal discharge (l/s);
- Irrigated area (ha);
- Section length of the immediate upstream branch (m) as well as its nominal diameter (mm).

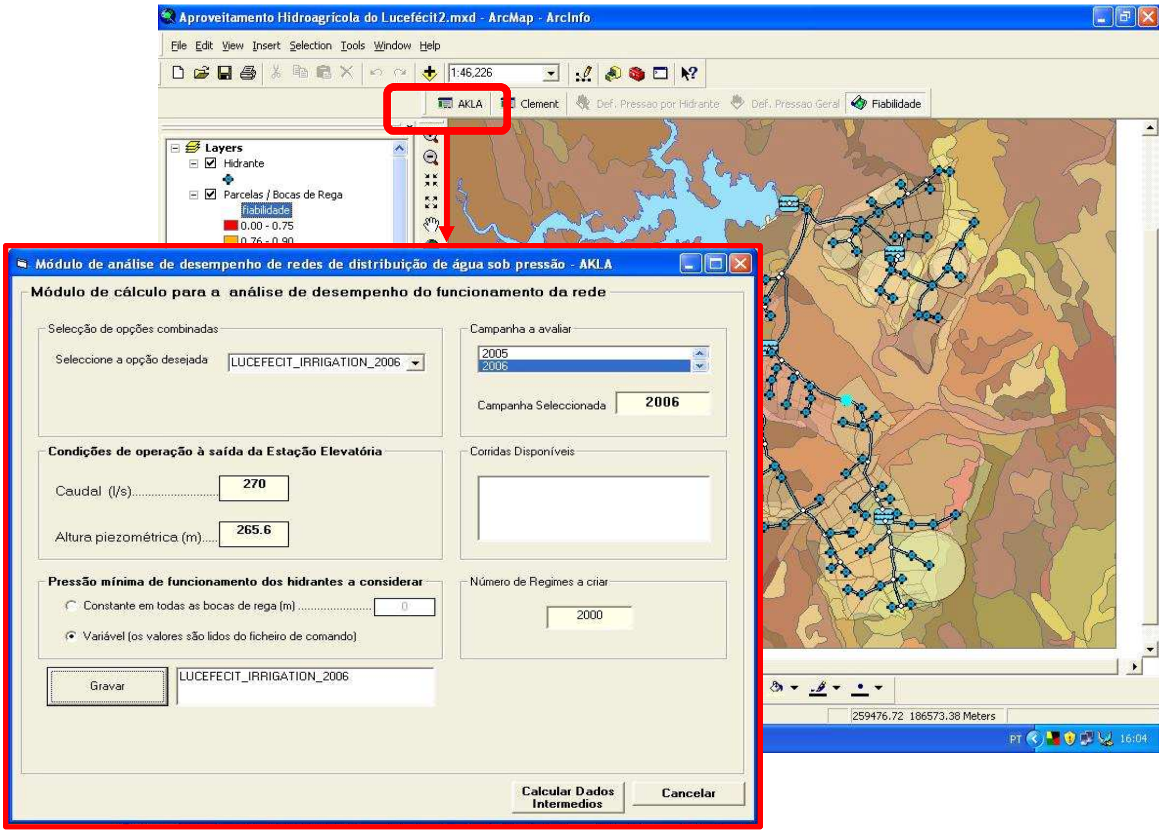

Fig. 6. Graphical user interface of AKLA model applied to the Lucefecit pressurized system

In each scenario, as seen in Figure 6, the user can then alter all of the following parameters:

- Demanded discharge at the network upstream point (l/s);
- Avaliable piezometric elevation (m a.s.l.);
- Minimum head at each active hydrant (m), to which can be atributed a constant value – to be inserted in the graphical user interface, or to use predefined values that are already in the IP database;
- Number of flow regimes to be calculated by the SFRM module in the AKLA model.

When parameters and information referred above are inserted for the first time or modified following previous simulations, the user will be prompted to save that configuration of parameters into a run-configuration, so that, at any time, a simulation using previous data can be performed again and compared to other simulation results.

Fig. 6 concerns the scenario for the IS 2006 in the Lucefecit Irrigation Project, which was a drougt year. It refers to an upstream discharge Q = 270 l/s, which is the mesured average discharge during the 2006 season, and the upstream piezometric elevation Z = 265.6 m a.s.l. These two values, the upstream discharge and the upstream piezometric elevation, are commonly referred to as “set-point” and characterize the operating conditions of the distribution network.

The minimum head at the hydrants is read from the database with help of an option button; other options refer to the number of flow regimes to be simulated and the number of hydrant configurations, up to 2000. When the user has selected the desired options and inserted the demanded values, the model can be initialized by clicking the highlighted button, as in Fig. 6.

A new data table will then appear giving the user the opportunity to choose the model-run to be selected. This feature is useful to compare or quickly visualize diferences based on different setpoint values, using different minimum head requirements at the hydrant (Figs. 7 and 8). The colouring and criteria to visualize different intervals of reliability are user defined.

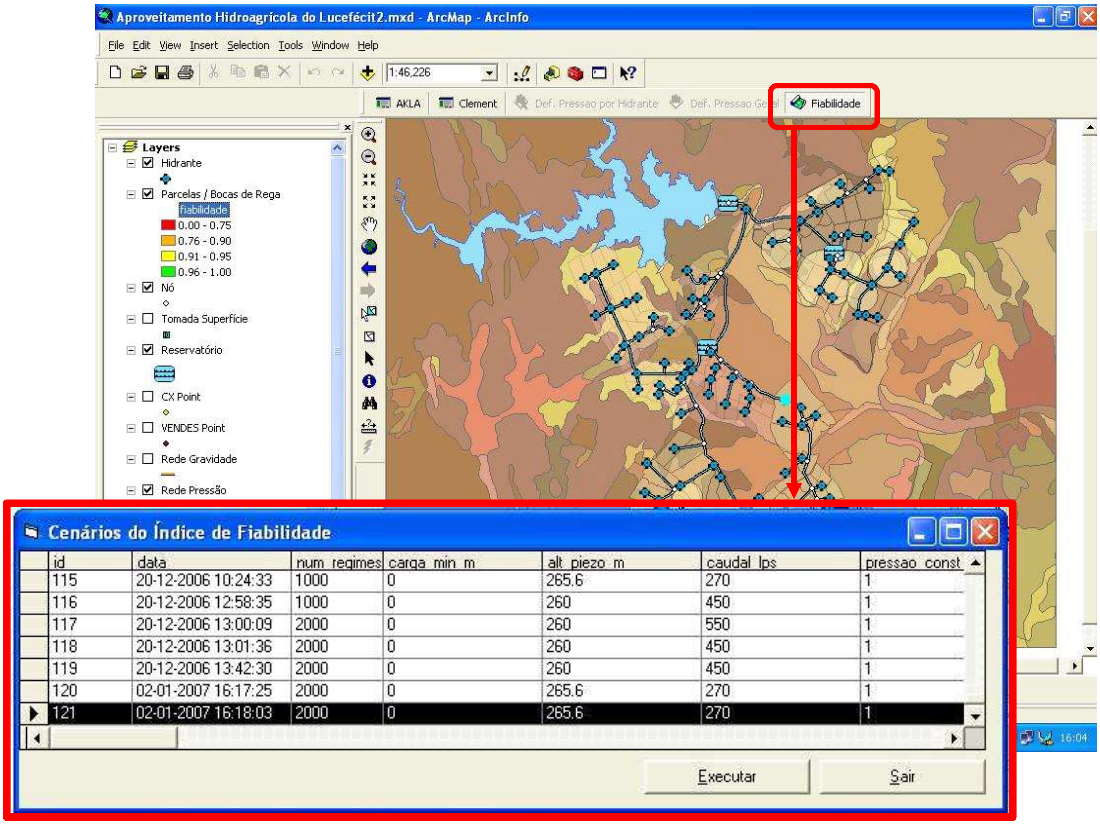

Fig. 7. AKLA model runs for computation of reliability for the specified scenario for 2006

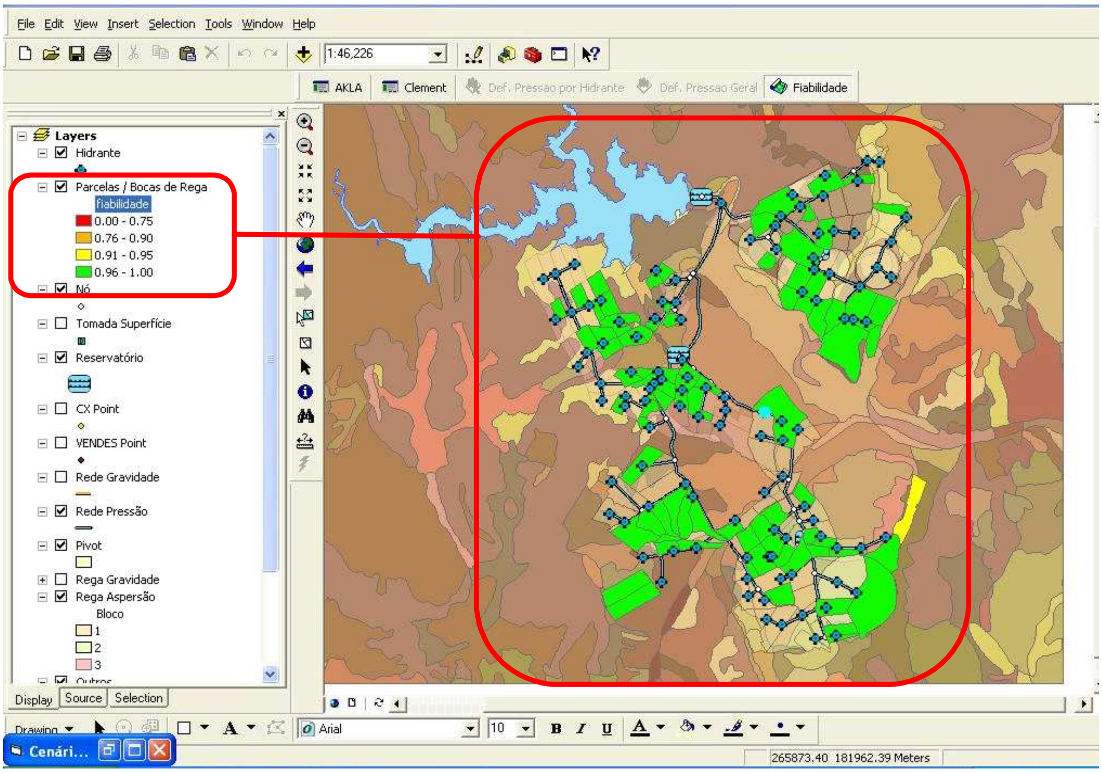

Fig. 8. Visual output of the and of the reliability in the units served by each hydrant in 2006

After the calculation and visualization of model results, a shape file is created allowing that the actual data can be consulted. In Figure 9 are shown the actual computed values relative to the tertiary network; with identification of the areas served by hydrants that are not operating properly. The user can also use the single hydrant analyst device to view the relative pressure deficit values calculated for all the flow regimes in a particular model run (Fig. 10).

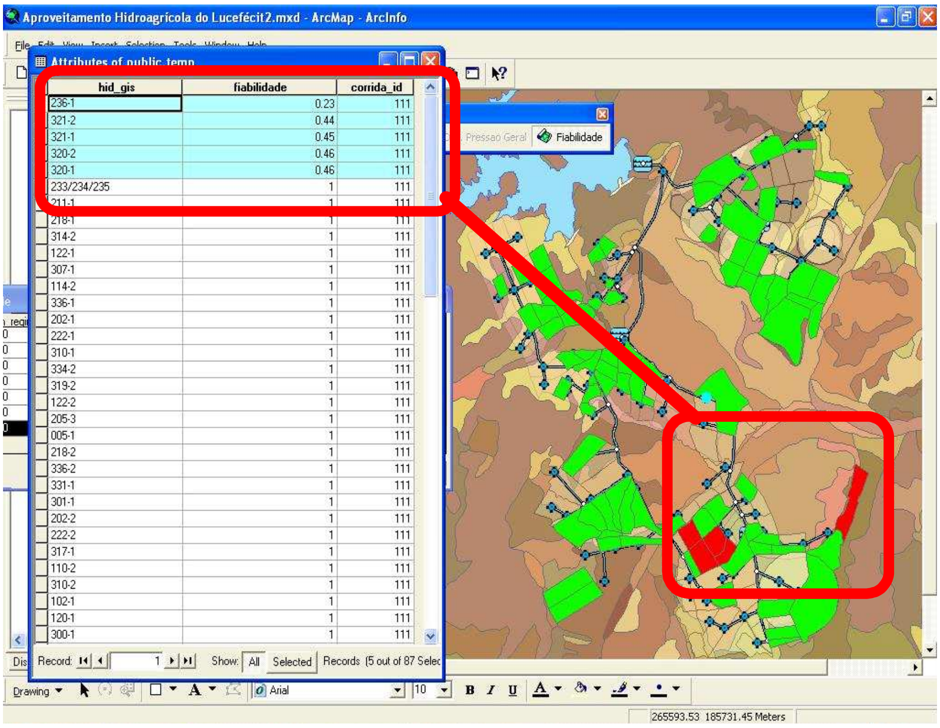

Fig. 9. ArgGIS tabular and visual data relative to the reliability indicator with identification of areas served by low performing hydrants

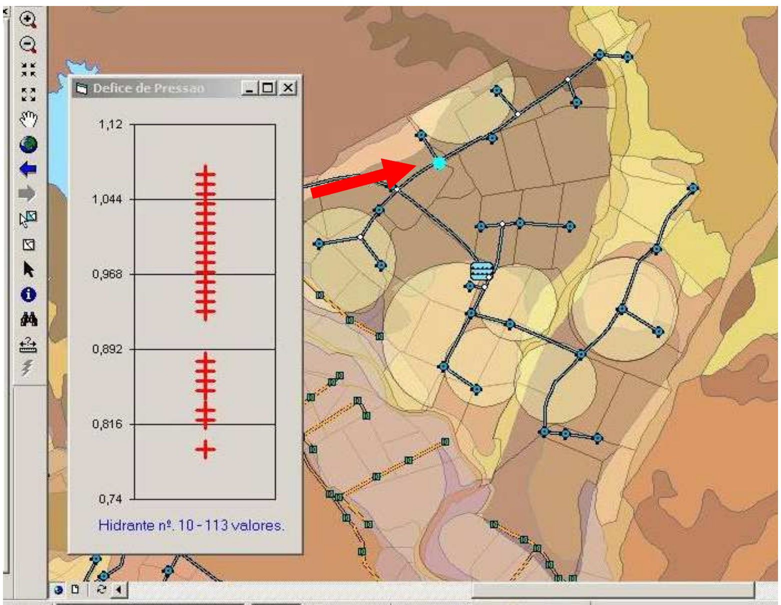

Fig. 10. Relative pressure deficit visualized with the single hydrant analyst device for the hydrant number 10 referring to 113 computed values relative to 2000 hydrants configurations

PERFORMANCE RESULTS

Figs 11 and 13 show the relative pressure deficit for the active hydrants in 2006 for two different set points where the discharge is constant (Q = 270 l/s) but the different piezometric elevations Z are respectively and 260 m a.s.l. It can be is noticed the overall decrease of the relative pressure deficit values when there is a reduction of avaliable piezometric elevation at the upstream end of the network. In Figs 12 and 14 can be observed the same effect on the reliability indicator: while for Z = 265.6 m a.s.l there were no unsatisfied hydrants, with Z = 260.0 m a.s.l there are 5 hydrants working under non-optimal conditions.

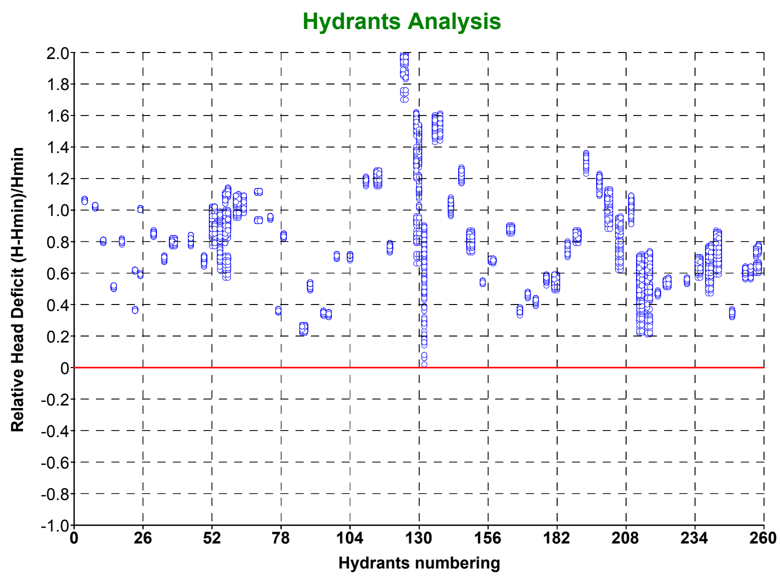

Fig. 11. Relative pressure deficit when the set-point is Q=270 l/s and Z = 265.6 m a.s.l.

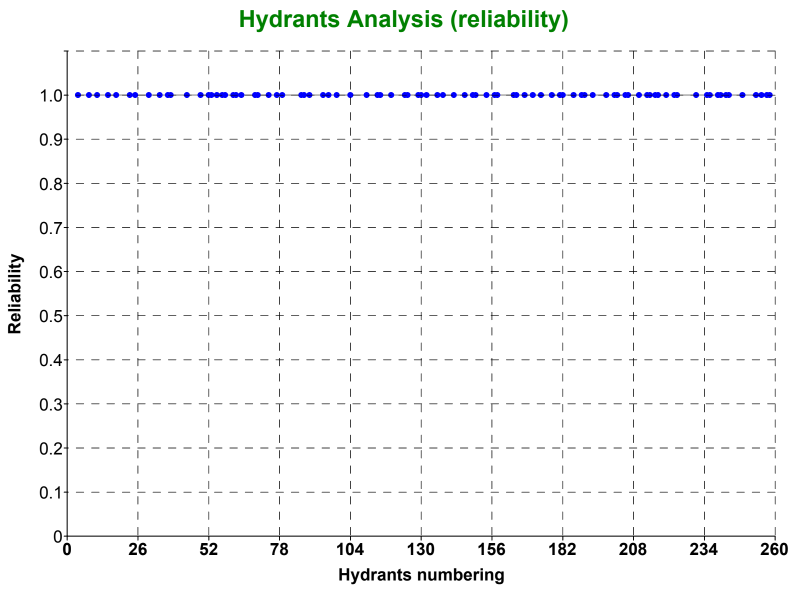

Fig. 12. Reliability indicator when the set-point is Q=270 l/s and Z = 265.6 m a.s.l.

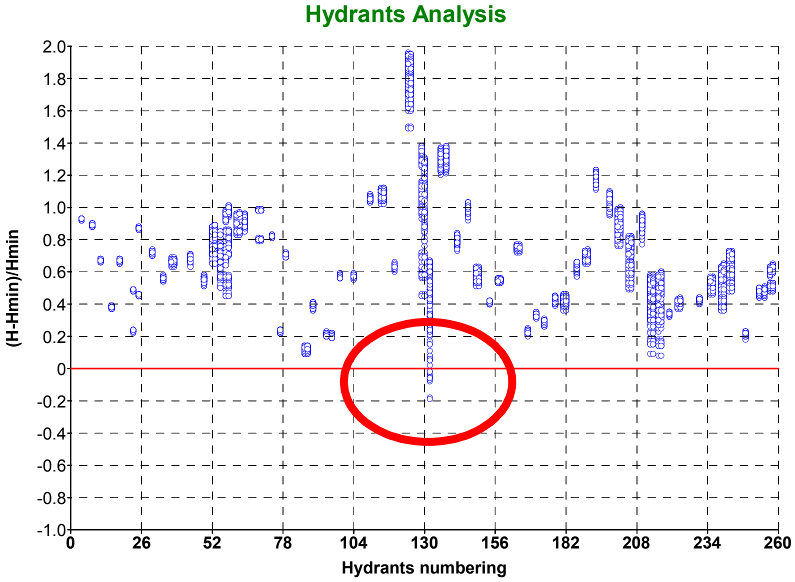

Fig. 13. Relative pressure deficit when the set-point is Q=270 l/s and Z = 260 m a.s.l.

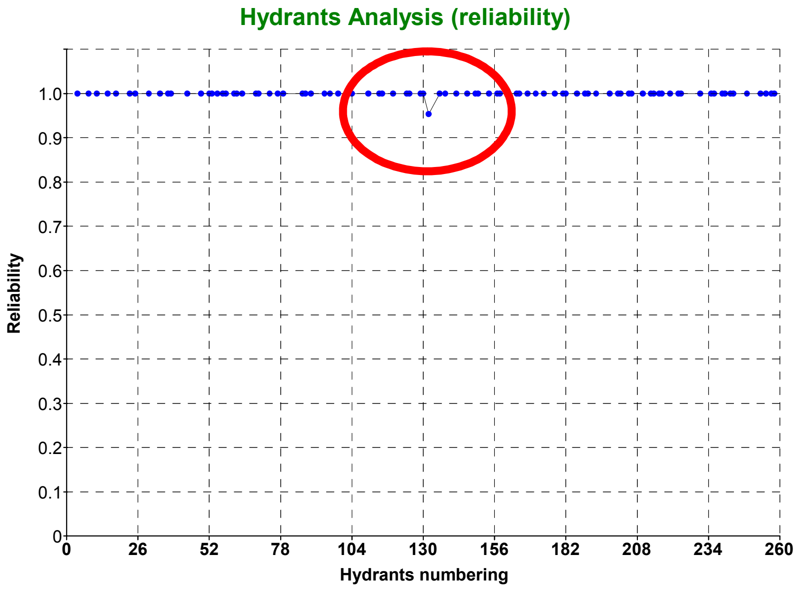

Fig. 14. Reliability indicator for the 2006 IS considering a set-point of (Q=270 l/s; Z = 260 m a.s.l.)

It can be concluded that for both cases the Lucefecit irrigation network is functioning without problems and is well adapted to the average demand. To be noted that 2006 was a drought year and the model was used previously to define the season management rules during that IS. Various meeting with the farmers were also performed.

CONCLUSION

The HIDROGEST framework proved to respond well to hte objectives of its development, i.e., to work as an intelligible link between modern technologies and users in the perspective of management of an irrigation project. Consisting of a management system composed of several databases, spatially and non-spatially referenced, and tools to analyse and access them in a friendly fashion, HIDROGEST works as a cross-platform interface that uses several mathematical models and simultaneously manages the required input data and the storage and handling of models output data including for later use with different models.

In this application to the Lucefecit irrigation system, HYDROGEST proved to be able to support the AKLA performance analysis model and integrate it with previous existing databases in different formats, and extending this model with GIS functionalities that did not exist before. Although AKLA model integration was successful, the closed structure of the model raised difficulties developing the database and model interfaces. The results of application of AKLA when presented in a visual interface are appropriate for supporting discussions with farmers at level of the respective WUA to formulate management scenarios and to base farm decisions on selecting the farm irrigation systems as constrained by the working conditions of the used hydrants. The application for the 2006 irrigation season, a drought year, as shown that the Lucefecit irrigation network was functioning without problems and was well adapted to the prevailing demand conditions.

Future work refers to further integration of other farm irrigation simulation models and the exploration of HYDROGEST capabilities for increased participatory mangement and training.

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