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Experiences with management support models in Egypt and Indonesia

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Abstract
DELFT HYDRAULICS has developed since 1989 a model package for the local water managers of irrigation schemes called OMIS. The OMIS, acronym for Operation Management of Irrigation Systems, model package supports the essential aspects of irrigation water management at the planning, operation, and performance evaluation phase. The model package can be used in practice as well as for training of irrigation officers involved in irrigation water management. So far, the OMIS model package has been introduced in four irrigation projects in Indonesia, Egypt, India, and Nepal.

1 Introduction

It is generally acknowledged that the performance of most irrigation schemes is below expectation, and that poor irrigation water management is a major contributor. To improve irrigation water management one should make a *performance assessment,* then a *diagnostic investigation,* followed by an appropriate *treatment* plan. In this process management support models can be used beneficially.

Although the basic principles of water management are fairly simple, the enormous amount and diversity of data involved makes water management of irrigation networks a complex task. Since 1989, DELFT HYDRAULICS has developed a decision support system for the operation management of irrigation systems (OMIS) (DELFT HYDRAULICS, 1989), (Verhaeghe & Krogt, 1991). The system supports the following management tasks; planning a cropping pattern at the start of the irrigation season; operation of the canal system during the season; and evaluation of the performance at the end of the season. Moreover, the model has recently been extended with a hydraulic module that computes the operational instructions to accomplish the scheduled water allocation (Schuurmans & Krogt, 1992). The OMIS model package has been developed exclusively for local water managers without computer and modelling experience.

In this paper the process of irrigation performance improvement will be discussed, and how computer models, like OMIS, can play their role in this process. A brief description of the OMIS model package will follow, and two applications will illustrate its use in practice.

2 The process of improving irrigation water management

2.1 Performance assessment

Performance can be described as the ratio of an actual and a target situation, and is characterised by indicators which are measured by performance parameters. For example, the reliability of supply is a performance indicator, which can be measured by computing the performance parameter actual versus intended supply. To determine whether a certain performance constitutes a good performance, performance criteria are needed, and here the perspective becomes important.

The performance assessment is usually made from the viewpoint of the donor, who is targeting for optimal yields and equity, and not from the water manager's. For a water manager the main performance indicator is complaints, if there are no complaints he is apparently doing a good job. Complaints are received from both farmers and his superiors. Complaints are, however, no good performance indicator for the irrigation scheme. Farmers not receiving irrigation water for a long period of time, will stop complaining after a while, whereas influential farmers might complain about shortage while they are receiving more than their share. If the different perspectives are not identified, both the water manager and the donor will become frustrated in their attempts to improve the performance.

2.2 Identification of causes

Once the actual performance has been assessed, the underlying causes should be identified. In general three types of causes for a poor performance can be distinguished: *unawareness*, *unwillingness* and *unableness* of the water manager. In practice, they all play a role, and it is often difficult to distinguish them.

Unawareness

Given the poor information available, and the perspective of the water manager it is well possible that the water manager is not aware of the actual (often poor) performance of his system. It is a delicate matter to demonstrate a poor performance, and care should be taken that the information is not used against him.

Unwillingness

Once the water manager is aware of the poor performance, he should be willing to improve it. He will only be willing if he is supported (or compelled) by his superiors, so that complaints from influential farmers can be put aside and that he is judged by his superiors on new standards. Furthermore, he should be convinced that he is be able to do a better job.

Unableness

Once the water manager is willing to improve the performance, he should be provided with the necessary knowledge, tools and information to do a better job. The agricultural revolution with high yielding varieties requiring more precise and frequent water deliveries, hardly had its impact on the irrigation departments responsible for the water supply. Very often, the methodology and technics of water management has not been changed significantly during the last century.

2.3 Treatment

Depending on the actual performance, and the underlying causes a treatment plan has to be made and implemented. It is relatively simple to make the water manager aware of the poor performance, but it is much more difficult to make him willing to improve it. Somehow, he should be compelled to, either by farmers organisations or the irrigation department. On the other hand, he will never be willing to improve the performance, when he feels he is not able to do so.

To enable the water manager to improve the management, a management information system (MIS) is essential. The information system provides him with information about, what is actually going in, and what the effect of proposed measures will be. Implementation of a management information system does not imply automatically that the water manager is willing to use it. However, a MIS is a pre-requirement for improved management, and it might be stimulating.

2.4 Computer models

Computer models are fast data manipulators, and their role in irrigation management whereby huge amounts of data have to be stored and processed in real time, seems trivial. In the performance assessment phase, computers can be helpful to compute performance parameters. In the analyses of the underlying causes, models can be used as training tools to demonstrate that it is impossible to manage the system without proper information. Moreover, the effect of wrong decision can be manifested. If the water manager can work with the model himself, he can discover, in a protected environment, that "no complaints" is not similar to good system performance.

Most water managers know quite well what is going on in their system, but the data is not structured and is not used when decisions are taken. This is not surprisingly, because as long as the system is operated on basis of complaints, no such information is required. However, management information is indispensable to manage the system properly. Computer models, play an important role in a management information system.

3 Description of the OMIS model package

3.1 Model Components

Main components

The OMIS model package (Operation Management of Irrigation Systems) is part of an Irrigation Management Information System. The OMIS model package has been developed exclusively for local water managers without computer and modelling experience.

The main components of the OMIS model package are depicted in Figure 1. Data of the real irrigation system can be stored, manually or automatically, in the model's database system. This data can be analyzed by the data analysis system. The data analysis system consists of a set of programs to calculate ,for example, crop water requirements,and water distribution schedules. Results are presented to the water manager by means of: (1) a Geographical Information System (GIS), (2) graphs, and (3) reports. On basis of this information the water manager can take his decisions. The model even allows him to test his decisions in the model environment prior to execution in the real life system.

Database system

The database system contains all relevant information of the system. If a particular data item is not available, default data are used in order to keep the model running. In this way the data analysis system is always using the best data available. The databases can be categorized into four main

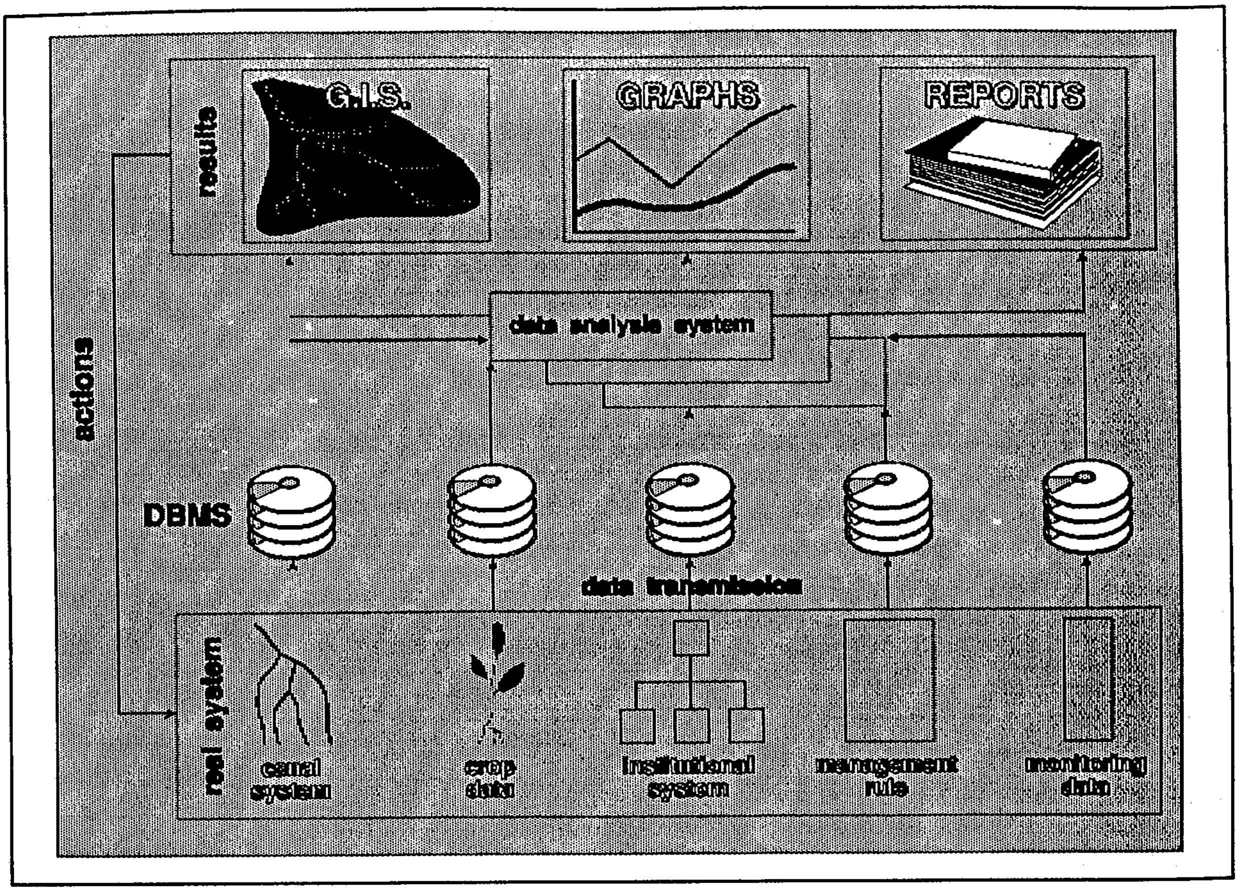

Figure 1 Main components of the OMIS model package

groups, which are listed:

Canal network data

The canal system is represented by branches and nodes. Several types of node are distinguished including diversion nodes, reservoir nodes and inflow nodes. The diversion nodes are used to link canals or to link the canal system to the command areas. The reservoir nodes contain information of the level-storage curve, the level of the gates, and the reservoir operation curves. The branch data includes length of canals and seepage losses from canals. Finally a map of the canal network is needed for GIS.

Agricultural data

The total scheme is divided into command areas. For each command area the area and the localized crop are given. Moreover, soil characteristics such as percolation rate, saturation and wilting point are given for each command area. For each crops data are stored such as the crop factors, and the depth of the root zone. For paddy the desired water layer and the pre-saturation depth are to be specified. Finally, a map of the scheme with the boundaries of the command area is needed for the GIS.

Hydrological data

The river flow data comprises dependable, expected and actual flow time series. The dependable data are used for planning, the expected time series are used for predictions during a simulation, and the actual flow time series are used for historical simulations. The location and name of several rainfall gauging stations can be stored and for each station the dependable, expected and actual rainfall time series are stored. Finally reference evaporation time series are needed.

Institutional data

Data of district and village boundaries, and gate operators are used to generate reports and instructions.

Data analysis system

The data analyses system contains, among others, programs to:
- Generate a crop plan prior to the irrigation season.
- Generate and evaluate a seasonal operation plan for both the reservoir (if present) and the irrigation canal system.
- Validate monitoring data collected from the field.
- Generate updated operation schedules for the reservoir (if present) and canal system.
- Evaluate the irrigation performance. The output parameters include, among others:
  - crop drought stress.
  - overall water balance of the irrigation system.
  - ratio actual and intended supply of each command area.
  - irrigation efficiencies of each command area.
  - actual and target reservoir operation curve.
  - overall water balance of the reservoir.

The user interface

The OMIS model package is to be implemented at the local or district irrigation services which are responsible for the management of one or more irrigation systems. At those locations monitoring data are collected, processed and operation schedules are prepared in a more or less structured way. At this level no prior knowledge of computers, data processing and water management modelling is assumed. A number of features were implemented to cope with the above mentioned condition:
- *Visualisation* of data and results, and the use of *diagnostic* performance parameters for easy interpretation. The geographical related data can be presented on a GIS system, which allows for a quick detection of spatial variations. To review, for example, the drought stress of crops during a certain period of time, a map of the scheme with all command areas is presented, and each command area is coloured according to its drought stress. Moreover, the results can be shown on graphs and printed in standard reports.
- A *task oriented menu* system. A particular task, like entry of monitoring data or preparation of a crop plan, can be selected from a set of layered menus. These menus go from a selection of major options via subsequent more detailed sub-menus to a complete definition of the task.
- A *Geographical Information System* (GIS) shows a map of the irrigation scheme on the screen, and plays a key-role in the interface. The user can enter or edit geographical related data via the GIS system. Moreover, graphs can be shown via the GIS system.
- *On-line help* information at each menu item. All, nearly 200, menu items are support by specific help information of that menu item.
- *Interactive* response of the computer. For example, any change made in the crop plan, is directly shown on the screen and the water requirements are directly updated.
- *Graphs* to show trends and computation results, such as performance parameters over time and to get a quick overview of the overall water balance.

3.2 Applicability to other schemes

The OMIS model package has a modular set-up. This implies that new databases and additional data analysis programs can be easily added. For example, it is possible to add a module for the generation of maintenance schedules or detailed operational instructions based on hydrodynamic calculations.

The modular feature of the OMIS model package strongly emphasizes its potential for application to any irrigation system with similar governing physical and monitoring process. However, to apply the OMIS model package to another irrigation scheme, in-depth knowledge of the schematization and modelling procedure is required. So far, OMIS has been successfully implemented in Indonesia, Egypt, and Nepal.

3.3 Hardware requirements

The OMIS model package put a minimum of requirements on the hardware. It runs on any *IBM-compatible* MS-DOS Personal Computer with a *80286* processor, or higher, a minimum of *640 Kb* RAM memory, *10 MB* free hard-disk space, and equipped with a *VGA* color monitor. Furthermore, at least one, *5¼"* or *3½"*, high density diskette drive, a *mouse*, and an *Epson* printer, or alike, is required. The execution time for an average scheme for a one year simulation is in the order of minutes on an ordinary AT PC.

4 Cidurian irrigation scheme

4.1 Scheme

The first application of OMIS described in this paper is for the Cidurian irrigation scheme (Fig. 2). The scheme is situated on West Java, Indonesia. The size of the scheme is about 12.000 ha.

The *source* for irrigation water supply originates from the unregulated river Cidurian. Characteristic for the Cidurian scheme is that both the rainfall and river flow are highly variable, e.g. in the first half of november 1986 the rainfall was 185.6 mm while in 1987 this was 60.0 mm. Dry spells occur even in the middle of the rainy season.

In order to sustain a high irrigation intensity and high yields, irrigation water supply is necessary to extent the wet season by supplying irrigation water before and after the rainy season, and to provide, in spite of the relatively high rainfall, for a reliable source of water during the rainy season.

The *scheme* is split up into 153 command areas or tertiary units. Each command area is supplied, via primary and secondary irrigation canals, by regulated gates.

OMIS was implemented in 1989 within the Cidurian Upgrading and Water Management Project at the Cabang Dinas PU Pengairan, Tangerang, Indonesia (District Irrigation Service). The *aim* was to introduce an improved and more efficient irrigation water management.

4.2 Crops

The preparation of a water allocation plan for the coming season is based on an inventory of what will be cultivated on each piece of land. Depending on the intensity of land-use, one or several crops can be grown sequentially within one year. Each cultivation is characterised by (Fig. 3).

- the start of cultivation,
- the time required to prepare and plant the total area of the cultivation,
- the length of time required for crop growth and harvesting.

Based on these considerations, a *crop plan* can be prepared for both the total scheme and/or for a particular command area. For the total scheme the overall cropping pattern will take into account general targets for crop cultivation, overall water availability, set-up of irrigation shifts to reduce peaks in water use, and timing of the canal maintenance period. The OMIS package provides facilities to create a cropping pattern using an on-line graphical presentation of the pattern under consideration. Total water requirements for this pattern are compared with dependable flow (Fig. 4). For the individual command areas the same procedure can be followed, but local deviations from the overall cropping pattern can be made.

figure 2

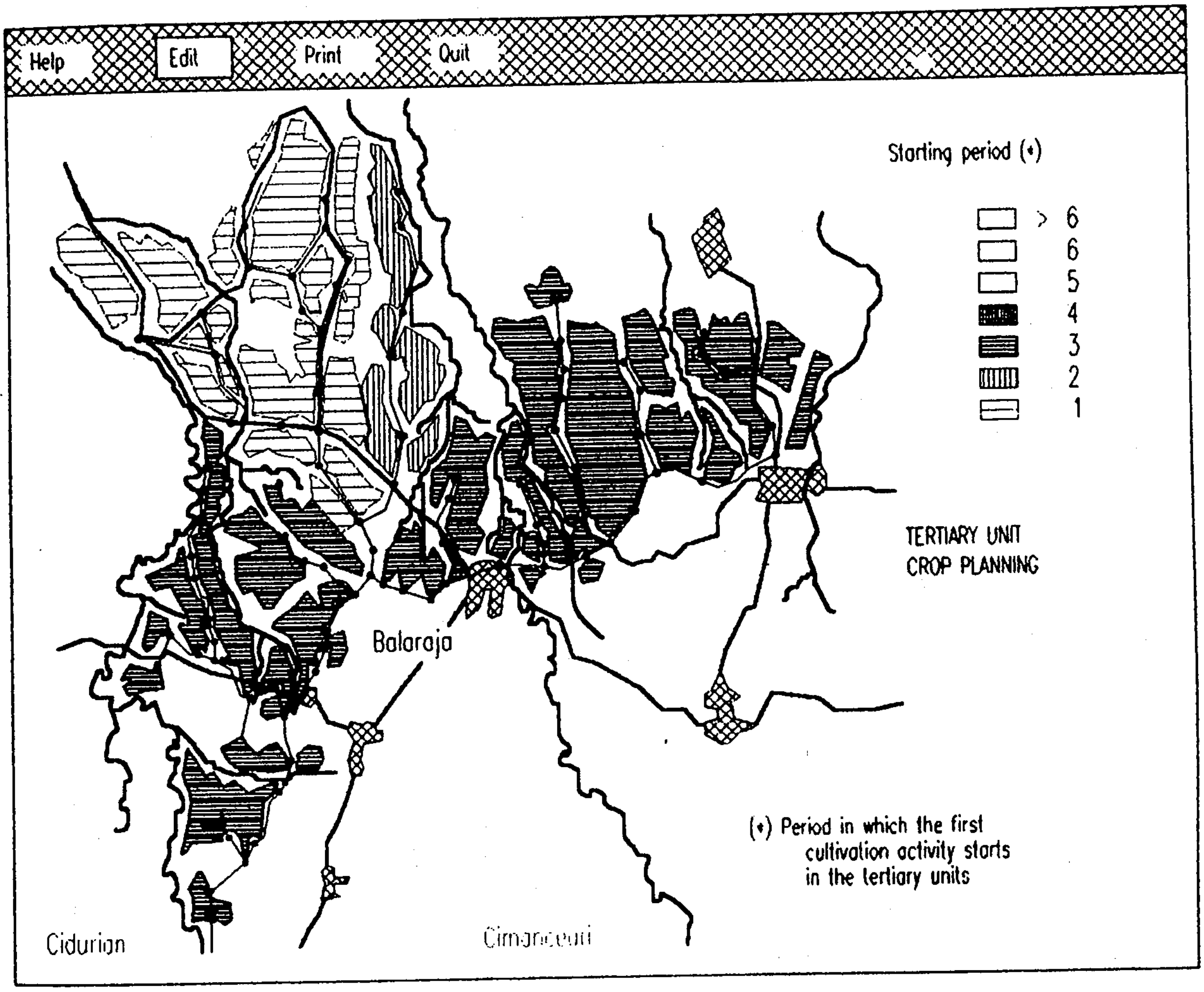

Figure 2 Map of the Cidurian irrigation scheme used for preparation of cropping pattern.

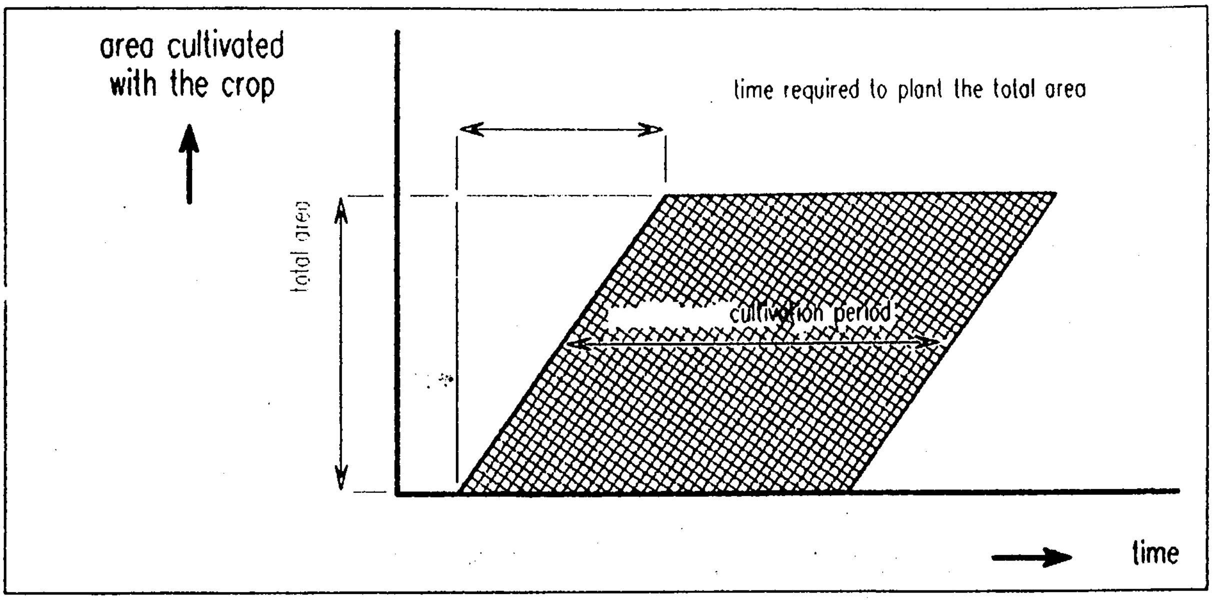

Figure 3 Presentation of a planned crop for a particular area.

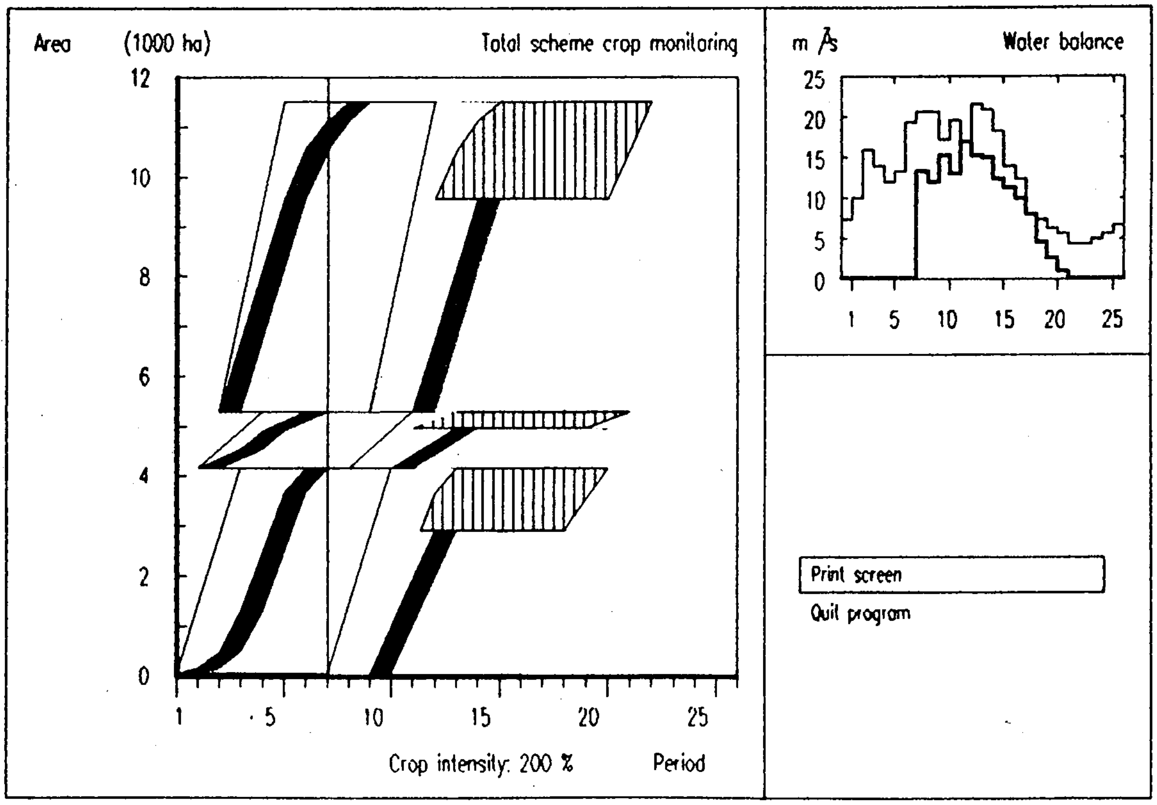

Figure 4 Crop time diagram and associated water balance for entire scheme.

For the computation of *crop water requirements* the standard method is applied using crop factors and evapotranspiration data (FAO, 1977). For non-rice crops a linear planting progression is assumed. For rice crops the progression for land preparation is expressed with the "van de Goor" formula which is highly non linear. During land preparation the water requirement for rice crops is calculated by a pre-defined water layer requirement. After transplanting, the water requirements are calculated using crop factors.

4.3 Soil moisture balance

During the growing season a soil moisture balance of every command area is calculated. The amount of water made available to the plants through capillary rise is considered to be nihil. Therefore, soil moisture and its availability to the crops is characterized by :

- wilting, field- and saturation capacity;
- rainfall and irrigation supply which replenish soil moisture;
- evapotranspiration and seepage which deplete soil moisture.

During operation the water balance is computed on a daily basis for the past operation interval of e.g. two weeks using the monitored discharges and rainfall. This computation establishes the field condition at the end of this past interval, and is then used to estimate the irrigation water requirements for the next interval.

4.4 Allocation of water

Computation of the water allocation schedule is carried out in three steps:

Demand inventory. The demands in each unit command area are compiled and traced upwards through the network. The flow in the canal network is modelled in detail, including the gate discharges, evaporation and seepage losses, gate leakage and operation losses caused by inaccurate gate setting. At bifurcation or diversion point the relevant demands or losses are added. This upwards tracing establishes the target diversions at the various gates.

Balancing demand and expected supply. Demand at the head diversion is compared with an expected "dependable" available river flow for the coming period. If the available flow is not sufficient, first water allocation to unauthorised and unplanned crops is cut back, if necessary followed by a proportional reduction of water allocation to authorised and planned crops. Reductions in allocation are implemented by an adjustment of target diversions established in the demand inventory step.

Actual supply and allocation. The flow of water is traced downwards through the network, splicing diverted water and losses at each relevant node and branch. At each diversion an attempt is made to divert the target diversion flow established in the two previous steps.

Obviously, the quality of the expected (dependable) river flow forecast strongly determines the resulting operation policy. An optimistic versus pessimistic estimate has widely varying effects on the allocation.

4.5 Monitoring

In season monitoring is extremely important and forms the basis for adjusting operation of the irrigation scheme to the actual situation. Monitoring includes crop status, rainfall, river flow and canal flows. Monitoring data can be easily entered in OMIS and is directly processed. In this way, adjustments can be made during the ongoing growing season.

4.6 Performance indicators

The objective for water management is to make an optimal contribution to crop production by making a maximum use of the available water and minimizing the effect of drought periods. In order to facilitate judgement on alternative water management strategies OMIS applies a number of performance indicators.

Water stress as indicated by the field moisture balance are transformed into reduced yield or total loss of the crop. Crop damage due to *drought stress* can be presented on a map similar as presented by Fig. 2 and 6. A range of colours is used to provide a spatial view on the occurrence of drought damage. Drought damage is calculated based on the estimated field moisture balance using the monitored crop data, irrigation water supply data, and rainfall data.

To review the efficiencies a cumulative overall *water balance* of the total scheme can be presented indicating the inflow, rainfall, evapotranspiration, canal losses, and field losses. (Fig. 5)

5 The Fayoum irrigation scheme

5.1 Scheme

The Fayoum irrigation scheme in Egypt covers about 100.000 ha. and is located in a natural depression in the desert. The lowest area of the Fayoum is occupied by Lake Qarun, which receives all drainage water (Fig. 6). The rapid rise of the water level in Lake Qarun and the low uniformity of water distribution over the Fayoum are the main problems to be tackled. The entire scheme is divided into 21 command areas.

The rainfall is negligible, and all irrigation water is supplied from the river Nile. In principle, enough water is available and the river flow is not very erratic.

The spatial inequity of supply leads to over irrigation at some areas and drought stress in others. Over irrigation causes excessive drainage flows resulting in a rise of the lake level, whereas irrigation deficiencies leads to salinity problems. The *aim* of the model was to better tune the supplies with the actual demands.

The model has recently been installed in the offices of the Fayoum Irrigation Department (FID). The model's database contains all relevant information monitored by the Fayoum Water Management and Drainage Improvement Project. For the introduction of the model a water management course was organized for the local water managers. Further guidance will be given to integrate the model in the day-to-day operation practice of the FID.

5.2 Crops

For each command area a cropping pattern can be formulated by the user in terms of crop type, and starting date of cultivation. The crop water requirement is based on standard tables presently applied by the Fayoum Irrigation Department.

5.3 Allocation of water

The water allocation computation is rather straightforward. A water balance of the canal system is set up, in which the inflow of the supply canal(s), drainage re-use stations, seepage losses, and capacity constraints are incorporated. Presently the computation of the drainage flow is rather straightforward, a fixed leaching percentage plus the excess of supply is supposed to be drained. In the future more precise soil water balances could be incorporated.

The allocation priority is on a "first come first serve" basis, which reflects reality for upstream controlled systems: first the upstream located offtakes are served and the rest is used for downstream. If the resulting water distribution is not satisfactory, the supply to the upstream units should be reduced, or the intake supply should be increased by the water manager.

The simulation model provides the water manager with a sufficient degree of flexibility, but prevents the water manager from taking senseless decisions as he is directly confronted with the results of his action. The use of GIS enables the water manager to see at one glance the spatial inequities.

5.4 Performance indicators

To evaluate the performance, several performance indicators, such as the ratio of actual supply and demand, the drainage irrigation ratio, and the lake level can be visualised on a map of the scheme. To review the variation in time, the user can browse through time, and evaluate the performance by watching changes of the colours.

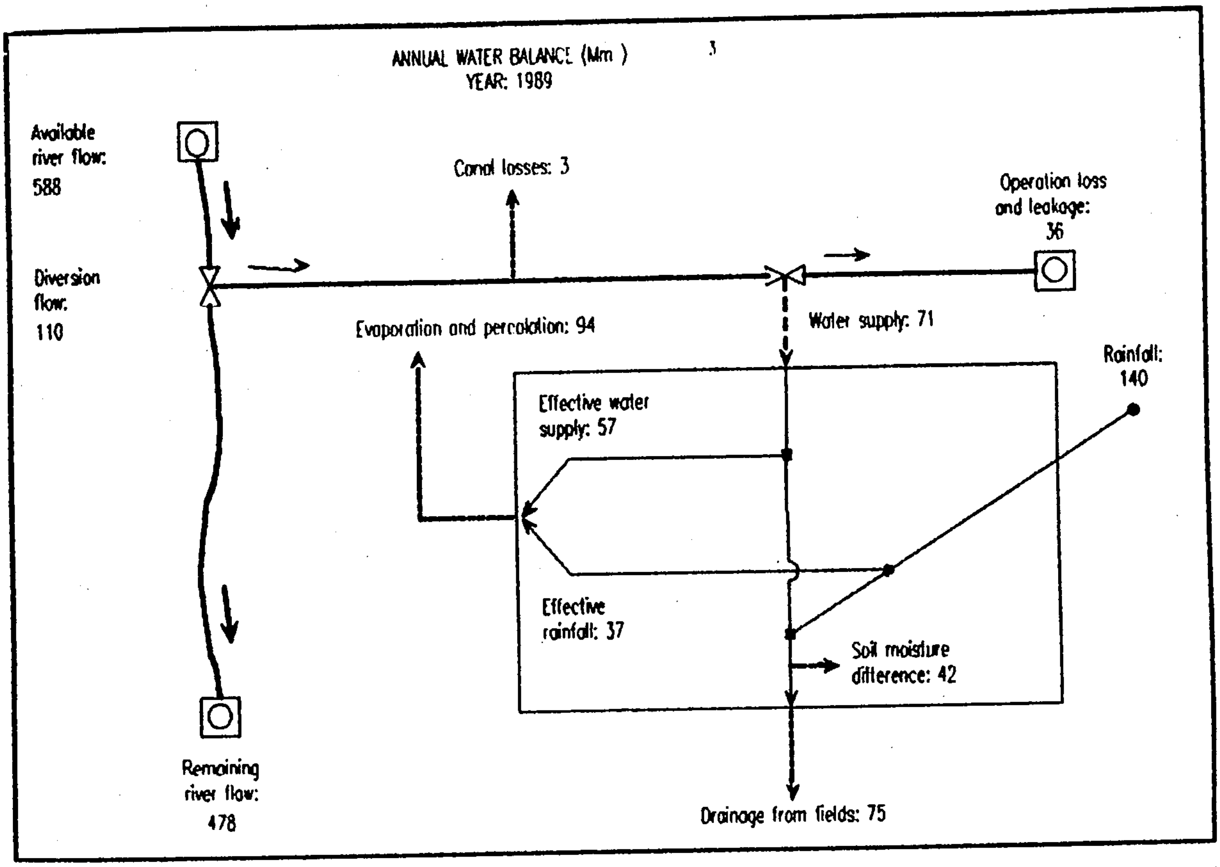

Figure 5 Overall water balance of the irrigation scheme.

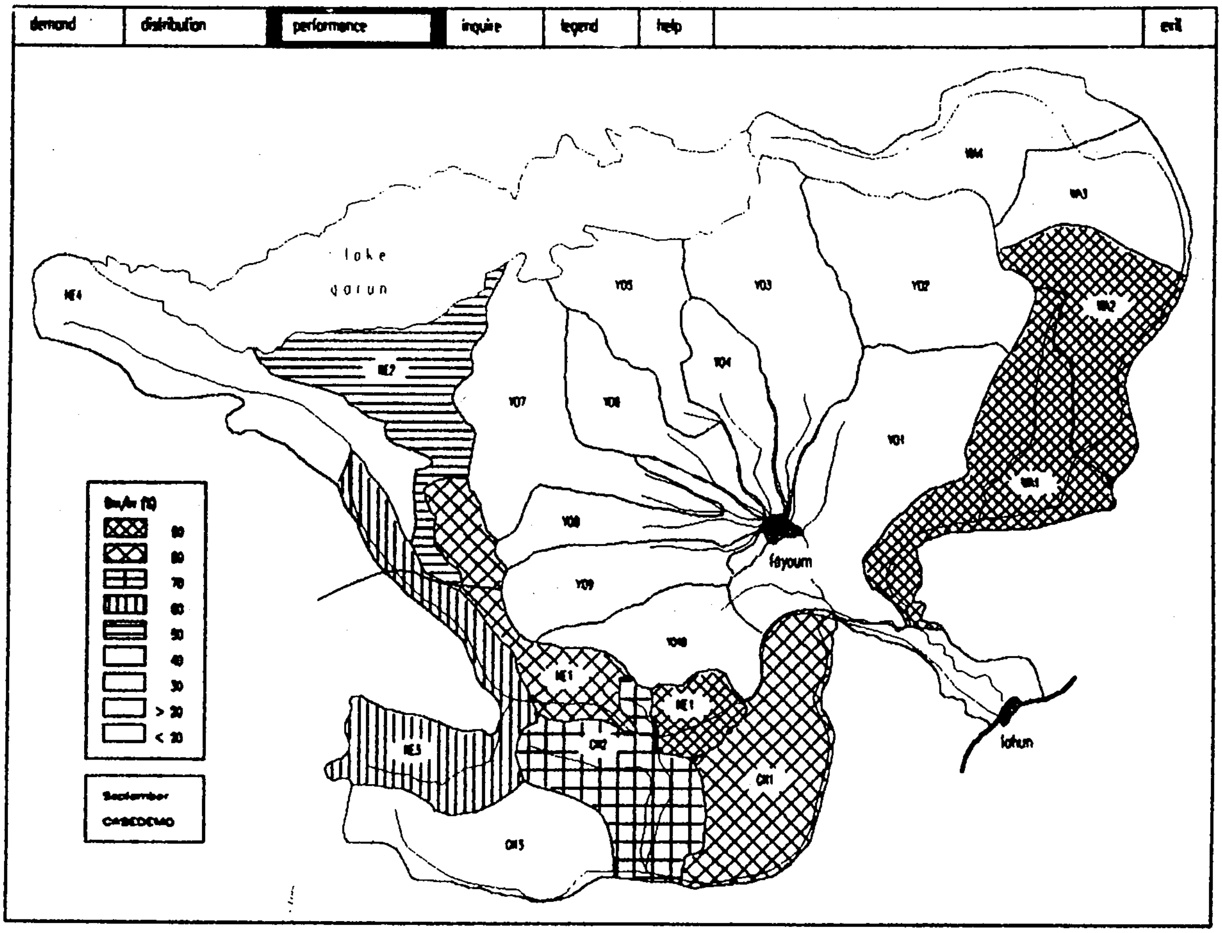

Figure 6 Map of the Fayoum irrigation scheme used to review the performance

6 Conclusions and observations

At the implementation of a decision support system for training purposes and daily operation the following is observed :

Although *computer knowledge* and experience in computer use of local officers are often lacking an user friendly and attractive decision support system makes them eager to learn within a short period (order days). It makes people enthusiast.

Requirements for the user *interface* are high: the operation should be simple and reliable, the generation of a crop plan or operation schedule should be reduced to routine actions. Only those parameters which are relevant for a quick interpretation of the situation in the field, should be presented.

Procedures for a reliable collection of *monitoring data* is one of the most essential and sensible elements in the whole process to a successful implementation of a decision support system. Monitoring data are raw materials to build upon the decisions.

Set up and introduction of a decision support system of irrigation networks requires a well and continuous *guidance* especially at the first period during which the software package has to be adapted to the local situation. Detected problems in use must lead to changes in the software e.g. better validation checks on monitoring data. The program can suggest data corrections based on previous periods like in expert systems.

The use of a *Graphical Information System* improves the ease of use considerably and facilitates easy interpretation of computation results and thus the actual situation in the fields.

Decision support systems like OMIS are still in a continuous *development.* New hardware and software options come available which facilitate the use of the decision support system. This must lead to the release of new versions. The guidance of the development and the guidance of those new releases can be given by central unit e.g. at department of irrigation within the ministry of Public Works in cooperation with research and engineering companies.

References

DELFT HYDRAULICS and DHV Consulting Engineering (1989), *OMIS, User's Manual,* Cidurian Rehabilitation and water management project, Jakarta, Indonesia

FAO (1977), *Crop water requirements,* irrigation and drainage paper no. 24, Rome, Italy.

Schuurmans, W., W.N.M. van der Krogt (1992), *Combined allocation and operation model,* Proceedings of ASCE conference Water Forum 1992, Baltimore, U.S.A.

Soenarno (1989), "*A new approach to development, operation and maintenance of irrigation systems in Indonesia*", Proceedings of the International Conference at the University of Southampton, UK.

USDI (1978), *Report on the water conservation opportunities study,* U.S. Dept. of Int., Bur. of Rec., Denver, CO, USA.

Verhaeghe, R.J., and W.N.M. van der Krogt (1991), *Modelling of irrigation water management,* Proceedings of the Eight Afro-Asian Regional Conference of the ICID, Bangkok, Thailand.

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Utilization of SIMWAT Model in an Irrigated Area of Mendoza, Argentina

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Abstract

For the design and operation of irrigation systems the use of numerical models has become an important tool. The model SIMWAT has been developed as an integrated part of hydrological models describing the water movements in the irrigation channels as well as in the saturated and unsaturated zone. The aim is to use these hydrological models to obtain operational guidelines for improving the water distribution and allocation strategy in time. The water movements in the SIMWAT model are described with the Saint Venant equation. Including the hydraulic structures and divisors in the model makes it very useful as a practical tool for water management problems in irrigation schemes.

Through a financial support of the European Community (EC), the model has been implemented at the Lower Tunuyan River (80 000 ha. irrigated area) in the arid region of Mendoza, Argentine. Giving an example, the Viejo Reduccion Canal (11 km long) serves 1,674 ha of irrigated area and delivers water to 26 Tertiary Canals (27 km length). Both the secondary and tertiary canals are earth lined. The operation system is throughout continuous flow at the primary and secondary canals and by rotation at the tertiary level. The most common hydraulic works are fixed divisors and gates to deliver water from the secondary to the tertiary canals.

The model SIMWAT will be used on three different levels. For example :

- Detailed scale for estimating the discharge through divisors.
  Operational rules require hte translation of water levels at these divisors to actual discharges.

- On a scale required for the design of irrigation channels.
  A secondary canal will be modelled using some 50-200 nodal points. Each structure can have one or more nodal points.

- Superficial scale for water distribution to the secondary canals.
  The SIMWAT model will then be used to describe the water flow in the main canals and a groundwater model is attached to estimate the impact of the irrigation.

The results show that SIMWAT model describes the real flow and water head in the canals acceptably, compared with the real situation. The model can be used in simulating other operation rules to improve the water management for the Irrigation General Department and the Water User Associations.

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1- Introduction

Mendoza province is an arid region located in the western part of Argentina, near the Andes mountains, with less than 180 mm annual precipitation. The snow melt from the mountains supply water to five rivers that support 477,500 ha of irrigated area (with water rights). The use of groundwater is also important (18000 wells). The water authority is the Irrigation General Department (DGI), which is self-supporting and independent of the provincial government. DGI administrates the rivers, dams and primary canals. The water users are responsible for the lower order canal system. Water users associations have been re-grouped recently, so that one association is responsible for water management within a command area of 10^3-10^4 ha. This requires new technical skills, which DGI must acquire to establish how to meet best the often conflicting needs of the associations.

At present water is allocated to an area as a function of the water rights and not by the cultivated area, that is approximately 280,400 ha (Thomé et al, 1988). The resulting over-irrigation may cause salinization, water tables close to the soil surface and environmental deterioration. Those aspects signify a high social cost. Annually a large amount of money is also spent on maintenance of the irrigation and drainage network, as well as for the repair and construction of expensive works.

Studies show that the irrigation efficiency in Tunuyan River is 63% on external use (from river to farm gate) and 78% on-farm if the user applies surface water with rotational supply and 62% if this is combined with groundwater extractions (Chambouleyron et al, 1983). During the 1989/90 and 1990/91 irrigation seasons the measured conveyance efficiency in some irrigation canals was 92% (Drovandi, 1991).

The operation on rotation basis, makes a more efficient water use difficult, because the water allocation is based on the water rights and not based on the cropped area. There are no need for changes, except during periods of water shortage. It will be necessary to change operation rules to other non-rigid delivery schemes (Ciancaglini, 1990).

The objective of the present work is to develop and evaluate tools for water management by DGI and water users associations, in order to plan and control the water allocation by means of mathematical models. The models must have the capacity to plan yearly, monthly and daily water distribution through the irrigation network. Some models developed at The Winand Staring Centre (The Netherlands) were adapted to the arid irrigated areas of the Tunuyan River. The aim is to implement the models in the Lower Tunuyan River District, an administrative department of the Irrigation General Department of Mendoza Province. Personnel will be trained to use the surface and groundwater flow models in order to improve the water use in all the irrigated area.

For the research project a pilot area of 40,000 ha has been selected within the Tunuyan River irrigation scheme (Fig. 1). The irrigation water for this scheme is extracted from the Tunuyan River at the Gobernador Benegas diversion work. To guarantee water requirements, the El Carrizal dam has been constructed upstream. This dam is 46 m high and 2 km long and has 39010^6 m^3 of net storage capacity. The hydropower generation is 17 mega watt. The new dam acts also as a silt trap, resulting in much less silt in the irrigation system than before. The disadvantage of less silt is an increase in weed growth and higher losses due to infiltration from the canals. The Gobernador Benegas diversion dam has 19 slight gates and a 65 m^3/s flow capacity, diverting water to the Right Bank Main Canal or Reduccion Canal (13,000 ha irrigated) and to the Left Bank Main Canal (75,000 ha).

The original irrigation scheme has been constructed about sixty years ago. Primary canals are partially concrete lined (trapezoidal) and serve lower order canals. The secondary and tertiary canals are unlined and require intensive maintenance in the form of weed and silt removal. The secondary canals are in general higher than the surrounding area. The irrigation scheme functions with continuous flow in the primary and secondary canals and with rotation delivery at tertiary level. The primary canals have a base width of about 1.5-4.5 m and for the secondary canals 1.2-3.2 m. A tertiary canal serves a number of farmers with water and is about 0.8 m. wide. The average irrigated area served by a tertiary canal ranges from 60 to 180 ha and the tertiary canals have a length of 1.5-2.5 km. The flow velocity ranges from 0.5-1.5 m/s. The drainage canals are distinguished in a primary and secondary system and the depths ranges between 1-1.5 m. Since this network is not sufficiently dense the water table can be near the surface (< 1 m), thereby reducing the agricultural productivity. Due to the high irrigation requirement and in certain periods a limited water availability, it is necessary to complement the superficial water use with groundwater.

The main crops in the region are grapes, pit orchard and vegetables. The common irrigation practice is surface irrigation with near zero slope (furrow and border). Due to the rotation system the amount of irrigation water is not sufficient to irrigate the total land of the farm within one rotation. Commonly the water is applied to about one third of the farm land, covering in one month all the farm area. In general, farmers tend to apply different amount of water depths depending on the crop type, but there is a tendency to over-irrigate.

2- Model Description

The model SIMWAT (simulation of flow in surface water systems) has been designed for general purpose to simulate water movements in open channels. For irrigation networks several regulation structures such as gates, weirs, divisors, etc. have been included. For the description of the water movements the well-known Saint Venant equation is used (Chow, 1956). The irrigation canals are divided into sections with nodes on either side. For each node a water level is calculated and for each section a discharge Q. For a section with nodes i and j the discharge can be written as:

$$Q = K \cdot (h_i - h_j) \tag{1}$$

where K represents the roughness and geometry of a channel section. Using the continuity principle and the above relation for all nodal points a set of equations is obtained in the form:

$$\{ Q \} = [K_i] * \{ h \} \tag{2}$$

where the matrix $[K_i]$ can be considered as a resistance and storage matrix. It contains all contributions to the flow resistance between point i and its adjacent nodes and the storage capacity at node i. Using matrix inversion, Eq. (2) can be solved to give the water levels in all nodal points. Because the resistance factor in the $[K_i]$ matrix is a function of the water level the solution is done by successive approximation. In general only a few iterations per time step are required. Abrupt changes in water levels and flow rates in time can be modelled, requiring very small time steps.
In situations where the change in flow rate is very small, gravitational forces can be neglected. Instead of using the dynamic equation, the so-called diffusion type of wave suffices, without strict limitations on the time step to be used. For numerical stability the time step is limited by factors like section length, change in flow rate, channel geometry, etc. In practice the time step for the diffusion type of wave is approximately 1-3 hours.

The flow rates in the canal system depends on the requirements for irrigation. These requirements are simulated by a groundwater flow model described in detail elsewhere (Querner, 1988). Both the surface water and the groundwater flow models have been combined also into a hydrological model (Querner, 1992). The advantage of such an integrated hydrological modelling approach is that the water requirements and the water allocation can be analyzed.

3- Application

Two cases demonstrating the use of surface water models for irrigation practice have been selected. The cases are presented in the following two sections.

3.1- Main canal

Figure 2 shows the scheme adopted by the SIMWAT model for the modelling of the water movements in the main canal system. Selected canals are Main Canal Left Bank and Main Canal Right Bank. Principal canal characteristics were described in the introduction. The discharge in the main canals is about constant with changes over the irrigation season.

For the simulations with the network shown in Figure 2, the irrigation requirements or the water distribution will be combined with calculations with a groundwater flow model. These combined calculations will be carried out in the near future in a manner described by Querner (1986). At present the water allocations for the tertiary units is not included in this schematization, these are the boundary conditions of the network represented by weirs. In the model, the fixed divisors are simulated by means of two weirs with each a width equivalent to the partitioning proportions (Fig. 2).

3.2- Secondary canal

The selected area is served by the Viejo Reduccion secondary canal, which receives water from the Main Canal Right Bank (Fig. 2). The schematization of this secondary canal is shown in Figure 3. Water is allocated to this secondary canal through a fixed water divisor, based on the water rights of the area of about 1650 ha. The secondary canal is earth lined and 2-3 m width on bottom. Water is allocated to tertiary units in an upstream direction in four turns. The first sector, denoted A on Fig. 3, serves 8 tertiary canals, the second sector (B) serves also 8 tertiary units. Water is supplied to tertiary units either through fixed water divisors located in the secondary canal or by means of sluice gates. All offtake points to the tertiary canals are operated by one ditch rider (tomero). Every section receives water at approximately 8 days interval, supplying water to the tertiary unit during 48 hours each. Tertiary offtake points are not monitored. The first sector to be supplied is the most downstream sector A (Fig. 3). The rotation scheme is the same for the entire growing season, altered only in the event of extreme meteorological situations. The discharge during the season depends in principle on the overall supply.

To adapt the irrigation network to model schematization, Figure 3 shows the nodal points. There are a total of 111 nodes, 26 gates and 14 fixed divisors (57 weirs in total). Figure 4 shows the proportional partition of flow from the Main Canal to the Viejo Reduccion Canal. This has been estimated with the SIMWAT model, because measured data was not available.

For this secondary canal case model calibration was made taking into account data from two canal sections. The first point is the gauging station that DGI operates at the canal head and the second is a non-permanent control point taken during the research period between nodes 173 to 174 (Fig. 3).

4- Results

4.1- Main canal:

Figure 5 shows the annual distribution of average monthly discharge of the 1987/88 irrigation season. Some of the lower values obtained during periods of maximum water use is due to interruptions in the operation service occurring in December and March (Fig. 5). For some points along the primary canals the water delivery is analyzed in time. Figure 6 shows one typical rating curve for Right Bank Main Canal (location shown on Fig. 2). The measured curve and the simulated rating curve by means of the SIMWAT model agree well.

4.2- Secondary canal:

The model was used to make a more detailed simulation of the Viejo Reduccion secondary canal. The model can calculate situations at different times. Figure 7 shows the difference between measured and calculated discharges for canal 173. The obtained values for the stage-discharge relation depends on different flow rates resulting from ordinary gate operation (non-permanent fluxes). In that respect there is an acceptable difference between observed and calculated values.

A second simulation concerns the Viejo Reduccion secondary canal operation for 3 full rotation cycles, considered to occur between days 2 and 26 (Fig. 8). The Viejo Reduccion secondary actual operation canal is divided in 4 operative sectors A, B, C and D, as shown in Figure 3. Figure 8 shows the discharge variation in time of 4 channel sections, as section 152 and 156 in sector D and section 161 and 187 in sector C. Taking an simple example such as section 152, it has a discharge of 0.68 m^3/s between day 2 to 8 due to delivering water to other sectors located downstream. After day 8 a rotation period starts which delivers water to a canal located upstream of section 152 and the discharge reduces to 0.57 m^3/s during days 9 and 10. The reduction in discharge is proportional to the canal water partition with the fixed divisor present in the canal. Subsequently there will be an increment to 0.68 m^3/s again for days 11 to 16. In similar form it is possible to obtain the different discharges in time from the more complex delivery cases for the locations of sections 156, 161 and 167. Figure 9 shows for the same example the changes in water depth for the same 4 locations.

5- Conclusions

In general, it is possible to describe with the SIMWAT model the changes in flow rate both in space and in time, due to the usual canal operation. The model is suitable as a planning tool for water use in the irrigation system.

Possible procedure is to have the annual water snow melt prediction translated into the availability of water on a monthly base. This data will be in fact the monthly dam discharges from the storage dam. SIMWAT model can assign the delivery flow to the different command areas, taking into account the possible losses. The groundwater modules translates these assigned quantities of water into actual evapotranspiration levels (crop production). In this way the water allocation can be analyzed. Separate simulations with this groundwater flow model have been described by D'Urso et al (1992). The combined surface and groundwater flow model will be applied to the pilot area in the near future. Such a modelling approach has been specifically designed for practical applications, but is comparable with the processes considered in the SHE model (Abbott et al, 1986).

Operational rules requires the translation of water levels at the divisors to actual flow rates. A detailed schematization by means of the SIMWAT model can give stage-discharge ratings. Maintenance problems, such as siltation and weed growth can be easily checked to what extend they may reduce the canal capacity, before action should be taken. The SIMWAT model can also simulate other water delivery conditions such as controlled demand, delivery upon request, etc. This means modifying various input data.

At present the model is already calibrated and is ready to be used. The future use of SIMWAT model by water administrators will demand more graphic support and a more friendly interface to make it easier to use.

Acknowledgement

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References

Abbott, M.B. et al, 1986. An introduction to the European Hydrological System, "SHE". J. Hydrol. 87: 45-77.

Chambouleyron, J. L. et al, 1983. Evaluacion y optimizacion del uso del agua en grandes redes de riego (Evaluation and optimization od water use in big irrigation networks). Italo-Latino Americano, Roma. 175 pp.

Ciancaglini, 1990. Selected countries of the southern cone. In: Irrigation Management in Latin America. IIMI, Sri Lanka: 33-59.

Drovandi, A., 1991. Informe actividades medicion de caudales (Report on flowmetering activities; draft)- Proyecto CEE (borrador); INCYTH-CRA. Mendoza.

D'Urso, G., E.P.Querner and J.A. Morabito, 1992. Intergration of hydrological simulation models with remotely sensed data: an application to irrigation management. Proc. Int. Conf. Adv. in Plan., Design and Man. of Irr. Systems as related to Sus. Land Use. Center for Irr. Eng., Leuven: 463-472.

Ernst, L.F., 1978. Drainage of undulating sandy soils with high ground water tables. J. Hydrol. 39(3/4): 1-50.

Querner, E.P., 1986. An integrated surface and groundwater flow model for the design and operation of drainage systems. Int. Conf. on Hydraul. Design in Water Res. Eng.: Land Drainage, Southampton: 101-108.

Querner, E.P., 1988. Description of a regional groundwater flow model SIMGRO and some applications. Agric. Water Man. 14: 209-218.

Querner, E.P., 1992. Aquatic weed control within an integrated water management framework. DLO-The Winand Staring Centre, Wageningen. In prep.

Thomé, R.; H.E. Yanez y J. M. Zuluaga, 1988. Determinacion del area bajo riego en la provincia de Mendoza, Republica Argentina (Cropped area determination at Mendoza Province, Argentina) - M. Menenti, Editor. Mecanismos de aprovechamiento hydrico en la region andina. Modelos de simulacion e imagenes satelitarias. ICW, INCYTH y CRICYT: 167-184.

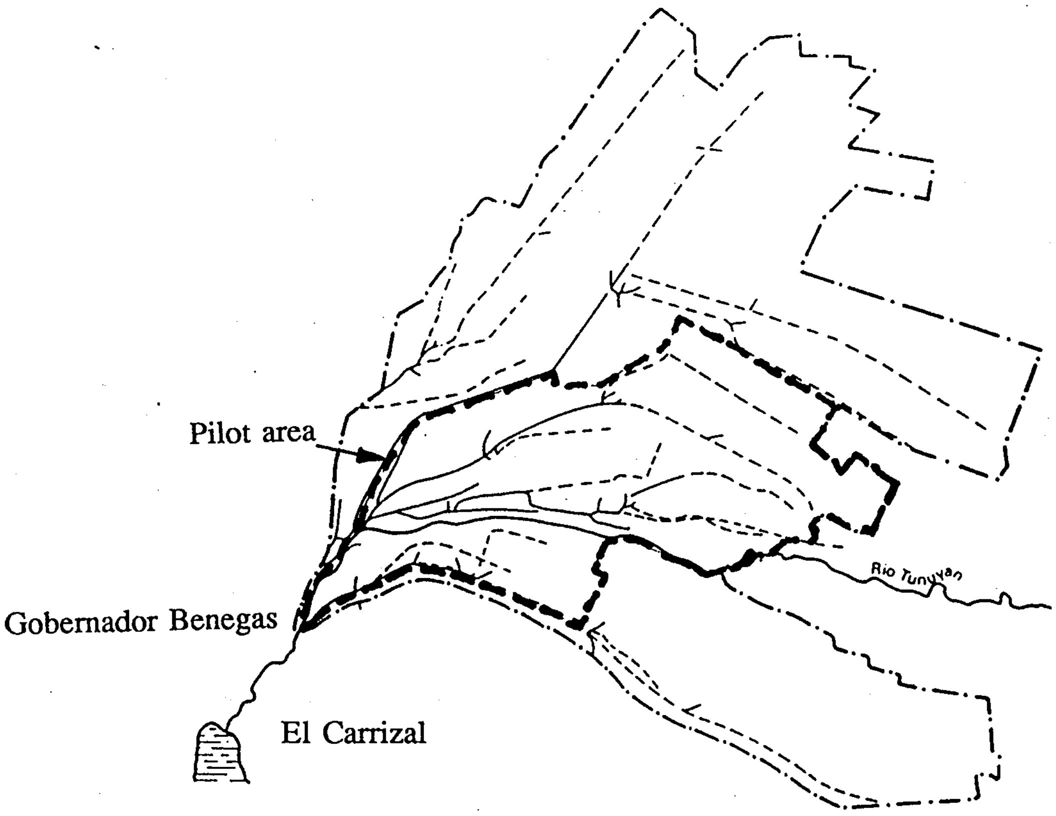

Figure 1 Layout of Lower Tunuyan River irrigation scheme and the pilot area of 40,000 ha.

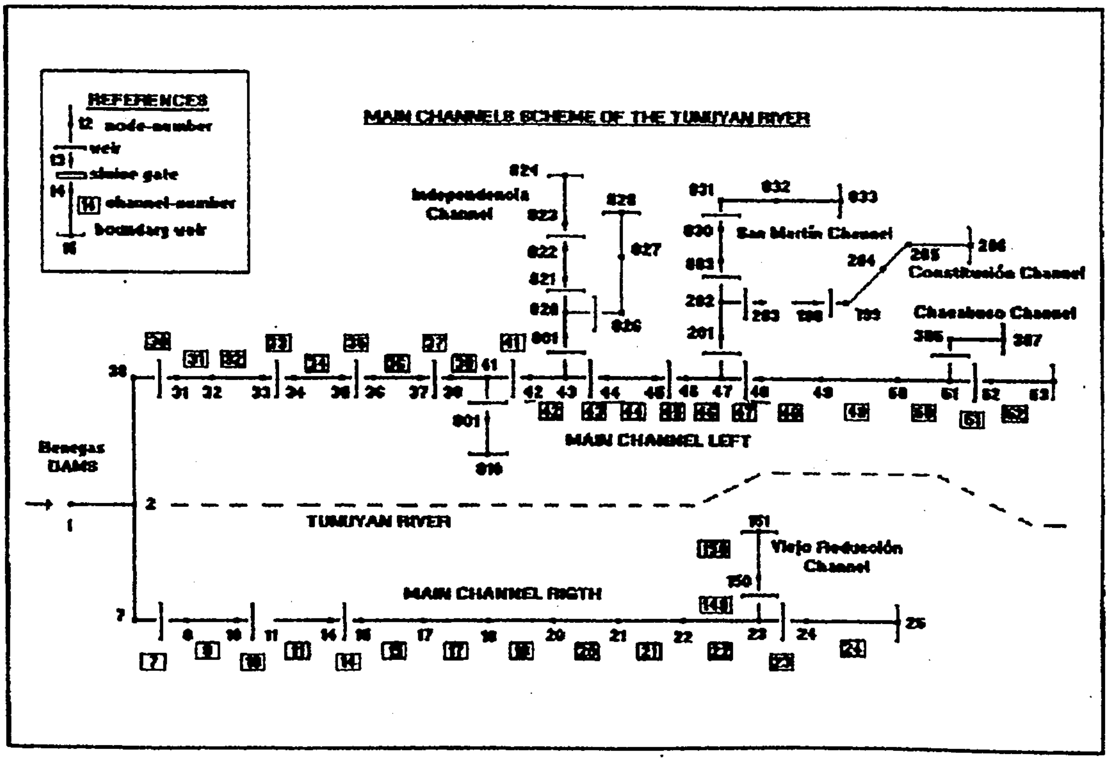

Figure 2 Schematization of primary canals for the SIMWAT model of the pilot area.

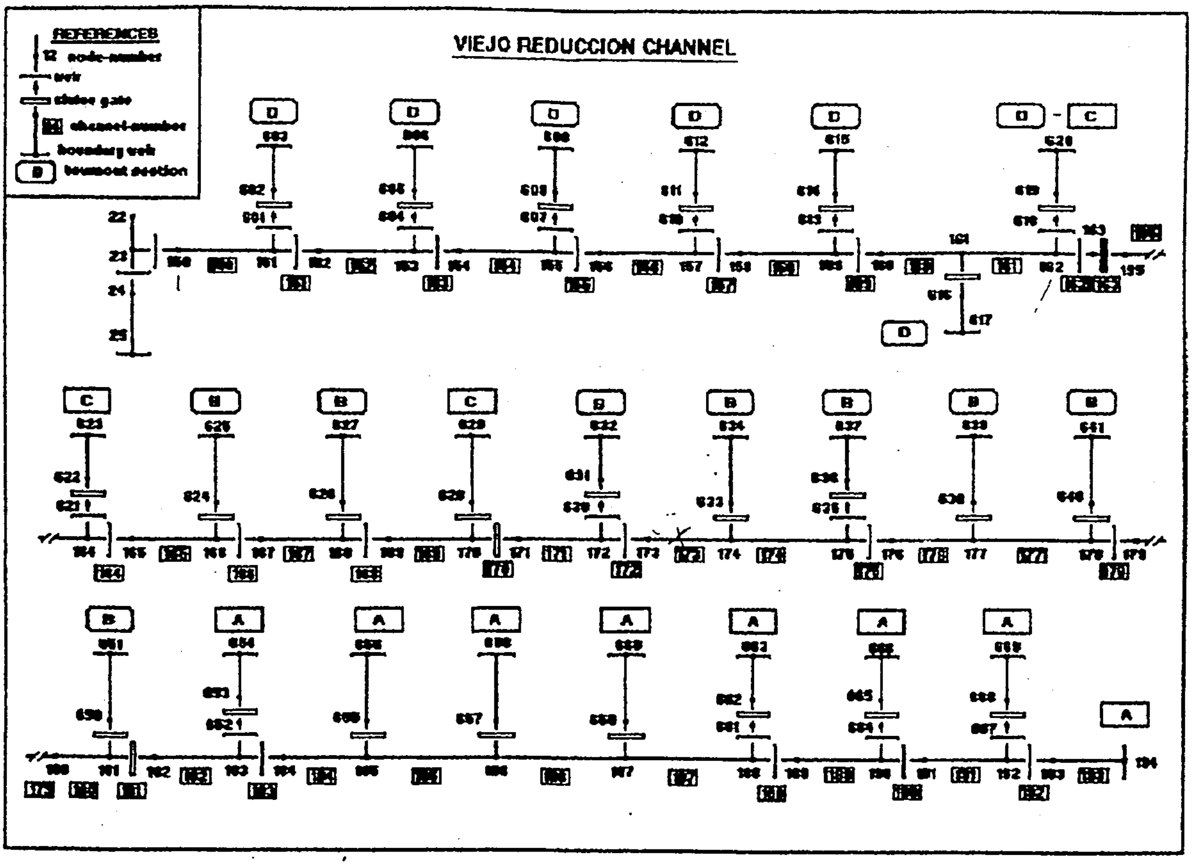

Figure 3 Schematization of secondary canal Viejo Reduccion for the model SIMWAT.

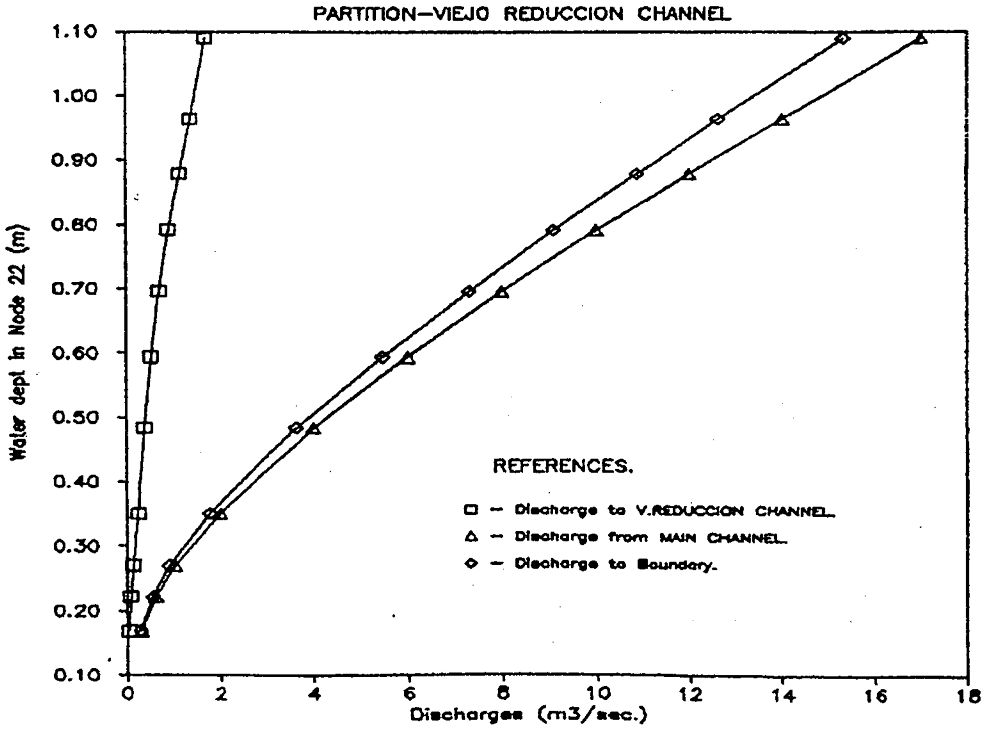

Figure 4 Partitioning of flow rate from primary canal to flow rate into the Viejo Reduccion canal and canal serving other areas outside pilot area (results model SIMWAT).

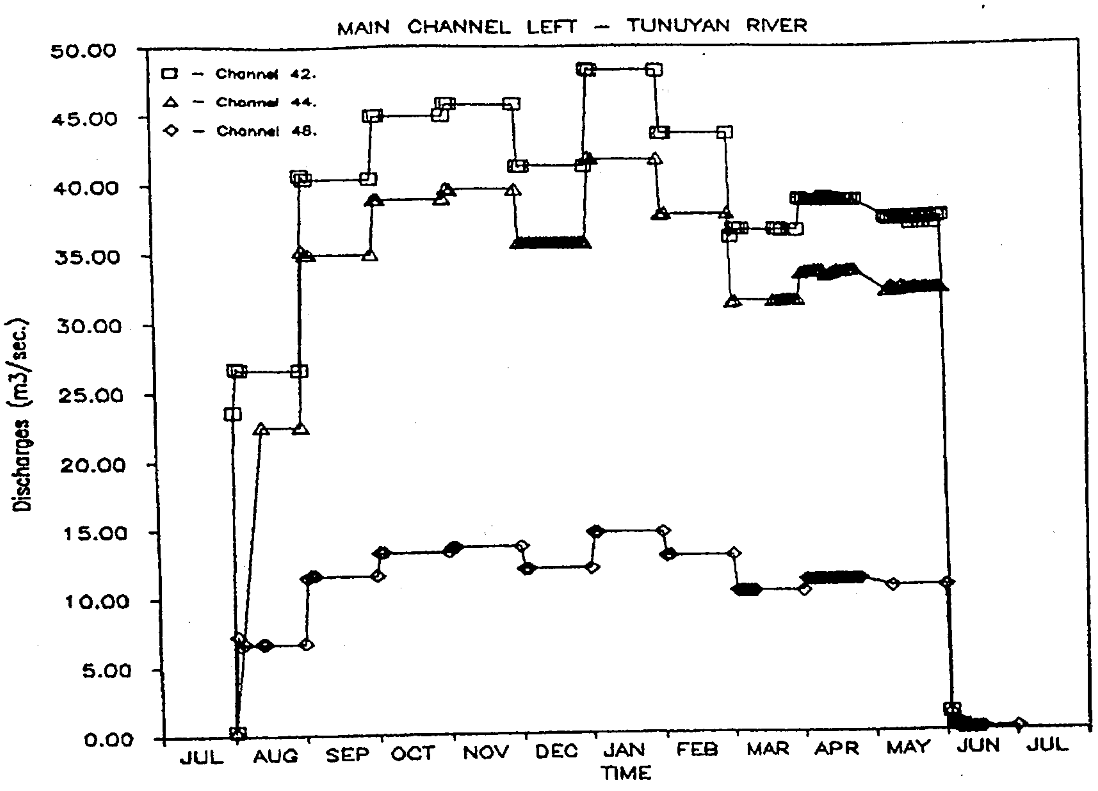

Figure 5 Variation of monthly flow rates in 3 canal sections of the primary Left Bank Canal.

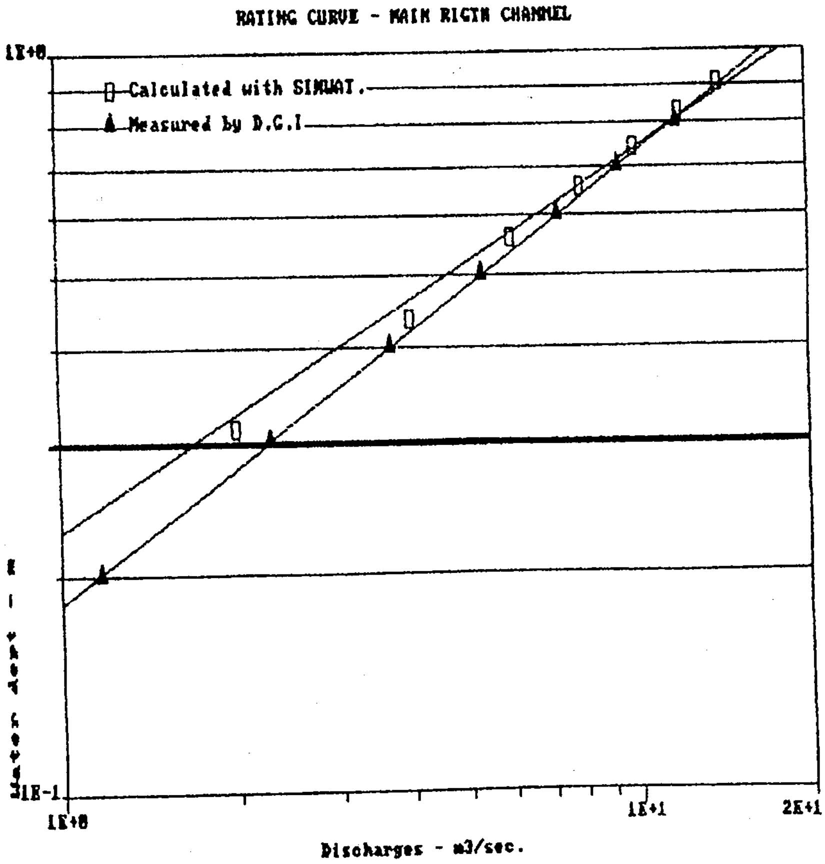

Figure 6 Rating curve measured and calculated by SIMWAT model for location in the primary Right Bank Canal.

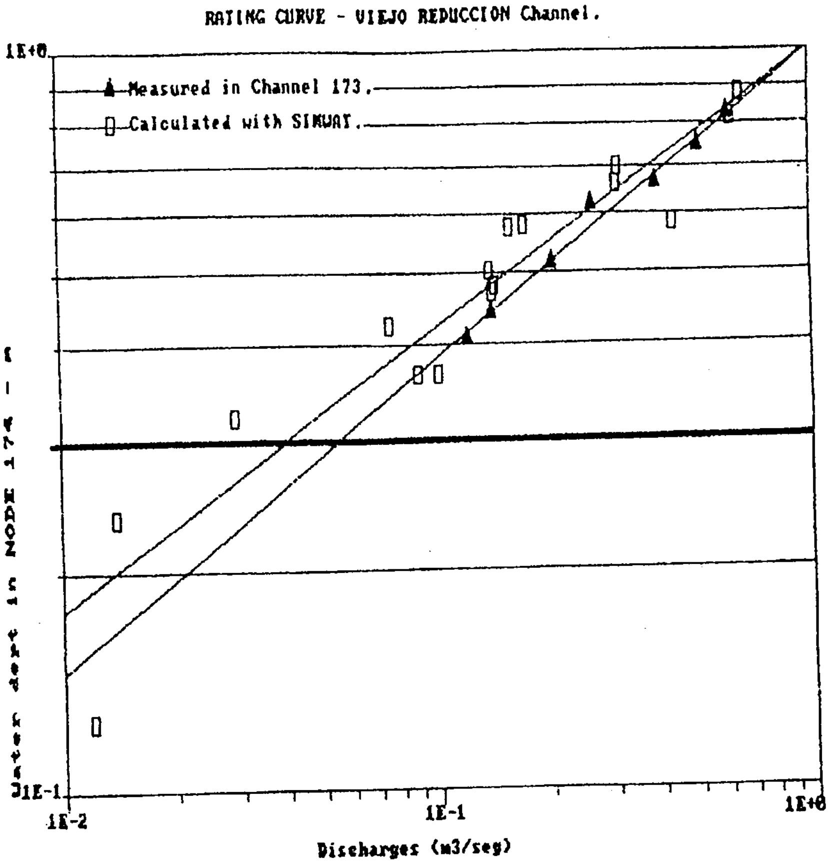

Figure 7 Rating curve measured and calculated by SIMWAT model for location in secondary canal Viejo Reduccion.

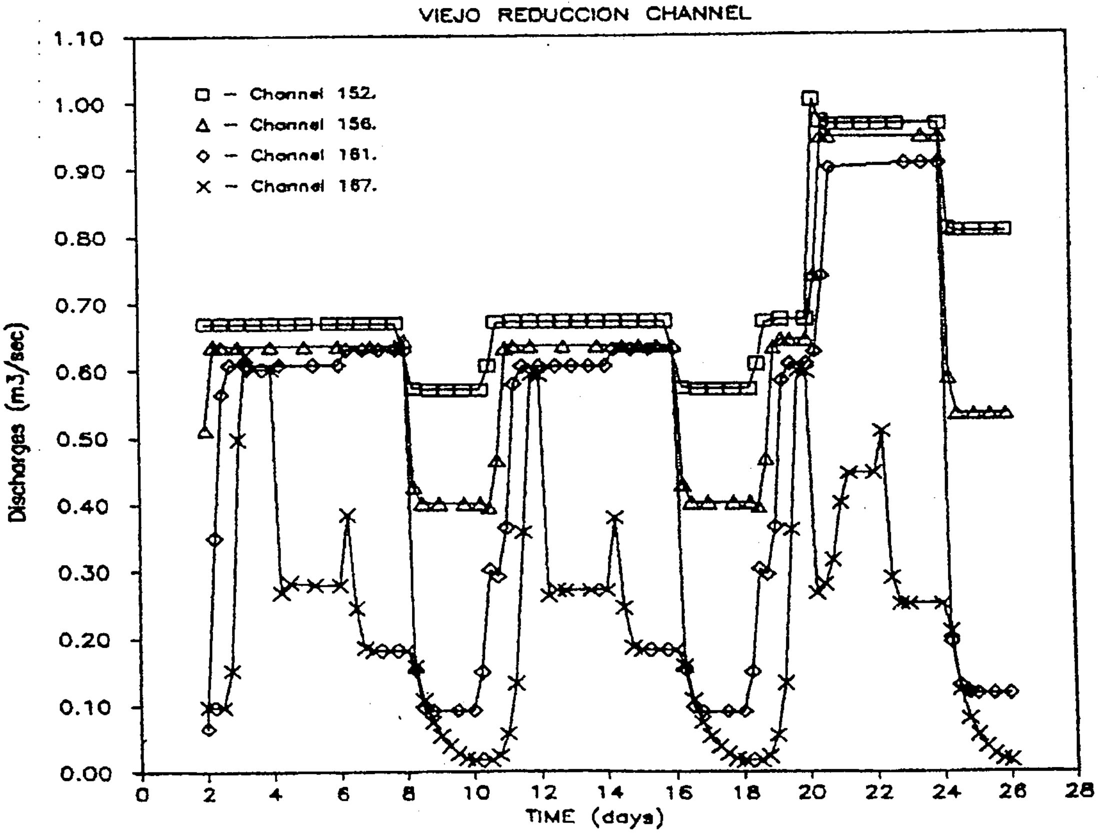

Figure 8 Variation in flow rates at 3 locations in the secondary canal Viejo Reduccion caused by the rotational delivery scheme.

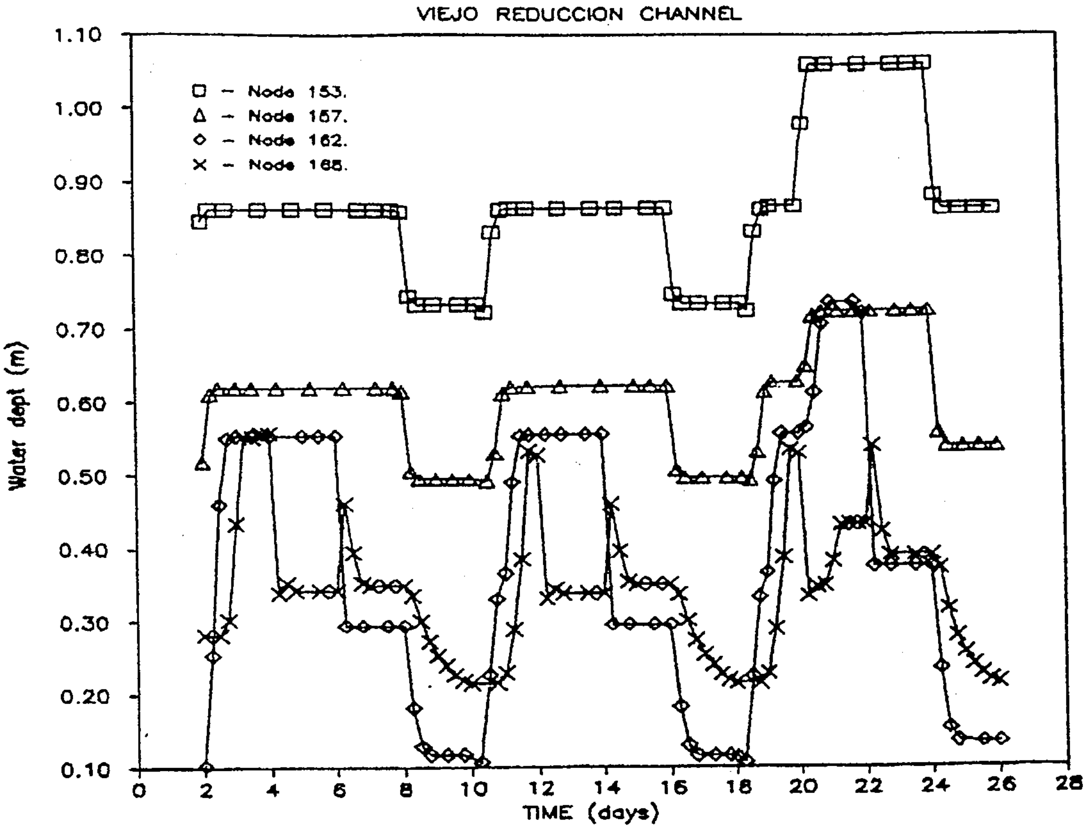

Figure 9 Variation in water levels at 3 locations in the secondary canal Viejo caused by the rotational delivery scheme.