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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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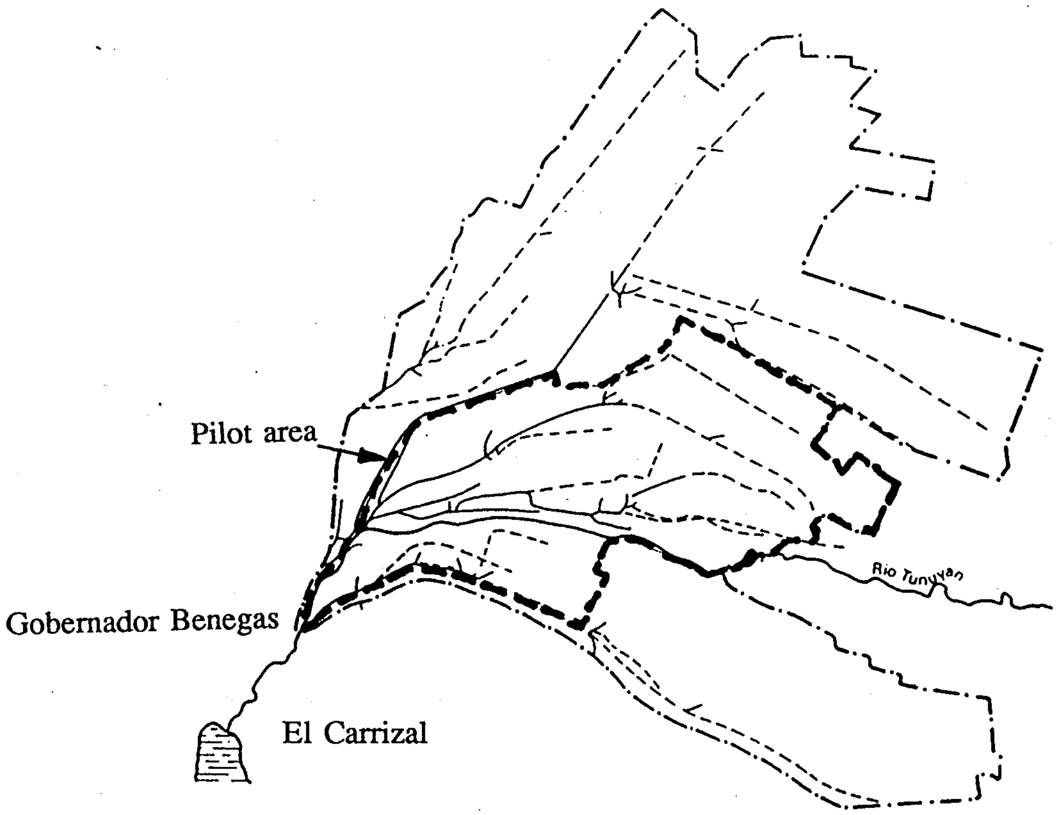

Figure 1 Layout of Lower Tunuyan River irrigation scheme and the pilot area of 40,000 ha.

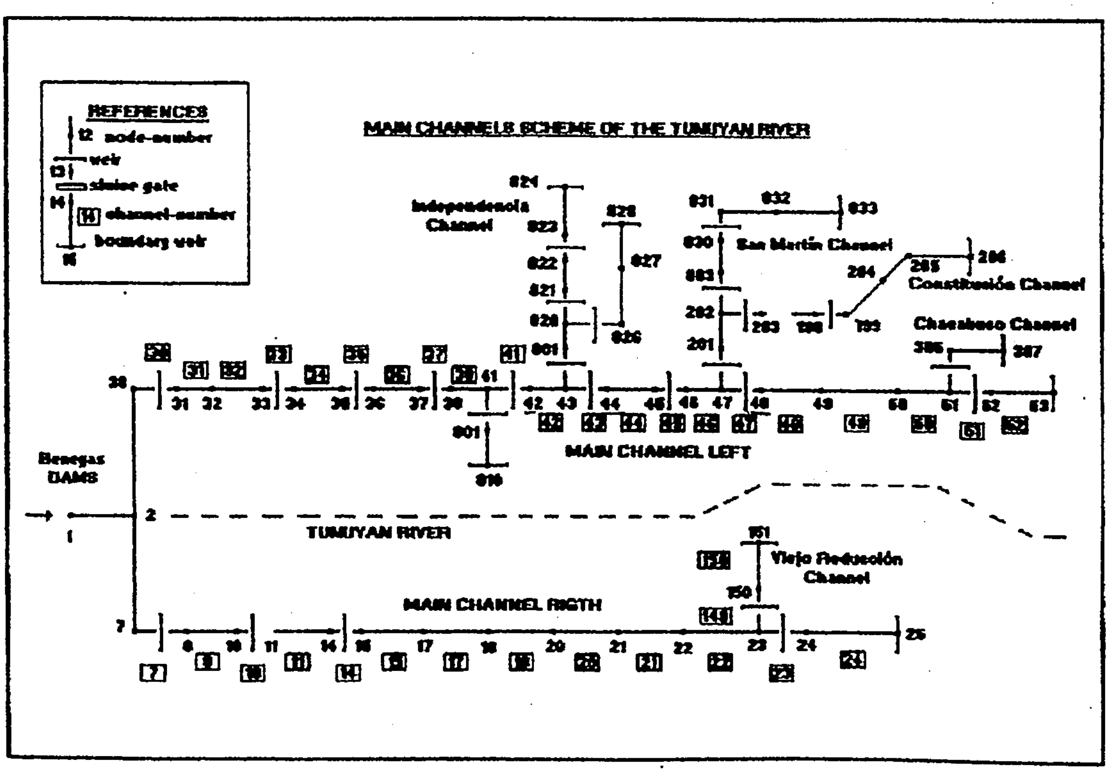

Figure 2 Schematization of primary canals for the SIMWAT model of the pilot area.

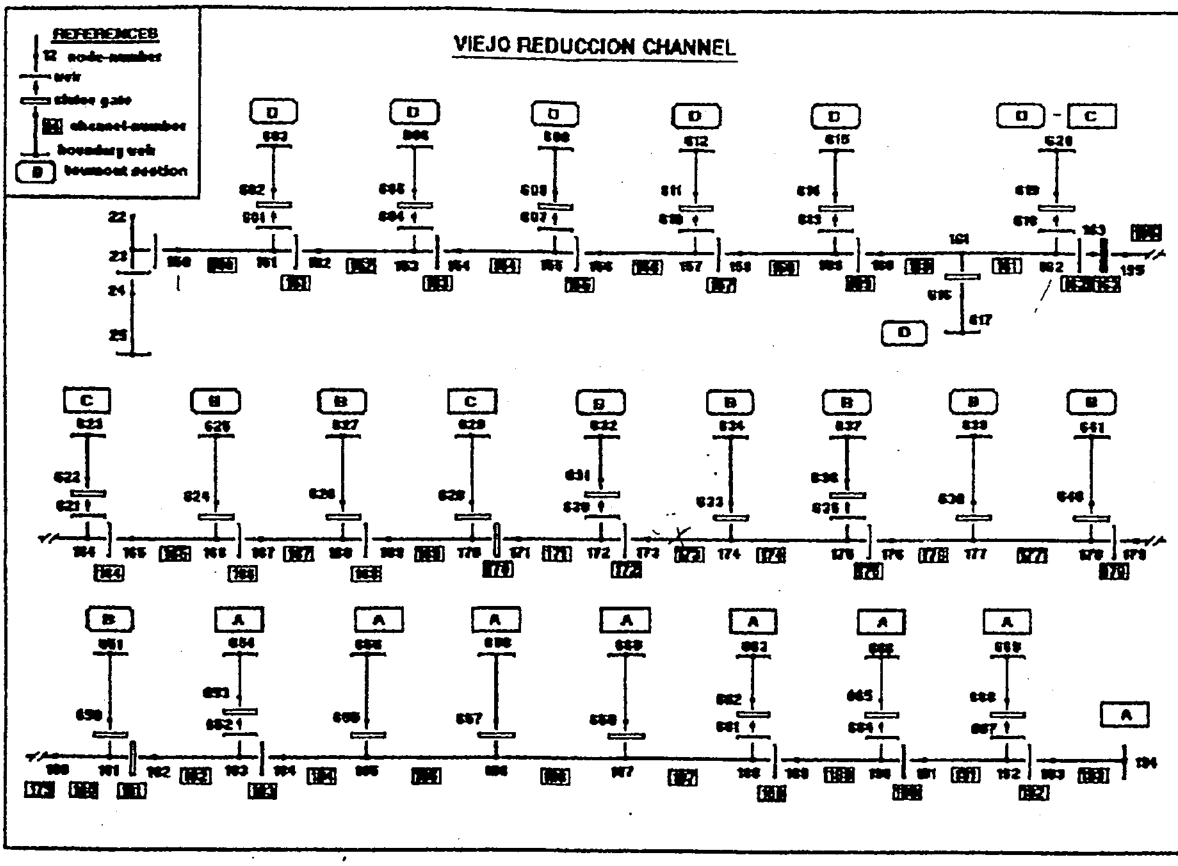

Figure 3 Schematization of secondary canal Viejo Reduccion for the model SIMWAT.

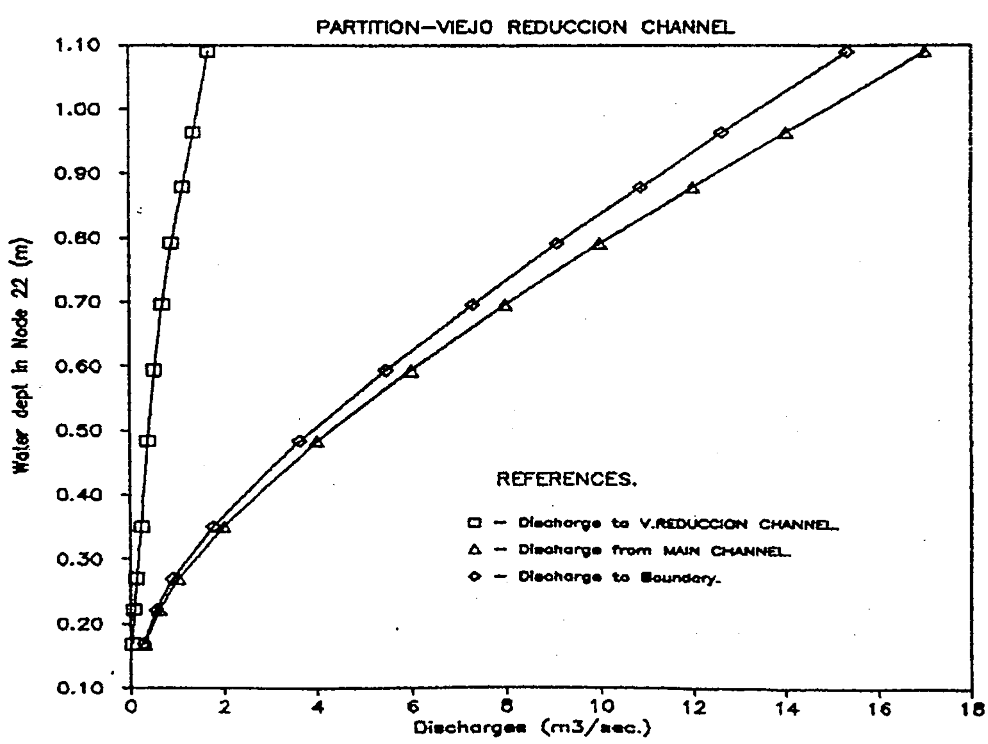

Figure 4 Partitioning of flow rate from primary canal to flow rate into the Viejo Reduccion canal and canal serving other areas outside pilot area (results model SIMWAT).

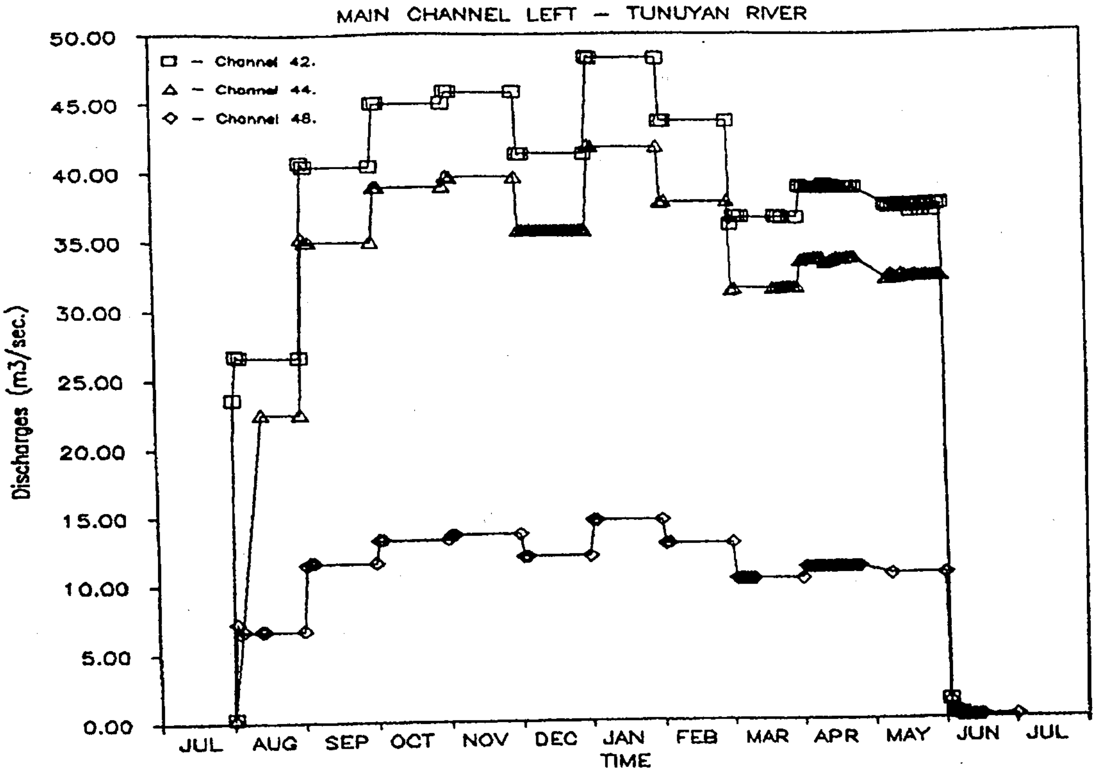

Figure 5 Variation of monthly flow rates in 3 canal sections of the primary Left Bank Canal.

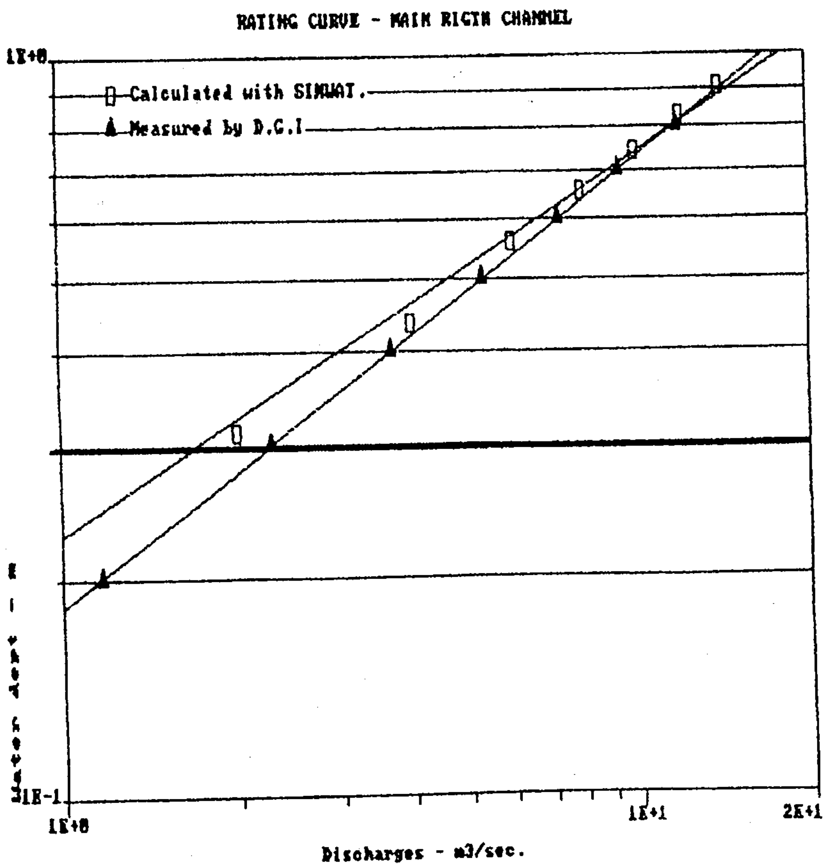

Figure 6 Rating curve measured and calculated by SIMWAT model for location in the primary Right Bank Canal.

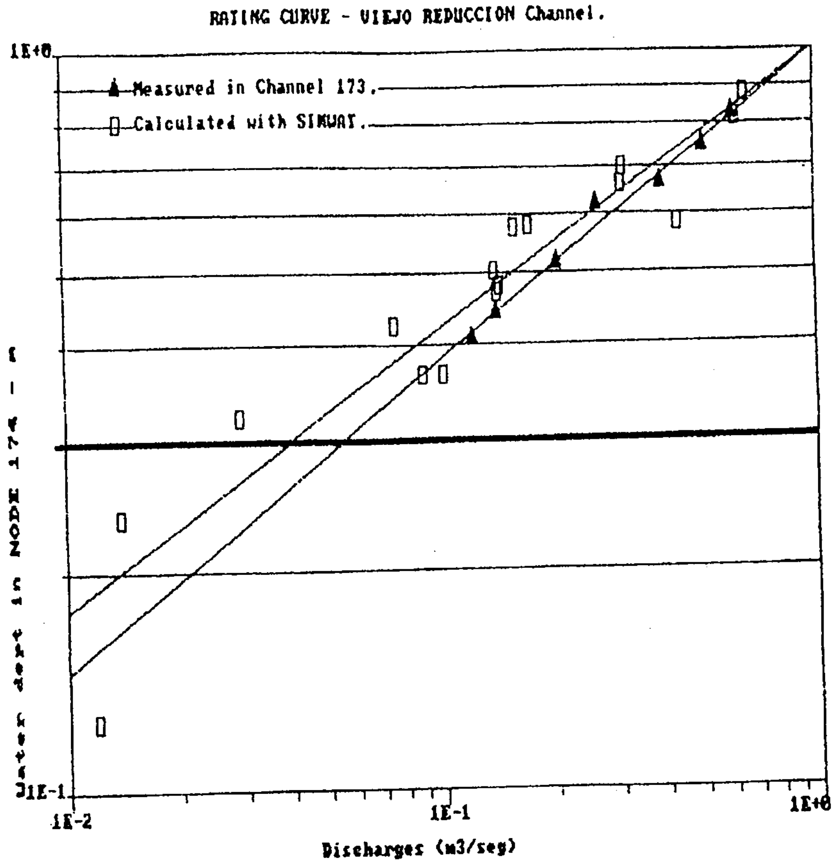

Figure 7 Rating curve measured and calculated by SIMWAT model for location in secondary canal Viejo Reduccion.

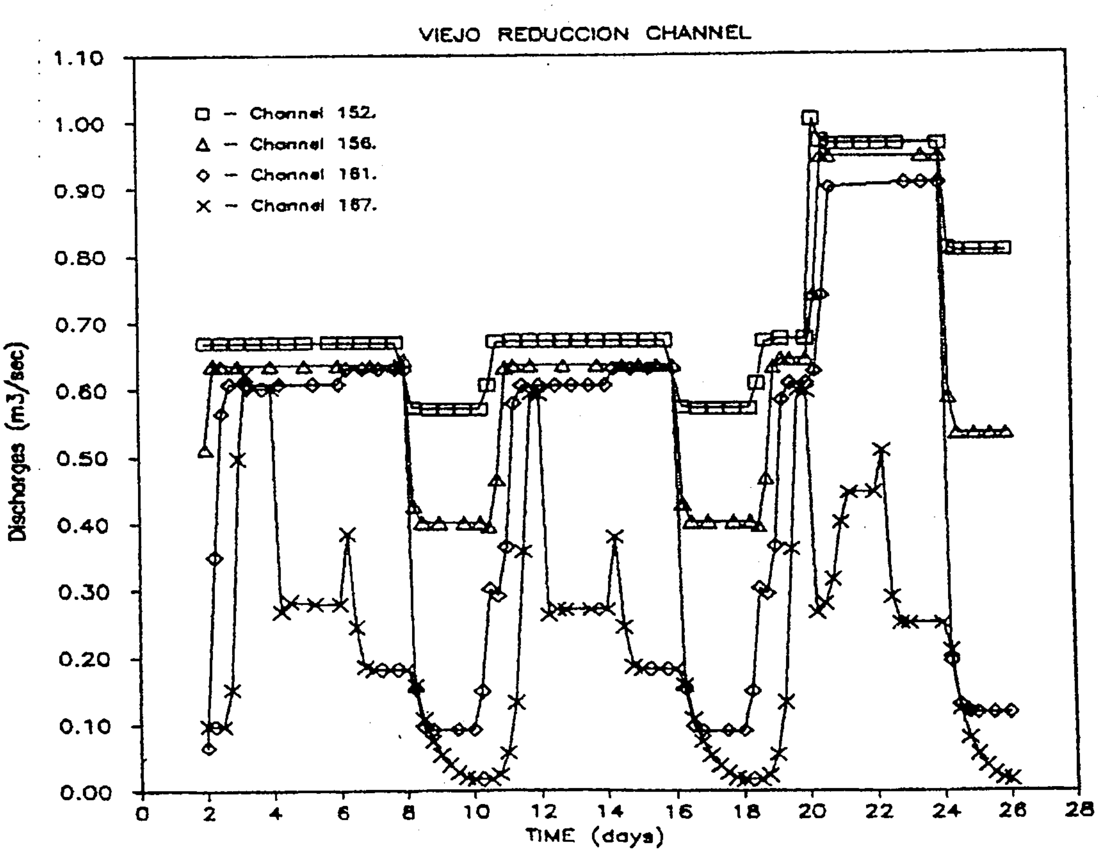

Figure 8 Variation in flow rates at 3 locations in the secondary canal Viejo Reduccion caused by the rotational delivery scheme.

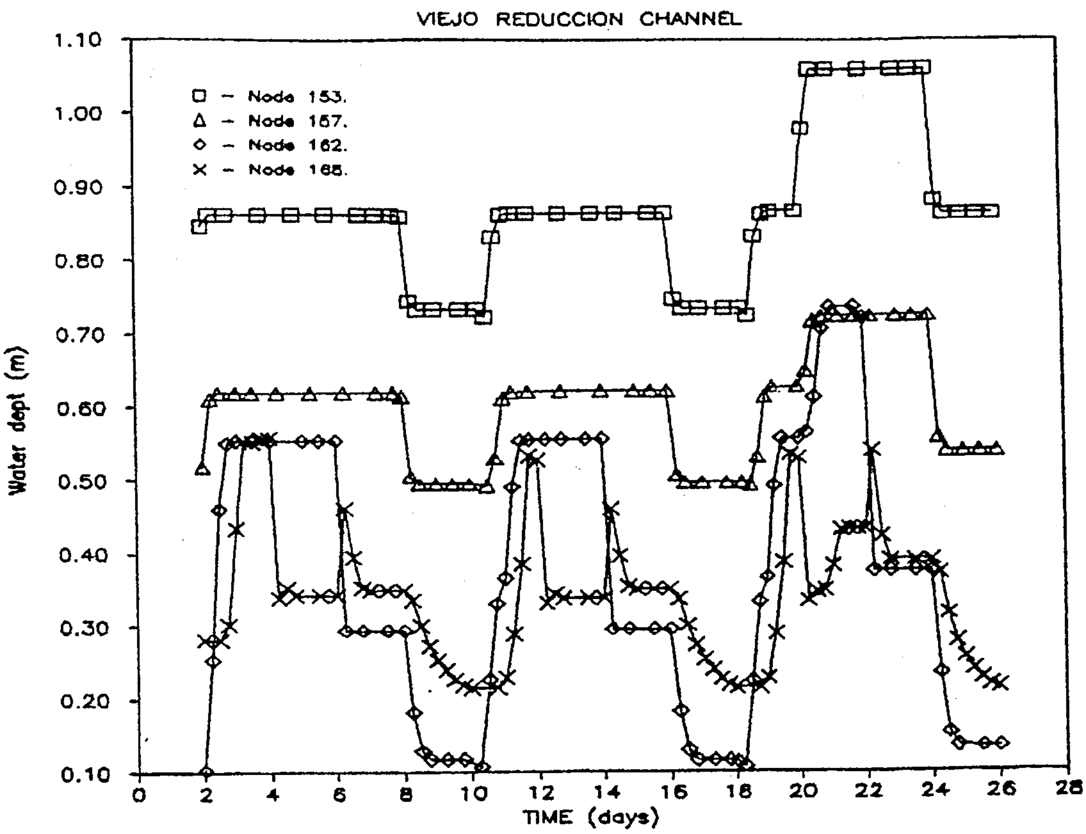

Figure 9 Variation in water levels at 3 locations in the secondary canal Viejo caused by the rotational delivery scheme.