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# THE USE OF HYDRAULIC MODELS TO OPTIMIZE THE REHABILITATION OF AN OPEN CHANNEL IRRIGATION SYSTEM THE EXAMPLE OF THE SENEGAL RIVER DELTA IRRIGATION SYSTEM<sup>Ψ</sup>

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## ABSTRACT

For more than thirty years, important investments have been undertaken for hydro-agricultural schemes in the Senegal River Delta. Indeed, the River's distributaries form a complex network of natural side channels with a high potential in terms of land suitable for irrigation. However, the current configuration of these channels and the lack of maintenance prevent this feeder system from conveying the flows required to meet the region's agricultural production potential. Consequently their rehabilitation has started. This takes into account the future water demand, the network's geometrical characteristics, the actual practice of irrigation, as well as the type of control used for managing the system and has led to the use of a mathematical model for design purposes: the *Simulation of Irrigation Canals* (SIC) software, developed by Cemagref. The SIC software has been chosen because it accommodates the simulation of automatic gates and performs transient state runs particularly well. Steady state runs do not take into account decisive factors like diurnal irrigation or the significant storage capacity of the system, and would lead to a flawed design of the system. This article illustrates the advantages of using the transient regime for the design of a networked feeder system with substantial storage capacity.

KEY WORDS: irrigation, hydraulics, design, optimization, modelling, transient regime.

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<sup>Ψ</sup> L'utilisation de modèles hydrauliques pour optimiser la réhabilitation d'un réseau de canaux d'irrigation gravitaire - L'exemple du système irrigué du Delta du fleuve Sénégal

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## RÉSUMÉ

Le Delta du fleuve Sénégal fait l'objet depuis plus de trente ans d'investissements importants concernant les aménagements hydro-agricoles. Les défluent du fleuve constituent en effet un réseau complexe de marigots aux fortes potentialités en termes de superficies irrigables. Cependant, l'état d'entretien et le gabarit actuels des canaux ne permettent pas de faire transiter les débits nécessaires aux objectifs de production agricole assignés à la zone. Un aménagement des adducteurs est donc prévu, qui doit prendre en compte, outre la valeur prospective de la demande, les caractéristiques géométriques du réseau, les pratiques des irrigants, ainsi que le mode de gestion retenu pour le système. Ces considérations conduisent à l'utilisation d'un modèle mathématique pour le dimensionnement : il s'agit du logiciel de *Simulation des canaux d'Irrigation* (SIC) développé par le Cemagref, qui présente l'avantage de bien gérer le régime transitoire utilisé pour le dimensionnement. En effet, des calculs en régime permanent ne permettraient pas de tenir compte de facteurs décisifs, notamment l'irrigation diurne ou l'importante capacité de stockage du réseau, et conduiraient à un dimensionnement imparfait des adducteurs. L'article présente ainsi les avantages du régime transitoire pour le dimensionnement de canaux à forte capacité de stockage.

MOTS CLES: irrigation, hydraulique, dimensionnement, optimisation, modélisation, régime transitoire.

## PRESENTATION OF THE STUDY AREA

The study area is located in the Senegal River Delta, next to the city of Saint-Louis along the Atlantic Coast in the northern part of the Republic of Senegal. The Senegal River is one of the longest rivers of West Africa as well as the driving force in the development of this region. This 1,800-km long river drains a river basin of 340,000 km<sup>2</sup> over four countries: Guinea, Mali, Mauritania and Senegal.

The Delta has shallow and saline ground waters. It is entirely included in the Sahelian climatic zone, with a regional nuance though, brought by the influence of the Atlantic Ocean. Average temperatures have a bimodal evolution with two maxima (35.5 °C in May and 36.7 °C in October). The annual average is 25 °C. Relative humidity is around 60% and annual average

evaporation reaches 2,400 mm. Annual rainfall is low (between 200 and 250 mm/year) and seasonal as it is spread over three or four months from June to September. The persistent deficit of rainfall as compared with evaporation has justified all main decisions in terms of hydro-agricultural schemes in the Delta and the Riverø Valley (Olivry, 1993).

This climate allows three different cropping seasons: the warm dry season (from March to June) and the rainy season (from June to November) dedicated to rice-growing, and the cold dry season (from November to March) to market gardening. The Delta offers great agricultural potential through the availability of both clayey soils suited for rice production as well as sandy soils suitable for horticultural productions. This has led the *Société Nationale d'Aménagement et d'Exploitation des terres du Delta et des vallées du fleuve Sénégal et de la Falémé (SAED)* to design some 61,590 ha for the development of irrigated crops in the Delta and elsewhere. This development has been speeded up in the 1980ø with the completion of two dams by the *Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS)*. These dams were designed to control the Senegal River and ensure permanent water availability. They are operated under the coordinated management of the *Commission Permanente des Eaux (CPE)*, one of the OMVS organs that brings together all member States. The two dams are:

- Manantali Dam (located in Mali) with a storage function: it controls around 50% of the total runoff of the Senegal River Basin and has a maximum storage capacity of 11 km<sup>3</sup> that allows for an inter-annual regulation with the following objectives: electricity production (800 GWh/year), dry season flow support (300 m<sup>3</sup>/s) for water supply, irrigation and navigation, and flood regulation in order to support flood subsidence farming and major wetlands, like the Djoudj National Park, the worldø third ornithological park. Releases are performed depending on an assessment and a hierarchy of the downstream needs (Bader et al., 2003);
- Diama Dam (located in Senegal, near the river mouth) which has primarily a water level regulation as well as a water quality control function: this dam blocks the intrusion of salt water from the Ocean and dictates a suitable level of fresh water in the Delta for irrigation and the controlled filling of depressions like the Guiers (Senegal) and Røkiz (Mauritania ) Lakes. The management of the Diama Dam must take into account the following rules:
  - \* the gates are designed to undergo up- to downstream pressures only. Hence the level of the reservoir should never be lower than the downstream water level under the influence of the tide;
  - \* the usual level of the reservoir ranges from 1.50 and 2.50 m+MSL (mean sea level). This does not apply during the rainy season.

According to these constraints and with embankment construction ongoing, the water level at Diama Dam is currently 1.50 m+MSL in the rainy season, and 2.20 m+MSL in the dry season. The timing of the regulation procedures strongly depend on the rainfall in the river basin area and are consequently rather variable. Nevertheless, the wet and dry season water levels are typically set in July and October respectively over a period of about a month.

## THE DISTRIBUTION SYSTEM

### *The canals*

The canal system on the Senegal side of the Delta consists of a  $\pi$ -meshed network with two head regulators on the Senegal River, the G - and Ronq gates. The channels that make up the system have extremely flat bed slopes and extend to over 140 km. The current maximum capacity of these channels is 20 m<sup>3</sup>/s. While the two dams have greatly increased water availability, this capacity is insufficient for the currently developed irrigated land.

Figure 1. Schematic lay out of the present network

The system comprises the following channels:

- the Upstream Gorom: this relatively narrow meandering channel is 25 kilometres long, from the village of Ronq to Boundoum where it feeds the Lampsar;
- the Downstream Gorom: while it has been formed by tidal flow, the Downstream Gorom is much wider and essentially feeds itself over 30 kilometres, between the G regulator and Boundoum;
- the Lampsar: branching from the Upstream Gorom at Boundoum, it forms with the latter the Gorom-Lampsar axis that conveys water to most of the schemes. It flows over more than 70 km to the storage area of Bango where the intake for the water supply to the city of Saint-Louis is located. It is principally divided into three reaches separated by two gates at Ross-Bethio and Ndiol.

### *Command area*

Currently some 26,910 ha of irrigable land have been located in the Delta region, of which 25,160 ha are exploitable. To this, about 8,000 ha of future extensions will be added. At present, only 8,870 ha are exploited during the rainy season. This drops to 1,430 ha and 3,500 ha during the cold and warm dry seasons, respectively. This unbalanced distribution of cropped areas per season is due to the predominance of rice-growing in the Delta region. Market gardening is not yet well developed. Except for a few commercial players, it is mostly applied at a small scale by family holdings. The agricultural production objectives for the Delta area are thus threefold: enlarge the cropped area, increase farming intensity, and develop market gardening. The latter objective particularly aims at the introduction of drip irrigation equipment that allows higher value added production.

### *Water demand*

The maximum water demand has been assessed on the basis of:

- the inventory, made by the SAED in 2006, of the net irrigable land and the planned extensions. The resulting database separates rice-growing areas (25,215 ha) from market gardening areas (8,255 ha) within the study area;
- the assessment of the rice-growing and market gardening surface flow rates, taking into account evapotranspiration, effective rainfall, the various cropping schedules, and the efficiency and modes (diurnal or continuous) of the various irrigation methods for rice and vegetables with traditional or micro techniques;
- the decrease of about 40% in the water requirement during the rainy season, once rice fields are flooded.

In this manner the 10-day rotation schedule throughout the year is obtained, and the design discharges are defined by the period with peak demand (end of the warm dry season). The peak flow rates are 2.7 l/s/ha for rice-growing and 2.2 l/s/ha for market gardening.

The resulting peak water demand, present and forecasted, is shown in Table I.

Table I. Present and forecasted peak demand and design discharges

### *Water management principles*

Water supply is demand-driven, and consequently the system is de facto under downstream control. This management is preferable in such a context of ample storage capacity, as it gives control to farmers. Besides, given the very flat bed slope and the corresponding low excavation costs, this flow control will be maintained after rehabilitation.

The significant storage capacity of the channels allows diurnal irrigation: withdrawals are only taking place during daytime and the system then fills up in the night. By storing during the night volumes that are released during the next day, the channels go through daily water level variations.

Therefore, the current management of the primary canals aims at minimizing water level fluctuations, with little information on inflows or withdrawals. In order to respect target downstream levels compatible with both bank levels and irrigation demand at key locations, gate positions at the various regulators (head or cross works) are operated by gate keepers. Since this is done manually these operation are not frequent. Consequently, overtopping often occurs where banks are very low, whereas the water level at the tail of the system (the lower part of the Lampsar) is frequently too low for plots to be gravity fed. This capacity problem shall be addressed by means of a new canal -the Krankaye canal- connecting the Downstream Gorom directly to the mid reach of the Lampsar thus conveying higher flows and strengthening the head in this area.

Finally, the lower water level at Diama Dam during the rainy season reduces the flow entering the system by gravity to a level largely insufficient for irrigation requirements. In order to supply a minimal flow in this condition, the Ronq pumping station (8.3 m<sup>3</sup>/s capacity) positioned parallel to the head regulator, is operated. This adverse situation is aggravated by insufficient maintenance of the Upstream Gorom.

### *Presentation of the upgrade strategy*

With the Diama-Manantali system put into service, the new hydraulic conditions have allowed to introduce double cropping, and diversify crop and animal production. Despite the positive impacts of these dams on freshwater availability and the economy of the Delta, the present lay out of the distribution system for irrigated schemes is still not functional (BCEOM, 1999). Due to limited dimensions and low embankment levels along critical reaches, the Gorom-Lampsar axis, which remains the main supply canal, cannot meet the irrigation requirements. This situation annihilates all the potential benefits from the dams. In order to launch their full potential in terms of agricultural production in the Delta, it is indispensable to

undertake an upgrade of the distribution network and to implement an overall hydraulic management.

The upgrade of the distribution system includes the following works:

- excavation of critical reaches with reduced dimensions that create disproportionate head losses;
- alignment of strongly meandering reaches through short-cuts;
- reconstruction of embankments along the entire network at a 3.00 m+MSL level. With a freeboard of 50 cm, this will allow the maximum water level at the Dama Dam to be raised to 2.50 m+MSL;
- construction of the Krankaye canal over 9 km, in order to connect the Downstream Gorom to the lower Lampsar, thus supplying to the latter an additional 12.3 m<sup>3</sup>/s and facilitating a more equitably spread of the water level over the entire network (Figure 2);
- construction of an automated gate in the lower Lampsar (type AVIO) (GEC Alsthom, 1975-1979) that allows to set distinct water levels for the upstream and downstream sections. This precludes the need to rehabilitate the embankments along the downstream part of the system where irrigation demand is low and the required level for pumping drinking water not restrictive;
- implementation and monitoring of flow and water level measurement equipment throughout the network so as to attain a comprehensive hydraulic management strategy.

Figure 2. Schematic lay out of the upgraded system (*the flows are given for a management of the dam at 2.50 m+MSL*)

## HYDRAULIC MODELLING

### *Necessity and choice of a model*

The use of a gradually varied, unsteady flow model appears to be essential (Cunge et al., 1990) for the following reasons:

- the network is meshed : the distribution of flows has to be computed at three bifurcations (Figure 2);
- the bed slope is essentially flat and therefore water surface profiles need to be calculated;



- the daily irrigation cycle makes it necessary to model a transient regime. In this case, transient effects are expected to be even more critical because the channels' storage volume is important compared to the daily water demand.

These constraints have led to the selection of the SIC software. This is a modelling tool developed by Cemagref with the specific aim to solve issues related to river hydraulics and irrigation canals. Its main advantages are the reliability and stability of transient computations, the possibility to model many different types of cross works (including AVIO gates) and offtakes, and the possible integration of user-defined regulation modules. This one-dimensional numerical model, based on full Saint-Venant equations, uses the Preissmann implicit scheme to solve the transient regime (Baume et al., 2005; Cemagref, 2009).

#### *Setting up the model*

The model is defined through a series of nodes corresponding to in- or offtakes, separated by reaches that include cross sections and devices like gates<sup>1</sup>.

The canal geometry is derived from natural cross sections. To reduce the number of cross sections to be simulated in the model, they are first screened according to their representativeness. Then they are re-shaped in order to take into account the target characteristics of their size (berm, slope of the embankment, etc.). Finally, in order to account for natural dimensions frequently larger than target dimensions, the model comprises 119 cross sections with post-rehabilitation characteristics that closely follow natural cross sections.

Under the usual one-dimensional flow and hydrostatic pressure distribution hypotheses, the gradually varied flows are being modelled by the Saint-Venant equations. These equations are completed by initial conditions (resulting from a steady state computation) and by boundary conditions.

The upstream boundary condition consists of a flow release from the Manantali dam. For the reason that subcritical flow conditions prevail, the downstream boundary conditions are defined by two rating curves at the model's downstream nodes:

- the first one on the River, which corresponds to the level at Diama Dam that determines the upstream water level for the hydraulic network (water levels at Ronq and Diama Dam are approximately equal). This level is set at 2.50 m+MSL during the dry season, and at 1.50 m+MSL during the rainy season;

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<sup>1</sup> Basic topographic and hydraulic input data available at <http://www.canari.free.fr/rbm.htm>

- the second one, at the tail of the system, is imposed by the management of the water supply to the city of Saint-Louis. Pumping water requires a minimum water level of 0.75 m+MSL in the storage area at the tail of the Lampsar. An AVIO gate located a few kilometres upstream on the lower Lampsar, with 0.80 m+MSL as a target downstream level, allows to control the upstream level in compliance with the upgrade strategy, and to respect this condition at the same time.

The boundary conditions for offtakes are simulated by an imposed discharge, the product of exploitable areas -extensions included- by the flow rates calculated above. With the inventory completed by the SAED, it is possible to assign to each plot one of the 38 nodes of the model. For computations in the rainy season, the ratio -rainy season demand / peak demand around 60%, is applied to each node. The different resulting peak demands are shown in Table I. Discharges are withdrawn following a step law, simultaneously on every offtake, between 6h and 21h for rice-growing, and between 7h and 19h for market gardening.

Moreover, a hydrometric campaign carried out in 2005 has provided measures of water levels and flows at the main cross structures. This dataset has been used, reach by reach, for a basic calibration of the Manning coefficient for channels in their present state. The resulting low values (between 0.100 and 0.053 depending on the reach) highlight the lack of maintenance of the network and the impact from invasive plant species like Typhas. Hence, for the rehabilitated channels, a Manning coefficient as modest as 0.04 would adequately account for this initial state and the uncertainty regarding future maintenance.

Infiltration-evaporation has been calculated in a previous study by BCEOM (BCEOM, 1999). They found a loss rate of 20.4 l/s/km. Over the entire network this amounts to 2.7 m<sup>3</sup>/s. Finally, thanks to the discretization scheme chosen in the SIC model, a relatively long time step can be set (10 minutes). The spatial step is set to 200 m.

Two scenarios are thus emerging, corresponding to two restrictive situations, in terms of peak water demand and water level:

- Scenario 1 dry season: peak demand (89.9 m<sup>3</sup>/s, including losses), water level at Diamo Dam set at 2.50 m+MSL;
- Scenario 2 rainy season: rainy season demand (54.7 m<sup>3</sup>/s, including losses), water level at Diamo Dam set at 1.50 m+MSL.

## RESULTS

### *Results in transient regime*

Transient state simulations are performed over a period long enough (generally 8 days) to reach a repetition of essentially identical diurnal cycles of filling and emptying of the network channels. The results presented below are taken on the last day, at the end of the irrigation period (21h), when inflows at the head of the system are at their peak, and the surface water profile is minimal.

The rehabilitation works for each reach are chosen so as to minimize the linear head losses, without excessively increasing excavation costs. The overall head loss between the upstream intake (Ronq head work) and the downstream end (AVIO gate in lower Lampsar) reaches a maximum of 37 cm along the Gorom-Lampsar axis, for a level at Dama Dam set at 2.50 m+MSL. In this situation, the gravity fed area is maximized, reaching 7,210 ha, with 26,260 ha requiring energy supply for irrigation.

Figure 3. Evolution of total inflow and downstream water level over three daily cycles - Dry season (scenario 1)

Besides, by taking into account the storage capacity of the channels, an appreciable benefit can be obtained on the upgrade, as storing water volumes in the channels during the night reduces the peak flow at the head of the system during irrigation. The Figure 3 above highlights this point by superimposing the peak water demand to the actual -and clearly lower- total inflow at the head works. The storage capacity of the channels can be quantified through an absorption rate  $A_r$ , defined as:

$$A_r = \frac{\text{peak demand} - \text{actual maximum flow at head inlet}}{\text{peak demand}}$$

In the present case, the maximum flow to be conveyed drops by 22% ( $A_r = 0.22$ ), from 89.9 to 69.9 m<sup>3</sup>/s.

It can be noticed that the minimum total inflow (inflow at 6h) is still far greater than the losses by evaporation-infiltration; the only demand during the night. This shows that, at the beginning of irrigation, channels are not totally filled (the water surface profile is not horizontal yet). This does however not prevent the daily cycle from repeating itself in identical manner.

The same kind of cyclic behaviour is found during the rainy season (Figure 4), when the level at Diama Dam is set at 1.50 m+MSL and the maximum water demand is 51.9 m<sup>3</sup>/s. Under these conditions the total head loss along the Gorom-Lampsar axis reaches 35 cm, and the maximum flow rate is reduced by an absorption rate of 24% ( $A_r = 0.24$ ).

Figure 4. Evolution of total inflow and downstream water level during one day - Rainy season (scenario 2)

#### *Evaluation criteria*

In contrast with the procedure described above, the sizing of irrigation canals by numerical modelling is generally carried out through steady state calculations (Das, 2000; Prabhata, 2000). Both methods (steady and unsteady state calculations) will be compared for the dry and wet season situations. For the present case, we will show that the use of the transient regime results in an optimization taking into account the storage capacity of the network:

- for transient simulations, the results are presented above in Figures 3 and 4 (situations 1a and 2a). These simulations use the peak demand, withdrawn during 15 hours for rice-growing and 12 hours for market gardening.
- for steady state simulations, two sub-situations are defined:
  - \* the peak demand is withdrawn continuously, considering that the system may actually reach a steady state within 15 hours of irrigation (situations 1b and 2b);
  - \* the average daily demand is withdrawn continuously, in order to consider the same daily water volumes as in transient simulations (scenarios 1c and 2c).

For both the dry and wet season scenarios, the transient simulations represent the reference calculation that gives the basic channel size required to convey the flow satisfying irrigation requirements. The final water level reached downstream of the system, at the lower Lampsar AVIO gate, will be the key-parameter for comparing the different calculations.

For each scenario, steady state simulations consist in testing various sizes for the network, in terms of negative or positive percentage of the reference size derived from the transient simulation, until one is found that both satisfies its irrigation demand and gives the same water level at the AVIO gate as in the corresponding transient simulation. The resulting size will thus generate the same total head losses as in the transient regime, all other things being equal.

Enlargements and reductions of the reference size are performed on all cross section by homothetic transformation, i.e. by increasing or decreasing the width of the profile at each level, at a uniform rate. The minimum modification rate is set at plus or minus 5% of the reference size.

Figure 5. Comparison of modified and reference cross sections

Accordingly, the comparison criteria are of two types:

- *the maximum total inflow entering the system* (through the G - and Ronq head works), because it defines the minimum dimensions of the channels, under a condition of restricted total head loss;
- *the minimum dimensions of the channels* that allow to obtain the same downstream water level between the three calculations, as excavation costs generally represent an important part of the total cost of such rehabilitation projects.

#### *Results in steady state*

For the two scenarios described above (dry and rainy seasons), the results are as follows. Both Tables II and III give the 100% reference size for dry and rainy season transient calculations with the storage capacity of the system accounted for.

Table II. Dry season (peak demand, level at Diama Dam: 2.50 m+MSL)

Table III. Rainy season (60% of the peak demand, level at Diama Dam: 1.50 m+MSL)

Had the rehabilitation of the network been based on the assumption that the network reaches the steady state after only 15 hours of peak irrigation demand (scenarios 1b and 2b), the size of the channels required to meet such demand would have been 65% and 70% higher in the dry and rainy seasons respectively. In such irrigation rehabilitation projects, excavation costs would easily become prohibitive. However, it must be said that, in order to simplify the method and results, the enlargement rate for cross sections has been applied over the entire network. A more targeted enlargement, restricted to the reaches associated with the highest head losses, would limit these added costs linked with steady state, non optimized simulations.

If we consider the total daily water volume supplied at a constant rate (scenarios 1c and 2c), the minimum dimensions required to convey the average daily demand in the dry and rainy seasons are respectively 25% and 15% lower than the reference dimensions calculated with the transient simulations. Unfortunately, this hypothesis does not consider the actual practice of irrigation in the Delta: the same daily volumes are supplied, but over only 12 hours for market gardening and 15 hours for rice-growing. This increases the real required inflow at the head of the system (69.9 m<sup>3</sup>/s against 55.0 m<sup>3</sup>/s, and 41.5 m<sup>3</sup>/s against 34.9 m<sup>3</sup>/s in the dry and rainy seasons, respectively). Consequently, if these reduced dimensions are now used in the transient simulation considering the same daily volumes, but conveyed in a reduced period of time, one can expect higher head losses, and a reduction in the gravity fed areas. And actually:

- in the dry season, head losses would increase from 37 to 58 cm, and gravity fed areas would decrease from 7,210 to 5,230 ha;
- in the rainy season, head losses would increase from 35 to 47 cm (no gravity fed areas in this case given the low water level at Diama Dam).

With regards to the main objectives of the project, the under-sizing of the system, in this case, is thus obvious.

Comparing the results obtained for the dry and rainy season, one can notice that the use of transient regime simulations indicates a stronger effect from increased canal dimensions in the latter case:

- the canal dimensions required to convey the peak demand continuously is higher in the rainy season scenario (170% of the reference size, instead of 165% for the dry season scenario);

- the canal dimensions required to convey the average daily demand continuously is higher in the rainy season scenario (85% of the reference size, instead of 75% for the dry season scenario).

This result -an improved optimization of excavation quantities in the rainy season scenario- is coherent with the higher absorption rate found in the rainy season (24% against 22% in the dry season).

## CONCLUSIONS

In the present case study, the transient simulation proves to be the only method to take into account the absorption capacity of the system which is a result of diurnal irrigation and significant storage in the distribution network. This calculation simulates the right peak demand linked to diurnal irrigation as well as the exact value of the daily demand, and thus optimizes the required minimum dimensions for the irrigation network.

Simulating the peak demand in steady state somehow considers diurnal irrigation (in terms of demand level), but not the storage capacity of the channels and therefore overestimates the daily volumes to be supplied to the schemes. This leads to an overestimation of channel dimensions.

A steady state simulation based on the average daily demand accounts for the right daily volumes, but does not consider the peak flow as it derives from irrigation practices. This leads to an under-sizing of the network and compromises the main objective of the project: boost gravity fed irrigation by minimizing head losses.

The use of the transient regime for the design of irrigation channels is thus particularly attractive in this precise context because of the following two conditions:

- the irrigation is diurnal. For continuous irrigation, steady state simulations would of course have been preferred;
- there is significant storage capacity in the channel system. Without storage, the steady state may be reached before the end of the irrigation period, and steady state simulations would have been adequate.

This opens up new horizons for irrigation network managers. The definition of a dimensionless parameter taking into account both the storage in the canals and the characteristics of the water demand, could be a valuable tool to systematically decide in which

case transient regime simulations should be used for design purposes and in which case steady state simulations would be sufficient. Ongoing research is focusing on this particular point.

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Table I.

Seasons	Area currently irrigated (ha)	Present peak demand (m <sup>3</sup> /s)	Planned area (ha)	Planned peak demand (m <sup>3</sup> /s)
Rainy season	8,870	24.0	33,470	51.9
Cold dry season	1,430	3.2	33,470	87.1
Warm dry season	3,500	9.5		

Table II

Scenario / calculation	Regime	Water level downstream the system, used as a reference (in m)	Maximum inflow through head works (G and Ronq gates, in m <sup>3</sup> /s)	Resulting size (in % of the reference size)
1a	Transient	2.13	69.9	100% (reference)
1b	Steady / peak demand continuously	2.13	90.0	165%
1c	Steady / average daily demand	2.13	55.0	75%

Table III

Scenario / calculation	Regime	Water level downstream the system, used as a reference (in m)	Maximum inflow through head works (G and Ronq gates, in m <sup>3</sup> /s)	Resulting size (in % of the reference size)
2a	Transient	1.16	41.5	100% (reference)
2b	Steady / peak demand continuously	1.16	55.9	170%
2c	Steady / average daily demand	1.16	34.9	85%