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Conversion of an old canal regulation system for a new water use method

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Abstract

Usually, traditional irrigation in mediterranean countries is upstream regulated and follows a rotational schedule.

Nevertheless, irrigators wish to develop old systems into more flexible irrigation schedules, and in particular on-demand schedules, so as to ease their task. For example, irrigation at night could then be avoided.

Such improvements require an adaptation of the main canal management, under the following constraints :

* the irrigation structures to be modified are usually old. Notes should be taken of the constructions locations, riparian habits, and theoretical and real construction capacities,

* costs should be limited, since financial opportunities may not be as interesting as with new constructions,

* the management habits, resistance to changes, and technicality level of the canal management personnel should be taken into account.

Therefore, the canal hydraulic behaviour should be analysed through field data collection, then simulation models that allow the visualisation of various typical cases (CALCAN and TRACANAL models) should be calibrated.

The lacks in the systems (transfer capacity, difficulty in fulfilling the demand changes, ...) and foreseen aggravations are then put forward.

Various changes may be suggested :
* emergency actions, easily and quickly applicable,
* solutions to modernize the regulation.

The hydraulic efficiency of these suggestions is then tested with the simulation model.

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During later studies and developments (APD, DCE, construction works ...), the simulations models are used to :

* calibrate the canal control models,
* educate the users (computer aided canal operation : CACAO),
* manage manually the canal.

B.R.L. is presently managing with this method four cases of main canals regulation rehabilitation :

* Main canal Bas-Service of Doukkala (Morocco)	:	35 m^3/s - 90 km
* Main canal of Beni Amir (Morocco)	:	15 m^3/s - 50 km
* Irrigation and drainage canals of Nilwala Ganga (Sri Lanka)	:	25 m^3/s - 150 km
* Macina canal (Niger Office - Mali)	:	50 m^3/s - 120 km

1 Introduction

GERSAR-BRL has several decades of experience in canal management, and the interventions can be classified as follows from the most "everyday" type to the most "unusual":

- Normal operation
- Maintenance
- Large repairs
- Extension
- Modernisation/Rehabilitation

Simulation models can be an effective aid in some of these operations.

In normal operation, a computer program for easy analysis of the behaviour of the canal by means of different fictitious operations will give the engineer well-adjusted empirical knowledge of "his" canal. Use and display of the results must be easy and "user-friendly".

This type of program has a teaching aspect and can be used in canal management training courses.

An example of this type of model - a "computer-aided canal management program" - is being demonstrated during this symposium.

Maintenance and large-scale repairs can be managed using appropriate management programs not related to hydraulics.

However, simulation models are currently very effective tools for the commonest operations such as canal extension (for increased irrigated area), modernisation or rehabilitation to meet new constraints which are generally more severe than before, since they are more comfortable for the operator and/or irrigators.

This aspect is discussed in the light of experience gained by BRL in its own canals and in its numerous missions as consulting engineer for this type of operation in France and above all abroad. Modelling is used throughout the following stages :

- analysis of the present functioning of the canal, the way in which it is managed and the evolution of its function,
- identification of malfunctioning and its probable evolution,
- proposals of emergency measures,
- analyses of possible solutions (short preliminary design) in the light of the results of this diagnosis, and possible new objectives for the use of water in the fields,
- final design of this solution (detailed analysis of hydraulic functioning).

2 Descriptions of canals

1.1 BRL Costières Canal

This is 19 km long. The head design flow is 15 cubic metres per second. It consists of 5 reaches separated by 4 mixed gates. It is solely for the supply of sprinkler irrigation sectors through several booster stations along the canal.

1.2 Macina Canal, Mali (1940)

There is a total of 100 kilometres of main canals carrying 45 m^3/s at the head. They are earth canals and a natural canal (Fala) is used as a common conveyance.

Distributors were equipped with cross weirs consisting of mobile coffer dams to set the level at the offtakes. Setting was therefore approximate and much human intervention was necessary.

Offtakes were equipped with manual gates.

The flow supplied was also approximate.

The common conveyance was regulated manually with a daily telephone contact between the upstream and downstream extremities of the Fala.

1.3 Doukkala Canal, Morocco (1950)

This is 110 km long and has a head flow of 32 m^3/s. It has earth, masonry and concrete sections. Upstream/downstream regulation by AMIL/AVIS equipment is used and there is intermediate buffer storage.

Information about head flow is poor (no measurement).

The canal was initially planned for gravity irrigation using a rota system, but some zones are now equipped with sprinklers.

The canal also supplies potable water from the downstream extremity.

1.4 Common Characteristics in all the infrastructures presented

They are all about 30 years old. They function, but sometimes not well enough. Land occupation has reached its normal level and so maximum water demand has now been attained.

Irrigators generally have good experience of irrigation and agriculture at field level and a high level of farm production can be attained.

This type of operation (rehabilitation) should therefore be accompanied by high profitability because the developments are immediately used at full capacity form the main canal to the fields.

2 Evolution of the system

Like the work at field level, the main canal has changed in relation to the design and the initial objective.

2.1 State of the Main Canal

The main changes are as follows :

Modification of the discharge section area by successive silting and dredging (variations between 1 m of silting and 1 m of scouring).

The establishment of an "equilibrium profile" which is more "natural" than the initial trapezoidal cross section .

There has sometimes been poor maintenance: vegetation (reduction of the Strickler coefficient) and a general decrease in conveyance capacity.

Maladjusted regulators in poor condition (corrosion, bearings, shock absorbers) and sometimes jammed or removed. Sector gates are sometimes used as extra regulators.

Oscillations are often observed. Waves can be up to 1 metre high and run along certain reaches, endangering the banks.

There may be unlisted offtakes.

Settling or maintenance of banks, embankments and tracks with a grader may lower their levels.

2.2 Evolution of operation type

This is most often necessary to adapt to new demand constraints (change from a rota system to sprinkling). Matching structures to the new type of operation is performed by changing the regulation method.

It is reminded that the traditional regulation methods are as follows :

* Upstream regulation: gravity irrigation with a water rota and a water management calendar. This requires a large, well-organised operation structure. It is the cheapest solution in terms of investment cost and historically the oldest.

* Downstream regulation with water "on request".
  Even the most sudden changes in demand can be handled by this system, but water must always be available . The operating structure is extremely light but it has the highest investment cost and requires hydromechanical regulators.

* Mixed regulation with buffer reservoir between the upstream sections controlled by upstream regulation and the downstream part with downstream regulation.

The reservoir is managed empirically and manually. Changes in demand result from maximum land use and sometimes from unforeseen extensions.

The crops initially planned often change (previously cotton and now maize), as does the irrigation method with a switch to sprinkling with greater changes in demand, the discarding of the water rotation schedule and consumption forecasts.

Demand often exceeds the present capacity of the canal.

An attempt is therefore made to compensate the decrease in conveyance capacity by increasing the depth of water. Minimum freeboard (almost or actually overflowing) is the first sign of malfunctioning. The other signs are water losses and temporary shortages. There are often reactions from users - blocked regulators or breaches in the canal - which aggravate the situation.

3 Diagnosis

The originality of rehabilitation is that, unlike a new scheme, it is based on an existing structure and thus reduces the designer's freedom. The problem is not that of designing a facility but rather of solving the operator's problems.

The following steps are required.

3.1 Good knowledge of the state of the works

Field reconnaissance must be carried out during peak operation of the canal with specialists in hydraulics and civil engineering. A list is made of all the visible "symptoms" - freeboard, Strickler coefficient, state of the banks and floor, vegetation, state of the lining, infiltration through the embankments, water rotation between reaches, submerged semi-modules.

Regulator malfunctioning is also noted (operation unwatered), as is corrosion of the hydromechanical equipment and blocked crossing siphons (causing excessive losses of head).

There is practically always erosion of earth section near regulator civil engineering structures.

Recommendations are made for the protection of works and equipment against vandalism.

3.2 Good knowledge of current operation

by the following means :

- questioning the whole of the operation team,

- analysis of operation registers

- finding out the results of extreme phenomena :

    * overflow points or operation of escapes,
    * parts in which there is a shortage of water,
    * transit times.

The type of reaction in extreme cases (rainfall, pumping station trip-out, bank or embankment failure), the time chart of the operations required to return to a normal situation, information/decision pathways, facilities available for obtaining quantitative knowledge (flow meters, staff gauges, gate opening state, pump operating times) will be reconstituted and assembled.

Some canal operation problems may also be caused by inadequacies of the operating team (lack of technical skill, lack of equipment, raw materials or training, insufficient staff).

3.3 A reliable topographical base is required

This is needed for good knowledge of the canal itself and also for links with ancillary facilities - head supply, lateral offtakes (level/flow constraints).

It is obtained in two phases :

A first systematic reconnaissance which will be more or less detailed depending on the state of the canal and whose specification will be defined after field surveying (cross sections and diagrams of singular features)

A second check survey will be performed after the elaboration and setting of the simulation model in order to remove undetermined points and residual incoherences.

Sonar is used to measure the depth of silting in lined canals.

3.4 A hydraulic survey and measurement programme is also required

The canal is subjected to several cases of extreme functioning and flows and water levels are measured and recorded at strategic points.

Surveys are carried out along the canal and at the works where problems can be located and shown: freeboard too small, instability, regulators jammed or not regulating, etc.

Estimation of line losses is made; these may be as much as 20% in earth canals (marginal evaporation).

3.5 Detailed analysis of the initial project is necessary

The initial design is compared with current use, leading to better understanding of the operating method.

This may show design defects or too great a difference between the initial objectives and subsequent requirements.

It should be noted that finding certain studies may be difficult because of incomplete records.

Unused works are sometimes found whose original functions are not always obvious. There may be one-off prototypes - fruit of the overflowing imagination of hydraulic engineers - mainly in the 1950s.

The problems caused are also mentioned: excessive lengthening of the time elapsing between two works phases (over 10 years) which affects the homogeneity of the project and its hydraulic functioning.

4 Hydraulic study of the present situation

When a synthesis has been made of the preceding observations, the simulation model is constructed on the current state of hydraulic functioning of the canal.

The model must operate under transitory flow conditions with complete St Venant equations and be capable of integrating all the data concerning the canal :

- reach geometry, including cases in which cross sections vary continuously (old earth canals),

- all types of singular features (siphons, weirs, etc.),

- all types of safety works (lateral siphons, lateral weirs, expansion reservoirs, etc.),

- all types of reservoir :

  . static (duckbill, etc.)
  . manual (jack-operated gates, etc.)
  electronic (locally automated sector gates)
  . hydromechanical regulators (AMIL, AVIS/AVIO, mixed, etc.),

- all types of regulation :

  . from upstream, downstream, mixed,
  . with several reservoirs along the canal (dynamic regulation , etc.),
  . bival system,
  . remote management,

- all types of manoeuvre, both at the head of the canal (supply) and at all the offtakes supplying irrigation networks.

The model is constructed and set using these observations. Setting consists essentially of choosing the right roughness coefficients (Strickler) and possibly modifying slightly the parameters which are characteristic of propagation times.

This phase of setting is generally difficult as part of the data to be "recovered" are inadequately quantified (observations made by the operator under extreme functioning conditions).

Once the model has been set, the functioning inadequacies identified and possibly observed during the diagnosis phase are compared with the functioning inadequacies shown by the simulations.

This sometimes contradictory analysis must lead to final knowledge of the causes of malfunctioning and their results for the operator.

Steady state calculations are required to show certain inadequacies (e.g. insufficient conveyance capacity).

There is sometimes a considerable difference between mathematical analysis and empirical observation. This is usually accounted for by the difficulty in understanding the real nature of a transitory hydraulic phenomenon by simple observation - even when repeated - because of its complexity (there is considerable deformation of hydrographs during propagation along the canal).

Simulations also confirm observed problems (inadequate conveyance capacity, poor regulation settings) and over-exploitation (exhaustion of reserves or overspilling).

The original project state will also be simulated to demonstrate the validity of conveyance capacity hypotheses.

It can be seen in the light of the transitory aspect of the phenomena that the interest of -the conveyance capacity concept decreases since as the canal is related to water reserves - maximum demand may be greater than the maximum conveyance capacity.

Possible measures to be taken rapidly to improve the usual functioning of the canal and proposals for modernisation can be proposed on completion of this phase.

NOTE

There is no model setting phase for a new project. Regulation solutions should only be proposed according to the following features :

- downstream water utilisation constraints,
- the investment cost,
- the operator's habits and targets.

5 Emergency measures

The aim is to use rapid intervention to improve the functioning of a canal in normal operation but without solving the basic problems. The steps to be taken are designed in the light of results obtained previously. They must be simple and rapid. Examples include :

- adjusting hydromechanical regulators to prevent unstable or limited flow,

- adjustment of safety works,

- local cleaning operations at identified bottlenecks (local obstructions, siphons with considerable sediment depth, etc.),

- better-planned operating methods for the systems downstream to attempt to reduce variations and uncertainty in flow demand at the canal offtakes, including systems for sprinklers, either by continuous flow limiting at the offtakes or by establishing water rotas sector by sector. The choice depends on the flexibility of operation of the network (compartmentation, gridding, ease of restarting, etc.),

- improvement of the method of operation of the headworks using tables taking into account the state of the canal (staff gauges) and leading to periodic intervention at the head of the canal (twice a day and as smooth as possible),

- the setting up of a corrective system based on the current operating structure to handle variations in demand by attempting to anticipate them (radio contact between the different operation centres close to the canal). Frequent observation of existing reserves,

- training programmes for the operating team.

6 Study of the different regulation solutions which can be envisaged

6.1 Methodology

The solutions proposed must be sufficiently individual and display differences in :

- geometry (civil engineering aspect),
- the degree of sophistication of remote management,
- operating methods.

They must be compared "for the same performances" with regard to good use of the water. They must ensure continuous meeting of requirements without surpluses for two or more standard cases of extreme operation. This sizing method is more rational than working on an "equal investment" basis.

The study of each solution will be at short preliminary design level.

The following types of rehabilitation solutions can be envisaged :

*Classic operations to restore "project conditions" :

Recalibration and overhauling of gates.
Specific operations to solve certain design problems revealed by the models (increasing bank height at a bottle-neck, etc.)

*Improvement of the performance of the canal in comparison with the initial project :

For example, this might be to handle greater downstream design constraints than in the past.
This could take the form of exceeding nominal flow for several hours, handling unexpected variations in demand, etc.
Solutions include the creation of reservoirs in different places, conversion from upstream to downstream regulation, different degrees of sophistication of remote management, etc.
The remote management solution makes it possible to multiply periodic interventions and thus adjust supply to demand as quickly as possible.

*Note :

Changing from upstream regulation to downstream regulation requires works to make the banks horizontal and changing the regulators. The cost is often prohibitive, unless the slope is small (cf. Macina). In addition, the operating team is theoretically competent in handling downstream regulation.

*Method :

Sizing is carried out by simulating previously designed scenarios. The initial model is adapted to represent each of the solutions examined. The design of scenarios of operation schemes is performed on the basis of observations made by the operator. Daily, day-to-day and random variations which can be forecasted are superimposed and details of the information/decision/manoeuvre process (human or automated) examined.

The works are generally sized for steady state and reservoir volumes for transitory states.

6.2 Solutions examined (and simulated)

Macina canal :

Changing distributors to downstream regulation.

Bival system (particularly well suited to the existing geometry) and remote management on the Fala.

Doukkalas canal : Three solutions (see diagrams)

1) Extension of the present reservoir
2) Extension of downstream regulation to the whole of the canal
3) Remote management

Various sub-solutions were also envisaged.

COMPARISON OF SOLUTIONS - DOUKKALAS

Solution N°	1	2	3
Investment cost (millions of dirhams)	9	70	9
Total costs capitalised over 50 years	20	84	18
Reliability	Médiocre	Excellent	Good

7 Works studies

During these phases, simulation models are only used to refine the solution chosen at short preliminary project level. No particular comments are called for.

8 Conclusion

The main subject of discussion has been simulation models.

Modernisation studies frequently lead to proposing designs based on remote management. These solutions make the best use of existing installations and limit the amount of extra works. They also have other advantages :

- small land purchase requirements and hence little compulsory purchase (difficult in irrigated zones),

- minimum canal down-time for the works.

Remote management solutions are frequently based on real time operation of management software.This uses real-time data on the state of the canal (levels and flows along the canal, etc.) to determine the flow setting to be transmitted to the regulation works (head gates or pumping station, gates controlling reservoirs). It thus includes the transfer function between different regulation points along the canal. It must reverse this function to find the most suitable operating instructions for the gates.

This operation program must therefore be set by the simulation program elaborated during the regulation studies to determine precisely :

- the transfer function (or functions) required,

- their inverse features.

These systems generally run automatically. The disadvantage of such convenience is the disappearance of daily management leading to the disappearance of a certain technical memory of hydraulic operation. This is only needed when parts of the remote management system fail.

Thus, software for the hydraulic management of canals must include the routines required for graceful degradation management -to handle failures in data acquisition or remote control.

Acquisition failure will be compensated by manual entry of the missing data obtained by emergency radio link. The latter is also used to make up for remote control failure as manual operation of all the motorised equipment must be possible.

It is obvious that in case of computer failure the disappearance of the technical memory which has just been mentioned will result in enormous difficulties for the operating personnel handling the system manually.

The use of teaching software of the "computer-aided canal management program" type provides at least a partial solution to this problem.

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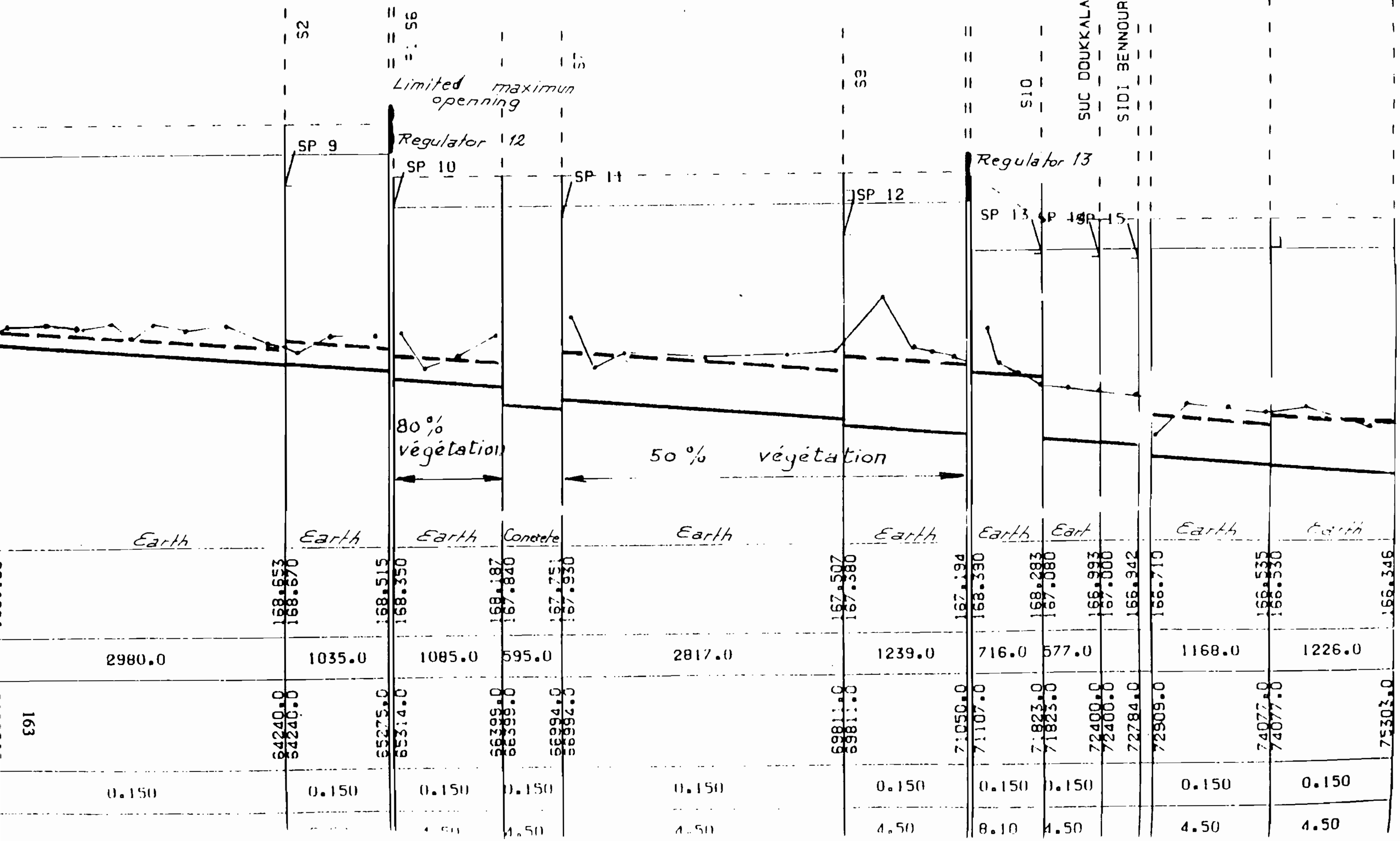
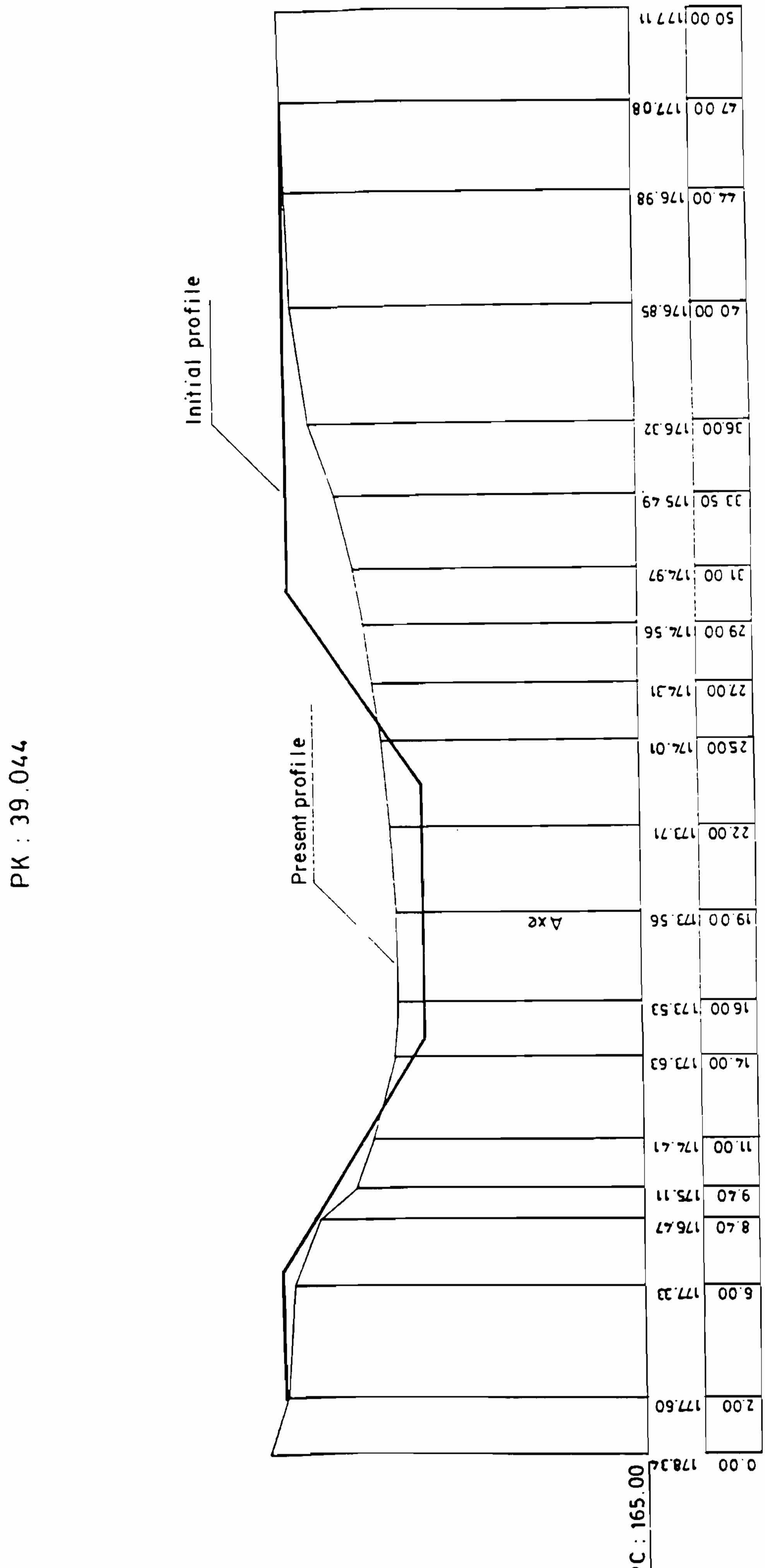
DOUKKALA LOWER MAIN CANAL
PART OF THE HYDRAULIC LONGITUDINAL PROFILE

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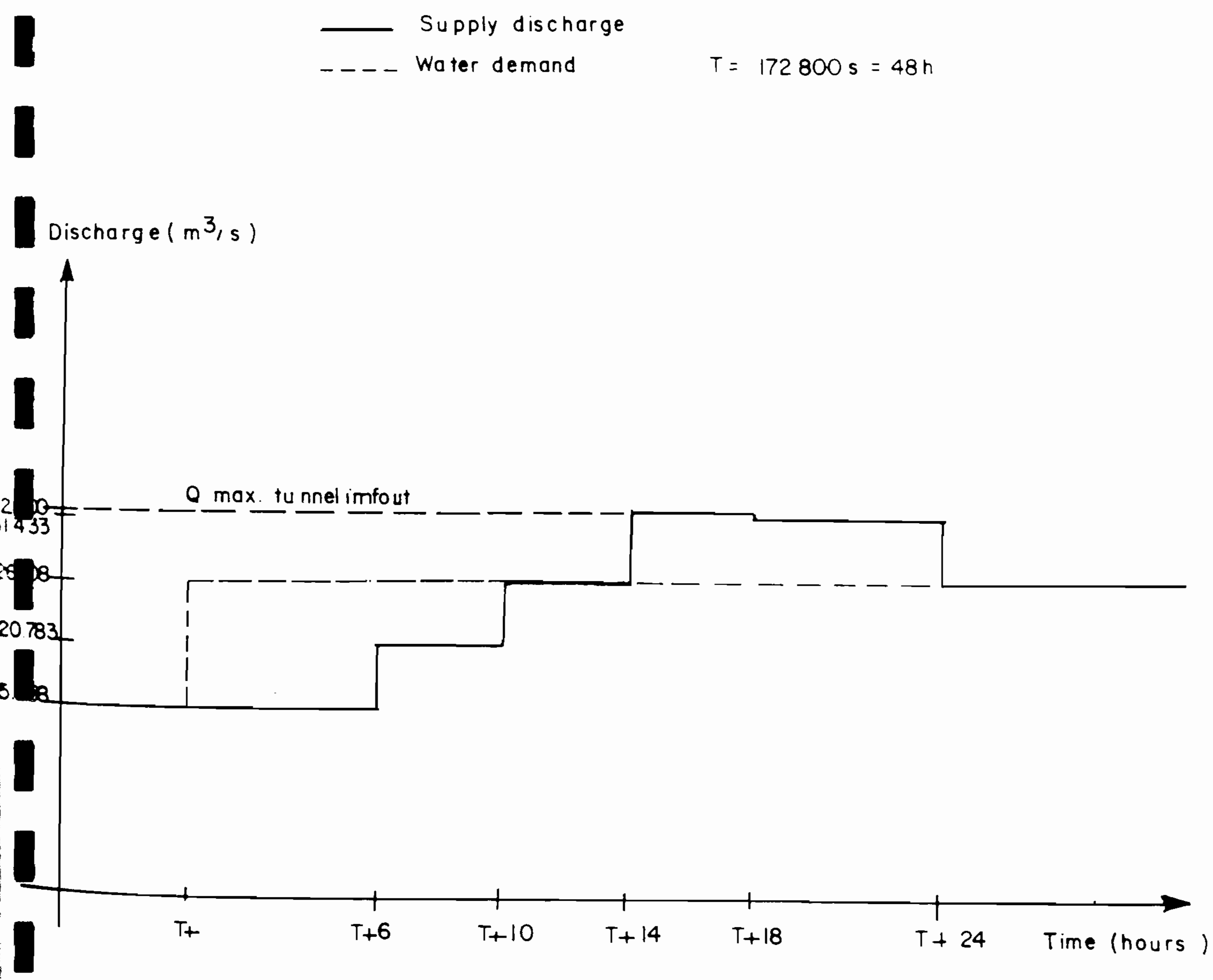

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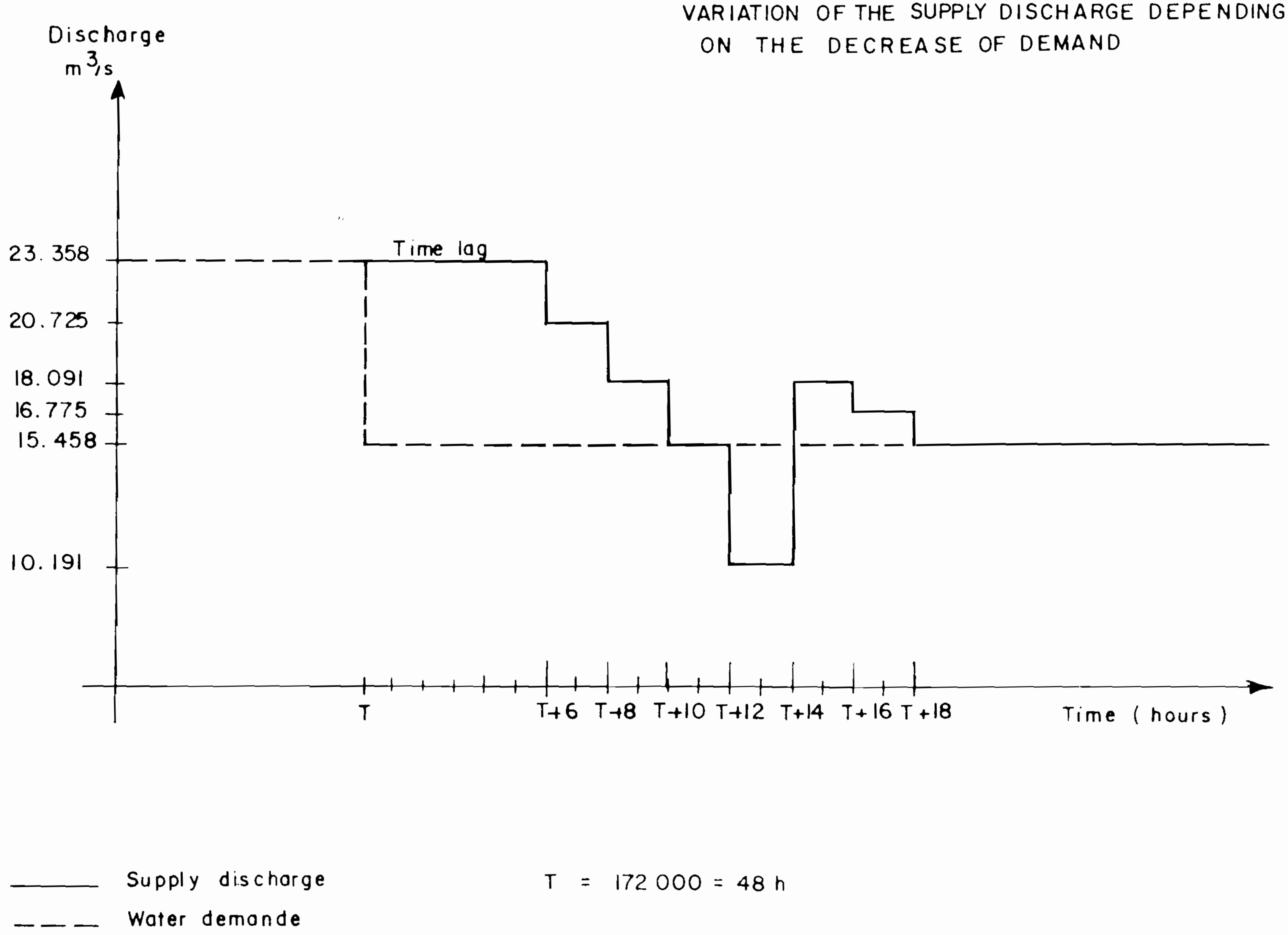
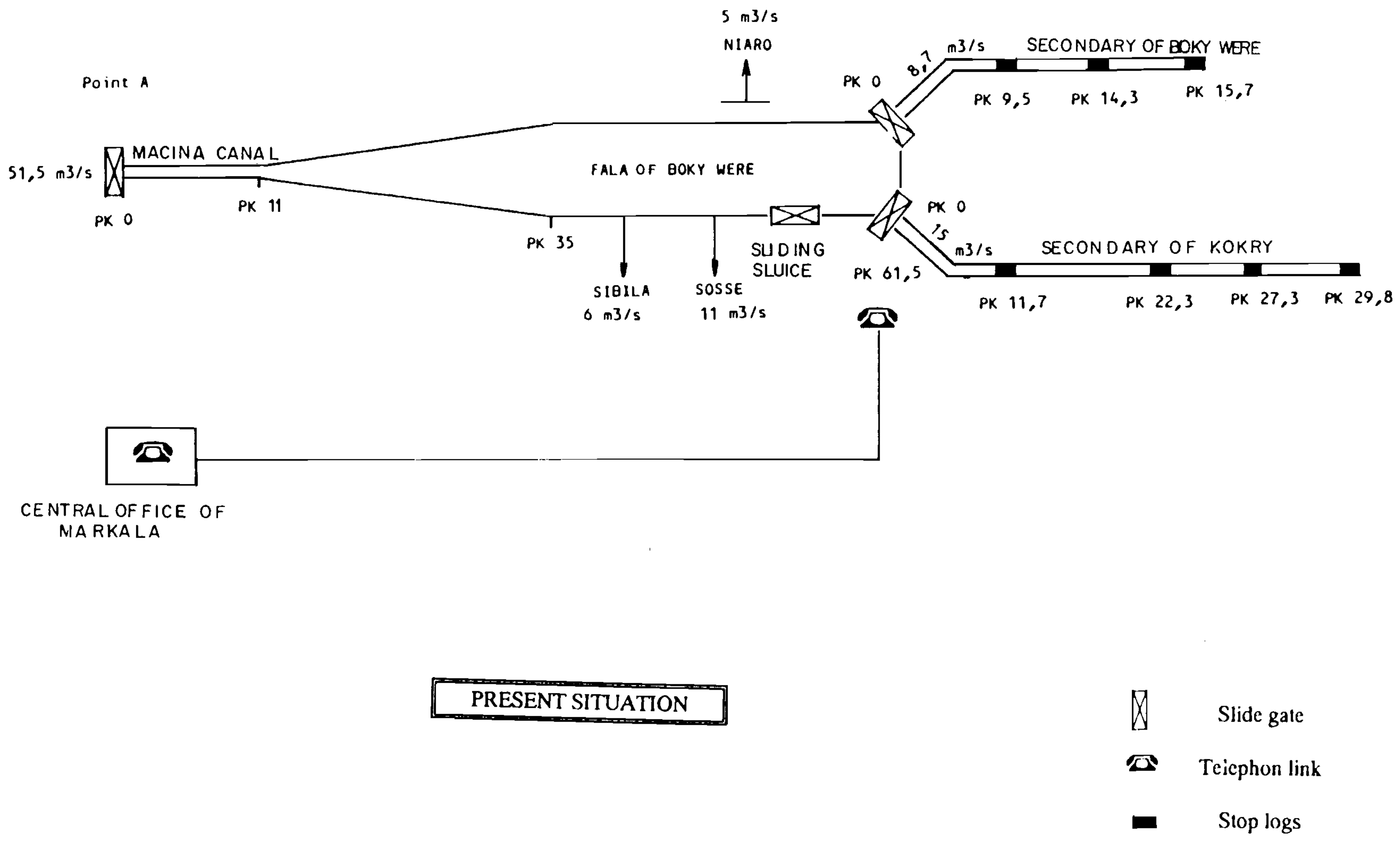


OFFICE OF NIGER – MACINA HYDRAULIC SYSTEM

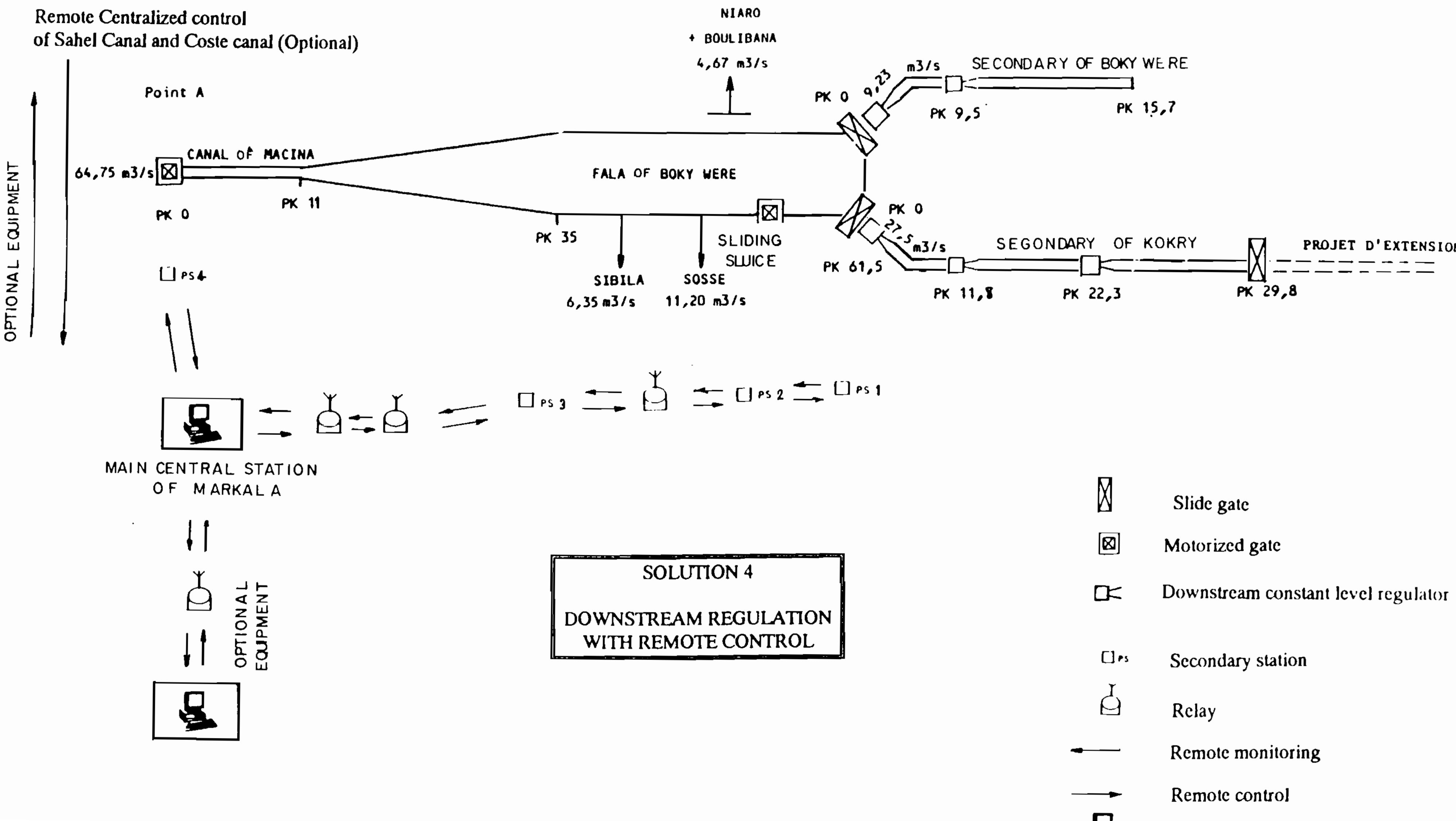
CHOICE OF THE REGULATION



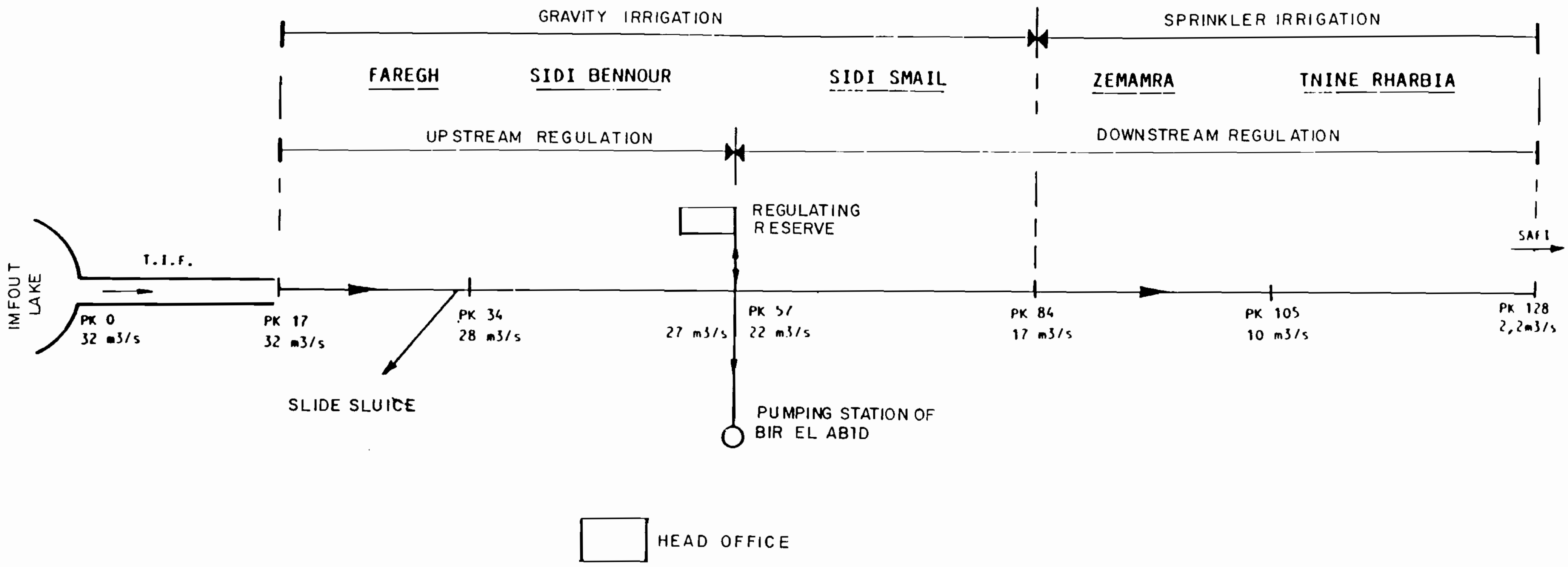
PRESENT SITUATION

OFFICE OF NIGER – MACINA HYDRAULIC SYSTEM

CHOICE OF THE REGULATION



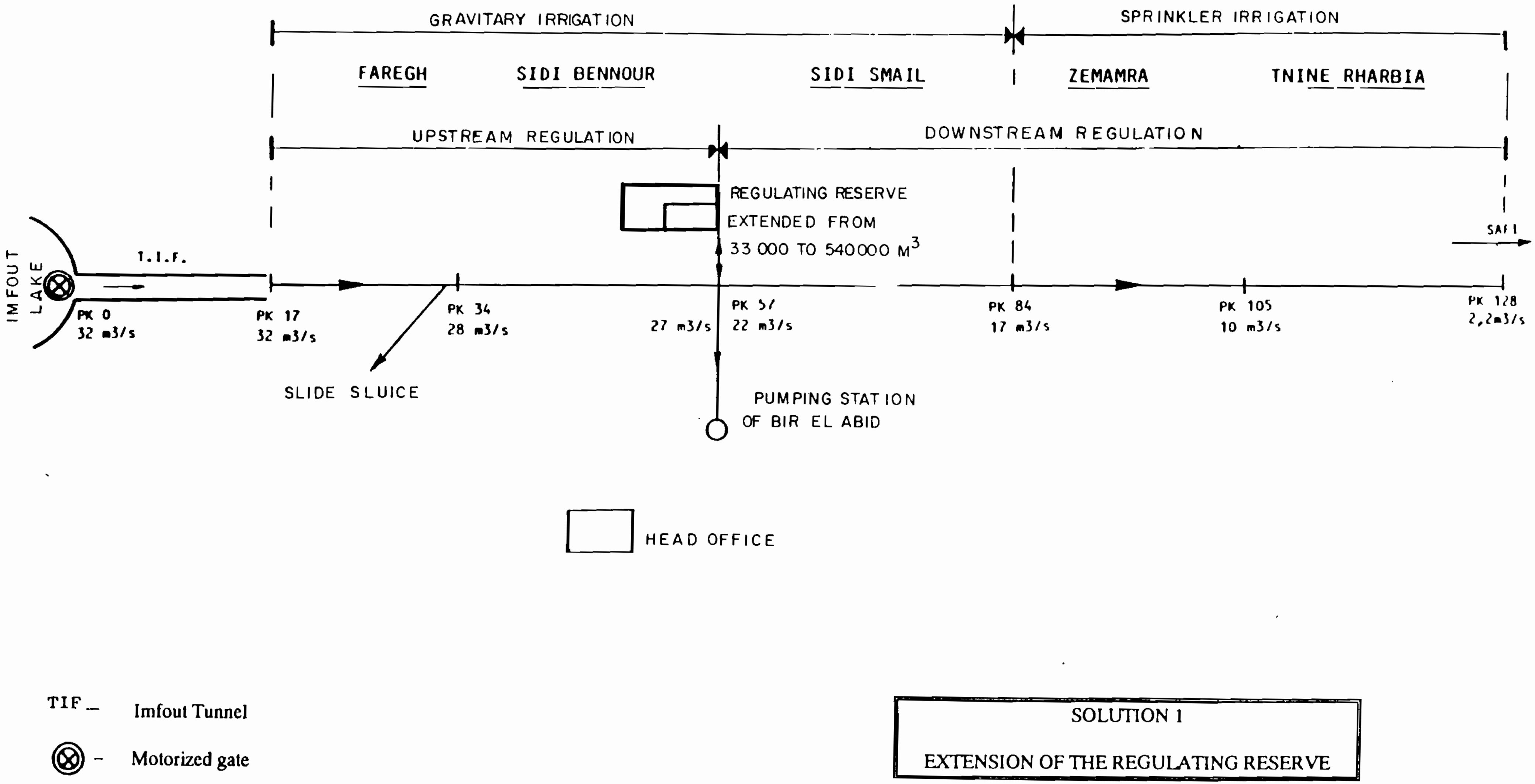
MAIN LOW SERVICE CANAL OF DOUKKALA



TIF – Imfout Tunnel

PRESENT SITUATION

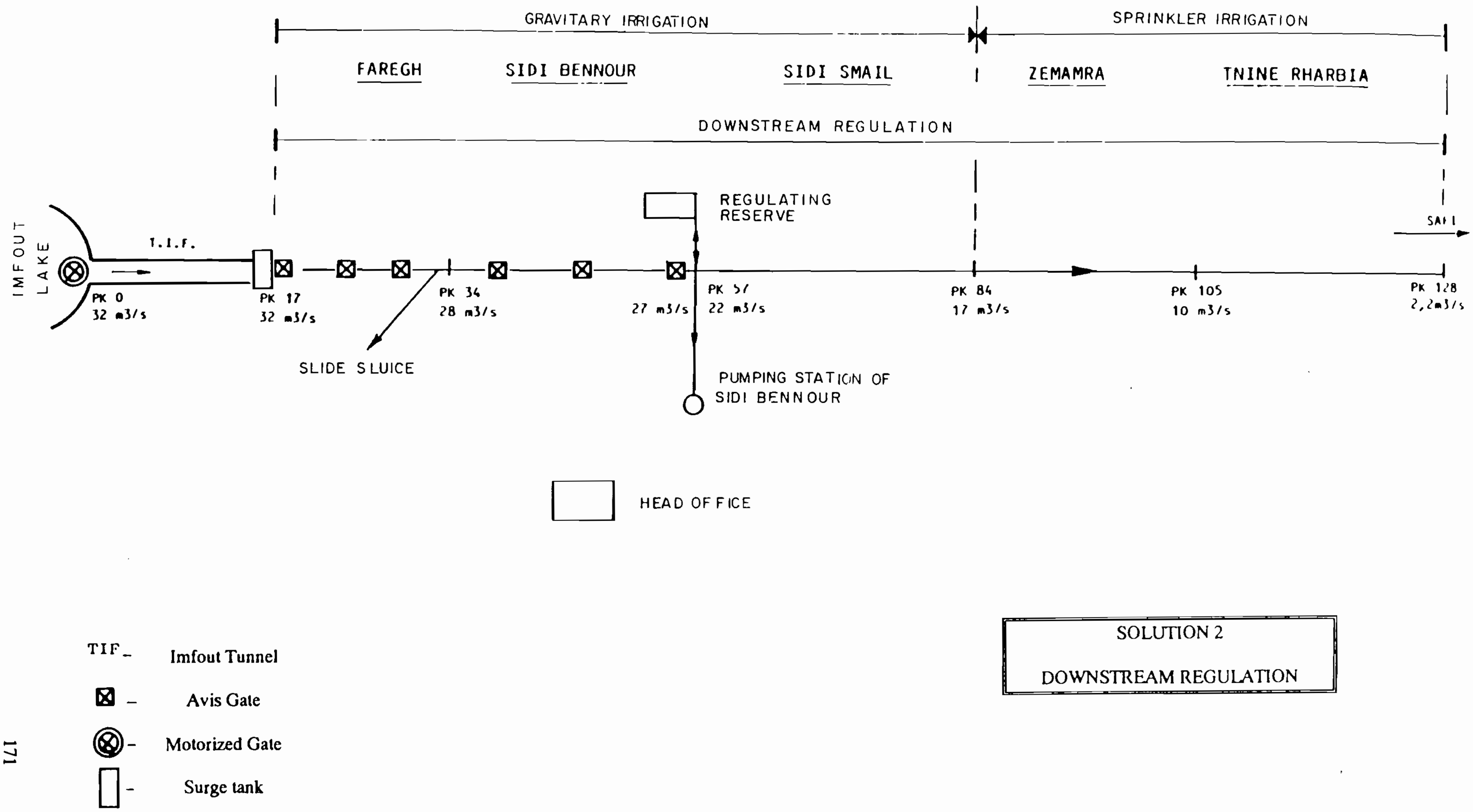
MAIN LOW SERVICE CANAL OF DOUKKALA



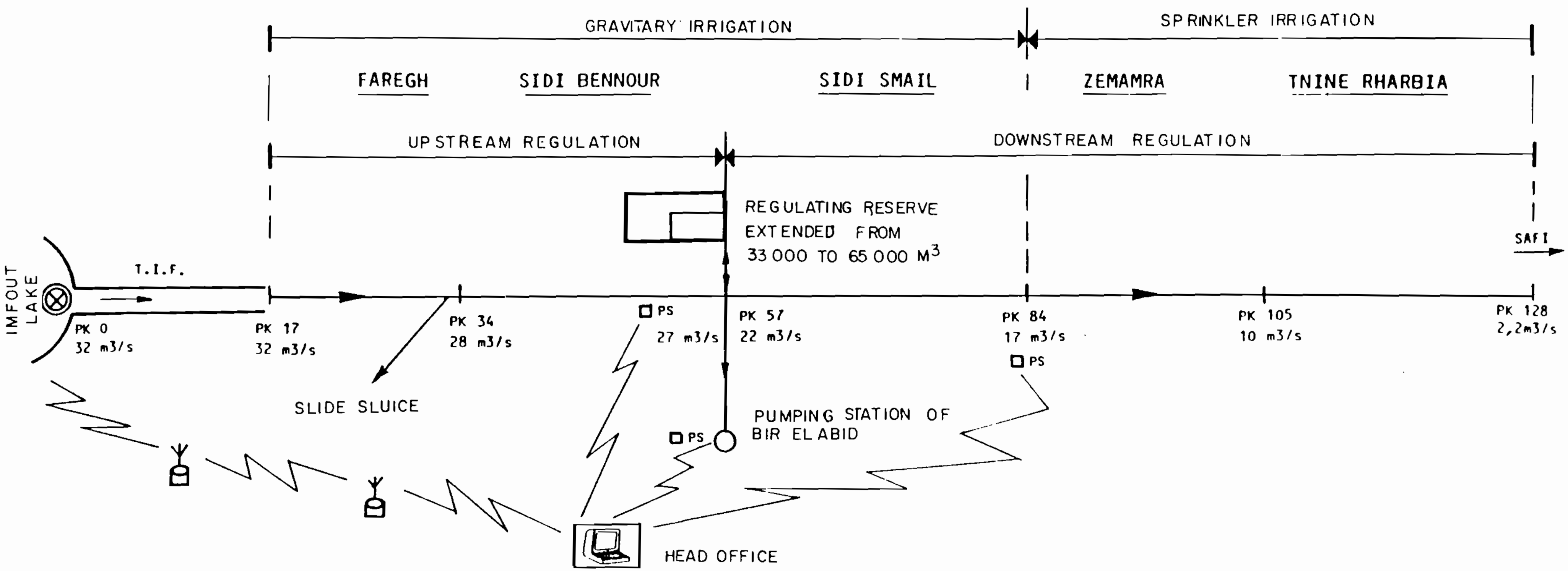
SOLUTION 1

EXTENSION OF THE REGULATING RESERVE

MAIN LOW SERVICE CANAL OF DOUKKALA



MAIN LOW SERVICE CANAL OF DOUKKALA



TIF – Imfout Tunnel

PS – Secondary station

– Relay

– Motorized gate

SOLUTION 3

CENTRALIZED REMOTE CONTROL