FEASIBILITY STUDY OF AUTOMATIC REGULATION OF AN IRRIGATION CANAL - A CASE STUDY

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER USE MANAGEMENT

By

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DECEMBER, 1988

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "FEASIBILITY STUDY OF AUTOMATIC REGULATION OF AN IRRIGATION CANAL - A CASE STUDY" in partial fulfilment of the requirement for the award of the Degree of Master of Engineering in Water Use Management submitted in the Water Resources Development Training Centre of the University of Roorkee, is an authentic record of my own work carried out during a period from 16th July 1988 to 15th December 1988 under the supervision of Prof.(Dr.) G.N. Yoganarasimhan and Sri Nayan Sarma.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ACKNOWLEDGEMENTS

I wish to extend my very special thanks to Dr. G.N. Yoganarasimhan, Professor and Sri Nayan Sarma, Reader for the encouragement and guidance they gave me for completing this dissertation.

My sincere thanks are due to all the authors whose literature I have used extensively.

I would like to thank Dr. A.S. Chawla, Director,WRDTC for the encouragement and guidance through-out the complete M.E. Course .

I am grateful to Sri S.T. Deokule, Secretary (I) to Government of Maharashtra, Irrigation Department and President, WALMI, Aurangabad for deputing me to M.E. Course.

I would like to thank Sri J.T. Jangle, the then Director, WALMI, Aurangabad for giving me the opportunity to join the M.E. Course.

I am also grateful to Sri N.R. Joshi, Director, WALMI, Aurangabad for his encouragement and advice. I am thankful to him for extending my deputation period and giving me opportunity to complete the M.E. Course.

I would like to thank Dr. S.B. Varade, Joint Director, WALMI for the encouragement and guidance he has been giving to me through-out.

I am deeply grateful to Professor M.M. Patwardhan, Head, Faculty of Engineering, WALMI for his moral support, guidance, helpful comments and help in every respect.

Thanks should go to numerous people who helped me a lot in collecting references. I gratefully acknowledge the help given in this respect by Sri H.V. Dhamdhere, Founder Director (Retd.), WALMI; Mr. LeRoy Salazar, Agro Engineering, Alamosa, U.S.A; Prof. M.M. Dandekar, Head, Civil Engineering Department, M.R. Engg. College, Jaipur; Prof. A.R. Suryavanshi and Prof. A.V. Chandorkar of WALMI; and Sri Bhatnagar, Librarian, WRDTC.

I would like to specially acknowledge the comments offered by Prof. M.M. Dandekar and Prof. A.R. Suryavanshi.

I must give very special thanks to my wife, Vidya, for her endurance and support at all times. She brought many a valuable references from U.S.A.

Neha, my daughter, deserves a special mention for being cooperative through-out this period.

I donot have words to express my feelings towards my mother, who at the age of 80, did every possible thing for me.

SYNOPSIS

Performance of Irrigation Canal Operation is often evaluated in terms of equity, flexibility and usefulness to farmers. To meet these requirements it is essential to maintain discharge as well as depth at strategic points in the distribution network. Towards this end Automatic Regulation of Irrigation Canal is increasingly being considered very useful. Nature, extent and logic of automation of irrigation canal depends on water distribution method, canal regulation technique and control equipment. Though Rotation method is appropriate for distribution system in general and below outlet in particular, principles of on-demand method can conceivably be incorporated in main canal operation. Computer controlled Real - Time Operation assumes importance in this context. Canal regulation techniques such as Upstream Control, Downstream Control, Combination control and Dynamic regulation have been widely discussed in literature. However, the discussion is in the context of irrigation in developed countries and is somewhat confusing and overlapping. An attempt is made here to critically review these techniques, bring out their exact conceptual differences and study their practical applicability considering the compulsions of Indian Irrigation. Control Equipment required for automation are also reviewed. Case study of a minor irrigation project suggests that upstream controlled semi-automation with hydromechanical gates and modules is appropriate and feasible for small irrigation schemes.

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CHAPTER - I

INTRODUCTION

1.1. GENERAL:

Irrigation Management is often evaluated in terms of productivity, equity, flexibility, environmental stability and usefulness to farmers. The productivity and environmental issues are very much related to on-farm water utilisation. The equity and flexibility are very much linked to canal regulation and irrigation water supply. Manually operated canals are characterised by inflexibility and inequitable distribution of water; the reasons being slow response to flow changes and lack of efficient water-level-and-flow-control at strategic points in the distribution network. Towards this end Automatic Regulation of Irrigation Canals is increasingly being considered as a necessity.

Automation can be defined as the process of rendering systems self-measuring, self-adjusting, or self-controlling without direct human intervention. It is a relative term since it represents a dynamic process and is implemented in degrees.

The degree of automation achievable depends on water distribution method, canal regulation technique and control equipment.

1.2. OBJECTIVES AND SCOPE :

The objectives of this dissertation are to :

(i) Review following aspects of automation

- Water Distribution Methods
- Canal Regulation Techniques
- Control Equipment
- Canal Operation Hydraulics.

(ii) Determine degree and feasibility of automatic regulation of irrigation canal of one particular minor irrigation project (case study).

Scope of this study is limited to the automation of main system of irrigation project.

CHAPTER - II

WATER DISTRIBUTION AND CANAL REGULATION

2.1. INTRODUCTION :

Nature, extent and logic of Automation of Irrigation system obviously depend upon water distribution method (WDM) selected. Once selected it is very difficult, perhaps impractical, and certainly costly to switchover to another WDM.

To implement any particular water distribution method (WDM), it is necessary to select an appropriate canal regulation technique (CRT) out of many techniques available. Techno-socio-economic feasibility of a CRT, in turn, limits the choice of WDM. Nature, extent and logic of Automation of Irrigation canals depend on both-WDM as well as CRT.

Hence, a brief review of WDMs is first taken in this chapter and then some aspects of CRT are discussed.

2.1.1. W.D.Ms Establish Flexibility :

The transfer of water from the source to the point of use is influenced by the distribution and regulation concepts and methods used. Water distribution method (WDM) establishes the flexibility of a canal system operation and the physical and operational requirements. It is, thus, linked to the design of the conveyance system. (Gichuki, 1988).

2.1.2. Reasonable Trade-offs :

WDM decides about frequency, flow rate and duration of water delivery. The relationship between these three factors control the capital cost and operating expenses of the delivery system. The same factors bear heavily on the effective and economical use of water, labour, energy and capital investment on the farm. (Replogle, Merriam, Swarner, Phelan, 1981). To make reasonable trade-offs, the various combinations of flexibility and rigidity of frequency, rate and duration have to be considered (Gowing & Merriam, 1984).

2.1.3. Three Methods :

Three distinct WDMs are continuous flow, rotation system and on-demand supply system. Seldom if ever is all irrigation water delivered strictly according to any one of the three. It is more usual to find a modification or combination of these methods being used at various times or in various locations as conditions dictate. (ASCE, 1980).

2.2. CONTINUOUS FLOW :

2.2.1. Definition :

In continuous flow systems, water is delivered at a fixed rate on a continuous basis, usually only during growing season. (Clemmens, 1980) All flow rates within the system (in all conveyance and distribution canals (Gichuki, 1988) are fixed (either at the beginning of the season or at a few times during the season or both). Except in unusual circumstances, the delivery flow rates would not vary. (Clemmens and Dedrick, 1984) Water is always made available. Right to secure water when needed is continuous. The actual use may be intermittent. (ASCE, 1980).

2.2.2. Simple Operation, Little Regulation :

Operation is usually simpler than for either rotation or demand delivery. Water not used can be readily disposed off with adequate wasteway facilities. There is also less fluctation in use. The operation consists solely of maintaining the optimum canal stage by manipulating reservoir discharge facilities. Little canal regulation may be required at the beginning or at the end of season when the use of water is more irregular. (ASCE, 1980).

2.2.3. Low Flexibility and Efficiency :

The emphasis is on physical infrastructure and, therefore, requires minimum communication. This concept has the lowest physical and operational requirements but generally has low water use efficiency and flexibility in delivery (Gichuki, 1988)

2.2.4. Tail Enders Suffer :

To be equitable, the size of the stream should be related to the area to be irrigated. If farms are small, the stream is also small, and usually small streams are less efficient because a greater percentage of the water is lost in seepage. Getting water to the end user is perpetual problem. Seepage losses are also higher because the entire system is functioning all the time and losses are continuous. (Bishop and Long,83).

2.2.5. Avoid Continuous Flow :

The system is more restricted to area where water is plentiful and its efficient use is therefore less important (FAO 40, 1982) This is a primitive system which came into existence in many irrigation projects.

2.3. ROTATION :

2.3.1. Rotation for Equity :

This method is perhaps the most widely used of modern irrigation delivery methods. It has been successfully used in many parts of the world and it improves equity. (Bishop and Long, 1983).

2.3.2. Rotation for Efficiency :

For surface irrigation, it is not practical to supply water at the rate at which plants need water. For example, plants may use water at a rate of 2 - 10 mm/day, where as surface irrigation systems generally are designed to apply from 50-150 mm/day irrigation, which will generally be applied in a period of 1 - 48 hrs. This is dictated by soil water holding capacities, root zone depths, soil infiltration rates, and efficient irrigation stream sizes. Thus to achieve even a reasonable efficiency, an available irrigation stream must be rotated between different areas of land. (Clemmens, 1986).

2.3.3. Definition :

In the rotation system water is delivered at a set (predetermined) interval for a set amount of time (fixed period) at a set flow rate. (Clemmens, 1980) Water is delivered at larger flow rate (as compared to continuous flow) for a shorter duration. (Gichuki, 1988) Rotation may be made between two water users, two or more groups of water users, two or more different minors or between definite divisions of the entire irrigation development.

2.3.4. Modifications :

This method has the flexibility of combinations. Some modifications of this might be -

(i) Fixed amount - fixed frequency
(ii) Fixed amount - variable frequency
(iii) Varied amount - fixed frequency.

Fixed amount - fixed frequency delivery schedule is most convenient from Engineers pointof view but very inconvenient to users. The other two methods can, theoretically, be optimised for a specific crop on specific soil and field conditions. (Replogle, Merriam, Swarner, Phelan, 1981).

2.3.5. Fixed Amount - Variable Frequency:- Desirable :

Surface irrigation systems are generally designed to be efficient within a small range of application depths. Since crop water use rates vary widely over the season, the period between irrigations should also change. Thus variations in frequency rather than flow rate are necessary to adjust a rotation schedule to match plant needs for surface irrigation. (Clemmens, 1986).

2.3.6. Regulating Reservoirs and Rotation :

Rotation methods can possibly be modified by using regulating reservoirs. This modification may enable Rotation method moving closer to the Demand System. (Replogle, Merriam, Swarner, Phelan, 1981). It is this possibility which needs to be explored in Indian condition particularly in the context of some type of automation.

2.4. DEMAND :

2.4.1. Sophisticated W D M :

This method is perhaps the most sophisticated of the water distribution methods. It consists of making water delivery to the farmer's field upon receiving indents from him specifying the time and amount. It is analogous to a city water system where one can get water by just turning on the tap. (Bishop and Long, 1983).

2.4.2. True Demand :

For a True demand system water is delivered immediately at any time, at any rate, and for any duration requested. (Clemmens, 1980). It aims at providing water upon request without any prior notification (Gichuki, 1988).

2.4.2.1. Unrealistic True Demand :

True demand is obviously unrealistic. (Clemmens, 1980). The demand schedule in which the irrigator may have water - flexible in frequency, rate and duration - is often too expensive, especially if large rates or complete time flexibility are offered. The capacity of such a system would be too large for reasonable capitalisation and operating costs, since it must be large enough to meet the combined probable demand of all the users at any one time. (Replogle, Merriam, Swarner, Phelan, 1981).

Some modifications make Demand System plausible. When demand exceeds systems capacity a MODIFIED demand practice involving rotation is usually used (ASCE, 1980).

2.4.3. Modified Demand: (Scheduled Delivery or Semi-Demand)

This type of water delivery can be described as delivery of a stream on the day or days the farmer demands water, but MODIFIED as necessary when demand exceeds capacity to deliver (ASCE, 1980).

2.4.3.1. Demand Plus Rotation :

Scheduled delivery concept combines demand and rotation concepts. Rather than supplying water on a fixed rotation or forcing the user to adhere to that schedule, the users are required to place their requests in advance and the operating agency tries to meet the demand subject to capacity, time lag and operational constraints in the network. If the demand can not be met as made, it is modified in time, rate, and/or duration.(Gichuki, 1988).

Two categories of Modified delivery schedules in terms of constraints placed on rate, frequency, and duration are Frequency Demand Schedule and Limited Rate Demand Schedule. (Replogle, Merriam, Swarner, Phelan, 1981).

2.4.3.2. Frequency Demand Schedule :

It is a compromise between the convenience of the farmer and that of the water agency. Though the flow rate is as requested by the farmer, the frequency of the deliveries is modified. There is generally a time-lag between demand and actual supply. Prior notification by the farmer is required.

2.4.3.3. Limited Rate Demand Schedule :

It allows flexible rate and duration deliveries as well as frequency but with a limit on the maximum flow rate.

Freedom to Farmers :-

The maximum flow rate is set fairly high to economically use labour on the farm but it is limited by the economics of the total farm and distribution systems. Obviously, this schedule requires operational spillage/or storage or automation of supply since Flows are Varied by the Irrigators within the stipulated limit.

Level top canals and pipelines :-

When distribution system is automated by use of level-top float controlled canals and field channels are replaced by pipelines (of increased capacity), the operations become very simple. Automated main canals and regulating reservoirs are also required.

Nearly all large projects in the northwestern United States operate on a type of limited-rate demand schedule. Merriam's trials in Sri Lanka since 1981 are also quite interesting.

2.4.4. Some Other Features of Demand System are Listed Below :

(i) Operational Problems :-

It offers maximum flexibility and convenience to the irrigators but creates operational problems associated with random changes in demand. (Gichuki, 1988).

(ii) Management Intervention :

The on-demand system provides flexibility without needing extensive management intervention, but, because of the need to provide sophisticated hydraulic control structures and greater canal capacities, results in a very high capital cost. In some circumstances management intervention may still be required to to deal with inadequate water availability (Gowing, 1984). If this occurs, a change to rotation or continuous flow method may be necessary (ASCE., 1980).

(iii) Closed pipe systems Desirable :

The success of on-demand systems in developing countries depends on many factors, but in any case, the closed pipe system has better possibilities than the open channels. They can not be manipulated by anyone, and thus operational and social problems (e.g. stealing of water etc.) are reduced (FAO - 40, 1982)

(iv) Capacity requirements not Investigated :

The literature contains very little information regarding field verification of required distribution network sizes for irrigation systems operating on a demand (or even modified demand) basis. This may be due to the very few demand systems operating. (Burt and Lord, 1981). Until this work (deciding magnitude of increases in capacity) has been accomplished, it would be extremely difficult to perform an economic analysis to justify a demand or modified demand system. (Clemmens, 1980).

2.5. FLOW REGULATION ACTIVITIES :

2.5.1. Introduction :

Management of flows involves the procedures that are required to distribute water in accordance with the allocation plans. Improved control of water will increase the farmers' productivity, water, labour, and capital as well as create conditions conducive to long term sustenance of irrigation by alleviating the problems of environmental degradation, system deterioration, loss of productivity, and social conflicts. Water control activities are extremely important and should consider both long and short term contexts. Long term activities require realistic forecasting so that water can be stored at strategic locations (canal storage or regulating reservoirs) and be made available when and where it is needed. Forecasting storage requirements, in case the irrigators reject the water they ordered, should also be considered. Short term activities deal with day to day operations.

2.5.2. The main problem in managing the regulating flow are attributed to -

(i) Simplified way of considering steady state conditions always,
(ii) Unexpected variations in demand,
(iii) The unpredictable time lag peculiar to each canal section.

2.5.3. The basic questions in the management of flow are :

(i) Where and when are flow control changes required? and
(ii) How and when should the changes be made ? (Gichuki, 1988)

2.5.4. Motivations for Improvements :

Burt (1983) identified three motivations for improvements in canal control logic and hardware:

(i) The desire to make adjustments of water levels and gates easier, while still maintaining the same delivery schedule criteria.

(ii) The canal operators have the potential to properly determine water delivery schedules based upon an assessment of agronomic needs; and

(iii) The canal control improvements would enable canal systems to automatically respond to user's demands, possibly without advance notice for receiving or turning off water.

Burt (1983) has made very interesting and critical comments about these motivations. Regarding first motivation he says that improvements must occur along two fronts: concepts and hardware/software. Regarding second motivation he is sceptical. He has seious doubts about accuracies of prediction of evapotranspiration and irrigation timing for individual fields using representative fields in an irrigation project. He favours the third motivation because that means accepting user-oriented appreach.

"It is more desirable to develop systems, which automatically respond to user hydraulic demands and thereby BYPASS much of the ordering and scheduling difficulties".

2.5.5. The main purposes of open - channel regulation are to :

(i) Control the discharge from each canal at any instant so that the canal or its branches can satisfy the net demand of the area they serve. The response to demand must be as accurate and immediate as possible.

(ii) Raise water level as high as economically possible with a view to increasing the area under irrigation;

(iii) Control variations in the water level to:

   (a) a minimum level, to prevent canal lining deterioration due to changes in hydrostatic pressures or to store water in the network.

   (b) a maximum level, if there is a danger of overflowing.

   (c) a restricted range, as to minimize turnout flow fluctuations.

   (Neyrpic, undated)

2.5.6. Manual Vs Automatic Control :

Canal Regulation can be accomplished by manual or automatic control depending on -

(i) the nature of farm water demand;

(ii) size of the system;

(iii) availability of funds, electric power, communication systems and skilled staff;

(iv) skill and mobility of canal operators;

(v) local traditions and a variety of other cultural and social influences.

(Gichuki, 1988)

CHAPTER - III

CANAL REGULATION TECHNIQUES

3.1. INTRODUCTION :

Over the years, several canal regulation techniques have been developed. They are generally classified under four categories, viz:

(i) Upstream control
(ii) Downstream control
(iii) Combination control
(iv) Dynamic Regulation.

These concepts are discussed in this chapter.

3.2. UPSTREAM CONTROL :

3.2.1. Concept :

Many authors have explained the concept of upstream (U/S) control in different terms revealing one or more shades of the meaning of the concept. However, literature review indicates that there is no standard universally accepted definition of U/S control. Following are some of the definitions :

(i) "Conventional upstream control means releasing water from an upstream source in anticipation of demand downstream. Once the water is released on sloping canal systems, the water must be used or spilled at the lower end". (Burt and Lord, 1981).

(ii) "When changes are initiated at the supply point and routed downstream(d/s) to the delivery point, the method is referred as upstream control". (Gooch & Graves, 1986).

(iii) "Upstream control implies that the discharge is anticipated, ordered in advance, or otherwise determined, and that the source headgates are set accordingly. Once released the flow goes to its destination" (Replogle and Clemmens, 1987). Fig. 3.1 is a definition sketch of upstream control.

3.2.2. Simple Steady Flow Rate Operation:

A very simple concept of canal control design is to size each canal section of a series to carry a particular maximum flow rate. Water must be withdrawn within each reach so that the capacity of the downstream reach is not exceeded. In order to maintain a desirable head upstream of a turnout, the flow rate in the canal section at the turnout must always be the same. No check structures are used for regulation of water depth. This system is probably the most inflexible conceivable. (Burt, 1983).

3.2.3. Standard Manual Operation :

3.2.3.1. Supply Oriented:

With upstream control, the operator always tries to maintain a relatively constant water level at the off-takes. If any off-take is suddenly shut off there is no way to stop water coming from upstream short of closing each gate in succession starting with the gate at the water source. Or alternatively, a change in flow rate anywhere in the canal system must be matched by a comparable, opposite change somewhere else in the system at the same time. On canals having a few hundred kilometres length this is very difficult. Because of transient flow hydraulics it is also difficult to adjust gates properly if there are many flow changes. (Burt and Lord, 1981, 1983). The result is that withdrawal of water and gate openings need to be strictly regulated by the manager on the basis of predetermined schedule considering previously collected/aggreated downstream demand and predicted travel time. This makes upstream control 'Supply Oriented' (Dandekar, 1984), labour intensive and inflexible (Burt 1983).

3.2.3.2. Tailenders Suffer :

Due to sequential operation of gates, the water availability to all the farmers is not equitable. Tail end farmers suffer. (Dandekar, 1984).

3.2.3.3. Uniform Flow Design :

The canal is designed for uniform flow conditions and there is no channel storage in the canal to cope up with sudden changes in the demand. Hence, the withdrawal of water needs to be strictly regulated, if the canal is to function successfully. The canal has no in-built flexibility to cater to sudden changes in the demand unless it is designed for the peak demand of all the farmers within its command. This is economically unfeasible and the canal is usually designed for normal average conditions. (Dandekar, 1984).

3.2.3.4. Manual Operation :

Manual operation of cross regulators (CR) poses following problems (Plusquellec, 1988; Suryavanshi,1988).

* Frequent adjustments at different C.Rs.. are required to be done as the flow change moves downstream gradually.
* It is difficult to predict the changes at C.Rs because of large number of hydraulic variables.
* When the changes are large, adjustment at individual structure may require several hours.
* Utmost care, strict vigilance and frequent visits to the C.R.s are required to be done.
* For successful operation, the operators have to be experienced, efficient and alert.

3.2.4. Automated Upstream Control :

3.2.4.1. Constant Upstream Level:

Upstream control can be considerably improved with the use of automatic devices which maintain a constant level upstream of each regulator. Automatic upstream control makes the job of the operator considerably easier and water levels at the offtakes can be controlled much better than with manual operation. The

Basic Principle of upstream operation remains unchanged, however. (Burt & Lord, 1981).

3.2.4.2. Where it is Appropriate :

Automation of upstream control is most appropriate for structures where inflow can not be scheduled such as spillway control gates on dams. Other situations which are compatible with traditional operation are long lengths of conveyances with insignificant offtake requirements and conveyances where travel time is not critical, such as a channel which transports water from a large storage source to a large storage sump. (Nelson, 1980)

3.2.4.3. Wastage of Water :

If the upstream offtake demand increases, the downstream gates automatically shut down to maintain the constant water level. The result is that the users on the far downstream end of the system do not receive enough water. A decrease in upstream demand has the opposite effect. The gates automatically open to allow the extra flow to pass by. This flow is ultimately wasted at the lower end of the canal system. (Burt & Lord, 1981).

3.2.4.4. Partial Automation of Gates :

For normal operation of a canal system, rapid flow fluctuations may only be 10 - 20% of the average. Therefore, it may not always be necessary to automate all the gate structures. Check structures are often comprised of parallel gates, only of which may need to be automated to provide the control need for normal flow changes. For larger flow changes, the other gates can be manually operated. (Burt and Lord, 1981).

3.2.4.5. Inherent Disadvantages :

Gate automation, however, does not alleviate following two inherent disadvantages of upstream control. (Plusquellec 1988).

(i) Slow Response and Advance Scheduling :-

The unavoidable time lag in the transmission of water arises from the fact that the amount of water stored in each canal section, and therefore the storage capacity of the network increases with canal discharges (Fig.3.1) If the amount of water supplied at the head increases, the first section has to fill up to the level associated with the higher discharge before the first gate lifts; similarly, the second constant upstream level gate does not open until the second reach has found its new level, and so on all the way down the line. To increase the discharge at the tail of such a system, a certain amount of water (which is stored in the successive upstream reaches) has first to be sent through the system; conversely, closure of the head gate does not have any effect on the flow at the downstream end until some of the water in all the reaches has first run off. Thus, several hours may sometimes be required for a given discharge set at the headwork to reach the farmers, particularly where canals are long and conveyance velocity is low (Kraatz & Mahajan, 1975).

Satisfactory operation requires scheduling in advance considering response time.

(ii) Wastage of Water :

(a) It is almost impossible to set the flow released at the headworks to exactly the amount needed to meet cumulative demand and to compensate for seepage and evaporation losses on the way. To ensure that lowest offtake is adequately supplied, the flow released at the headworks must include an additional amount as a safety margin which may result in operational waste.

(b) When there is an unscheduled fall in demand due, for example, to a rainstorm, the offtakes are closed to avoid crop damage from overwatering. Water stored in the wedge volumes is then lost through the escapes to the drains.

3.2.4.6. Feast or Famine at Tail End :

In general, upstream control is by nature a control system which passes all of the problems to the downstream end of the system. Water levels can be controlled on the majority of the canal, but all of the errors show up at the downstream end. At that point, it is often a case of "Feast or Famine" for water users (Burt 1987, quoted in USU WMS Report - 1988).

3.3. DOWNSTREAM CONTROL :

3.3.1. Concept:

The concept of downstream control has been widely discussed in the literature. An attempt is made below to systematically bring together all available piecemeal information to have a compreshensive idea.

(i) "The discharge (Qirr) taken from a canal reach will be immediately satisfied because of available channel storage (aa'b).....For a constant, level at point A (downstream of regulator), the gate A opens till the dischargeis sufficient to that effect" (Fig.3.2)(Cunge and Woolhiser, 1975),

(ii) "Equipment that is operated to regulate a water surface downstream from the controlling element provides down - stream control". (Nelson, 1980).

(iii) "Downstream control consists of adjusting a control structure based on data obtained by monitoring the water surface downstream of the structure" (Dedrick and Zimbelman, 1981).

(iv) Downstream control is a method which uses information (downstream water-level) from a pool to determine the movements of the gate at the upstream end of that pool. Water is released from the source and upstream pool only to match downstream needs. Therefore, downstream control often is used synonymously with the term 'Demand Delivery' (i.e. on-demand). Downstream control is by definition automatic and user - oriented. It allows water users to have flexibility in frequency, flow rate, and duration. The term downstream control is commonly associated with local automation of check gates i.e. some type of water-level sensor controls one gate. There is no electrical connection between controllers at different gates. (Burt & Lord, 1981; Burt, 1983).

(v) "When changes are initiated at delivery point and routed upstream, the method is called downstream control". (Gooch & Greaves, 1986)

(vi) "Downstream control implies that immediate actions to regulate the discharge through a particular gate can be made at the gate". (Replogle and Clemmens, 1987).

(vii) "Contrary to upstream regulation, downstream regulation reacts directly to any disturbance and any unexpected demand deviation is automatically sent back upstream. This is due to the fact that, in a plain, the flow in a watercourse (channel) is always sub critical (i.e. downstream conditions influence upstream water levels) and that irrigation water can serve as a data transmitter along the canals". (Jean Verdier, 1987).

Very recently, Herve Plusquellec (1988) has explained the concept of downstream control with very good illustrative slides. He emphathatically points out that downstream control should not be confused with a distribution system on pure - demand at the farm level. Downstream control (seen only as "downstream water-level regulates upstream gate") can be used only for main canal to simplyfy its operation. The distribution system (distributories and minors) can still be under manually operated upstream control.

Furthermore, Replogle and Clemmens (1987) observe that in all systems, upstream control and downstream control are often interchanged at selected points in the system. For example, a small reservoir near the canal can be used to change from upstream to downstream control. Almost all downstream control eventually switches to upstream control at some point, which sometimes is at the field inlet and sometimes at the head of the lateral canal.

(Fig. 3.2 is a definition sketch of down-stream control).

3.3.2. Level Top Canals :

3.3.2.1. Constant downstream Water Level :

The check gates are automatic devices which adjust depending upon the level at the end of downstream reach. The gate is so designed (a float rests on the downstream water surface) that the water-level immediately on the downstream of the gate is constant at all discharges. (Dandekar, 1984).

3.3.2.2. Water Release on-Demand :

An increase in demand from a pool (formed by check gates) will lower the water surface at delivery point causing necessary hydraulic gradient for water flow in the canal. When the (negative) wave reaches the upstream end of a pool, it causes the float to move, thereby changing the radial gate position. The upstream pool then supplies more water and reacts in a similar manner. Such signals for increased (or decreased) demand continue upstream to the source. Thus, water is released from the source only if a demand is sensed downstream. (Burt and Lord, 1981; Burt, 1983).

3.3.2.3. Why Level-Top, Stepped Bank Canal :

At the maximum demand within the downstream reach, the gate opening is maximum and the water surface is parallel to the sloping bed of the canal. If there is no demand within the reach, there is no withdrawal and the water surface (in the reach) reaches a horizontal state and gate adjusts to a minimum opening position. The canal banks have to be designed with a level-top in order to correspond to the horizontal water surface. Because of this peculiar feature, the canals are known as Level - Top canals. There is a drop in water-level at each check gate and the canal bank top also can have a drop in elevation at the check gate level. Thus, it is a stepped bank instead of a sloping bank. As a result of the permissible range of water surface in the reach corresponding to $Q = 0$ and $Q = Q_{max}$., a triangular wedge of storage space is always available as channel storage. (This channel storage must be large enough to satisfy the demand during the time $(\frac{2L}{C})$ necessary to bring the water from upstream storage. (Cunge, Holly, Verwey, 1980).

The canal, as a result, responds more quickly to changes in the demand (increase/decrease/rejection) as compared to upstream control. There is an unsteady flow in the canal and alteration of discharge results in wave formations. (Dandekar, 1984).

3.3.2.4. Lag Time :

Downstream control has slow reaction time. It depends upon a wave travelling upstream to the gate from the point of flow rate change before gate action takes place. A compensative wave then travels back to the point of water level change. Water levels at turnouts or at the downstream end of pools can fluctuate greately because of this lag time. This can cause problems with canal bank stability. (Burt, 1983).

3.3.2.5. Conversion of Upstream Control to Downstream Control:

In a level top canal the water levels in the upstream end of the pools remain relatively constant with the exception of a small decrement necessary for stability in the case of Neyrtec gates. At the dowstream ends of the pools the water levels fluctuate between a low (at maximum flow rate) and a high (at zero flow rate) affecting the offtakes situated there. This problem can be partly solved using offtake devices which have a discharge coefficient that varies depending on the upstream head, delivering a relatively constant flow rate regardless of the upstream head. (Burt 1983, Burt and Lord, 1981). In an upstream controlled canal the fluctuations occur at the upstream end of the pools, and the turnouts are located at the downstream ends of the pools where the water levels are more constant. There is very little opportunity to convert existing upstream controlled canals into downstream controlled systems with existing local automation techniques because of the location of turnouts and the requirement of level banks.

3.3.2.6. No Wastage of Water :

No water is wasted if demand suddenly drops. The water released during the time required for the hydraulic transmission of demand is temporarily stored in the wedge volumes. Downstream control saves water because the volume of water released at any check structure and headworks exactly matches the amount of water diverted at the offtakes, including seepage. (Herve Plusquellec, 1988).

3.3.2.7. Flow Measurement not Required :

An attractive aspect of downstream control is that flow rates in the canal system do not need to be known because the system automatically releases the proper flow rates throughout a canal. Calculations of flow rates are unncessary except to check that demands do not exceed the carrying capacity of the canal. This simplifies the operation considerably. (Burt and Lord, 1981).

3.3.2.8. Impossible to Check Consumption :

It is quite impossible to keep a check on consumption in a downstream controlled system, which can therefore only be used if the upstream resources can be trusted to always meet the consumers' requirements. This strictly implies the following: (Neyrpic, undated)

(i) There must be a main canal large enough at all points to handle the maximum foreseeable discharges. (otherwise, some sort of rostering will have to be done).

(ii) The resources must be unlimited, compared to the demand, If demand exceeds the supply, the canal gradually drains from upstream to downstream. This deprives the head reach farmers of water while the tail enders get their full supply.

3.3.2.9. Drawbacks :

When downstream control uses hydromechanical gates it has several drawbacks.

(i) Since set levels are determined by the positioning of regulation gates, distribution policy is established once and for all when the structure is designed. Evolution in management policy caused, for instance, by significant changes in crop production, often requires costly modifications of the structure's physical characteristics. (Verdier, 1987).

(ii) Downstream control regulators are more expensive and less easy to install than upstream ones. (Verdier, 1987).

(iii) Downstream control may prove to be unstable. It can result in practice in an oscillation of regulator gates which is dependent on the structure's physical characteristics and totally independent of external influences. The system becomes completely uncontrollable. (This phenomenon is known as 'Hunting') (Verdier, 1987).

(iv) In case of canal breach, the sudden outflow in a reach cause the gate on the upstream side to open fully rather than close. Canal clouser is not easy. Also, a simple jamming of a gate in the open position may cause dangerous over spills. (Dandekar, 1984).

(v) Downstream control with float controlled gates is the most valunerable system because these gates operate with very weak mechanical power. This makes them very sensitive to blockage by suspended foreign bodies such as deposits of algae which are frequent is some canals. (Clement, 1970).

(vi) Since canal banks have to be level-top, the longitudinal slope of a canal should not exceed approximately 20 to 25 cm per km. (i.e. 1:4000 to 1:5000). Moreover, the canal should not be large. Otherwise, the civil works required to raise the canal embankment in fill section may be too costly. Existing structures also pose problems. (Plusquellec, 1988).

3.4. CONTROL SYSTEMS :

3.4.1. Introduction :

Many other CRTs use one or the other concept of control system engineering. Hence control system concepts are briefly discussed below.

The simplest form of a control system receives an input and acts upon it or modifies it to produce an output. The input might be a signal representing departure from a desired condition, e.g. water level, while output might be a corrective signal based on the .. departure characteristic.

However, the control action does not have to be dependent on the output of the control system. A system with independence between control action and output is classified as an open-loop system.

Control systems which have control actions somehow related to or dependent upon the output are classified as closed-loop systems. These are often called feedback control systms. (Zimbalman and Bedworth, 1983).

The more commonly used terms viz. **Semi-Automatic System** and Fully Automatic System are, in fact, synonymous to open-loop system and closed-loop system respectively.

3.4.2. Open - Loop Systems :

Open - loop system requires the intervention of an operator for one of the five functions viz.aquisition of data, data communication, processing, transmission of orders, and operation of control facilities.

An example of an open-loop, centralised, computerised system is the Salt River Project in Arizona, U.S.A. Next day's water orders along with current water levels, gate openings and flow rates are entered into the computer which, in turn, determines the next day's schedule including the gate settings to maintain variations of water-levels within permissible limits. The operators then run the system from a master console. The open channel distribution system is operated locally. (Plusquellec, 1988).

3.4.3. Closed Loop Systems :

. . Closed-loop system is entirely automatic. It requires no input from operators for normal operation. Arrangements of equipment sense physical conditions and make the decisions and adjustments necessary for operation. These systems are designed to return a portion of the output signal to the input of a controller to maintain a prescribed relationship between input and output signals. (Nelson, 1980).

Due to the feedback features of closed-loop systems, they are generally more accurate or precise in their control than are open loop control systems. The disadvantage of closed-loop systems is the tendency or potential for these systems to become unstable.

Dynamic Regulation on Provence de Canal, France is an example of Closed-loop system.

3.4.3.1. Characteristics of Closed-loop system :

(i) Sufficient sensitivity to respond to significant deviations of the variable from its desired value.

(ii) Response time short enough to prevent extended deviation.

(iii) Sufficient response to restore equilibrium without causing the deviation to increase or the variable to oscillate above its desired value.

3.4.4. Basic Components of an Automatic Control System :

(i) A process with various inputs and outputs (process variables)

(ii) A sensor or monitoring device to measure the output variable being controlled.

(iii) A controller to compare the value of the measured variable with the desired value and to initiate corrective action where necessary.

(iv) A set point or reference input, the desired value of the variable, which can be provided by human operator or by a higher control system.

(v) A final control element regulating the process and changing the output variable by manipulating an input variable.

(vi) Means of communication for transmitting information from one system component to another.

The sensor measures the controlled variable, or the output, and provides the primary signal to the controller. The controller then compares the signal from the sensor to the set point. Through this comparison, the controller detects whether or not there is an error in the output. If an error is detected, the controller energizes the control element in such a manner that the magnitude of the error is reduced as rapidly and smoothly as possible. (Zimbalman and Bedworth, 1983).

Water levels as indicators :-

Because of difficulties in estimating realistic friction factors for conveyances and discharge coefficients for gates, operators of water conveyance systems normally utilize water surfaces at selected locations within the system as indicators of desirable conditions. It thus becomes appropriate for automatic control equipment to utilise water levels to control operation (Nelson, 1980).

Computerized Control : -

When a computer is used as the controller the system becomes a computerized control system. In a computerized system the functions of the computer are expanded to include estimation and optimization.

Estimation and Optimisation :-

Estimation represents the ability to estimate from a mathematical model some dependent variables which can not be directly measured from the process. Optimization means the ability to determine an optimum operating condition from knowledge of the process status and economic objective. The control function then is the ability to manipulate the control variables of the process in such a manner that the optimum operating condition is reached and maintained. Fig- 3.3. is a block diagram of a computerized control system. (Zimbalman & Bedworth, 1983).

3.5. MODES OF CONTROL : (Nelson, 1980).

The characteristic manner in which feedback controls perform control functions, or react to deviations of the controlled variable, is called the mode of control. Five common modes of control are two-position control, floating control, proportional control, reset action, and rate action.

Two - position, floating, and proportional controls provide three different control functions. Reset action is generally used with proportional control to eliminate the offset that is inherent in this mode of control. Rate action may be combined with proportional or proportional plus reset actions to increase the speed of response and reduce overshoot of the controlling element.

3.5.1. Two - Position Control :

Two-position control (Fig. 3.4) is the simplest mode of automatic control. The control function moves the controlling element to one of two extreme positions as determined by the controlled water surface. When these two extreme positions become fully opened or fully closed, the controller becomes an ON-OFF controller, and can be an electrical switch for the operation of pumps. Water surfaces controlled by two-position controls will cycle continuously from one side of the operating range to the other.

3.5.2. Floating Control :

Floating control (Fig. 3.5) changes the position of the controlling element at a predetermined speed whenever the controlled water surface deviates from its target depth by a predetermined amount. The direction of gate movement is determined by the direction of the deviation. The controlling gate makes no movement as long as the controlled water surface is within the dead band (the desired range of operation). When the controlled water surface is outside the dead band, the controlling gate will continue to move until either the water surface returns to the dead band or the gate reaches a fully opened or fully closed position. 'Littleman' controller is an example of floating control.

3.5.3. Proportional Control :

With proportional control (Fig. 3.6) the position of the controlling element has a fixed relationship to the controlled variable. A controlling gate has a position for each water surface elevation that is defined by multiplying deviation of the water surface by a gain factor. (Gain factor is defined as ratio of output, e.g. gate position, to error i.e. deviation of water surface from target level). The elevation of the controlled water surface varies from one edge of the proportional band for no flow to the other edge of the band for full flow. Zimbalman's algorithm is an example of proportional downstream control. Variable speed motors are required for gate movement at variable speed in proportional control.

3.5.4. Proportional Plus Reset Control :

Proportional control can be made more acceptable for open channel systems by the addition of a Reset function (Fig.3.7) to eliminate the proportional deviation. Addition of the reset function does not eliminate variations of the controlled water surface elevation that occur when flows change, but it does return this water surface to the elevation that existed before the change.

'EL - FLO' downstream control system is an example of Proportional Plus Reset Control.

3.6. DOWNSTREAM CONTROL - FURTHER IMPROVEMENTS :

The quest for further improvements of the downstream control concept led to the development of the BIVAL, the EL - FLO Zimbelman and CARDD control techniques.

3.6.1. Downstream Control - BIVAL System :

This system patented by SORGREAH of France requires sensing of two levels simultaneously at the downstream and upstream ends of a reach. The information thus recorded is used to command the upstream regulator.

3.6.1.1. The System Functions as Follows (Fig.3.8):

When the discharge demand is sensed at the downstream end, a negative wave propogates in the upstream direction.

At the same time the upstream gate, controlled by the averaged levels at both ends of the reach begins to open and the positive wave propogates downstream. Two waves meet in the middle of the channel, pivoting the water surface twice as quickly as in the classical downstream control system. (Cunge & Woolhiser, 1975).

The BIVAL system (Fig.3.8) introduces a weighing factor(α between two sensor indicators A and B, making it possible to use Yref. level which is situated between the reach limits. Use of the BIVAL system requires that the engineer determine parameters such as weighting coefficient (α), reference level Yref, insensitivity range, speed of gate clouser, positioning of the sensor B etc. (Cunge, Holly, Verwey, 1980).

When the flow rate changes, the water level curve pivots around a given axis situated in the reach at a point determined by the proportion of the upstream & d/s flow depth changes. Consequently, the canal bank at the upstream end can remain parallel to the bottom of the canal (thus, minimising the canal work) but the downstream part must be kept horizontal. This technique maintains nearly constant reach-storage regardless of the flow rate because the pivot point is normally at the mid-point of the reach. It has a good hydraulic stability because additional flow is not required to increase wedge storage when demand increases. (WMS Report 72, 1988).

3.6.2. Downstream Control :- EL - FLO Plus Reset :

3.6.2.1. Concept :

Electronic Filter Level Offset (EL-FLO) plus Reset algorithm was designed by USBR. In year 1973, it was tried on Corning Canal in northen California, U.S.A. The algorithm is based on control theory concepts and is built into an analog computer. Gate automation is achieved through an electronic feedback from the water-levels at the downstream end of a sloping canal section (Burt and Lord, 1981) The feedback is achieved through electroni sensors and conveyance system of cables ending in an electronic circuitry which is shown in Fig. 3.9. The block diagram of Fig.3.9 indicates the general arrangement which actuates and stabilises the gate movement. In order to have stabilised operation the RESET circuitry is included. (Dandekar, 1984). The resulting electronic time delay circuit superceded the cumbersome hydraulic filter. It offers a great deal of versality and flexibility of operating automated flow regulation by smoothly regulating changes (WMS, 1988). Fig. 3.10 illustrates the location of each element of the system relative to the canal reach and adjacent canal reaches.

3.6.2.2. Control Parameters :

The El-FLO device has three parameters which provide primary control action during unsteady state flow conditions that occur immediately after a flow change downstream. These are -

(i) The electronic filter time constant TF
(ii) The water level offset (YT-YF)
(iii) The proportionality factor or gain, K1.

3.6.2.3. Limitations :

The complexity and difficulty of using EL-FLO is rooted in determining these factors. To determine the time constant and gain, a complicated computer programme must be run to closely analyze the hydraulics of a complete canal system. This is very difficult, if not impossible, because of unknown gate constants, changing friction factors, wind wave effects etc. EL-FLO depends upon a single measurement and extensive modeling must be done to estimate what is happening at other points between the canal gates. Although the EL-FLO method is very complicated, its development (over almost 10 years) has resulted in a significant increase in knowledge about open channel transient flow control. (Burt and Lords, 1981)

3.6.3. Downstream Control - Zimbalman's Algorithm :

3.6.3.1. Empirical Approach :

Zimbalman (1983) developed an algorithm (1981) for the centrally computerized control of an open-channel water distribution system to be operated on demand basis. The algorithm, which was of necessity empirical, is an adaption of proportional downstream control closed - loop system.

3.6.3.2. Input - Output of Algorithm :

Because of cost considerations and difficulty associated with monitoring each delivery point, monitoring is done only at the control structures in the aqueduct. The input to the algorithm is thus the water surface elevation measured by a sensor upstream of each control structure. The output from the algorithm is the adjustment in upstream gate movement based on the deviations of water level from the target and time adjusted rate of change.

A simplified flow chart giving an overview of the control algorithm is shown in Fig. 3.11.

3.6.3.3. Logic :

A linear equation is fit to the values of surface elevation Y (t) at past discrete time points (t) using the technique of exponential smoothing. Exponential smoothing allows polynomials to be fit to a set of data with the most recent data values being weighted more heavily than the older (in terms of time) data values. Estimating the rate at which the water surface is changing, and forecasting the water surface elevation, provides a mechanism through which the algorithm can begin to react to a change in demand prior to the water surface reaching the limits of the dead band. By anticipating the need for a change, the response time is reduced. Once all gate movements have been computed, the gates are moved nearly simultaneously to minimise hydraulic transients.

3.6.3.4. Control Parameters :

The algorithm depends upon several control parameters to operate properly:

(i) A smoothing constant used in exponential smoothing;

(ii) The width of dead band;

(iii) The selection of a critical value for the slope of the water surface;

(iv) The time parameter used in forecasting the water surface elevation; and

(v) The speed of the adjustments.

Selection of the the optimum set of values for the control parameters must be accomplished in harmony with the management objectives and operating criteria of the system to be controlled. This optimum combination may very between canals and the different times of the operating season.

3.6.3.5. Limitation :

When sufficient water is not available at the inlet, the control algorithm will have to notify the system operator, because action to supply additional water at the inlet, or to manadate a reduction in deliveries, is beyond the scope of the algorithm.

3.6.4. Downstream Control : CARDD

3.6.4.1. Introduction :

A local downstream control method for canal gates providing sloping Canal Automation for Rapid Demand Deliveries (CARDD) was developed by Burt (1983).

3.6.4.2. Input Variables :

Canal geometry, roughness factors, flow rates or gate coefficients are not required input variables into the controlle logic. Multiple water level readings each minute within a pool and gate opening measurements are the only input variables to be used in the logic to control upstream gate movements.

3.6.4.3. Hypothesis :

CARDD method is based on the following hypothesis:

(i) The water levels within a reach reflect the flow rate balance into and out of the reach;

(ii) A complete canal system with local controllers can respond quickly to a change in one reach and if a local controller responds quickly to a change anywhere in the reach it monitors, the hydraulic connection between reaches will have the same effect as electrical connection between controllers.

(iii) A controller can be developed, without expensive theoretical analysis to have the proper timing and magnitude of gate response thereby reducing the water level fluctuations and achieving flow stability within a reach and within the canal network; and

(iv) Downstream control can be implemented on canals with sloping banks.

CARDD is claimed to be applicable for conversion of existing upstream controlled canals into demand systems.

3.6.4.4. Logic :

To simplyfy the mathematics of describing the water surface within a pool, it is assumed that it would be reasonably correct to define the water surface with the equation of a line. The equation of the line is developed using simple linear reg-ression and it is used to estimate downstream water level and its rate of change.

To interprete and use the best fit line, downstream end of the pool is chosen as the pivot location because CARDD is developed to be adaptable to existing canals operating with upstream control. Turnouts are located immediately upstream of the check structures in many cases and the water level fluctations should be minimised there.

One of two values could possibly be used for downstream pivot point. The first is the actual downstream water level (labelled YS5). The second is the downstream water level estimated from the equation of the best fit line of the five water surface depths in the pool (called BINT).

CARDD is developed with the canal system depicted in Fig. 3.12. This canal system ends with a pump rather than a check gate and downstream constant level reservoir. Fig. 3.13 and 3.14 illustrate how CARDD will move gates in two possible situations.

3.6.5. Demand Irrigation Schedule (DIS) Pilot Project in Sri Lanka :

3.6.5.1. Merriam's Trials :

John L. Merriam's trials in Sri Lanka since 1981 have been reported by Maheswran, Satgunasingham, Merriam (ICID, 1981); Henry Guston (Odi,1983); Merriam (Odi, 1984); Merriam & Davids (ASCE, I and D Engg., 1986).

3.6.5.2. DIS System Description :

Instead of conventional open-channel rotation irrigation with water controlled by Government organisations, a 147 ha. pilot project (Block 404, distributory canal D-1, Mahaweli, System H, North-Central Sri Lanka) has put each farmer in control of his own water supply using a Limited Rate Demand Irrigation schedule. This system conjunctively utilizes sloping canals, on-stream regulating reservoirs, automatic float-controlled canal gates, level-top canals and buried concrete pipelines instead of field channels.

Limited Rate DIS :-

The limited - rate DIS used on the pilot project permits the farmer, without restraint other than limiting the rate to less than about 0.5-0.7 cfs (14-20 Lps), to take water at his field turnout at any frequency, rate and duration to fit his conditions.

Level Top Canals: -

Two Level - Top Canals are served by the reservoir through a constant downstream level Neyrtec AVIO gate of 25 cfs (700 Lps) capacity. The gate maintains a constant level regardless of flow rate. Concrete pipelines run downshill from the canals.

Closed Pipelines :

Pipe sizes typically range from 200 - 300 mm. The pipelines supply individual farms. The system is fully automated and permits any farmer to take water as needed upto the limit, which is about 0.5 to 0.7 cfs (14- 20 Lps) depending upon pressure in the pipeline. The pipelines are sized to permit all farms served by a pipeline to be irrigated on a random basis within a three day period (day time only). It is possible for the two lowest farms to take water simultaneously. The capacity is increased upstream to accomodate more farmers on a random date. Table 3.1 shows these pipeline capacity values, and table 3.2 shows the increased capacity used to design the distributory channel as more field pipelines are served moving up channels.

The only manual operation needed (other than manual operation of turnout by the farmer himself) is to regulate the distributory regulator as necessary to see that the reservoir does not overflow nor run dry.

Table - 3.1. Field Pipeline Capacities:

Number of farms	1-2	3-4	5-8	9-12	13-16	17-20
Flow Rate, Lps (cusec)	20(0.7)	40(1.4)	55(2.0)	85(3.0)	115(4.0)	140(5.0)

NOTES:

(1) The demand system, because of the random nature of withdrawls tends to an average flow where there are many turnouts and to concentration of demands where there are only a few.

(2) Irrigation at daytime only.

(3) A trial flow capacity for the pilot programme was set at about 20 LPs (0.7 cfs) to be sure that the system did not limit operations during the inaugural period.

(4) The 20 Lps will supply 75mm on a one hectare farm in 10.5 hrs. This depth would be needed at about 7 to 10 day intervals. The capacities indicated could supply all farmers in a group within a two or three day period.

*****

Table - 3.2. Factors for Distribution Channel Capacities :

Number of field pipelines	1	2	3	4	5	6	7	8	9	10
Factor	1.0	0.9	0.83	0.77	0.72	0.68	0.67	0.66	0.65	0.65

NOTES :

(1) Along the distributory canals in Demand System, the random demands will require proportionally greater flows near the lower end than required for rotation system. Table 3.2 indicates factors that were used to multiply the sum of all downstream field pipeline needs. They were arbitrarily selected considering probabilities and a conservative approach.

(2) The above table indicates, for example, that if the sum of four downstream field pipelines requirements was 400 Lps it should be multiplied by 0.77 giving a design flow in the channel at that point of 308 Lps.

*****

3.6.6. Downstream Control : Hy - FLO :

3.6.6.1. Problem of Instability :

The instability associated with downstream control can also be prevented by incorporating the Hydraulic Filter Level Offset (Hy FLO) controller into the feedback path. (Michel J. Shand, 1971).

3.6.6.2. Hy - FLO Controller :

Hy - FLO controller combines proportional control system with a hydraulic filter. The hydraulic filter consists of a filter well which is connected by a capillary tube to the canal. (Fig. 3.19). The hydraulic filter modifies/ dampens the water level changes at the point of sensing and prevents instability.

The Hy - FLO controller is physically simple. Its design is determined from relationships depending on the configuration of a canal reach and its check gates.

3.6.6.3. Disadvantages of the system are :

(i) The relatively large offsets;
(ii) The poor damping of oscillations at small discharges;

(iii) The time lag required for the system to respond to a change in discharge.

3.6.6.4. Burt (1983) reports that U S B R approach to develop Hy - FLO (like that of EL - FLO) method incorporated a complicated hydraulic analysis. Final selection of controller coefficients is done in a loosely defined manner and must be adjusted by trial runs.

3.7. COMBINATION CONTROL : (Neyrpic, undated)

3.7.1. Introduction :

Having discussed upstream and downstream control methods in great details, their main features can be summerised as follows :

- Despite all disadvantages, upstream control is the only possible method wherever the consumers can not be provided with unlimited water because of inadequate resources.
  It enables each user's consumption to be fixed within the framework of a 'fair shares for all' scheme.

- Inspite of all advantages, downstream control system unfortunately implies unlimited resources with respect to the demand and can only be used for very gently sloping canals without incurring provibitive expenditure.
  The first choice- determining factor should therefore be a consideration of the potential supply and demand, although the best results are usually obtained by combining both forms of control in a given network. Such a 'Combination Control' can be achieved by using two systems viz. 'Longitudinally combined System' and 'Composite Gate System'.

3.7.2. The Longitudinally Combined System :

3.7.2.1. Downstream Control on Main Canal & Upstream Control on Distribution :

In many instances it is advantageous to use different contrc systems in the lower and upper part of an irrigation network. Upstream control is usually resorted to for the terminal portions of a network in view of general necessity of keeping the offtakes under supervision of the operating staff, to avoid exhausting the water resources and to enable the consumption to be checked. The main canal, however, may be equipped for downstream control, thus making it very much easier to carryout the irrigation programme by doing away with the necessity of going all the way to the head intake (situated a considerable distance away) whenever the discharge supplied to the network has to be changed. Moreover, the system can be brought into operation much more quickly and no water will be wasted when setting the controls. With such a layout, the programme can be made very comprehensive and even allow for unexpected demand. Finally, a system of this kind can usually be kept within economic bounds since the main canals are often laid out along a contour line and the secondary canals run more or less down the steepest slope.

The example of this type of combination control is the Beni- Moussa Project, Morocco. (Plusquellec, 1988).

3.7.2.2. Up-stream Control for Upper Reaches, Downstream Control for Lower Reaches :

Burt and Lord (1981) discuss another type of combination control. They point out that though it is desirable to have the capability to deliver water to form turnouts on a demand schedule, it is not necessary to have downstream control structures throughout a complete canal system to achieve this. It may be possible to utilize upstream control structures on the upper 2/3 (or so) of a system, install a regulating reservoir at this point, and use downstream control in the remaining portion of the system. Whether a system is operated on an upstream or downstream control logic, the flow rates in the upper portions of the project will be approximately equal. Flow rates at the project source can be adjusted once or twice a day to balance the water level in the downstream regulating reservoir , thereby accomodating existing upstream control structures in the upper portions of the project.

Regulating Reservoirs :-

A key element in many simple but flexible delivery systems is the regulating reservoir which allows a demand schedule to be implemented in a largely upstream- controlled system. The two important elements to regulating reservoir design are locations and size. A purpose of a regulating reservoir is to allow easier control upstream. It does not have to act as a storage reservoir. Because regulating reservoirs can buffer imprecise upstream adjustments, the obvious proper location for them is in the downstream reaches a canal system. These reservoirs only need to hold the fluctuation volume of one or two days of system operation. In flat topography where no pumps are used and water must flow into and out of the reservoir by gravity, this translates into a very large surface area because of the availability of only 0.30 to 0.60 meter of fluctuation elevation. An alternative may be an elevated regulating reservoir that pumps can fill and which can be emptied by gravity flow (to better accomodate downstream control below the reservoir). The added expense of pumping can be more than offset by the decreased storage area and the improved efficiencies of irrigation due to more flexibility delivery schedules.

In the Doukkala project, Morocco the upper half of the main canal is under upstream control and the lower half is under downstream control. A regulating reservoir is provided at the mid point of the main canal. (Plusquellec, 1988) Plusquellec (1988) further reports that the Beni-Amir canal (Morocco), now being modernised, will include a succession of downstream and upstream control sections to minimise the investment cost in conveyance sections without offtake.

3.7.3. The Composite Gate System - (Neyrpic, undated) :

(Downstream control subject to upstream control)

3.7.3.1. Introduction :

This system features all the advantages of downstream control (including automatic distribution), with the added attraction that, if a shortage of water occurs, it stores water in the various canal reaches and protects the canals, although remaining restricted to relatively flat ground.

In this type of layout, the network is subdivided into successive reaches by composite control gates and the offtakes are controlled by constant downstream level gates followed by distributors.

3.7.3.2. Normal Conditions :

When conditions are normal, composite control gates behave in exactly the same way as constant downstream level gates and therefore have all their advantages (viz. fully automatic distribution, accurate and immediate response, no water wastage).

3.7.3.3. Supply more than Demand :

When the supply exceeds the demand (e.g. in case of sudden general stoppage of demand) the gates, which then control a constant upstream level, open to prevent overflowing, there the composite control gate serves exactly the same purpose as the emergency siphons or escapes in downstream controlled systems.

3.7.3.4. Supply less than Demand :

When the supply to the canal is below the overall downstream demand, the gates close before the reaches upstream of them are completely exhausted, so that some water is always kept in reserve throughout the system. This means that canals are no longer in danger of running dry, nor do the upstream users suffer while those downstream are still drawing their full supply. The total reserve available can be shared out fairly among all the users until fresh supplies are made available.

3.7.3.5. Function as Compensation Reservoir :

A canal network thus equipped with composite control gates can be made to function as a compensation reservoir, which can absorb supply-demand differences caused by -

- Varying head supplies resulting from upstream hydro-power generation.
- The need to make use of a constant flow supply while demand varies during the course of an irrigation day.
- Sudden rises due to storm water entering into the system.
- Sudden drops due to a canal breach or other breakdown .

3.8. DYNAMIC REGULATION :

3.8.1. Introduction :

3.8.1.1. Local vs Centralized Control :

The automatic methods of canal control described so far have local automation ('Zimbalman' is an exception) with some type of water level sensor or float controlling one gate. There is no electrical connection between controllers at different gates. Several other control methods do not use these local automatic control techniques. Instead, they are centralized remote automation. Such computerized automatic operation, called Dynamic Regulation, offers control possibilities far beyond any previous control system.

3.8.1.2. Definition :

Kraatz and Mahajan (1975) have defined Dynamic Regulation as a means of seeking and implementing the regulation optimum in relation to a set of conditions existing at a given moment and in line with a given number of criteria. In this context the set of conditions refers to water level, flows, gate positions, valve openings, etc. and criteria may be consumption forecasts, physical and economical constraints, and safety margins.

3.8.1.3. Downstream Control Vs Dynamic Regulation :

Unlike the downstream control which is blind to what happens in other parts of the system except the reach downstream, dynamic regulation is sensitive to flow condition changes throughout the network.

3.8.1.4. Examples of Dynamic Regulation :

Two of the widely and familiarly known aqueducts that use dynamic regulation method are the California Aqueduct in United States and Canal de Provence in Southern France. Differences between the two systems include what parameters are measured, how many of each are measured, how frequently gate positions are changed and how much flexibility is given to the users. Both are described here in detail.

3.8.2. Dynamic Regulation - California Aqueduct:

3.8.2.1. Introduction :

Dynamic Regulation on California Aqueduct is also commonly described as Controlled Volume Method of operation. The same description is followed here.

3.8.2.2. Background :

The controlled volume method was first evolved in California State Water Project and was adopted for the California Aqueduct. The special operational requirements of California Aqueduct dictated the evolution of this new concept of canal operation. Hence, it is necessary to understand the background.

Project Description : -

The California State Water Project consists of a series of reservoirs linked by rivers, pumping plants, canals, tunnels and generating plants. Along the main stream of the California Aqueduct there are 630 km of canal, 19 km of tunnel, and 66 km of pressure pipeline. Appurtenant facilities include eight pumping plants with 73 pumping units; one generating plant with two generating units; two pumping generating plants with 15 pumping generating units; 57 check structures with 186 radial gates; more than 200 turnouts ranging in flow capacity from about 0.28 m^3/sec (10 cusec) to 35 m^3/sec (1200 cusec); a project wide electronic remote monitoring and control system; and other miscellaneous facilities.

Primary Requirements :

The Primary requirements (Dewey and Madsen, 1976) for the operation of the California Aqueduct are to -

(i) Meet contractual agreements with water contractors;

(ii) Provide for minimum on-peak operation of pumping plants to reduce power costs;

(iii) React immediately to adverse operating conditions or emergencies and;

(iv) Minimise adverse hydraulic transients during flow changes;

Influence of Municipal Use of Water :-

Regarding the first requirement, water delivery is made to 31 Government agencies (and not to individual irrigators). These water contractors distribute the water for agricultural use (45%) and municipal use (55%). The dependance of municipal users on the aqueduct as their primary source of water dictated the need for a highly reliable continuous, year-round delivery system with nominal maintenance. (Frederiksen, 1969).

Prohibitive Enroute Storage: -

Secondly, the main stem of the California Aqueduct is 630 km long; consequently, water customer service does require special consideration since it would take a particle of water 8 to 10 days to travel that distance. Moreover the possibility of providing quicker response to customer service demands by use of forebay reservoirs or offstream storage enroute was prohibited in most instances by topographic, geologic, or cost considerations in case of California aqueduct (Reynolds and Madsen, 1967).

Influence of on-Line Pumping Plants : -

The second operating requirement, minimum on-peak operation of pumping plants, is important from an economical standpoint. Power costs during on-peak hours are considerably higher than costs during off-peak hours in U.S.A. Therefore, a maximum pumping is accomplished during off-peak periods and minimum pumping during on-peak hours. This scheme of operation requires great reliance on the method of flow control since flow modifications are greater in magnitude and occur more often within a given time period than for continuous operation. To accomplish this maximum off-peak operation, flow control over the entire aqueduct system must respond in minutes, rather than hours. (Dewey and Madsen, 1976

Danger of Seismic Activity : -

The third requirement is the capability of responding immediately to adverse operating conditions or emergencies. The California aqueduct crosses a number of earthquake faults and, throughout most of its length, is in seismically active areas. Failure or rupture of some portions of the aqueduct is possible. The method of flow control employed must have the capability of responding rapidly by closing check gates to isolate the damaged reach. This requires simultaneous adjustment of the flow in all pools upstream from the affected pool to a flow equal to water demand and stopping the flow and restricting diversions in downstream pools (Dewey and Madsen, 1976).

Difficulties in Providing Escapes :

In addition, the aqueduct through the San Joaquin and Antelope Valleys traverses areas where there are no natural drainage channel with capacity sufficient to carry away the full flow of the aqueduct if it were discharged into them during emergencies. Wasteways (escapes) or detention reservoirs to handle these emergency flow from the aqueduct would have been expensive to construct. The control system therefore, must have the capability to react quickly to stop or to reduce the flow so as to hold the water in the aqueduct itself (Reynolds and Madsen,1967).

Minimisation of Transients : -

The fourth operating requirement, minimizing adverse hydraulic transients, is based on restrictions with regard to maximum allowable water level fluctuations (established at 2 ft. i.e.0.61m in California Aqueduct) to reduce the risk of failure of the concrete lining. Adverse hydraulic transients during major flow changes coupled with strong winds could prove dangerous. Only by proper flow control can the magnitude of these hydraulic transients be maintained within the 0.61m limitation. (Dewey and Madsen,1976).

Thus, the peculiar site conditions, typical design of a project features and the special operational requirements virtually ruled out a conventional method of canal operation and necessiated the adoption of controlled volume method of operation.

3.8.2.3. Concept:

While describing new type of operation of California Aqueduct and Automation in California's State Water Project, Reynolds and Madsen (1967) explained the concept of 'Controlled Volume' as follows :

When a change in water delivery is required, all pumping plants would be started or stopped and all check gates would be raised or lowered simulataneously - that is, within several minutes. As additional pump units are started and the check gates are raised there would be a simultaneous increase in flow in every checked reach from one end of the system to the other with the system acting like a series of reservoirs with water spilling from each into the next one downstream.

Fig. 3.15 shows three reaches of the aqueduct. Under the controlled volume concept of operation when a change in flow is made the hydraulic gradient rotates approximately around the centre of the reach. For instance, when pumps are started and gates are raised for an increase in flow the wedge of water in the lower half of an upstream reach will flow into the upper half of the down-stream reach. There is thus maintained a controlled volume of water, which is nearly a constant volume, within each checked portion of the aqueduct. Conversely, for a decrease in flow, the pump units would be stopped and then checked gates lowered and the wedge of water in the upper half of each reach will flow into the lower half of that reach. By so operating all facilities simultaneously, Velocity in the aqueduct will increase or decrese without changing the volume of water in each checked reach by any appreciable amount. This will approach pipeline flow conditions in the open aqueduct.

Burt(1983) & Burt and Lord (1981) have explained the controlled volume concept as follows :

The controlled volume method of operation involves the integrated use of all storage, conveyance and supply capabilities of the system. Gate openings and water levels on both sides of all check structures are remotely monitored. Flow rates in the canal are measured at strategic locations. Flows into only a few of the very large turnouts are measured. The California aqueduct is essetially a series of Level-topped canals. Flow changes are initiated by knowing in advance what the users want in the way of water deliveries. A computer calculates the anticipated required flow rates in each section of canal. A second programme calculates gate openings, simulates the canal operation with these spacings, and then readjusts the calculated gate openings. These calculated gate openings are used during the day and readjusted periodically.

3.8.2.4. Characteristics :

(i) Utilisation of the canal for both storage and conveyance is the foundation of the method.

(ii) The storage in the canal is created by varying the water surface elevation through proper positioning of the gates in the check structures.

(iii) The height of the gates in check structures is made greater than normal design depth in order to fully develop the storage available. This capacity is required when a sudden demand occurs or rapid shut - down is carried out.

The minimum gate extension will be at least equal to one-half the drop in hydraulic gradient in the pool upstream of the check under maximum discharge.

(iv) The storage volume may be varied with respect to time and location along the canal. This is in contrast to the utility of a reservoir with a fixed location.

(v) The check spacing (spacing of cross regulators) in most canal reaches depends on -

  (a) the reach length
  (b) foundation problems
  (c) maximum spacing for emergency operation (the 60 cm (say) emergency shut-down limit establishes a maximum spacing for a gradient canal).
  (Characteristics 1 to 5, Frederiksen, 1969).

(vi) A water-surface drawdown restriction is generally established because the rapid drawdown can produce damaging hydrostatic pressures from the saturated soil behind the concrete. This restriction limits the amount of in-canal storage.

In California Aqudeuct a maximum rate of 15.0 cm in the first hour, and an overriding limit of 30 cm per day from a reference point is permitted under normal operation. The reference point for the surface water measurement is defined as water surface elevation that has not been exceeded in the prior 24 hours. Drawdown caused by emergency operation is limited to 60 cm.

The current limitations in Central Arizona Project (another project in USA where controlled volume concept is being followed) are 30 cm/hr, 60 cm the first day and 30 cm in subsequent days.

(vii) Timed gate operation (Dewey and Madsen, 1976) - an important refinement in simultaneous gate operation - is done at all check structures to minimise adverse hydraulic gradients. (Table 3.3. gives comparison of all three methods of gate operation). This method requires:

(a) more than one radial gates at each check structure;

(b) sophisticated arrangements to control the motion of each gate;

In California Aqueduct the normal speed of gate motion is 0.1 ft/min. In Central Arizona Project gates are being designed with variable speed motor controllers which can start the gate movement at a very low speed and can accelerate the gate at desired rates.

(viii) The canal is designed and operated based on unsteady flow conditions.

(ix) The hydraulic characteristics of controlled volume method of operation and conventional operation are discussed in Table 3.4 and depicted in Figs. 3.15 and 3.16.

3.8.2.5. Some Comments:

Burt (1983) reports following about the operation of California aqueduct.

With extensive remote monitoring and a massive canal simulation programme on-line at all times, the operators still require water districts to submit their water orders 24 hours in advance and only allow small deviations from the schedule. Schedules of water districts and pumping plants are combined with information of gate openings, water levels, and flow rates to produce a schedule of gate openings almost a day in advance. Water users are only allowed a maximum of ten percent deviation from their advance schedule at each turnout. If water levels deviate from predicted values a special programme can be called up to calculate necessary modifications to gate settings to compensate for the unpredicted variations. However, this is not standard practice and water users are strongly discouraged from making unannounced changes of any amount. Farmers must often given 48 hours advance notice to districts receiving water from the California Aqueduct in order to meet aqueduct and district operational constraints.

3.8.3. Dynamic Regulation - Canal de Provence :

3.8.3.1. Background :

The 'Centralised Control', 'user-oriented' approach which responds quickly and automatically to changes rather than requiring an advance schedule (as in the case of controlled volume concept) was first implemented in Southern France. Computerised dynamic regulation (DR) became operational in part of the Canal de Provence system in 1971.

Project Description : -

The Provence canal is supplied by the waters of the river Verdon, which is a tributory of river Durance, itself a left-bank tributory of the river Rhone. A flow of 40 m^3/s is diverted towards the East & West of Toulon, the city of Marseilles and industrial zones on the edge of the Berre pool (Coeuret, 1984).

The whole of the Provence Canal system consists of 260 km of canals, 3000 km of underground piped distribution system and storage tanks. The piped distribution system made system operation easily responsive to users' needs. This was not achieved in any canay system so far.

Two-thirds of the users are municipal or industrial, with a predictable pattern of water use which is easily evaluated through statistics. Only one-third users are irrigators whose demands are more difficult to predict (Plusquellec, 1988).

The hydraulic operation of the conveyance system is controlled by the General Remote Control Centre at Le Tholonet using the modern method of 'DR' driven by an industrial minicomputer.

3.8.3.2. Concept :

The electronic sensors are placed at regular intervals along the entire length of the canal and the data (downstream information) from these sensors is transmitted through a remote transmission network to a centrally located remote control centre which houses a network control panel which is computer controlled. Relevant data such as water-levels at different strategic locations, flow and demand rates in the various reaches and positions of all gates ar[illegible] at regular intervals (every seven seconds in case of Provence canal.) The computer processes this data continuously for every reach, compares it with the demand forecasts (i.e. statistical predictions which are updated at regular intervals - every 15 minutes in case of Provence Canal) made with a mathematical simulation model and calculates the gate positions at each canal reach and transmits the instructions for the adjustment of the gate positions to desired value (up-stream pre-regulation). The main control centre is aided by local csub-centre in its operation. For remote transmission, either communication lines of telephone or telegraph network are used or micro-wave transmission can be adopted. The conceptual flow-diagram (simplified) for the system operation is given in figure 3.17 (Dandekar, 1984, Coeuret, 1984).

3.8.3.3. Canal de Provence Vs California Aqueduct:

There are certain key differences between the French approach and that used on the California Aqueduct. (Burt, 1983). California aqueduct uses modified demand system with upstream control. Canal de Provence allows true demand operation on sloping canals with downstream control. Other differences are as follows:

(i) Several water levels in each pool are measured rather than just on both sides of each check structure.

(ii) The computer programme used to modify gate positions is not designed to be as accurate as the large programme used in California. The justification for using a small and somewhat inaccurate programme is that gate movements can be updated frequently and the whole system is quite responsive. A completely updated schedule is run every 15 minutes on the Canal de Provence rather than once everyday as on the California Aqueduct.

(iii) Statistical estimation of water demands reduces lag time.

3.8.3.4. Characteristics :

(i) DR regulates the discharges at the head of the various reaches of the supply system.

(ii) With DR each reach is controlled at every moment as a reservoir with a specific volume a rate of inflow and a rate of outflow.

(iii) For establishing the control mentioned in (ii) above 'Regulator' requires following information in Real-Time (Coeuret, 1984).

- * The values of several water-level measurements in a reach;
- * The value of any flows extracted from the flow in the reach;
- * The value of the opening positions of the gates supplying the reach and of the gates extracting from the reach down -stream ;

(iv) The whole of the supply system is controlled in an overall manner leading to Global Management. Each control device for the supply of a reach not only acts according to the state of the volume in the reach which it directly controls but also acts according to the degree of filling of the other reaches or diversion reservoirs. The system can thus look further up or down for the data to which the gates under downstream control are insensitive. All the reaches (must) take part in meeting a peak demand or in absorbing scheduled or unscheduled rejection of water. The system of canal acts as a big reservoir controlled by an industrial computer. (Clement 1970, Coeuret, 1984).

(v) As the name suggests, the DR has got a dynamic feature (Clement, 1970). While constantly watching development of the process to be regulated, at each stage a choice has to be made i.e. control parameters have to be determined in the light of :

* the data of the variables of the situation at a given moment (water-level, flow rate, position of gates.);
* dynamic constraints (hydrualic equations, inertia of gates..);
* economic constraints (minimum cost price of price of pumping power, loss in earnings caused by a demand deficit or by loss of water owing to overflow...);
* the maximum percentage of permissible failure laid down in contracts with the users;
* anticipated consumption and the probability of this estimate which together with foregoingelements, will provide the operation with a choice of well defined actions.

(vi) The purpose of D.R. is not merely to maintain levels at a given point, but to meet requirements without wasting water and respecting operational necessities along the supply line. This is done by controlling the volumes flowing through the reaches. As the requirements and operational constraints can vary in time, the volumes are not fixed, but are, on the contrary, automatically re-updated. Consequently, with DR, there is no longer any direct connection between water level elevations in the canal and the rate of flow through it. The flexibility of the method is therefore considerable.

(vii) The DR method which generally does not require horizontal banks along all or part of the reaches, can be applied without civil engineering modifications to modernize the operation of old canals designed with inclined banks. Conventional regualtion systems (e.g downstream control) require adaptation of the canal in order to be applied, whereas DR system adapts to the canal to be controlled. (Prefeasibility study of DR on Mahi Canal, (Gersar,1982) however, proposes raising of the canal banks to create canal storage to minimize the Response Time of canal).

(viii) From downstream to upstream, and from reach to reach, the regulation system determines the discharge I required upstream of the reach in order to meet the forecast downstream requirements (Ref. Fig. 3.18). One of the problems of this regulation method is the determination of function I (t) from the forecast values of discharge demand downstream of the reach: (Wignyosukarto et.al 1984)

Qs (t) which is the discharge required in the next reach;

Qp (t) which is the forecast consumption along the reach concerned.

To solve this problem, techniques involving digital simulation of wave propogation in the reach have been used.

However, precise hydraulic calculations are avoided because they are so cumbersome. By the time a solution has been obtained the problem would already have changed. The combination of statistics, approximations, frequent updating of commands and proper sequencing of gate motions provides a system which operates completely on-demand with high flexibility. (Plusquellec, 1988)

3.8.3.5. Some Comments :

Burt (1983) has made following comments regarding the control system in Provence de Canal -

(i) It was installed in a project with heavy Government subsides and was relatively expensive.

(ii) A full staff of competent hydraulic engineers are available.

(iii) The system is relatively small.

(iv) The system was installed over more than 10 years, and was perfected for that canal system while it was runing at well under peak capacity.

(v) Only one third of the water users are agricultural. The remaining users are industrial or municipal. The water use of industrial and municipal users is easy to predict and a statistical programme is used to anticipate demands.

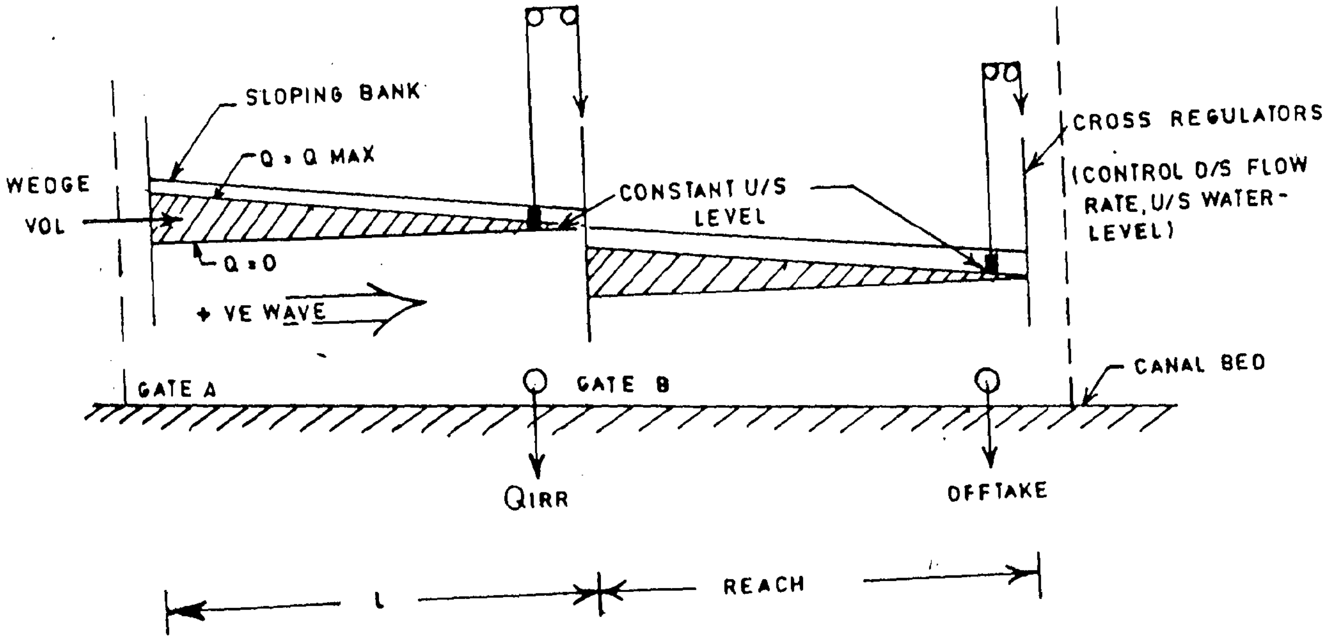
Serial	Simultaneous	Timed
* When a change in rate of water delivery is required, gates are adjusted to the proper setting to accomodate the flow change as the surge from this change arrives at each downstream check structure. * An increase in water delivery to the customer is a function of the time required for the new sustained flow to reach the customer's water delivery point from the water source. * Flow changes take too much time, and increased water demands cause greater hydraulic transients than allowable.	* All gates at all check structures are operated simultaneouly to the desired gate opening at a uniform speed without stopping. * As the check gates are raised there is a simultaneous increase in flow in every checked reach from the beginning of the system to the end. The canal system is operated with water flowing from all upstream pools into all downstream pools at the same time. * Response time is significantly reduced. * For major flow changes this method can not satisfactorily meet all conditions of the operational requirements - minimisation of hydraulic transients.	* Each gate at check structure is operated on a time schedule instead of moving all gates at all check structures along the canal uninterrupted to the predetermined gate position as in the case of simultaneous gate operation. * A variety of gate movements can be made to suit the operating situation. One or more gates can be operated at each check structure, each to the same or a different gate position. Gates can be timed to start and stop several times before reaching the predetermined gate position. * Minimises hydraulic transients effectively.

Table 3.4 : Hydraulic Characteristics :

Controlled Volume Concept	Conventional Method
* Water depth at mid-point of reach is constant except when flow approaches maximum design flow.	* Depth at downstream end of each reach is constant for all flows.
* An increase in flow results in an increased water depth in the upstream portion of the reach and a decreased depth in the downstream portion of the reach. These characteristics are reversed during a decrease in flow.	* Depth at all locations along the reach, except at downstream end, increases with an increase in flow and decreases with a decrease in flow.
* The total volume in the reach remains nearly constant for flow changes except when the flow approaches maximum or design flow.	* Any flow increase or decrease is accompanied by a corresponding increase or decrease in volume of water between any two check gates.
* All water conveyance facilities must be operated simultaneously	* All water conveyance facilities are operated serially
* The time required for changing deliveries in the aqueduct is reduced significantly. 'On-demand' would be possible if normal drawdown criteria is exceeded.	* The time for changing deliveries from the aqueduct is dependent upon the distance from the water source to the point of delivery along the aqueduct
* Water level fluctuations at each end of each reach are approximately one-half of those when facilities are serially operated under the conventional method.	

- CONSTANT U/S WATER - LEVEL
  - CONTROL OVER D/S DISCHARGE (FACILITATES CANAL CLOUSER IF BREACH OCCURS
  - ADVANCE AGGREGATION OF DEMANDS + ADVANCE SCHEDULING REQD.
  - SEQUENTIAL GATE OPERATION CONSIDERING TRAVEL TIME.
- SUPPLY ORIENTED OPERATION
  - NO CHANNEL STORAGE (NO IN - BUILT FLEXIBILITY TO CATER SUDDEN CHANGES IN DEMAND)
  - BANK LEVEL FOLLOWS WATER SURFACE OF QMAX (ECONOMY IN BANK HEIGHT)
  - CHANNEL DESIGNED FOR UNIFORM FLOW CONDITIONS.

** SLOW RESPONSE + WASTAGE OF WATER. **



AT TIME, T = 0
GATE A BEGINS TO
OPEN (U/S)

AT TIME, T = L/C
+ VE WAVE REACHES
AT GATE B (d/s)

C = CELERITY

L = DIST. BET.
GATES A AND B

FIG. 3·1: UP-STREAM CONTROL (DEFINITION SKETCH)

✱FLOW CHANGES INITIATED AT DELIVERY POINT✱
✱CONSTANT D/S LEVEL ✱ CHANNEL STORAGE REQD. (aa'b)
(REACH DEMAND DURING TIME 2 L/c)

✱LEVEL - TOP CANALS - STEPPED BANKS. ✱ NO WASTAGE OF WATER.
✱UNSTEADY FLOW✱
✱WATERLEVELS AT D/S END OF POOL FLUCTUATE.
✱IMPOSSIBLE TO CHECK CONSUMTION✱ LARGE CANAL CAPACITY REQD.
✱ABUNDANCE OF WATER NEEDED✱ IF SHORTAGE - ADVANCE SCHEDULING
✱ INSTABILITY LIKELY✱ CANAL CLOSUER DIFFICULT.

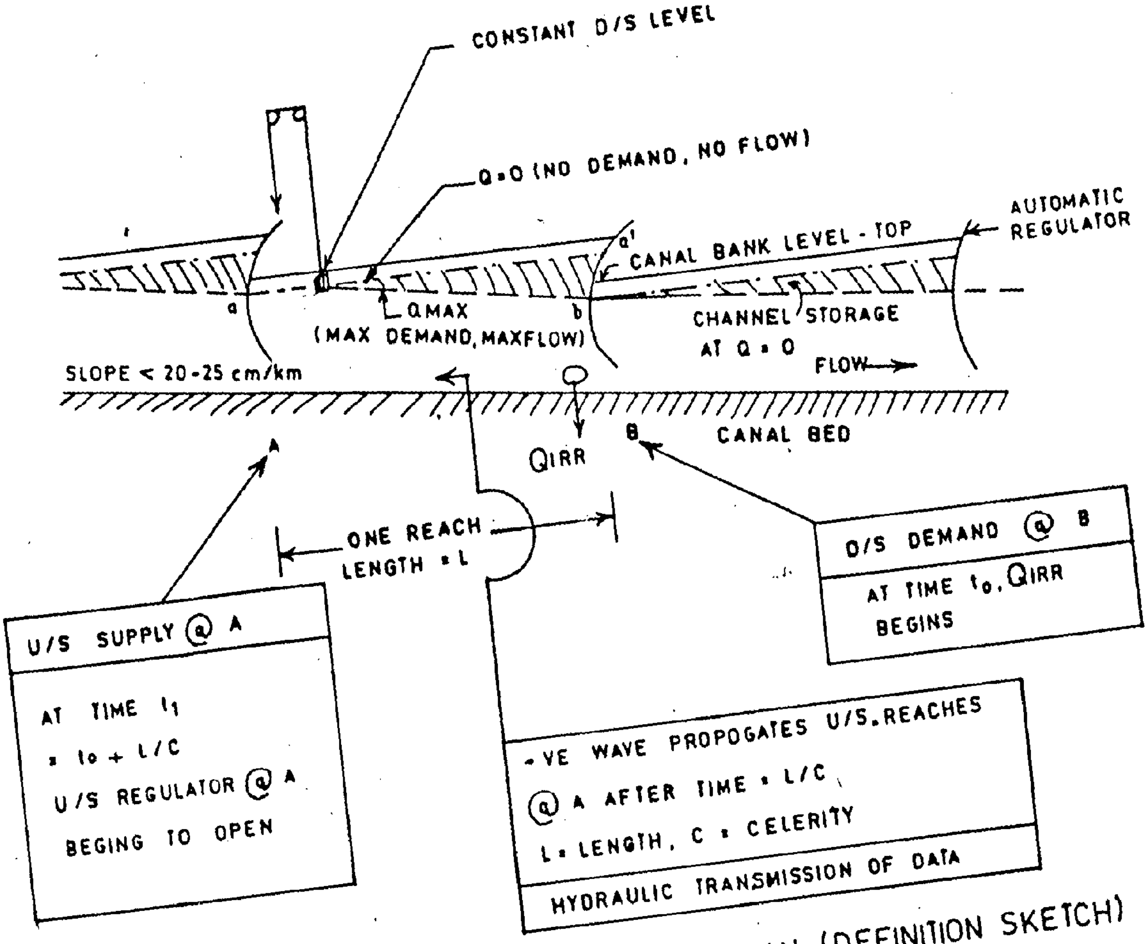


FIG.3·2: DOWNSTREAM CONTROL: LEVEL TOP CANAL (DEFINITION SKETCH)

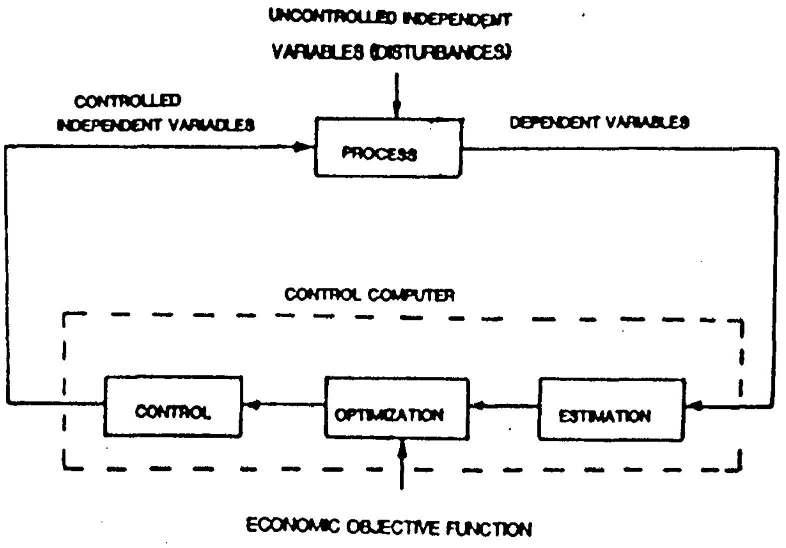
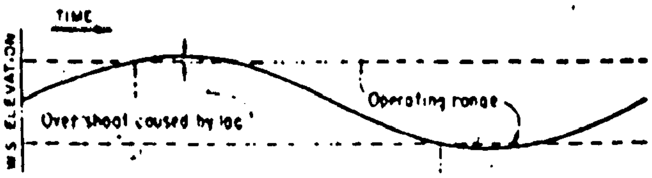
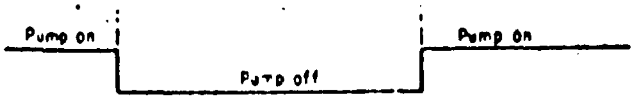


FIG.3.3—Computerized Control System

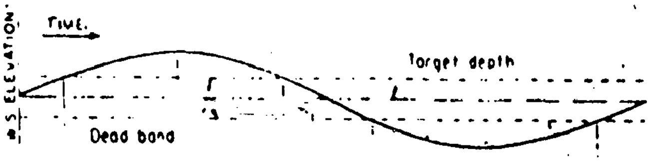


a. Controlling water surface (controlled water surface similar).

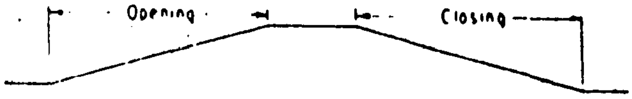


b. Control function in pump operation (oriented for downstream control).

Figure 3-4 - Two-position control.



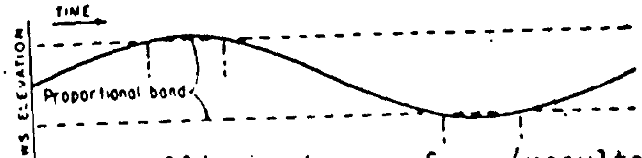
a. Controlling water surface (results of control not shown).



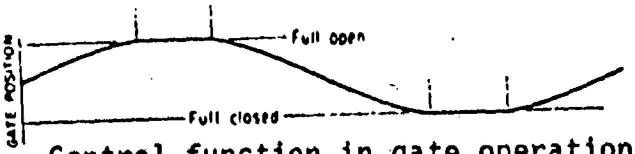
b. Control function in gate operation (oriented for upstream control).

c. Control function modified by antihunt.

Figure 3-5 - Floating control.

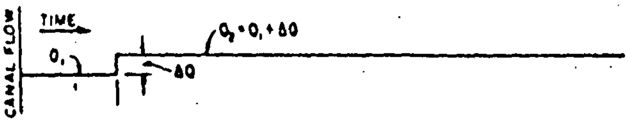


a. Controlling water surface (results of control not shown).

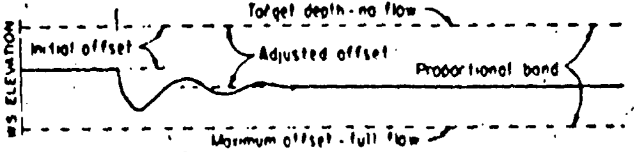


b. Control function in gate operation (oriented for upstream control).

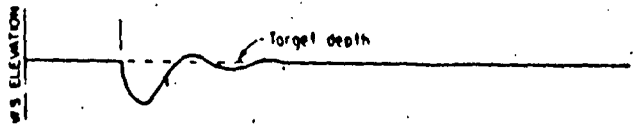
Figure 3-6 - Proportional control.



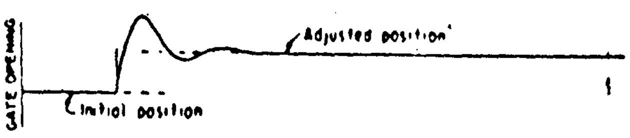
a. Demand change at controlled water surface.



b. Controlled water surface - proportional control.



c. Controlled water surface - proportional plus reset control.



d. Controlled gate operation.

Figure 3-7 - Characteristic results of control by proportional and proportional plus reset modes oriented for downstream control.

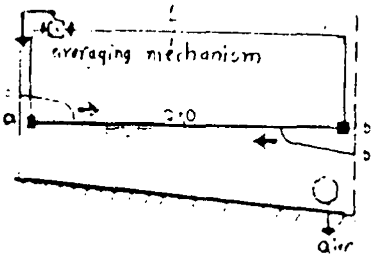


Figure 3-8a BIVAL system operation.

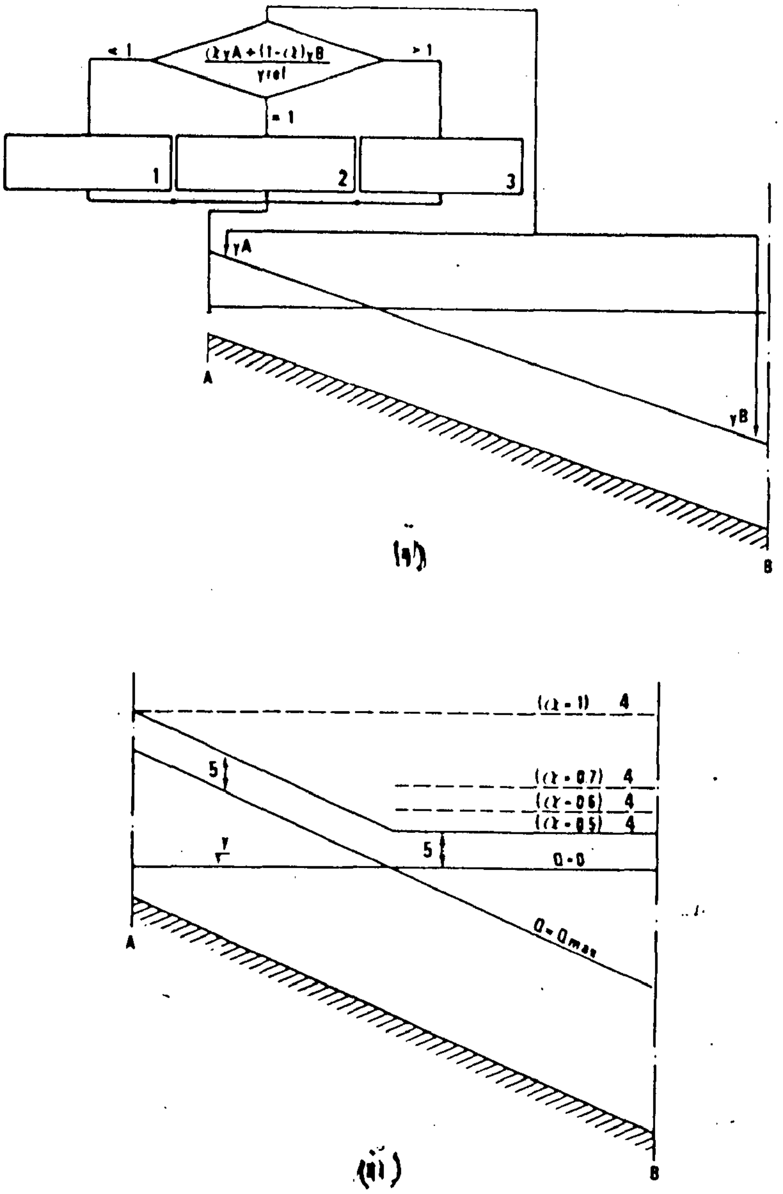


Fig.3-8b BIVAL Control System. (i) Schematic representation. (ii) Required bank level for different values of α. 1, gate opens; 2, no action; 3, gate closes; 4, maximum bank level for different values of α; 5, freeboard

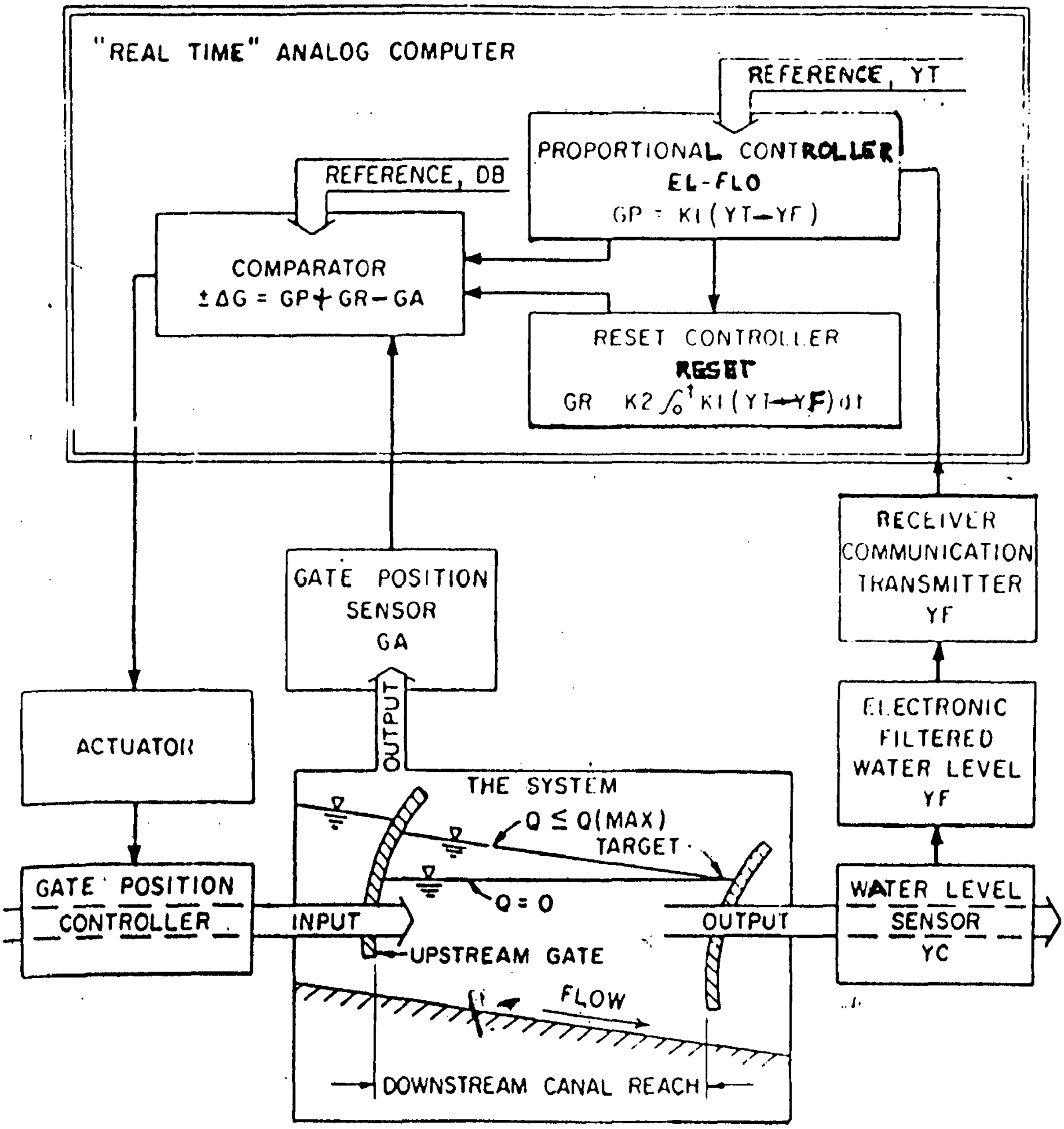
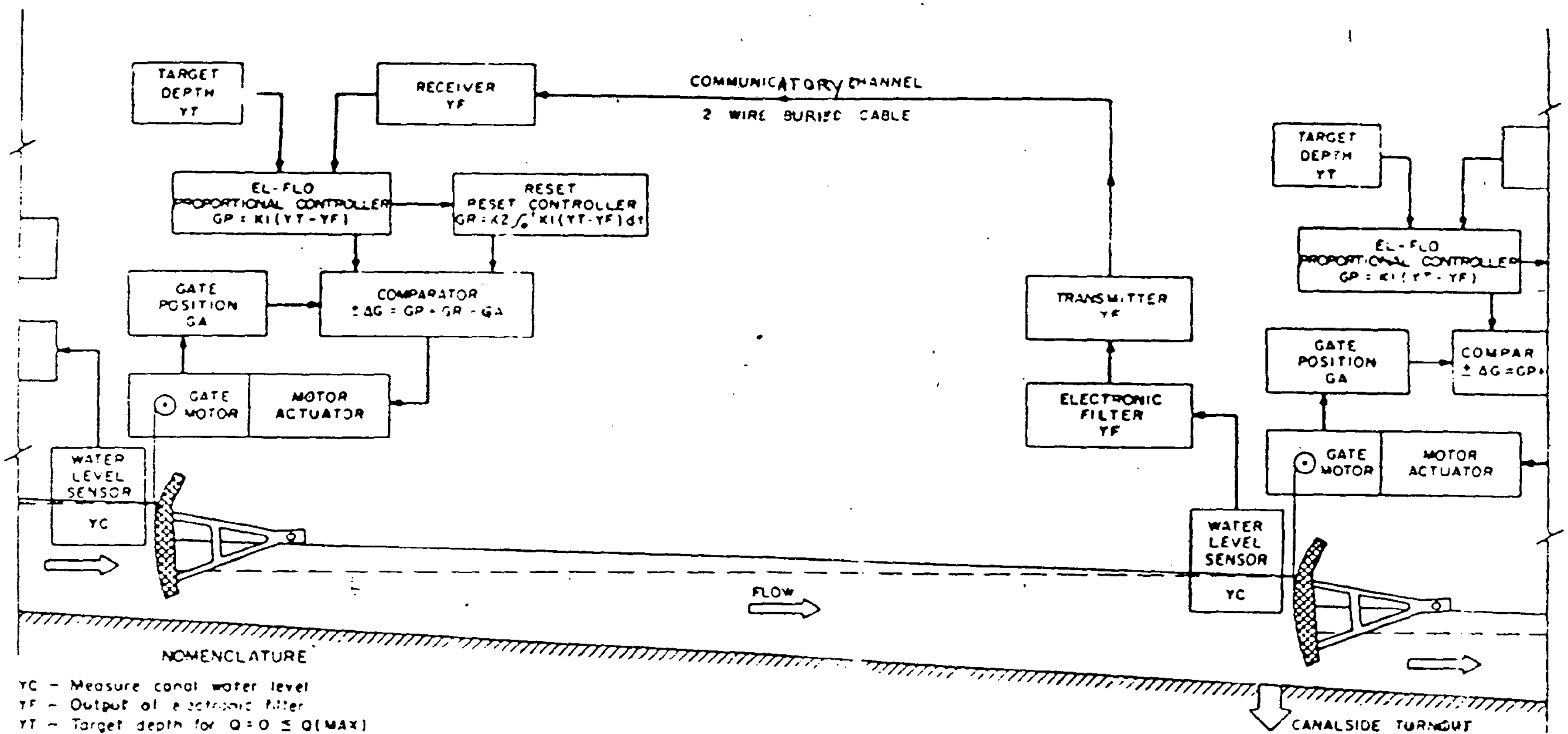


Figure 3.9. EL-FLO plus RESET feedback control system



NOMENCLATURE

YC - Measure canal water level
YF - Output of electronic filter
YT - Target depth for $Q = 0 \leq Q(MAX)$
K1 - Gain of proportional EL-FLO method
K2 - Gain of proportional RESET method
GA - Actual measured gate opening
GP - Computed desired gate opening by EL-FLO
GR - Computed desired gate opening by RESET
$\pm\Delta G$ - Direction and amount of gate travel

FIG 5·10 EL-FLO + RESET feedback control system

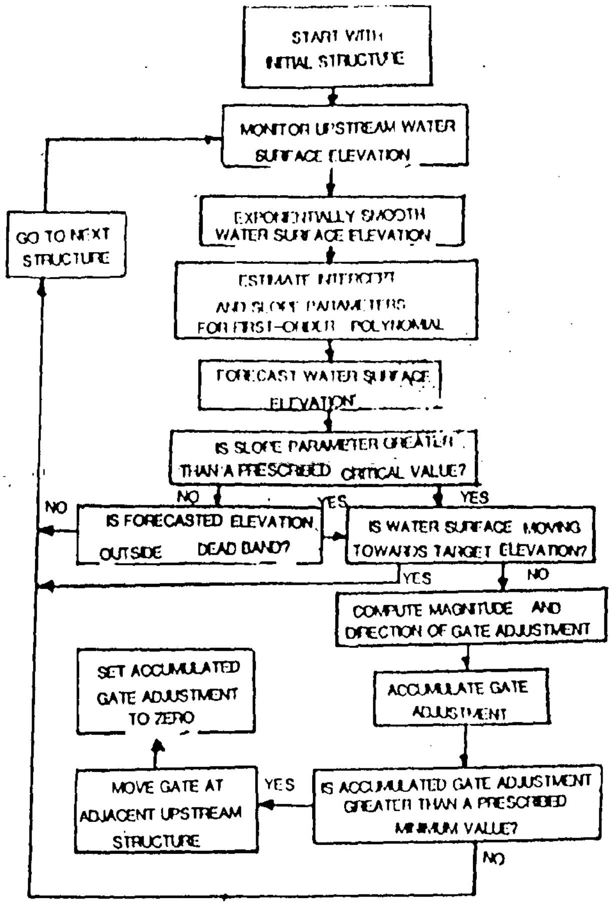
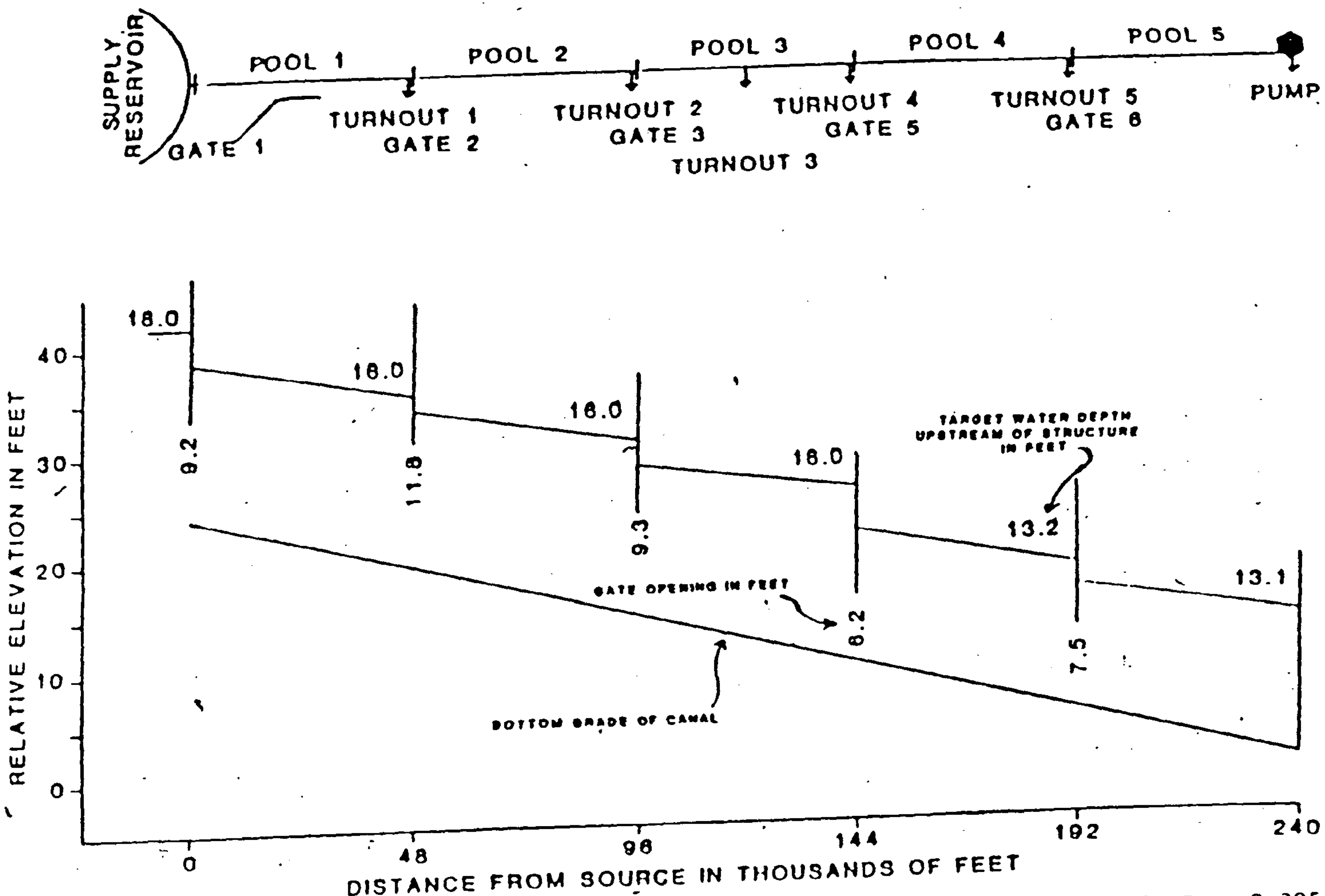


FIG. 3-11-Simplified Flow Chart for Control Algorithm

(Zimbalman)



(1 Ft = 0.305 M).

Figure 3-12 Plan and Profile Views of Test Canal (CARDD)

□ WATER SURFACE PROFILE AT PRESENT

○ - WATER SURFACE PROFILE 1 MINUTE EARLIER

- - - BEST FIT LINE AT PRESENT

..... BEST FIT LINE 1 MINUTE EARLIER

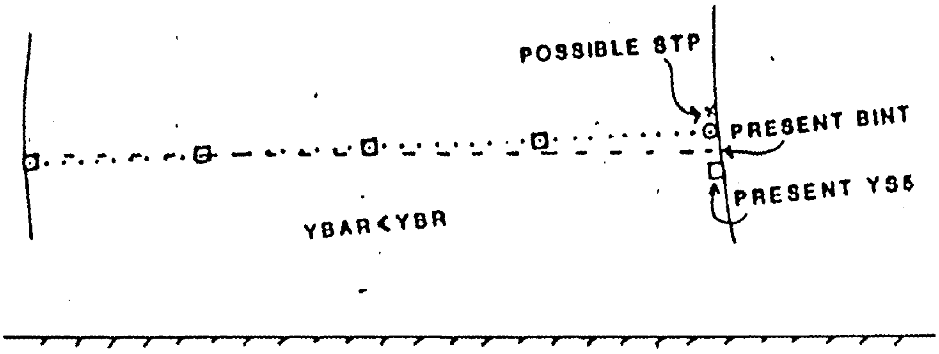


Figure 3-13 Effect of Lowering the Water Depth at One Point on the Best Fit Line Equation. Upstream Gate Must Open.

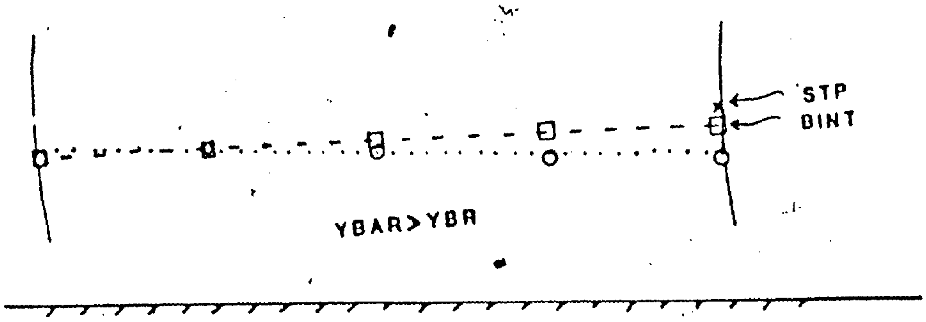


Figure 3-14 Case of a Low Downstream Water Depth (YS5) Which Is Slowly Returning to Desired Setpoint (STP). YS5 Will Pass STP Unless Upstream Gate Is Closed Slightly.

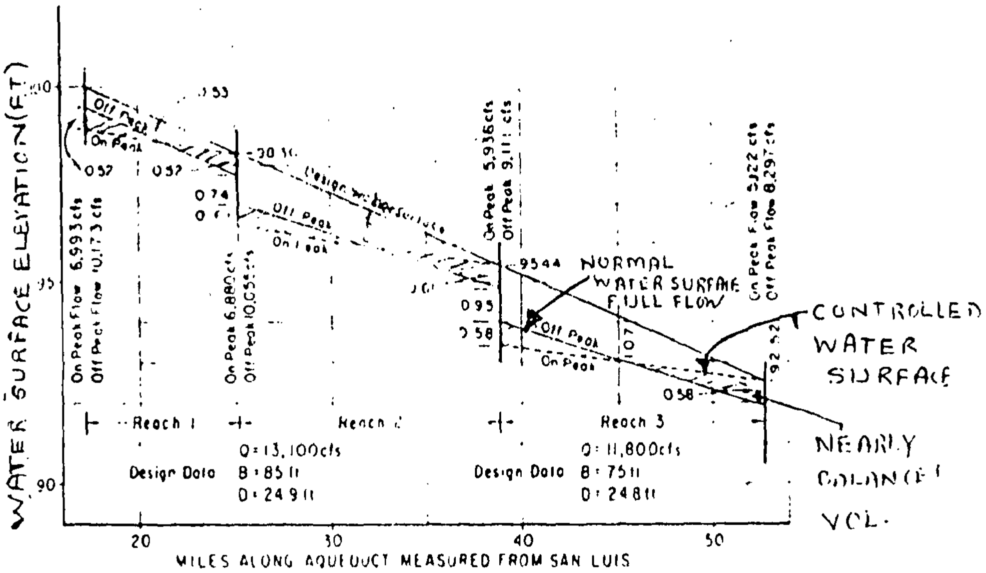


FIG. 3-15 WATER SURFACES WITH CONTROLLED VOLUME CONCEPT OF OPERATION

OFF PEAK ⇒ max. flow

ON PEAK ⇒ Low flow

'OFF AND ON' PEAK TERMINOLOGY IS USED IN THE CONTEXT OF IN LINE PUMPING PLANTS. OPERATION AIMS AT MINIMUM 'ON PEAK' PUMPING FOR ECONOMIC CONSIDERATIONS

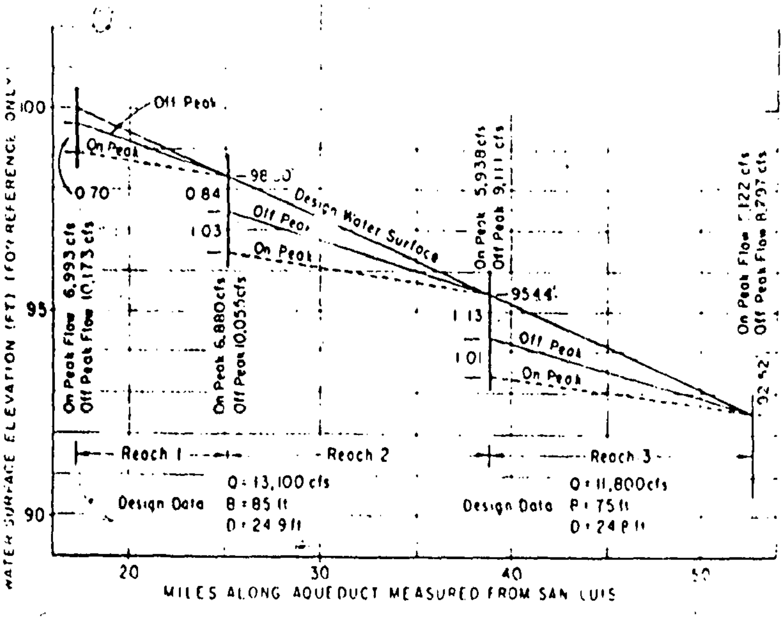


FIG 3-16 WATER SURFACES WITH CONVENTIONAL METHOD OF OPERATION

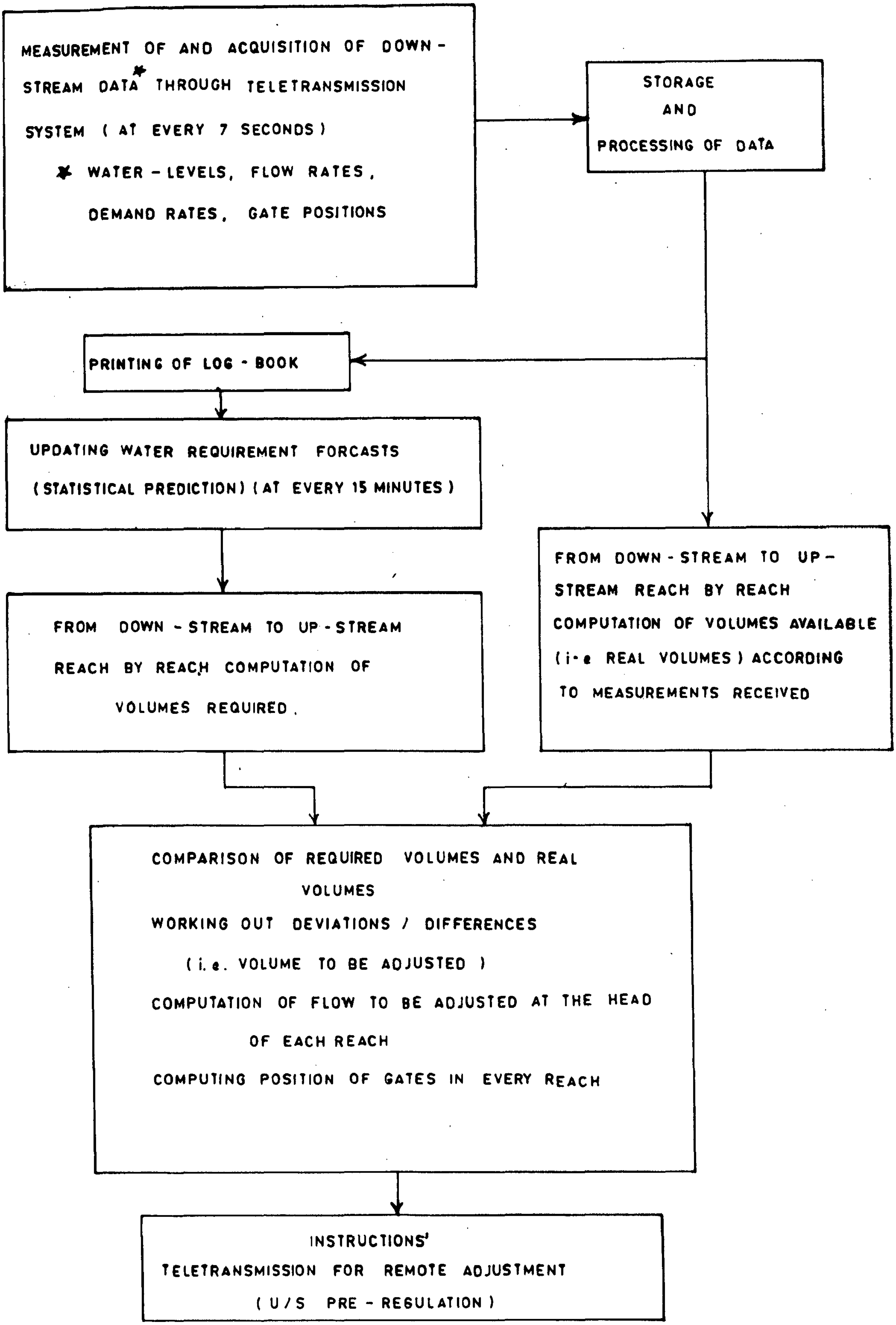


FIG. 3·17 - FLOW - DIAGRAM FOR DYNAMIC REGULATION

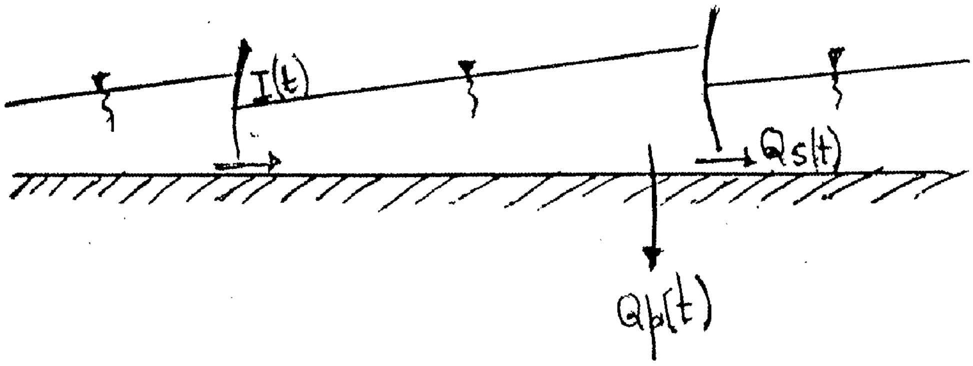


FIG 3.18 Dynamic Regulation

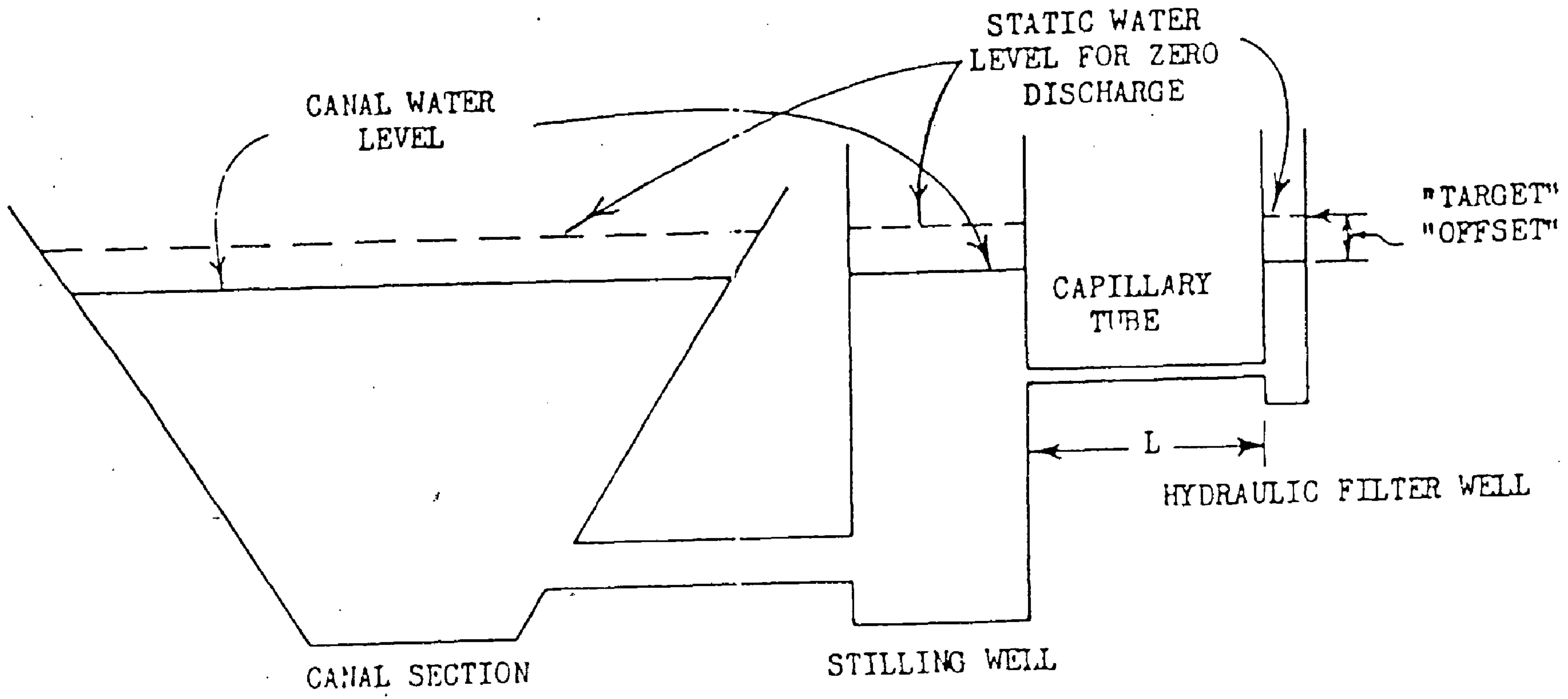


FIGURE 3.19 SCHEMATIC OF CANAL AND HYDRAULIC FILTER

CHAPTER - IV

CONTROL EQUIPMENT

4.1 INTRODUCTION :

Automation of irrigation canals using different canal regulation techniques becomes possible only when appropriate control equipment is used at appropriate level of control in canal network. A brief review of some of the important control equipment necessary for Flow - and Water - level - control is taken in this chapter. The objective is to study what control equipment is available and how, where, when it can be used for achieving different degrees of automation in different situations.

4.2 WATER LEVEL AND FLOW CONTROL ALONG CANAL :

4.2.1 Fixed Weirs :

A fixed weir controls the water level at a given height within relatively narrow limits. This height and the crest length are determined in relation to the discharge to be passed over the weir crest and to the control requirements (e.g. maximum permissible level fluctuations, etc.) The narrower the tolerances, the greater must be the crest length. In distribution channels the available width is usually insufficient to accomodate a transversal weir with a crest long enough to pass the full supply discharge within the level tolerances. Usual tolerances are of 5 to 10 cm.

These conditions have led to the development of the diagonal weir; the duckbill weir; and the Z-type or other specially shaped weirs. Of these the duckbill weir is the most commonly used (in Europe) because it is, under most conditions, the most economical one, providing optimum discharge cpacity in relation to length of structure and amount of construction material. (Kraatz and Mahajan, 1975). Burt (1983) however reports that duckbill weirs are seldom used in new designs because of the very long crest needed. In small systems with flow rates less than 1.4 cumec (50 cusec) they can be very simple, effective and relatively inexpensive.

Figure 4.1 shows transversal, diagonal, duckbill and Z-type weirs.

Design procedure and standard designs are available in FAO - 26/2 (1975) and BOS (1976).

Another typical example of water level control structure is a side weir (Fig. 4.1). This weir is part of the channel embankment, its crest being parallel to the flow direction in the channel. Its function is to drain water from the channel whenever the water surface rises above a predetermined level so that channel water surface downstream of the weir remains below a maximum permissible level (BOS, 1976)

4.2.2 Movable Weirs :

In relatively flat irrigated areas where the water demand downstream of a structure is variable because of different requirements during the growing season and because of crop rotation, following types of movable weirs have been in use for over 60 years.

(i) Butcher's movable standing wave weir developed in Sudan, 1922.

(ii) The Romijn movable measuring/regulating weir developed in Indonesia, 1932, (Bos, 1976).

They are simply broad crested weirs fitted into a type of slide-gate structure so that the weir can be raised or lowered with a gate lifting mechanism, (Replogle and Clemmens,1987). The weir crest can be lowered or raised with respect to the water level in the main or lateral irrigation canal so that the diverted flow through the offtake can be measured and regulated. Movable weirs also can be placed in the continuing supply (main or lateral) irrigation canal. Besides the two above mentioned functions, a movable weir can also be used to check the upstream water level. (BOS, Replogle, Clemmens, 1984)

The movable weir is frequently recommended for situations where head loss is extremely limited. Motorised and automated movable weirs are possible solutions to steady discharges because they can both measure and regulate flow rate. Special sensor locations can convert them to holding a downstream water level and monitor the resulting discharge, it that arrangement is needed. Such systems can become costly for large flow rates into lateral canals because the water-volume forces developed can increase proportionately faster than discharge rate. They usually need a reliable electric power source for practical application. Hydraulic arrangements using canal water pressure from an upstream source to actuate some of these weirs has been tried in small canals in the Netherlands. Reliable maintenance information has not been documented. (Replogle and Clemmens, 1987)

Weirs with vertically movable HORIZONTAL crest are the modified versions of Romijn and Butcher's movable weirs. These are described in detail in BOS, Replogle, and Clemmens, 1984. Fig. 4.2 shows 'Bottom-Gate Type' movable weir. Fig. 4.3 shows 'Bottom-Drop Type' movable weir.

4.2.3. Automatic Gates :

4.2.3.1 Introduction :

The need for more accurate water level and flow control than is possible with hand-operated check gates has, among other needs, led to the development of automatic gates. Gates which automatically open or close to the desired degree, depending upon a certain reference water level, are central to canal automation. There are a variety of canal gates in a canal system, starting from head regulators down to the smallest outlet gates. No matter whether it is a large gate or a small gate, it has to be controlled. The degree of automation of a particular gate may depend upon its location and importance in the canal system.

4.2.3.2 Basic Requirements :

For satisfactory canal operation, automatic gates must fulfill following basic requirements: (Dandekar 1988)

i) The gates must be sensitive and should respond to the input signal. (They must not operate for very small signals too).

ii) Their design must be such that they are given to easy movement with a very short lag time.

iii) Their operation must be stable and free from hunting. They have to reach a new equilibrium position quickly.

iv) The automatic operation must be trouble-free and free from jamming.

v) The gate must be reasonably water-tight in a closed condition when the head over the gate is maximum.

vi) Head loss must be limited and head loss characteristic must be well established.

vii) The operational range must be over the entire discharge spectrum within the permissible head loss value. At Q = Qmax, the head loss must not be greater than the available head (difference of water levels between upstream and downstream of the gate). From Q = Qmax to Q = Qmin the gate characteristic curves (head-discharge) must be known and they must match with canal characteristics.

viii) The gate must have a sturdy construction and must withstand frequent closing and opening.

There are mainly two types of automatic gates -

(i) Hydromechanical Gates (Hydraulic regulation)

(ii) Electromechanical Gates (electric/electronic - regulation)

4.2.4 Hydromechanical Gates :

4.2.4.1 Introduction :

The commercially available Neyrtec AMIL, AVIO, and AVIS gates (Fig. 4.4, 4.5 and 4.6) are examples of float balanced hydromechanical gates. Their operation relies entirely on the forces in the system itself, such as hydrostatic thrust and the weight of the device.

The AMIL gate maintains a constant water level upstream from the gate. The AVIO and AVIS gates maintain constant downstream water levels. The AVIO gate is designed to control flow through an opening in a breast wall with pressures upto about 11 meters and is suited to control flow from a reservoir. The AVIS Gate is similar but works directly in a canal without a breast wall and can control a maximum head of 2 metres. (Replogle and Clemmens, 1987). The AVIO gate can also be used for controlling an offtake when the discharge of the supply canal is large and the discharge to be taken off is small. The choice between the AVIO and AVIS is solely determined by the maximum level differential likely to occur between the upstream and the controlled levels. (Kraatz and Mahajan, 1975).

4.2.4.2. Working Principles :

Neyrtec gates consist essentially of a shutter and a controlling float immersed in the canal section to be regulated. Both components, which are sector-shaped, are mounted on a frame moving about their common centre line, the latter being set at the level to be controlled. Movable and/or pre-loadable counter weights ensure that the device can be set permanently when installed. Due to a preliminary adjustment producing a proper mass distribution, the gate is in equilibrium whatever its position, provided the controlled level and hinge centre line are at the same height.

When the water level in the canal rises (when incoming flow increases and AMIL gate is not open far enough or when downstream demand decreases and AVIS or AVIO gate is too far open), the float will rise and vice versa. If the float is on the same side of the hinge as the gate (as in AMIL gate), the direction of movement of both would be the same and the gate would open. On the other hand, if the float is on the opposite side of the gate with respect to hinge (as in AVIS/AVIO), the direction of movement of float and the gate would be opposite to each other and the gate would close. (Neyrpic, undated; Dandekar, 1988). Technical characteristics of AMIL, AVIS, AVIO gates are available in various brochures of Neyrpic Company.

4.2.4.3. Tilting Gates :

The automatic tilting gates, as the name implies, tilts open as compared to the vertical lift and radial gates that open by being lifted up. As the opening and closing of the gate is achieved by making use of water pressure acting on the gate, its working is entirely automatic. Tilting gate can maintain constant water level in canal at all discharges. (Fig. 4.7).

Tilting gates (developed by Godbole Gates (P) Ltd., Nagpur) have been in use mainly for automating spillway operations in Maharashtra and Madhya Pradesh since 1974. Tilting gate type cross regulators - one on Pench Right Bank Canal, Maharashtra and two on Hasdeo Right Bank Main Canal, Madhya Pradesh - are reportedly in operation since 1983-84. (Godbole Gates, undated) However, the literature regarding their performance is not available.

4.2.4.4. Danaidean Controlled Leak System :

A number of Danaidean systems have been in use for water level control for over 30 years. Examples include canals of the Tranquility Irrigation District in California, the Welton Mowhawk Irrigation and Drainage District in Arizona, the Northen Colorado Water Conservancy District in Colorado, and more recently, the Imperial Irrigation District in California.

A diagram of Danaidean system for controlling the water level downstream from a gate is shown in figure 4.8. The sump pump shown is usually not required for controlling the water level upstream from a gate. Gate movement is controlled by the addition or removal of water to the float chamber. Since in general the rate of addition or removal of water is small, it is called leakage. And since it is the control of this leakage that determines gate movement, these systems are called controlled leak systems.

The Danaidean systems get their name from the Danaidean tub flow measuring device (BOS, 1976). A Danaidean tub is a container that is open at the top and has an orifice at the bottom. Flow enters through the open top and fills the tub. When the system reaches equilibrium, flow out of the orifice matches the inflow, and the discharge can be determined by the water level in the tub.

Under the Danaidean controlled leak system, water enters the float chamber over a weir at the level to be controlled, and exits the float chamber through a drain valve, which effectively acts as an orifice. When the system is in equilibrium, flow over the weir exactly matches flow through the drain valve. When the water level being controlled is too high, the weir inflow will exceed the orifice outflow and the level of water in the float chamber will rise. This rise will evantually cause a change in float level and thus gate position. Eventually, the system will return to equilibrium at a new chamber water level and a new gate setting. However, since the float chamber level is now higher to account for a new gate position, the orifice outflow (leakage) will also be greater, as will bthe weir inflow. When the level to be controlled is upstream from the controlled gate, the gate float and the gate must act in the same direction against a common counter weight. When the downstream level is to be controlled, the gate float moves in the opposite direction to the gate and can be used as combination float/counter weight.

Limitations of Danaidean Systems :-

i) Only the inflow leakage rate is controlled by the error in the desired water level;

ii) Use of a weir inflow can result in poor control response;

iii) Use of the weir inflow for downstream control systems often necessiates the use of a drainage pump;

iv) Only one option exists for either upstream or downstream control on how the gate and float are configured. (Clemmens and Replogle, 1987)

4.2.4.5. Dual - Acting Controlled Leak (DACL) System :

A new control scheme is developed to overcome the limitations of the Danaidean systems (Fig. 4.9).

The new system is called a dual-acting controlled leak system (DACL), because both the inflow and outflow to the float chamber are controlled by the deviation in the desired water level, instead of just the inflow as with the Danaidean Method.

The mechanism chosen for DACL consists of two float valves. These valves are plumbed to operate in opposite direction. Water is supplied from the upstream canal or other source with sufficient pressure. A pipe is connected from this source to the float chamber. A valve regulates the flow into chamber. When the water level in the downstream channel is too high, the valve opens, the water level in the float chamber rises, the gate closes, and the flow is decreased. A similar valve is also connected to the drain pipe. In this case, however, a high water level will cause this valve to close, allowing the float chamber to fill more rapidly. Thus, both valves work to rapidly fill the chamber for a high channel water level and to empty the chamber for a low water level. If the gate were arranged to open when the gate float rises, the valves would be reversed. When the system is at equilibrium, the leakage flow passes through the two valves to the drain and does not actually pass through the float chamber. (Clemmens and Reploge, 1987).

The DACL system can be used to control upstream water levels, downstream water level, or offtake discharges. However, Replogle and Clemmens (1987) in their paper have given more emphasis on applications in lateral-size canals with flow capacities of the order of 0.5 to 2 m^3/sec. The system does not depend on electricity or motors which are vulnerable to electric outages and lightening strike damage. It can control water levels to within very narrow band.

4.2.5. Electromechanical Gates :

4.2.5.1. Introduction :

Electrically or electronically controlled motorized gates represent another group of control devices developed using control system theory. Such type of gate automation has following advantages: (Dandekar, 1988).

i) The signal transmission from the sensor to gate motor is instantaneous. (In case of hydraulic controls, there is a time lag because information transmission is through a unsteady flow wave).

ii) The concept of dead band can be made practical through filtering the incoming signals.

iii) The sensor can be located at just downstream of the gate or at any other convenient point within the reach.

iv) Rectification/moderation of the output signal can be made using a comparator arrangement.

v) Unlike hydraulically operated gates, electronically controlle gates can be reset to suit new operating conditions.

vi) They are more adaptable to computerised remote control system.

Limitation :

However, the reliability of electromechanical gates is linked to the power reliability in the particular region of application. (Replogle and Clemmens, 1987)

Examples :

Concepts such as EL - FLO, BIVAL, Zimbalman, CARDD and Dynamic Regulation use Electromechanical Gates for automation. Upstream or downstream control using 'Littleman' controller is also based on Electromechanical Gates.

4.2.5.2. 'Littleman' Controller :

The Friant - Kern Canal on the Central Valley Project in California, and West Canal on the Columbia Basin Project in Washington utilize a large number of electromechanical controllers (nick-named 'Littleman').

Fig. 4.10 and 4.11 show schematic of basic components of a Littleman installation. 'Littleman' controller uses Floating Control with antihunt device. It was basically developed to automate local upstream control. (Nelson, 1980). However, it can be utilised for local downstream control with necessary alterations. Microprocessors which incorporate the logic of the Littleman have been introduced recently (Burt, 1983)

4.3. FLOW CONTROL AT OFFTAKES :

4.3.1 Introduction :

The two options for controlling flow at offtakes again, are hydraulic or electrical equipment. The objective is to deliver a constant flow at offtakes inspite of the water level variations upstream of control structure.

To solve the staffing problems of manual adjustment, the structure could be automated if it were motorized. One alternative is to use an electroprocessor to activate the gate to maintain a constant hydraulic parameter such as the target level over a flow - calibrated weir or the differential head over an orifice until the next flow target is set. This adjustment could be controlled locally or remotely. (Herve Plusquellec, 1988)

The second alternative is to use hydraulic distributors, commonly called modules.

4.3.2. Neyrpic Modules :

The baffled weir module, usually referred to as Neyrpic module, is used as an intake for distribution canals as well as an outlet from distribution canal.

The module (Fig. 4.12) consists of a fixed round - crested weir sill with sloping upstream and downstream faces. Above the weir, either one or two steel plates (baffles) are fixed in a well-defined position. These sloping plates cause the outflowing jet to increase its contraction when the upstream head increases. This nearly constant discharge per unit width is a function of the height of the inclined blade above the weir. Because this height can not be altered, the only way to regulate flow is to combine modules of different widths into one structure, called distributor (Fig.4.13). Two basic modules are manufactured, the X - 1 and XX -2. The Roman numeral stands for the discharge in Lps per 0.10 m and the Arabic numeral, 1 or 2, stands for the number of baffles. The discharge through double baffle module remains within narrow limits over a considerable range of upstream head. (Replogle and Clemmens, 1987).

The discharge regulation using distributors is very simple. There is no gate opening to be regulated, no regime to be established, no water levels to be checked, no head discharge curve to be plotted. (Kraatz and Mahajan, 1975).

Maharashtra Engineering Research Institute, Nasik has done module studies on Neyrpic-type modules and recommended double baffle module (1 Lps/cm; 30 cm width) for outlets. (Nagarkar and Grampurohit, undated)

4.4. FLOW CONTROL AT OFFTAKES IN CONJUNCTION WITH FLOW AND LEVEL CONTROL IN THE SUPPLY CANAL :

4.4.1. Introduction :

To achieve flow control at offtakes in conjunction with flow and level control in the supply canal, offtakes and cross regulators should be located judiciously to make the best use of control equipment.

Some typical arrangements/layouts of control equipments are discussed below :

4.4.2. Upstream Control :

Fig. 4.1.4 is a diagram showing the layout of a upstream controlled network. In a given canal reach the smallest level range between full and zero discharge occurs immediately upstream of the gates or weirs, while the highest level range occurs downstream of these control structures. Consequently it is desirable to group offtakes in the vicinity upstream of control structure (Zone B). Offtakes which for other reasons have to be located near the downstream side of a control structure (Zone A) have to be equipped with a device for automatic constant downstream level regulation (e.g. an AVIO or AVIS gate) in order to ensure that the discharge in the offtaking canal is independent of variations of water level in the parent canal. Alternatively, the distances between the constant upstream control gates in the parent canal may be reduced. The optimum design to employ has to be arrived at by comparing the results, and construction costs, of using a given number of small level gates in the offtaking canals with the addition of one large gate in the parent canal. In this system, the shutters of the offtakes or outlets are usually semi-module type and manually operated. Once set they give the desired discharge. The most commonly used devices are the Neyrpic distributers.

4.4.3. Downstream Control :

Figure 4.15 is a diagram showing the layout of a downstream controlled system. As can be seen, the offtakes equipped with shutters only are grouped immediately downstream of the constant level gate (I is Zone A) while offtakes located further down the reach and particularly those near the upstream side of the control gate (II is Zone B) are equipped with additional constant downstream level gates (III), in order to ensure that the discharge is independent of level variations in the parent canal (level range "a"). Similar to the upstream control system there is an economical optimum between the length of the control reaches in the parent canal and the number of offtakes to be equipped with constant downstream level gates. Shutters are of the same type as in the upstream controlled system.

4.5. COMPUTER CONTROLLED REAL - TIME OPERATION :

4.5.1. Introduction :

Automation can be defined as the process of rendering systems self-measuring, self-adjusting, or self-controlling without direct human intervention. It is a relative term since it represents a dynamic process and is implemented in degrees. (Labadie, 1985)

4.5.2. Real - Time Control :

The term 'REAL- TIME CONTROL' actually refers to a subset of the higher levels of automation. Control in 'real-time' implies that the computer is performing direct on-line functions during actual time of the operational process (Labadie, 1985).

4.5.3. Structure of Real - Time Control Systems :

A real-time control system is composed of the following elements in varying degrees of emphasis: (Labadie;Shamir; 1985)

(i) Measuring instruments and sensors (water-level gauges, position sensors, flow meters).

(ii) Control instruments (regulators, gates, weirs etc.).

(iii) Telemetry systems (VHF radio, microwave etc.) and associated repeater and power boosting equipment if needed, for both receiving data and alarm information as well as transmitting control signals to the control elements.

(iv) Centralized computer hardwave and operating system for integrating possible remote microprocessors, receiving and processing data, display system status, including alarm and emergency information, and computing and sending control signals.

(v) Simulation model software for predicting flows, levels and system behaviour, given certain measured or forecasted inputs.

(vi) Forecasting models for forecasting random inputs such as rainfall, or meteorological data affecting evapotranspiration and water consumption.

(vii) Multivariable control strategy, including -

- open loop control
- closed loop control

(viii) Input-output equipment for critical human-machine interfacing.

4.5.4. SCADA :

Uri Shamir (1985) points out that a control system with all (abovementioned elements) but the system software (i.e. hydraulic system software, control software) is a Supervisory Control and Data aquisition (SCADA) system.

A SCADA system has software to manage data collection, the data base, graphics and tabular screen displays of the system and data, and to transmit manually imposed controls from the center to the proper locations in the field.

Only when system software exists does the system begin to move from a SCADA to computer control.

4.5.5. SCADA to Computer Control :

Moving from SCADA to computer control should be done gradually with caution. Shamir (1985) suggests following strategy-

"First, do the analysis off-line and present the results to the operators, to accept or reject. When sufficient experience and confidence in the computed operating plans are gained, one can begin to close loops: first, those that look safest to delegate to the computer and then, with time, more and more. This is the way to minimize the chances of doing worse than the operators did without the computer. Thus, it is recommended to operate "With-a-person-in-the control-loop" as long as necessary, possibly always, and automate ONLY PROVEN ALGORITHMS".

Alternative Modes : -

Experience in Taiwan (Tsao, 1981) has also shown that prudence usually is the best policy. Necessary provisions should be made from the beginning itself so that the gates of centralized remote control system can be operated by any one of the following four alternative modes.

(i) Closed loop remote control.
(ii) Open loop remote control (push button control at the control center).
(iii) Push button control at the site.
(iv) Manual operation at the site.

4.5.6. Power Supply :

As the electricity network in India is subject to frequent power cuts elaborate alternative arrangements will be necessary. Generally following strategy is recommended (Gersar, 1982)

Alternative Arrangements :-

Each remote transmission station should have :

- Power supply by a branch-line connection on the existing mean voltage network (in Mahi Project, power requirement is worked out as 10 kw/point)

* A standby generating unit.
* A battery - charger unit and DC/AC converter

Three Levels of Operation :

With these arrangements Three Levels of Operation are also suggested :

* Electricity network inoperation - normal working of the system;

* Electricity network off, operation of standby generating units :-
  normal working of the remote transmission network, power supply to gate motors, outage of the non-essential power network such as lighting system;

* Electricity network off, standby generating unit out of order, battery in operation; the remote transmission network works normally, the orders are conveyed to the regulators but are carried out manually, regulation is done according to a so-called "Graduated procedure" which reduces the frequency and rapidity of the manoeuvres inorder to preserve the security of the canal and to ensure a minimum service.

4.5.7. Operation and Maintenance :

General belief:-

Contrary to the general belief, it must be stressed that the acquisition of specialised and complex systems does not make less work, it makes more. It does not make work, however, for the less skilled but for the more skilled members of the community, increasing an already heavy loading.
(Trickett and Fleming, 1969)

Strategy in Indian Conditions :

Because of cost considerations and complexities involved, at least for years to come automation of irrigation system in India will probably be limited in its scope upto main canal only. Proposals for dynamic regulation of Mahi Canal and Tungabhadra canal are the examples. Even controlled volume concept being tried on Narmada canals will only be for canals having capacity greater than 8.5 cumec. The network below the main canal-particularly water distribution at tertiary level-will continue to be under manual operation.

Additional Manpower Required :

This strategy virtually means that existing organisational structure will remain as it is. Not only that but it will be necessary to create two independent teams dealing respectively with operation of the remote transmission and with the maintenance of the electronic and electrical apparatus; the operation and maintenance of automated system being totally different and very skilled job.

4.5.8. Control Equipment Used/Proposed :

Some of the important control equipments used for real-time operation of canal de provence, France and California Aqueduct, U.S.A are summerized in Table 4.1 The same table also gives details of control equipments proposed for Dynamic Regulation of Mahi Canal and Tungabhadra canal, India.

Most of these control equipments are standard and hence, not discussed here. Only some of the important and recent Data Aquisition equipments are briefly dealt with in following paragraphs:

4.5.9. Measurement of Stage :

4.5.9.1. Pressure Transducers :

The pressure transducer is a general term applied to devices which convert changes in water pressure and hence water level into changing electrical signals which can be recorded remotely from the point of measurement. There are several different types of transducer distinguished in the way each converts the mechanical pressure signal into an electrical output. The transducer may contain signal processing electronics which change the low level sensor output into a form suitable for transmission over long distances. Since all open channel flows are subject to atmospheric pressure, the vented guage type is the most suitable for application to water level measurement. (Herschy, 1985).

4.5.9·2. Ultrasonic Water Level Gauge :

In the ultrasonic water level instrument the sensor is located at either a fixed point above the water surface or a fixed point below the surface depending on design. In operation the instrument generates an acoustic pluse which is directed by the sensor at the water surface. The pulse is reflected from the surface back to the sensor. The time of travel from transmission to reception is electronically measured by the instrument.

From a knowledge of the velocity of sound in air or water, as the case may be, the distance between sensor and reflecting water surface can be computed. The time measurement is converted electronically into a distance signal for recording on suitable form of 'memory' device (Herschy, 1985).

4.5.9.3. Syncro-Transmitter-Receiver-Type Water-Level-Pick-Ups:

Float sensors are placed in a protective guide tube which is fixed in a vertical position in the canal. The displacement of float is mechanically transmitted to a synchro-transmitter which produces an electric current proportional to the displacement. A synchro-receiver at the station copies the position of the transmitter and produces, by means of a potentiometer and a generator, a measurement signal which is sent to a local indicator and to the remote transmission installations. (Gersar, 1982).

4.6.0 DISCHARGE MEASUREMENT :

4.6.0.1 Ultrasonic Method :

The velocity of flow is measured by transmitting an ultrasonic pulse diagonally across the channel in both directions simultaneously, The difference in time transits is a measure of the velocity which has to be multiplied by the cross-sectional area to derive discharge. (Flow depth can be measured by a suitable transducer) This method therefore also follows the principles of velocity area measurements. (Herschy, 1985).

4.6.0.2. Electromagnetic Method :

The discharge is found by measuring the electromotive force (emf) produced by a moving conductor (the flowing water) through a magnetic field produced by a coil placed either below or above the open channel. The emf is proportional to the discharge.

The ultrasonic and electromagnetic methods provide a continuous measurement of discharge for all designed stages of flow and continue to do so under backwater conditions. For both methods source of electrical power should be available. For ultrasonic method, the canal should have no weed growth or significant sediment transport. The electromagnetic method however continues to measure under weed conditions or heavy sediment load. (Herschy, 1985).

4.7. GATE POSITION SENSORS :

The position of the control gates is transmitted in exactly the same way as in the case of water-level pick-up using syncho-transmitter-receiver- system. (Gersar, 1982).

4.8. COMMUNICATION MESSAGES :

Typical communication Messages such as commands, interrogations and alrms are presented in table 4.2. Nature, frequency, number of various communication messages depend upon water distribution method, canal regulation technique, mode of control and degree of automation.

Table - 4.1: Equipments Used/Proposed for Remote, Centralised Control.

Projects / Levels of Control	Canal de Provence France (1)	California Aqueduct U.S.A (2)	Mahi R.B.Canal India (3)	Tungabhadra L.B.L.L Canal, India (4)
1	2	3	4	5
Project Operation control center (POCC) (Main/central)	Two industrial mini-computers. One for Hydraulic Regulation Another for supervisory control.	UNIVAC 1100/60 computer. Two CPUs of 1000 k words (36 bit) each Secondary storage: magnetic disc or drum, 262 k to 512 k word (16 bit) General purpose mini-computer.	Industrial mini-computer Structure: 16 bit word Mos tech. with standby batteries; Estimated configuration 128 kilo bytes. Secondary storage to be defined	Two computers (one standby) 32 bit, each with 2 MB, RAM; Two winchester drives 100 MB each; Floppy disc drive 560 KB.
Area control centre (ACC) (Regional/sub/secondary)	Details N.A.	General purpose mini-computer. 24 k to 32 k words of 16 bit core memory. Secondary storage as at POCC	20 stations along 100 km long main canal. Other details N.A.	Same as at POCC but with 1 MB,RAM 5 No. of ACCs located at 41 km interval along 204 km long canal.

Note - All computers at POCC level for all projects compared are 'On-line,Real-Time' with 'Self-Diagnostics'.

table contd..2....

1	2	3	4	5
Local check structure control (Remote terminal units,RTU)	Syncro-devices	Small,general digital computer 4 k memory, interface with communication terminal equipment, local operator control panel, measuring and control devices Site/Remote control facility.	Gate motors with servo-mechanism Elect.supply only for corrective action, Site/Remote control facility.	Details N.A.
Turnout control (offtakes)	N.A	Major T.O.: Monitoring and control capabilities Minor T.O.: Only monitoring capabilities. Major T.O.: means capacity > 5% of pool capacity or > 200 cusec (whichever is less)	Discharge > 0.5 cumec Existing gates to be motorised. Control with the help of two level-sensors. Discharge between 0.1 to 0.5 cumec AVIO/AVIS gates+modules with remote control. Discharge < 0.1 cumec AVIO/AVIS gates * + modules with manual control.	Micro-processor based controllers with gate position transducers. Site/Remote control. Controllers at 106 Dy.heads only.

(table 4.1. contd...3...)

(table 4.1. contd..)

Data Aquisition: Levels: 1. Discharge: 2. Gate position: 3	1. Syncro-transmitter receiver type Water level Pick-ups, 2. Electromagnetic/ ultrasonic pick-ups, 3. Syncro-devices,	Details N.A.	1. Syncro-transmitter receiver-type float sensors placed in protective guide tubes, 3. position sensors 2. Discharge: Details N.A.	1. Pressure-transducer type water-level measuring device (output 4-20 m A)
Data/Instruction Transmission : (Telemetry)	Underground/ Submersible cables by two different routes Data: Inquiry - Reply System. (Multiplexing) Instruction: 'Double-echo'/ 'Double-return' System	Cables by two different routes. Inquiry-Reply System	150 km long cables (1 meter below G.L) along canals.	VHF: DATA & VOICE 6 Nos. communication (high power transreceivers at POCC and ACCs. 111 Nos. low power transreceivers at other places. Dual signal repeaters at each ACC (except last one)

Table - 4.2 : Communication Messages - Commands, Interrogations, Alarms * (Golze - 1968)

Commands	Interrogations	Alarms
To Checkstructures : Water level set point(u/s or d/s): raise/stop/lower Gate:raise/stop/lower Gate speed: slow/medium/fast Control location:U/S or D/S water level Select control mode: local-manual/ local automatic/remote-manual/ remote-automatic	To Checkstructures and Returning Data/status: Water level: U/S, D/S Water level set point:U/S,D/S Gate position Gate No.1,2.. Status :	From Check Structure : Highwater level error: U/S, D/S Low water level error: U/S,D/ Gate out-of-range:high/low low voltage Remote control lockout Emergency power on communication line failure
To Turnouts: Flow setpoint: raise/stop/lower Valve position: raise/stop/lower Select control mode: As for check structure.	To Turnouts & Returning Data/ Status: Totalised flow, flow, flow setpoint, valve position, control mode To Aqueduct Water flow meter and Returning Data: Flow rate, totalised flow	From Turnouts: Low voltage Remote control lockout High Flow rate, Low flow rate, valve out-of-range: high/low communication line failure.

* As for California Aqueduct, U.S.A (1968) List not exhaustive. (only for illustration purpose)

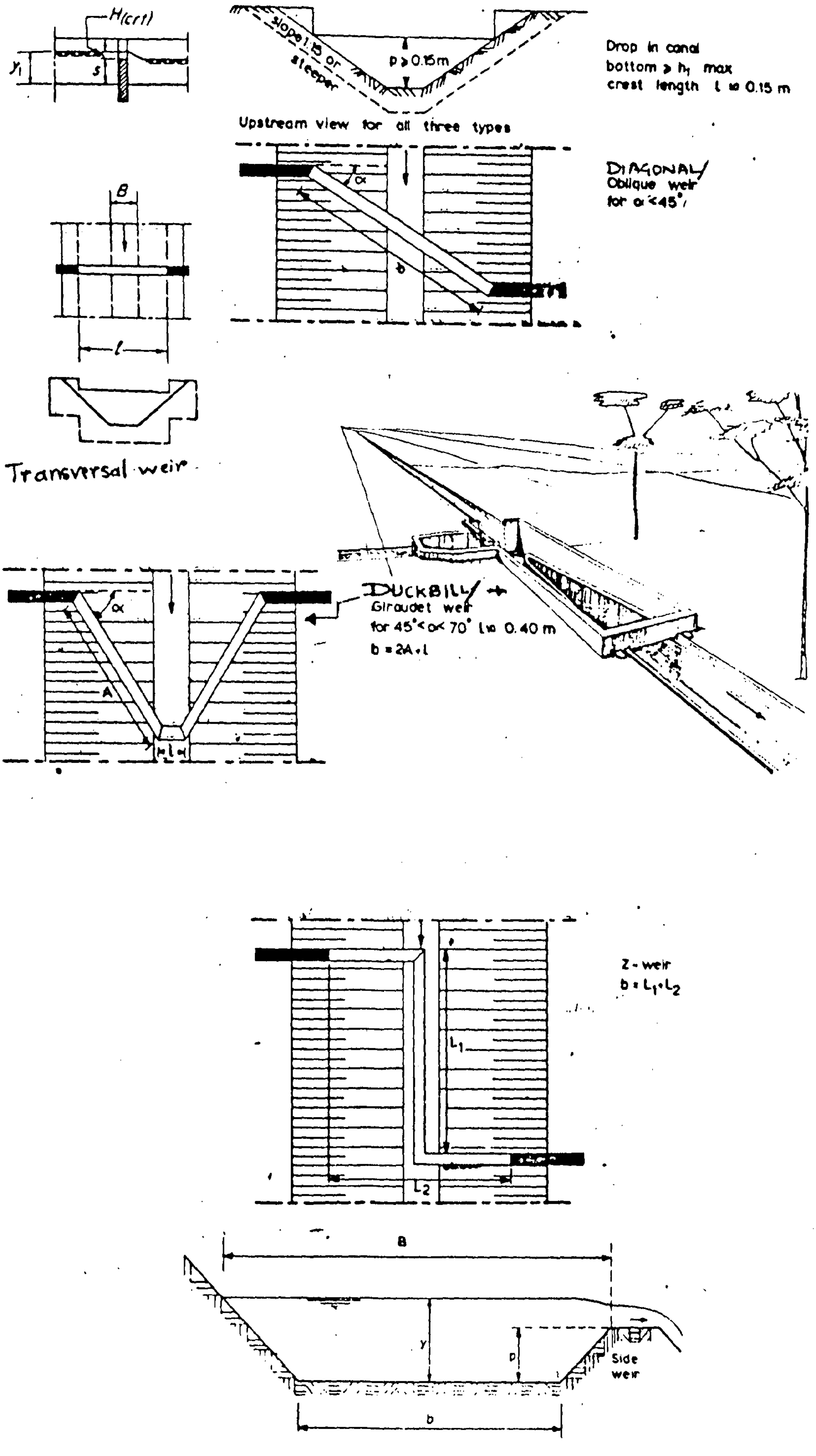


Fig 4.1 FIXED WEIRS

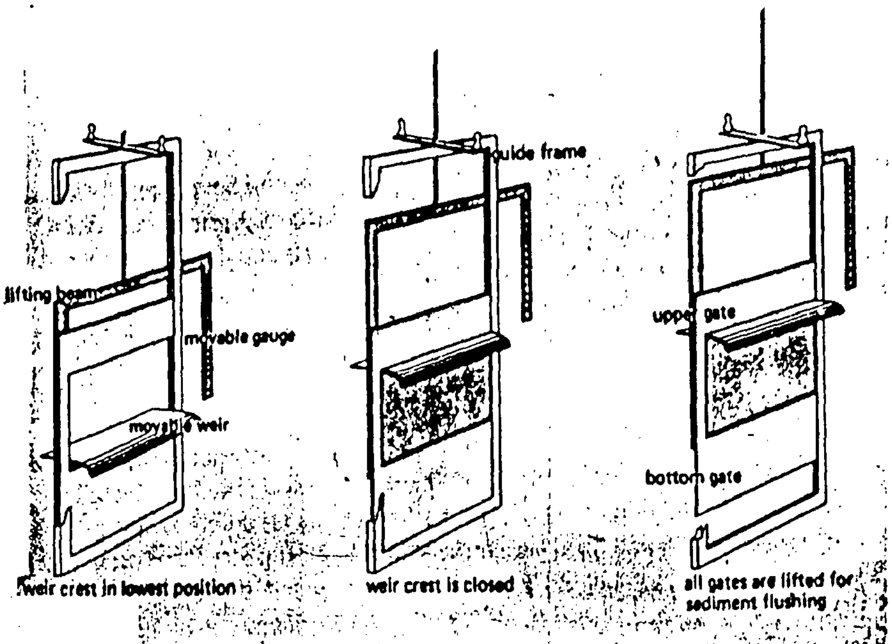


Figure 4-2 Movable weir with bottom gate (Bos, 1974).

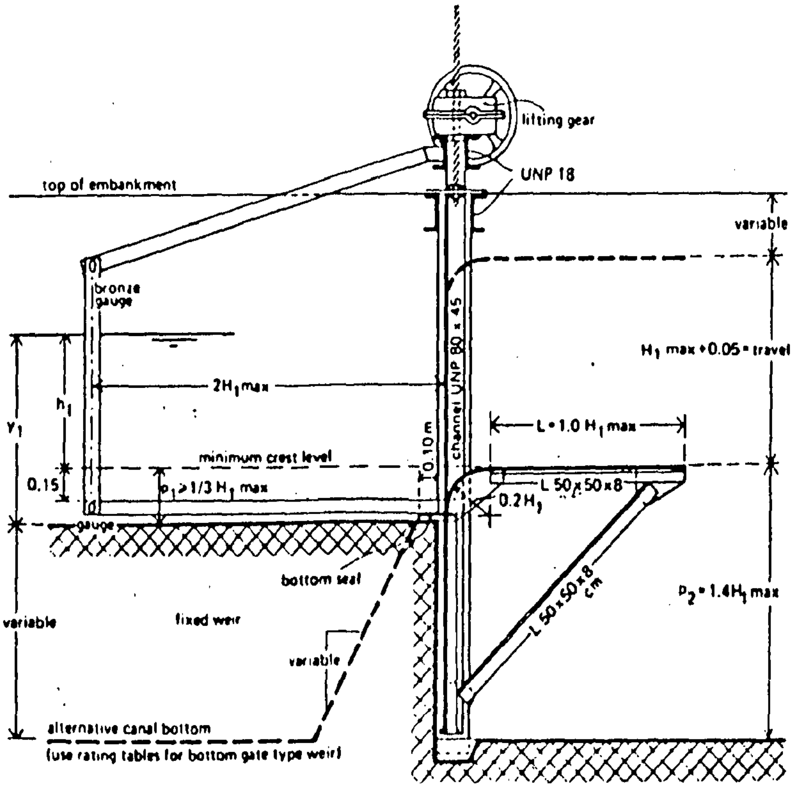
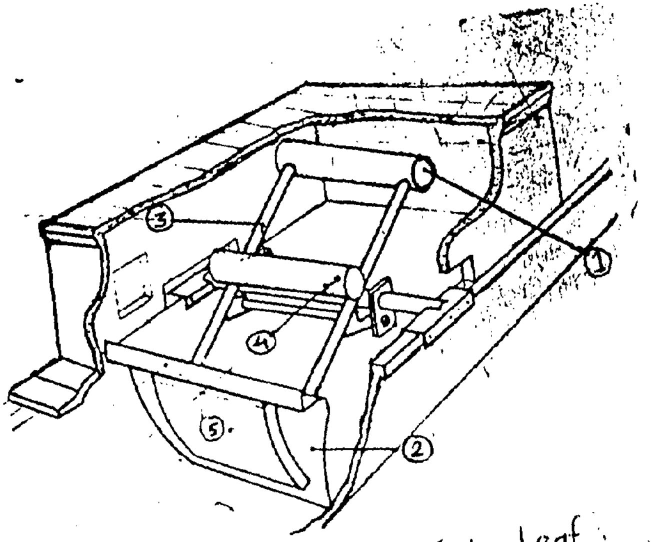


Figure 4-3 Longitudinal section over bottom-drop-type movable weir.



1 Counterweight 2. Gate Leaf

3 Tubular frame 4. Counterweight

5. Float

FIG 4.4 ANIL GATE

FIGURE 4.5

Standard AVIO gate layout

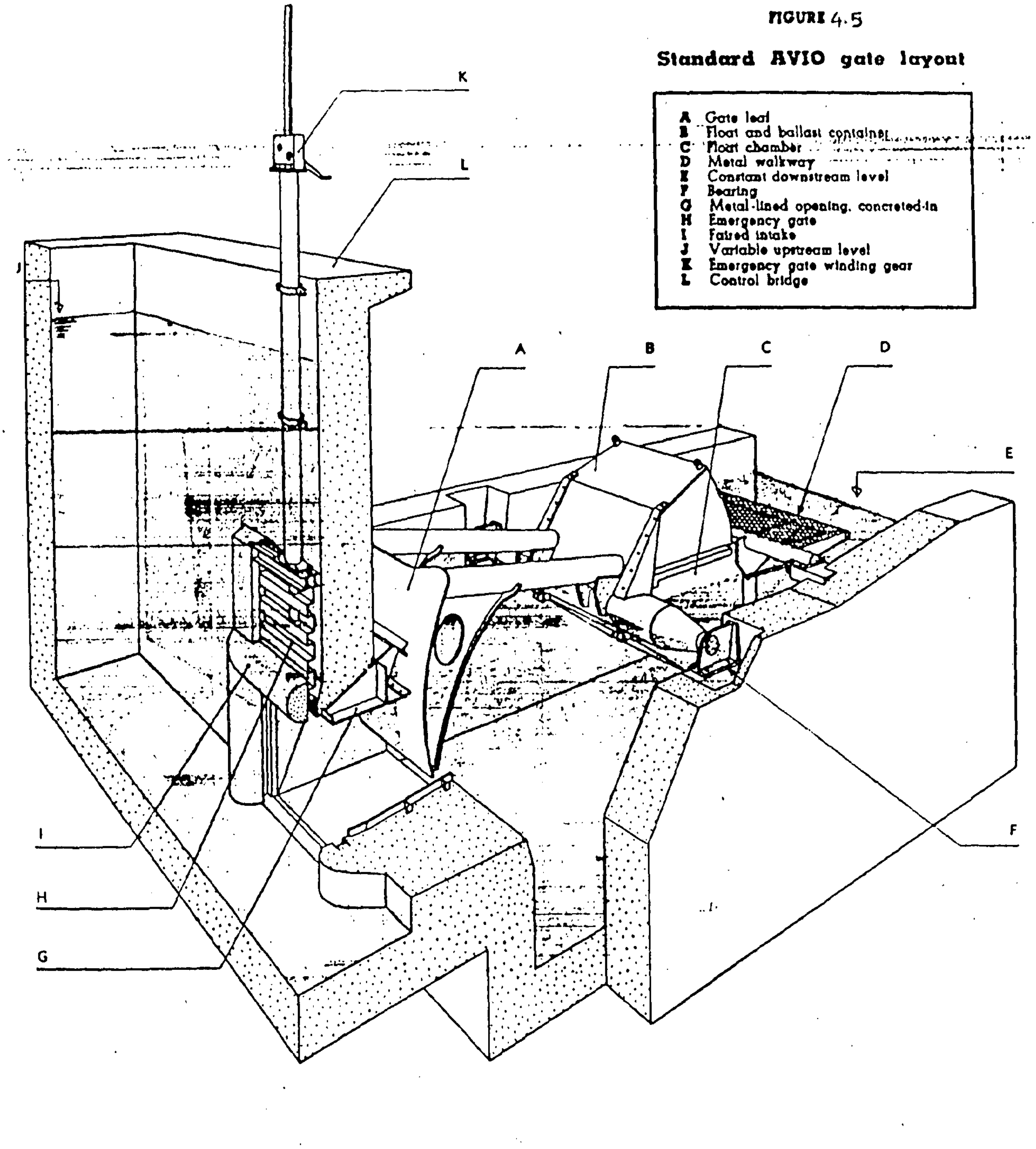
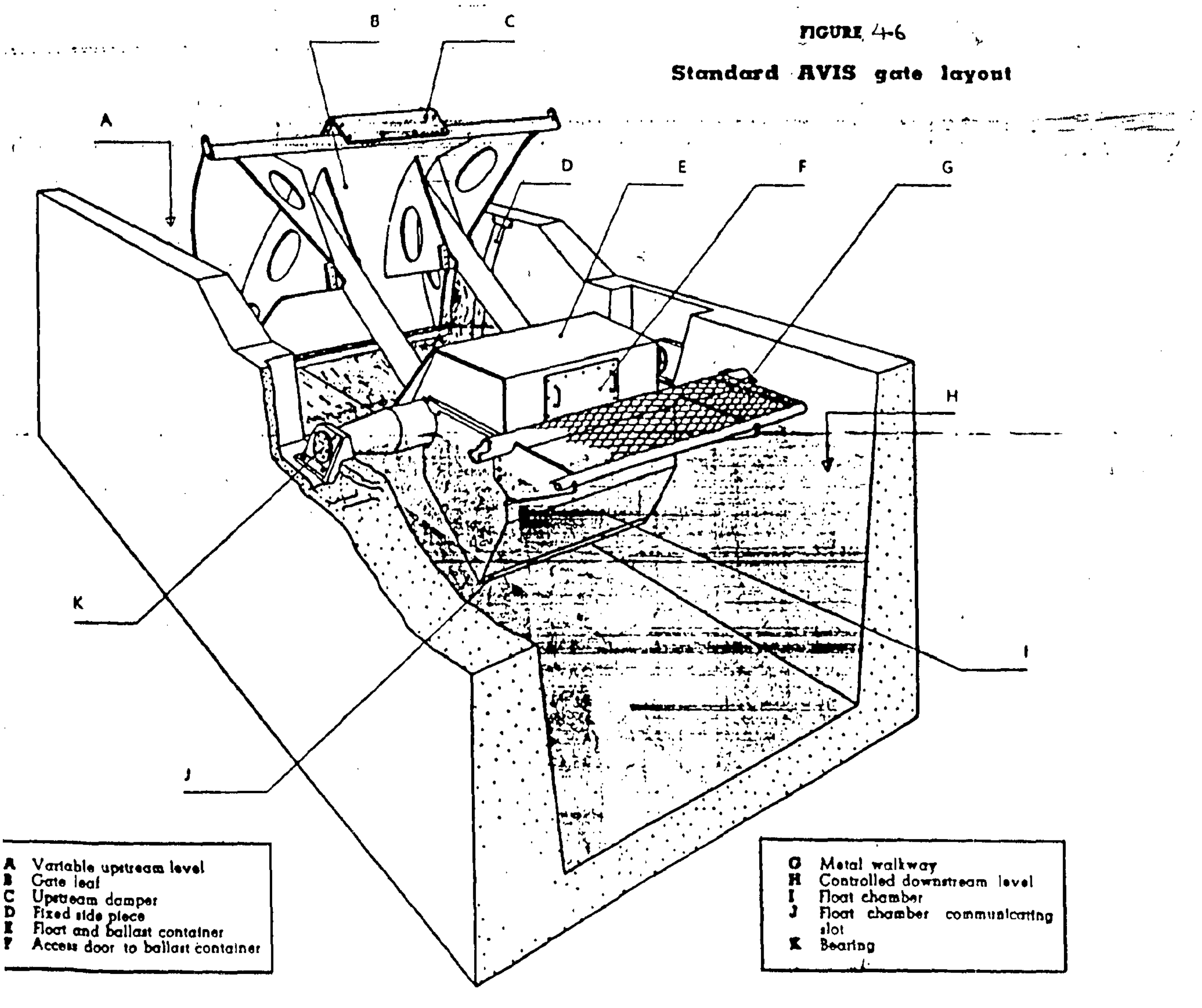


FIGURE 4-6

Standard AVIS gate layout



A Variable upstream level
B Gate leaf
C Upstream damper
D Fixed side piece
E Float and ballast container
F Access door to ballast container

G Metal walkway
H Controlled downstream level
I Float chamber
J Float chamber communicating slot
K Bearing

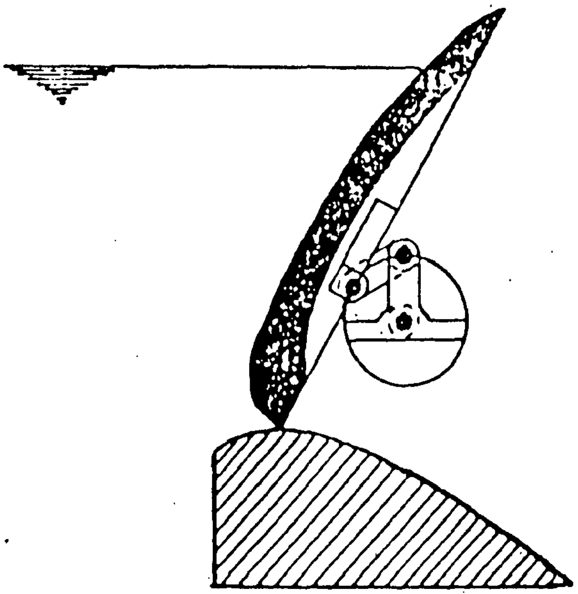


FIG 4·7 TILTING GATE

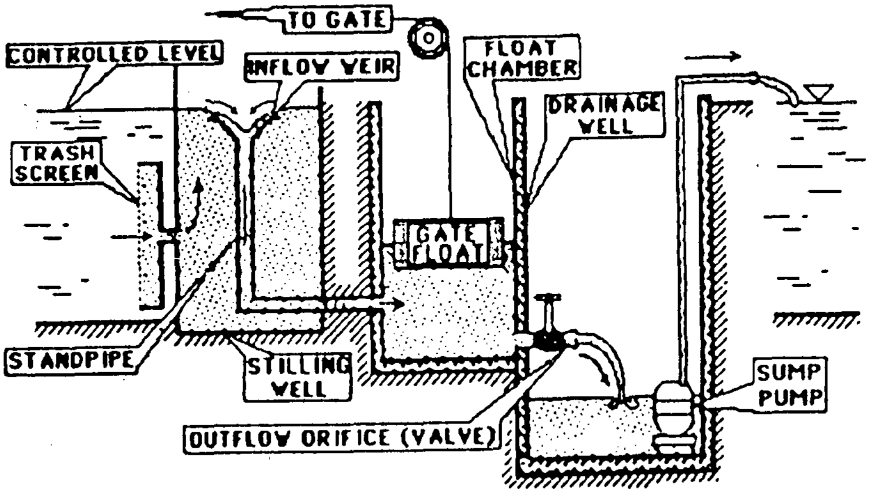


FIG.4·8-Schematic of Danaidean Controlled Leak System for Controlling Downstream Water Levels

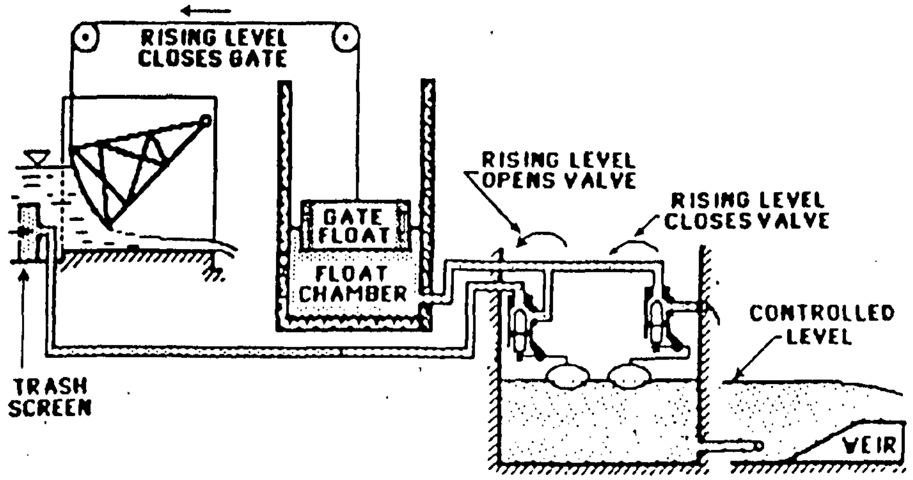


FIG.4-9 Schematic of Dual-Acting Controlled-Leak (DACL) System for Control of Water Level Downstream from Radial Gate; In this Case, Flume Downstream from Gate Effectively Makes this a Constant Flow Rate Control Gate

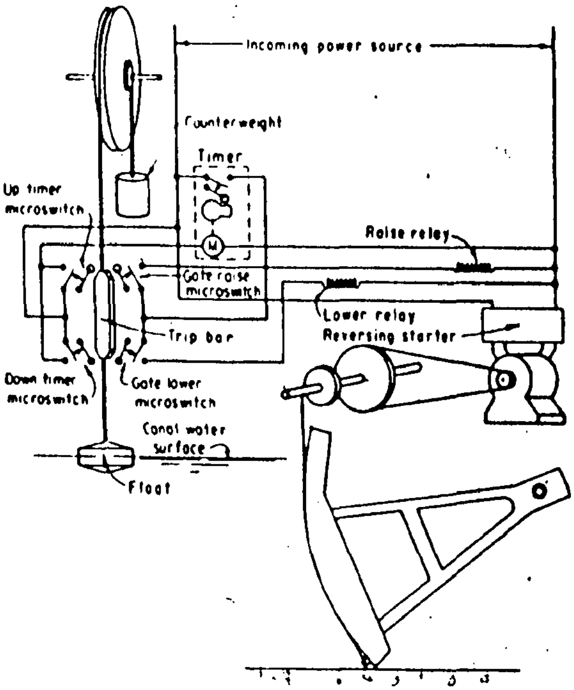


Figure 4.10 - Schematic diagram for a Columbia Basin type "little man" controller.

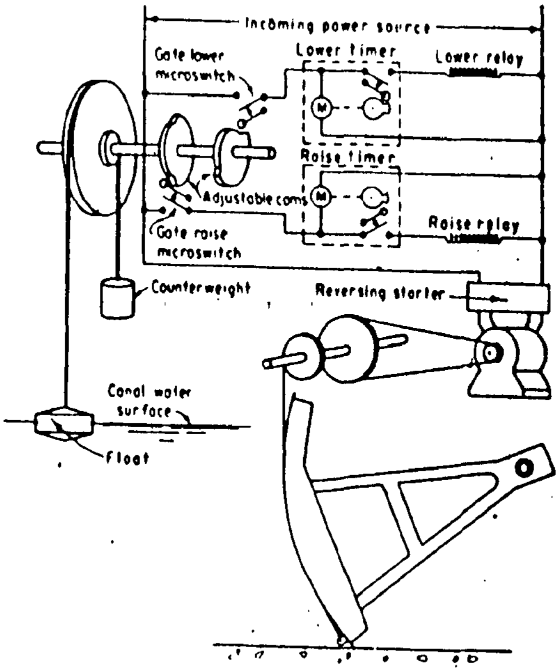


Figure 4.11 - Schematic diagram for a Friant-Kern type "little man" controller.

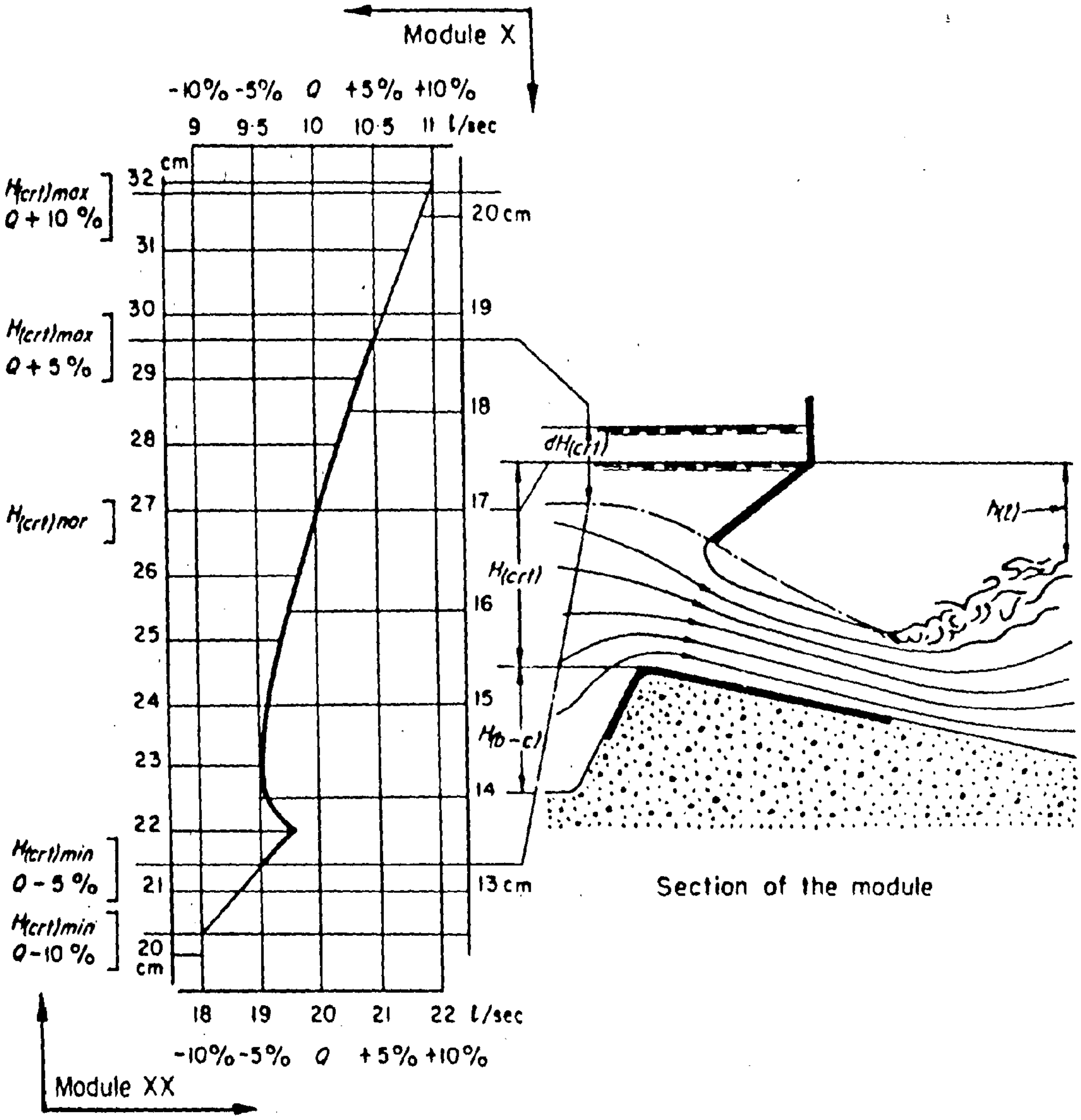


FIGURE 4.12 . - Per cent variations in discharges of modules Types X and XX for variation of $H_{(crt)}$ within pre-determined limits.

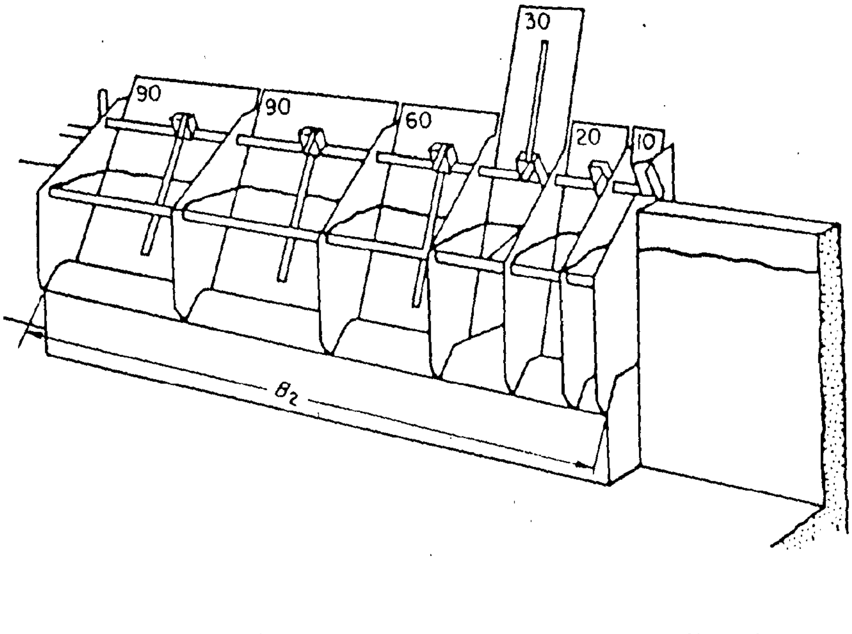


FIGURE 4.13 - Upstream view of Neyrpic distributor type XX/300.

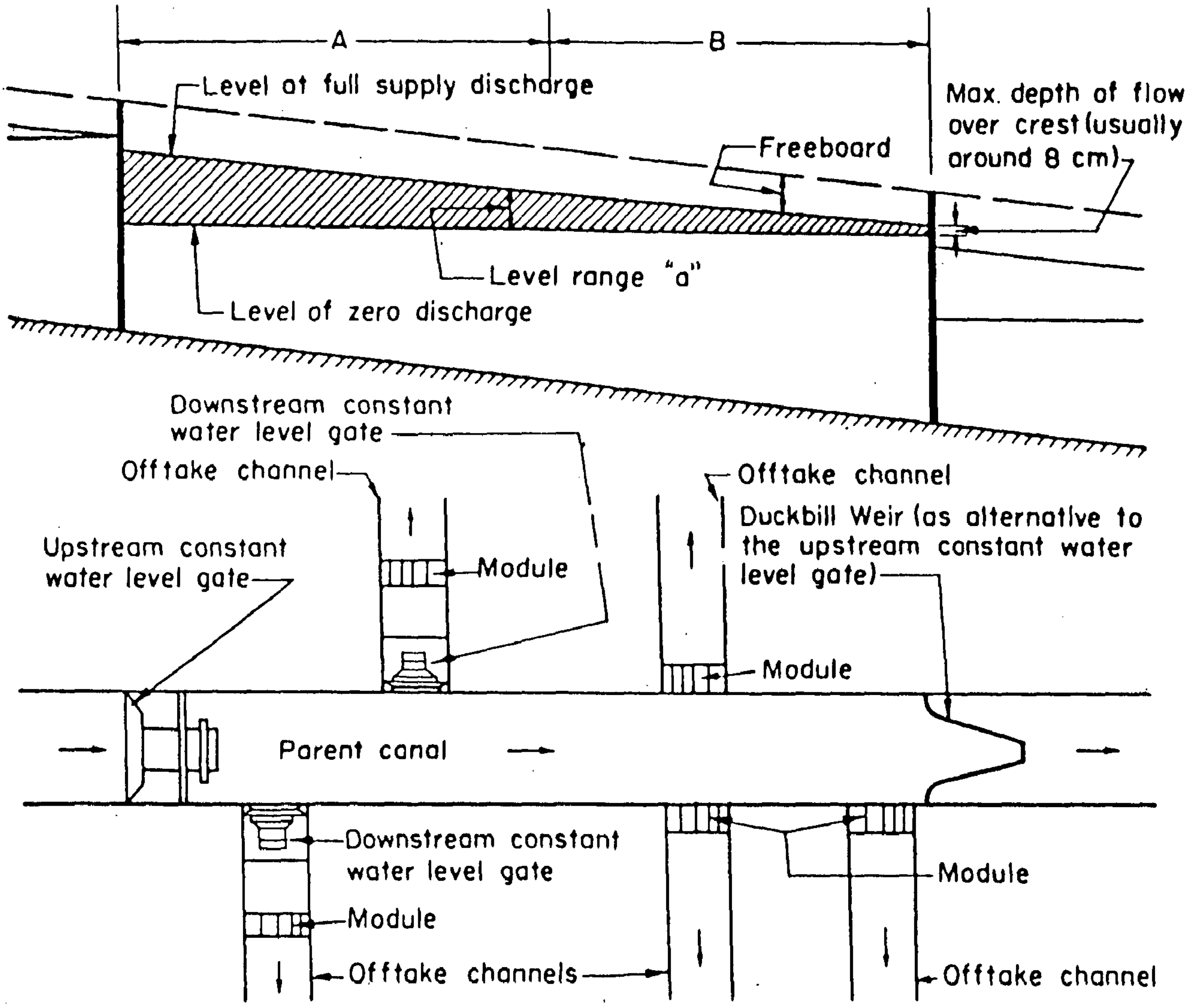


FIGURE 4.14 - Diagrammatic layout of an upstream controlled network.

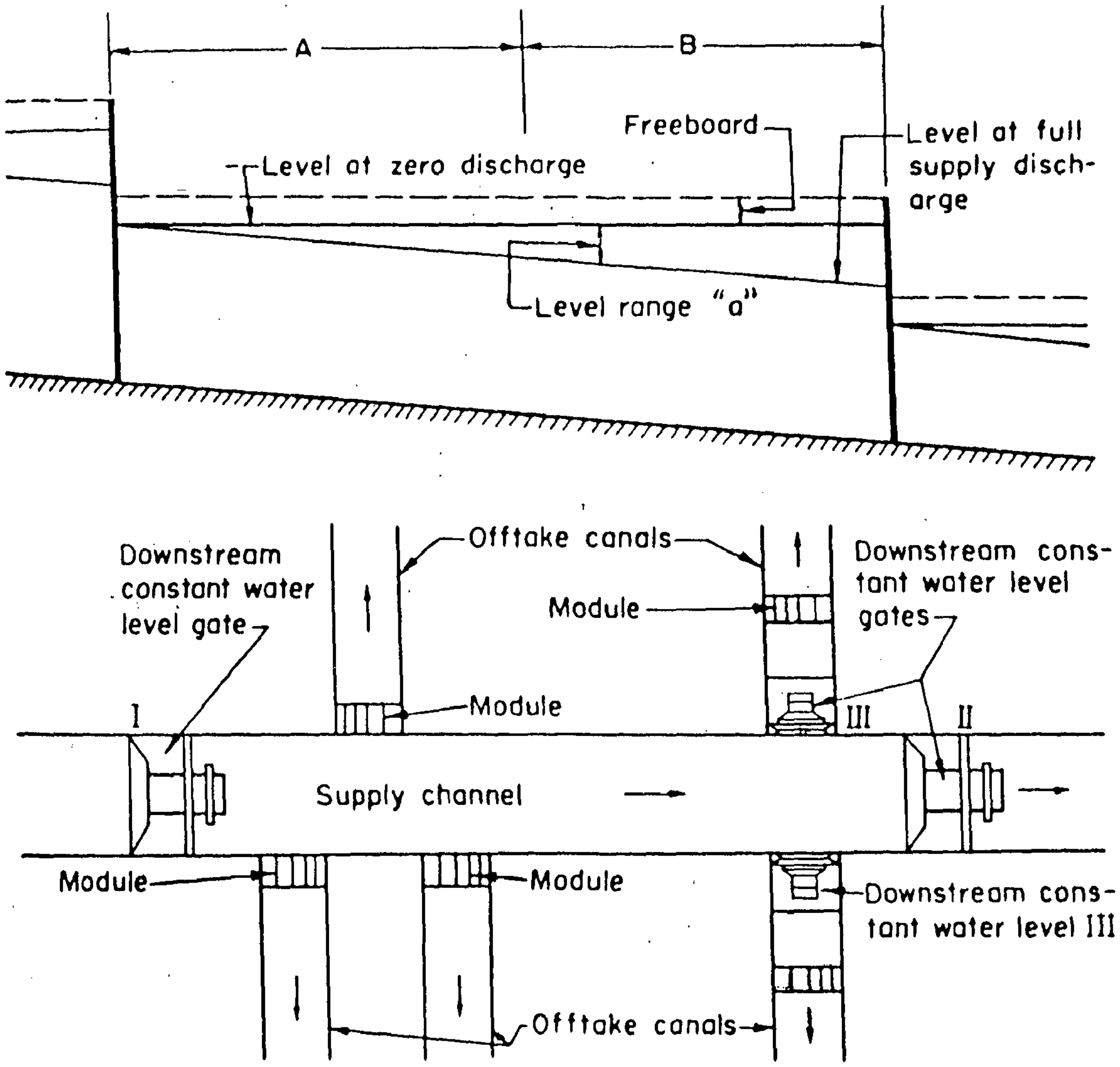


FIGURE 4·15 - Diagrammatic layout of a downstream controlled network.

CHAPTER V

CANAL OPERATION HYDRAULICS

5.1. INTRODUCTION :

Existing manually operated irrigation canals in India are basically designed, constructed and operated assuming steady uniform flow conditions. Automation of irrigation canals entails significant changes in canal operation hydraulics. Considerations of gradually varied flow and especially that of unsteady flow assume more importance in the context of automatic canal operation. This chapter briefly reviews some of these aspects from irrigation manager's point of view who wants to incorporate these hydraulic aspects in canal operation to improve it but at the same time also wants to make daily automatic canal operation simple, understandable and most important of all, workable.

5.2. STEADY STATE OPERATION :

Steady state flow conditions occur when there is no change in flow properties with time and can be either uniform or non-uniform.

5.2.1. Steady Uniform Flow :

This is a hydraulic condition in which the water depth and canal cross section does not change over some section of the reach. Although, this condition rarely exists in nature due to the spatial variation in canal properties, this assumption provides reasonably good results for most man-made channels. The Manning's equation is generally used to evaluate the relationship between discharge and channel properties.

5.2.2. Steady Nonuniform Flow :

A flow with spatially varying velocity and depth, called non-uniform flow, occurs in open channel because of the effect of -

(i) Canal slope,
(ii) Channel geometry and size, and
(iii) Control structure settings.

The resulting water surface elevations are of importance in the design and operation of a canal network.

If the flow changes occur over a long distance, the flow regime is termed as a gradually varied flow, Otherwise it is rapidly varied flow.

Gradually varied flow occurs at -

(i) the entrances and exits of a chanal reach;
(ii) change in longitudinal slope;
(iii) change in cross section geometry and/or size:
(iv) flow control structures

(Gichuki, 1988).

Though gradually varied flow has been dealt with in Hydraulics Textbooks in general, it has not been discussed with particular reference to irrigation canal. For example, the relationships that relate the change in flow depth to distance along flow path, do not consider lateral outflow which is a must. Gichuki (1988) gives one relationship which includes terms for flow entering or leaving the channel

$$\frac{dy}{dx} = \frac{So - Sf - \frac{Qq^{*}}{gA^{2}} - F_{q}}{1 - F^{2}}$$

where,

So = longitudinal slope (dimension-less)

S_f = friction slope (dimensionless)

Q = discharge (m^3/sec)

A = flow - cross sectional area (m^2)

Y = flow depth (m)

X = distance (m)

g = acceleration due to gravity (m/sec^2)

F = Freud No. (dimensionless)

q^{*} = the lateral flow per unit length (m^2/sec)

F_q = 0 for bulk lateral outflow;

$= \frac{Qq^{*}}{2g\,A^{2}}$ for seepage outflow

$= \frac{(V-u)\,q^{*}}{g\,A}$ for bulk inflow

V = velocity in main canal (m/sec)

u = component of velocity in the direction of the main channel flow (m/sec).

However, the literature explaining all details of abovementioned relationship could not be obtained during dissertation period.

5.3. UNSTEADY FLOW OPERATION :

5.3.1. Definition :

The flow of water in canals for which the velocities change with time, is defined as unsteady flow (non-permanent, non-stationnary or time-variable free-surface water flow) (Yevjevich, 1975).

5.3.2. Why Unsteady Flow in Canals :

Irrigation canals experience unsteady flow problems due to

(i) initiation and termination of irrigation;

(ii) sudden changes in demand (i.e. sudden releases or stoppages of lateral water flow);

(iii) automatic or semi-automatic flow regulation to match sudden changes in demand.

5.3.3. Importance of Unsteady Flow :

Data (table 5.1) presented by Sritharan, Clyma & Richardson (1985) shows why it is important to consider unsteady flow, called transients, in canal delivery systems for developing operational plans.

Table 5.1 Response Time for Realizing 100% Flow Step :

Base flow (cfs)	Flow step (cfs)	Time of Response (hrs)		
		at 2 miles	at 4 miles	at 16 miles
10	1	4.0	6.5	18.0
100	10	3.5	6.0	12.0
1000	100	3.0	4.0	8.0

From this table it is clear that it takes a longer time for a system to completely respond to the flow step as the downstream point of interest moves farther away. Neglecting transients, thus, can result in considerable reduction in targeted supply to the water user.

5.3.4. Unsteady Flow Consideration - a Must :

No matter what type of water distribution method or canal regulation technique is employed an unsteady flow in the canal can not be altogether avoided. Extent of transients, frequency of their occurance and duration of their existance may however differ for different water distribution methods and canal regulation techniques. It can be expected that for Rotation Method with upstream control the transients in main canal may be relatively less serious (because of pre-scheduling and tight control over deliveries) as compared to Demand Method with downstream control. Transients in context of Demand System have been widely discussed in the literature. However, transients associated with rotation methods have not been reported.

5.3.5. Flow Problem of Canal Operation :

Minimising the extent and time of unsteady flow is the objective of canal operation. Contrelling the unsteady flow in canals presupposes a complete knowledge of the flow characteristics and the general hydraulics of the canal as well as the discharge characteristics of the gates at various openings. These characteristics when used in conjunction with the basic differential equations of unsteady flow can help in solving the flow problem. (Dandekar, 1988).

5.3.6. Equations of Unsteady Flow :

The Continuity and Dynamic Equations were first published by Saint-Venant and hence, are named after him as Saint Venant's Equations.

Continuity Equation :

It is based on the principle of conservation of mass and states that the inflow minus outflow equals the change in control volume. (Gichuki, 1988)

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} + q = 0$$

Dynamic Equation: (Momentum Equation)

It is based on Newton's Second Law of Motion. For the control volume, the unbalanced external forces resulting from the interaction of hydrostatic, gravity and friction forces are balanced by the time rate change of momentum (Gichuki, 1988)

$$\frac{\partial V}{\partial t} + V \frac{\partial V}{\partial x} + g \frac{\partial y}{\partial x} = g\,(S_o - S_f)$$

where -

Q = discharge (m^3/sec)

A = flow cross-sectional area (m^2)

Y = flow depth (m)

q = net lateral inflow or outflow (m^2/sec)

x = distance (m)

t = time (sec)

g = acceleration due to gravity (m/sec^2)

S_o = channel slope (dimension less)

S_f = friction slope (dimension less)

V = velocity (m/sec)

Saint Venant's equation constitute a difficult mathemathical problem because of non-linear hyperbolic nature of the two simultaneous partial differential equation. (Miller and Cunge, 1975)

5.4. PROBLEM OF IRRIGATION MANAGER :

Complex unsteady flow hydraulics and state-of-the-art simulation models based on Saint Venant's equations may be very much fascinating, challenging and appealing to hydraulics engineers, systems analysts and computer modelers. But the problem of Irrigation Manager is how to incorporate considerations of unsteady flow in canal operation and at the same time make it simple, understandable and especially, workable in day to day Real - Time operation. Following paragraphs describe some of the practical difficulties involved. Also described are the experiences in different countries which may throw light on this intriguing question.

5.4.1. Difficulties Involved :

The unsteady flow conditions are very complicated due to the infinite possible combinations of flow rates and water levels in a canal pool. The reactions of water levels of one pool due to changes in flow in adjacent pools are very difficult to calculate. Detailed knowledge of flow rates, hydraulic coefficients and gate openings is required for accurate hydraulic simulation. (Burt, 1983).

The accuracy of "accurate hydraulic simulation programmes" is limited by the difficulty of correctly estimating hydraulic values in the field. For example, the roughness of a canal may fluctuate widely during an irrigation season due to weed growth. Discharge coefficients must be calibrated in the field for individual gates under a wide range of flows. Old unlined canals are difficult to model because of irregular and variable dimensions. (Plusquellec, 1988).

A control method which relies on precise mathematical modeling of hydraulic processes must be so precise as to be cumbersome and difficult to apply to a particular canal.

By the time a solution has been obtained, the problem would already have changed. Therefore, state-of-the-art simulation models are not always the best tools for daily Real-Time management. (Burt, 1983; Goldsmith, Bird, Howarth, 1988 ; Jean Verdier, 1987; Plusquellec, 1988)

Gichuki (1988) reports current hydraulic models' limitations as follows :-

(i) High computational time;
(ii) Application to only non-branching systems;
(iii) Limited range of water control structures;
(iv) Intermediate turnouts not included;
(v) Not available on micro-computers;
(vi) Requires steady state initial conditions;
(vii) No simulation of the canal filling phase.

USU Hydraulic Model (1988) is said to be aimed at overcoming a lot of above mentioned limitations.

Irrigation managers' fears about turning systems operations and possible decisions over to computer programmers and modelling specialists have also been discussed in the literature (Labadie and Sullivan, 1986).

5.4.2. Experiences :

(i) Even where sophisticated flow control techniques are used, such as in canal de Provence, France, a simplified analysis method is adopted.

A large canal hydraulic simulation model was formulated but is not used for control. It was only used to develop the present short computer programme control logic. It is based on combination of statistics, approximations and frequent updating of commands. (Plusquellec, 1988).

2. Field trials on California Aqueduct showed that gate movements dictated by the theoretical calculations resulted is unstable flow. The complex mathematical solution which dictated gate movements was disçarded in favour of an operation using slow and multiple gate movements. (Burt, 1983)

3. The USBR approach to develop the EL-FLO method incorporated a complicated hydraulic analysis, Final selection of controller coefficients is done in a loosely defined manner and must be adjusted by trial runs using the Unsteady Model (USM) programme. (Burt, 1983).

4. Zimbalman's algorithm and CARDD discussed in Chapter-III are the recent examples of empirical and/or stitistical approaches.

5. The state-of-the-art USU hydraulic model for branching systems is presently under field evaluation in north-eastern Thailand. The calibration process is understood to be onerous and the routine data requirements are high (Goldsmith, Bird, Howarth, 1988).

5.4.3. Alternatives :

To avoid the difficulties discussed earlier, the researchers propose two alternatives (Verdier, 1987).

(i) Developing heuristic procedures which can be sharpened through the experiences acquired during the first years of operation. This is the method successfully adopted for Dynamic Regulation of Provence de Canal, France.

(ii) Simiplyfying the mathematical models of flow propogation. This is usually done through:(Miller and Cunge, 1975).

(a) use of continuity equation alone

(b) use of momentum equation alone

(c) simplification of momentum equation by neglecting some of the terms.

These alternatives may provide answers in much less computer time with simple computer programmes. There data requirement also may not be very high. But there are two important limitations. They are -

(i) These simplified/empirical/heuristic solutions may lack generality (Miller & Cunge, 1975).

(ii) In both the above cases, and particularly in second, there is no question of directly implementing rough alogorithms for computers managing irrigation schemes in real-time. Indeed it is not easy to determine if necessary simplyfying hypotheses will not result in biased solutions or if the algorithm will react properly in extreme situations. In order to avoid any disruption of the canal system due to a design fault in the control algorithm it is necessary to test them on a simulator before their implementation on site. This is a difficult and time consuming process. Long and costly studies are required even when the projects are relatively simple. (Verdier, 1987).

Considering all these difficulties even for alternative solutions, Verdier (1987) aptly summerises as follows :

(i) The development of computerised management of irrigation water distribution is currently hindered by an inadequate theoretical approach to the design and development of optimal, or at least pseudo-optimal, control algorithms.

(ii) The development of control algorithms has not kept abreast of the progress in computer hardware. That is why, contrary to predictions made some years ago, the remarkable expansion of opportunities offered by microcomputers has not significantly altered the methods of water distribution and management of irrigation deliveries.

5.5. IDENTIFYING COMPUTATIONS REQUIRED :

Identification of computations required for automation of Irrigation Canal obviously depend upon SELECTED -

(i) Water distribution method (WDM);

(ii) Canal regulation technique (CRT);

(iii) Mode of control (MOC) ;

(iv) Control Equipment (CE) and

(v) Theoretical approach for hydraulic simulation.

In the initial stages, it is quite likely that because of -

(i) The inability to identify appropriate theoretical approach for hydraulic simulation and

(ii) Absence of workable/proven hydraulic model

many a computations will not be possible immediately e.g. Flow profile computations for real-time operation. This may, in turn, put restrictions in selecting particular - WDM, CRT, MOC, CE (for immediate implementation) which necessarily require those computations. Alternatively, efforts should be made to develop workable hydraulic models.

Being aware of these limitations, still an attempt is done to identify the computations required. Those are presented below :

List of computations which will be required for implementing CRTs and for on-line canal operation :

(i) Fixing reach lengths;

(ii) Working out channel storage:

(iii) Working out travel time/filling time;

(iv) Working out lag time for 100% realization of flow-step at different locations starting with different base flows.

(v) Selection of gates and fixing their sizes;

(vi) Selection of weirs and fixing their sizes;

(vii) Determining fluctuation - volumes and capacity requirements of Regulating Reservoirs;

(viii) Flow profile computation;

(ix) Determining extent of transients/flow instabilities and fixing norms for freeboard;

(x) Demand - and/or water-level-forecasting;

(xi) Determining direction, speed of movement and opening of gates at different times.

Flow profile computations being the most important their practical use in canal operation is explained in the following paragraphs with self-explanatory figures:

For a particular canal reach, for a particular discharge there can be innumerable number of flow profiles depending upon opening of downstream cross-regulator and downstream water depth. Changes in flow profiles are due to either change in discharge (volume remaining constant) or change in volume (discharge remaining constant) or change in both - volume and discharge within acceptable zone of operation. Flow profile computations help in determining these changing flow profiles. The flow profiles, for example, in Dynamic Regulation (to be adopted for an existing project) can be used for following purposes:

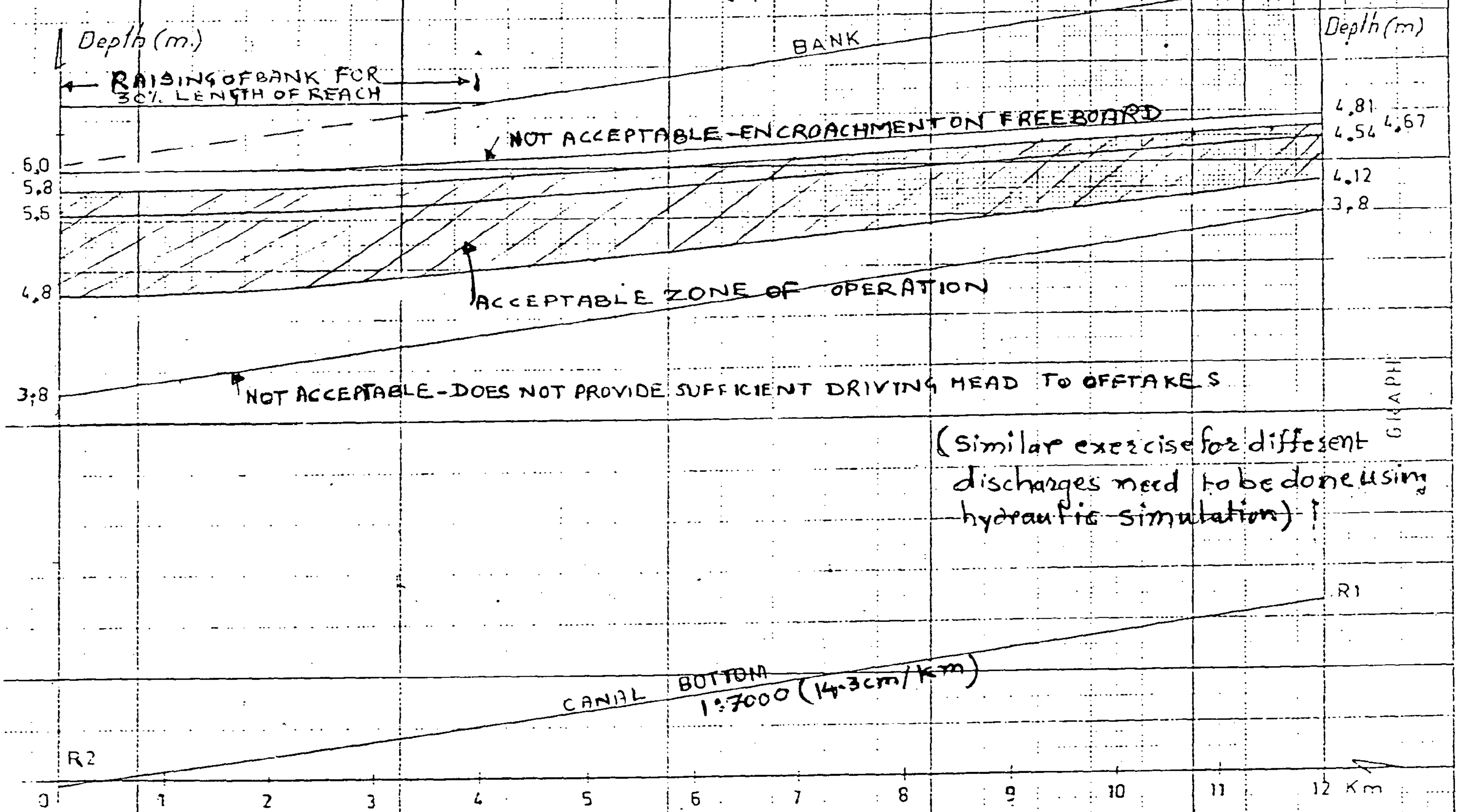
(i) to determine height of raising of bank and length in a reach for which raising of bank is required (Fig.5.1).

(ii) to determine acceptable zone of operation (Fig.5.1)

(iii) to determine nature and extent of operational modifications of the reach (Fig. 5.2)

Fig:5.1 FLOW PROFILES (FOR Q= 100 m³/sec)

(GERSAR, 1982)



(Similar exercise for different discharges need to be done using ~~hydraulic simulation~~) !

Bottom width = 14m Side slope 1.25:1 FSD = 5.2 m FB = 0.9 m (ORIGINAL)

n = 0.016 Max Q = 175 m³/sec R₁ & R₂ = CROSS REGULATORS

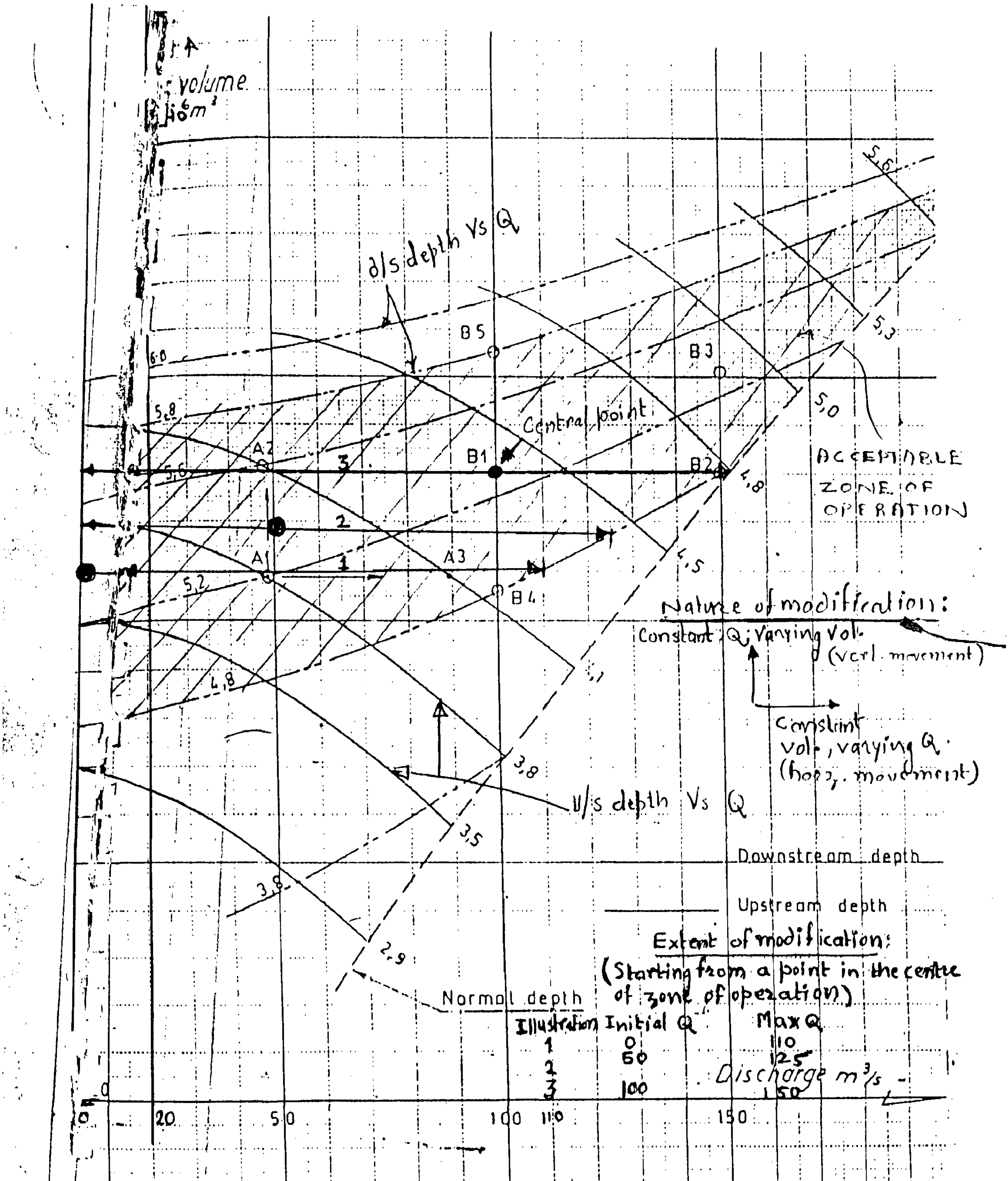


Illustration	Initial Q	Max Q
1	0	110
2	50	125
3	100	150

Fig: 5.2 Diagram to determine nature and extent of operational modifications of the reach

CHAPTER - VI

A CASE STUDY

6.1. INTRODUCTION :

On the background of different aspects of automation discussed in Chapters II to V, an attempt is made here to study how automation can be achieved on a minor irrigation project.

6.2. OBJECTIVES :

The objectives of this exercise are to study :

(i) which concepts of automation can be immediately applied in practice in existing minor irrigation project in order to improve operation of main canal and distributories;

(ii) which control equipment can be used to achieve objective(i)

(iii) what better operational and managerial changes can take place as a result of proposed automation;

(iv) whether higher productivity, increased equity and better resource conservation can be achieved through proposed automation;

(v) techno-socio-economic feasibility of proposed automation.

6.3. SCOPE :

This study is limited to automation of main canal and distributories. It does not include automation on - farm.

6.4. SELECTION OF PROJECT FOR CASE STUDY :

Nirgudi Minor Irrigation (M.I) Project, district Aurangabad, Maharashtra was selected for case study considering following :

(i) The Government of Maharashtra has signed an agreement, called Maharashtra Minor Irrigation Project (M.M.I.P), with USAID (Project No. 386-0490). The project will support the construction of 90 new MI projects bringing approximately 31,000 ha. of land under irrigation. MMIP includes Research & Technology Development through Special Studies, Pilot Activities and Diagnostic Analysis (D.A). Twelve existing MI projects will also be renovated under MMIP. The renovation proposals are to be framed after carrying out detailed DA by interdisciplinary teams;

(ii) Nirgudi M.I. Project is one of these 12 projects. Its DA has already been carried out by WALMI, Aurangabad (candidate's parent organisation)..As such, the problem has already been diagnosed and discussed with concerned irrigation officials who are now preparing renovation proposals. Moreover, reliable and authentic data was available from WALMI.

(iii) To start with, for automation experimentation a pilot project can only be taken up on small irrigation scheme with less operational and administrative difficulties.

It would be not only managable but also less costly and risky as compared to experimentation on bigger schemes. Moreover, results can be obtained relatively quickly and performance can be evaluated more thoroughly. Since, Nirgudi M.I. project is already being considered for renovation under MMIP, authorities and funding agencie can be persuaded to consider proposal for its automation. As mentioned earlier MMIP includes Research and Technology Development through pilot activities.

(iv) Nirgudi project can very well be considered as representative of other MI Projects in Maharashtra as far as physical managerial and operational problems associated with Main System are concerned. The findings of present study may therefore be reasonably generalised to cover majority of MI projects in Maharashtra.

6.5. PROJECT DESCRIPTION :

6.5.1. Project History :

Nirgudi MI scheme is completed in the year 1968 and irrigation commenced from the year 1969-70. The scheme consists of storage dam across Gan Nalla (tributory of Shivana River, Godavari Valley) and one canal on right bank having two main distributories.

Index plan and Line Diagram of the project are presented here as Fig. 6.1 and Fig. 6.2 respectively. The salient features of the scheme are given in Annexure 6.1.

6.5.2. Climate :

The project area is located in semi-arid tropical zone having two irrigation seasons viz. Kharif (July 1 - Oct. 14) and Rabi (Oct. 15 - Feb. 28/29). The maximum and minimum temperature in the area are 30°C and 13°C respectively. Annual average rainfall is 650 mm.

6.5.3. Soils :

60% soils of the project area are silty clay in texture with depth more than 90 cm. Remaining 40% soils are sandy loam and are shallow.

6.5.4. Crops :

The seasonal crops grown in general in the canal command are as under :

Kharif : Bajara, Sorghum, Pulses, Cotton
Rabi : Wheat, Sorghum, Gram.

6.5.5. Socio - Economic Conditions :

The project area is comparatively less developed having low literacy percentage, small to medium land holdings and belongs to lower income group. Most of the population belongs to a tribal group known as Banjara community.

6.6. DIAGNOSIS OF THE CENTRAL PROBLEMS :

6.6.1. Utilisation of Potential :

The design potential of the project is of 547 ha. in Kharif and Rabi seasons. The actual utilisation is less (Fig. 6.3) mainly because low demand for Kharif and Two Seasonal crops because of more or less assured rainfall.

6.6.2. Crop Water Requirements :

The concept of protective irrigation was adopted in the original planning. The crop water requirements (CWR) were calculated on the basis of Duty in acres/ Mcft of water at canal head and 547 ha. of Irrigation was proposed.

The revised water planning with proposed crop pattern based on CWR as per Modified Penman Method is done and it was found that irrigable area reduces to 240 ha. against 547 ha. contemplated. Since reducing command area is just not possible, it has now been proposed to provide irrigation water only at critical stages of the various crops. With this approach, the irrigable area works out to 475 ha.

6.6.3. Canal Design :

In project design, the canal capacity was determined on the basis of 14 days rotation period (12 days 'ON' and 2 days'OFF') with AI/DC = 4 acres (i.e. area irrigated per day cusec of flow) at canal head. This amounts to a delta of 150 mm (6"). As all crops originally proposed in the cropping pattern are seasonals, it was proposed to irrigate the crops in alternate rotation with irrigation interval of 28 days. That explains the low carrying capacities of main canal and distributories (Annex. 6.1) as compared to number of outlets on them. Table 6.1 gives a comparison between existing canal capacities and required capacities if outlets are to run simultaneously.

Table - 6.1: Carrying Capacities :

Canals	Carrying capacities at head (LPS)	
	Existing	Required if outlets are to run simultaneously
Main	360	645 (4)
Dy - I	170	405 (27)
Dy - II	130	180 (12)

Note:

(i) Col. 3 shows net capacities based on 15 LPS outlet discharge.

(ii) Figures in bracket give number of outlets.

6.6.4. Productivity :

Productivity in terms of area irrigated (Fig. 6.3) and yields obtained (Table 6.2) was found to be low in this project.

In addition to many socio-economic constraints (poor economic status of farmers, inadequate credit facilities and poor extension services resulting in wild irrigation and neglect of standard agronomic practices) many physical, operational and managerial 'Main System' factors also were found to be limiting for high productivity. They are :

(i) The main canal and distributories are operated without any planning of releases resulting into haphazard irrigation which often leads to moisture stress for crops.

(ii) Too much of seepage and operational losses (conveyance efficiency 61%) in conveyance and distribution result into less availability of water for irrigation.

(iii) Since delivery of water at outlet itself is not reliable, predictable, timely and adequate, farmers take least interest in maintaining field channels and forming water Users' Organisation.

6.6.5. Equity of Water Distribution :

The supply of water in the head, middle and tail reaches of canal is inequitable as seen from low cropping intensity in the tail reach (Fig. 6.4) of the system. Besides host of other reasons, lack of in-built water - level- and flow - control in conveyance and distribution system (due to absence of cross regulation and proper outlet structures) is also the important reason. When all outlets run simultaneously, full supply level in the distributories is not maintained and not a single outlet is able to draw its design discharge. Farmers then put bunds of mud and stone in the channel bed to raise the water level.

6.6.6. Resource Conservation :

In addition to undulating fields and wild irrigation on-farm, seepage and operational losses (39%) in conveyance and distribution system are the main sources of considerable wastage of scarced resource like water.

6.6.7. Summary :

To summerise, the present problem of irrigation in existing MI projects, like Nirgudi, has its origin in the concept of protective irrigation. The system designed based on this concept is very difficult to operate as per new concepts. The problem further gets aggravated due to several constraints; main-system constraints being the most limiting of them.

6.7. POSSIBLE SOLUTIONS :

6.7.1. Present Trend :

As per present trend some of the following solutions are generally recommended to remedy the main-system problems diagnosed:

(i) usual civil engineering repairs;

(ii) replacement of lift-type-gate-outlets by screw-type-gate-outlets;

(iii) canal lining for reducing losses and/or accounting of losses in scheduling;

(iv) provision of humps on crest of falls to create sufficient head for outlets upstream of falls;

(v) provision of measuring devices;

(vi) provision of service roads;

(vii) adoption of Rotation Water Supply System.

6.7.1.1. Limitations of present trend :

Recommendations (i), (iii),(iv),(vi) &(vii)are no doubt essential and should be followed. But opinions may differ as far as recommendations (ii) and (v) are considered. The alternative argument can be as follows:

These recommendations, if implemented, do not necessarily guarantee improved performance of canal operation simply because they do not provide for in-built water-level and flow-control. It is quite likely that even after routine renovation, Water-level and flow-control problem may remain unsolved and farmers may again have to go for their own crude cross regulation.

6.7.2. Alternative Solution :

Certain degree of automation of main system for maintaining water levels at different strategic points and allowing constant discharge through outlets may provide better alternative solution. This aspect is further analysed in following paragraphs.

6.7.3. Identifying type of Automation for Main-System of Nirgudi M.I. Project:

6.7.3.1. Water Distribution Method :

Rotation method is proposed to be continued because of -

(i) scarcity of water (para 6.6.2);
(ii) less canal - carrying capacities (para 6.6.3);
(iii) compulsions of Indian Irrigation (para 2.6.1).

Possibility of increasing availability of water is nil. On the contrary, percolation tanks being proposed in the catchment and silting may further reduce the yield. Similarly, increasing canal capacities would also not be practical.

6.7.3.2. Canal Regulation Technique :

Dynamic Regulation is not proposed for Nirgudi considering:

(i) point (i) and (ii) of para 6.7.3.1. above,
(ii) that Nirgudi is a minor irrigation project for providing essentially protective irrigation to seasonal crops which are non-remunerative;

(iii) other difficulties regarding computer controlled real - time operation and unsteady flow (para 4.92, 5.6)

Downstream control and/or combination control are not proposed because:

(i) Bed gradients of main canal (1:2000) and distributories (1:1500) are too steep to go for Level Top Canals. Moreover, there are number of existing H.P. Aqueducts and C.T. Bridges on main canal and number of falls on distributories (Fig. 6.2). This makes conversion of the system difficult. (Para 3.3.2.9 (vi)).

(ii) Sub-critical flow condition necessary for hydraulic transmission will be difficult to achieve due to number of falls (0.6m to 1.0 M drops)(para 3.3.1 (vii)).

(iii) Outlet locations have been fixed for upstream control (para 3.3.2.5).

(iv) It will be impossible to check consumption of water by farmer in downstream control (para 3.3.2.8)

(v) Rotation method is proposed.

Automated upstream control is proposed for Nirgudi project for following reasons:

(i) Other canal regulation techniques are not feasible as discussed above;

(ii) Existing manually operated upstream controlled main-system without any cross regulation creates problems for water-level and flow-control (para 6.64, 6.65, 6.72).

6.7.3.3. Control Equipment:

Control equipment such as hydromechnical gates (AVIO) and Neyrpic modules are proposed for Nirgudi Project for following reasons:

(i) They offer a low-cost, low-technology solution;

(ii) They have been successfully used for last 5 decades in at least 20 countries;

(iii) Neyrpic module has already been developed in India;

(iv) Hydromechanical gates can be manufactured in India if so desired.

6.7.3.4. Canal Operation Hydraulics:

Though unsteady flow will be involved in canal operation the gates automatically get adjusted as per flow conditions. The canal operator himself does not have to do anything. Travel time, however, will have to be considered while preparing rotation schedules. Realistic assumptions based on actual observations during one or two irrigation seasons will serve the practical purpose.

6.7.3.5. Summary:

Rotation method and automated upstream controlled canal operation with hydromechanical gates and Neyrpic modules are proposed for Main-system of Nirgudi M.I. Project. Details are presented in next section.

6.8. EQUIPMENT PROPOSED :

Details of equipment proposed at different control points are presented in Table 6.3.

High head AVIO gate and XX/360 Distributor are proposed at the head of main canal. AVIO gate will maintain downstream water level constant for distributor which will maintain and/or regulate constant discharge. Depending upon demand, discharge can be varied by either closing or opening the different compartments of the distributor.

Low head AVIO gates and distributors are proposed at the head of distributories.

Humps on crest of selected falls are proposed to create sufficient driving head for outlets upstream of falls,

It is suggested that old outlet be replaced by Double Baffle Neyrpic modules. These modules give 5% and 10% variation in discharge for 14 cm and 17 cm water-level fluctuation respectively.

6.9. COST CONSIDERATIONS :

As shown in Table 6.3 the only significant additional expenditure to be done is for 3 AVIO gates. This additional cost is worked out as follows.

Item	Unit	Rate	Total Amount
(i) Purchasing AVIO gates	3	Rs.25000/-gate (assumed)	Rs. 75000
(ii) Civil Engineering works and installation of gates	3	Lump	Rs. 75000
	Total		Rs.1.50 lakhs

I C A of the project = 540 ha.

.'. Cost/ha. of ICA = Rs. 277.77/- say Rs. 280/ha.

6.9.2. The cost of modernisation (without AVIO gates) of Nirgudi M.I. Project as per recommendations (pare 6.71) is estimated as follows: (only major items are considered)

Item	Unit	Rate	Total Amount(Rs.)
(i) Replacement of old-outlets by screw-type-gate outlets	43 Nos.	Rs.2500 per unit	Rs. 1,07,500-00
(ii) Major repairs and/or new construction of falls	25 Nos.	Rs.2000 per unit	" 50,000-00
(iii) Chak development (part-I works)	540 ha.	Rs.2000 per ha.	" 10,80,000-00
	Total	Rs.	12,37,500.00

I C A of project = 540 ha.

.'. cost/ha of ICA = Rs. 2291.66/ha. Say Rs. 2300/ha.

6.9.3. Expenditure as estimated above (Rs. 2300/ha) (in para 6.9.2) is required for routine renovation. This expenditure does not guarantee the water-level and flow control - a central problem of main system. An additional expenditure of Rs.280/ha. may guarantee such control and remove one of the limiting constraints of the main system. It may be pointed out that this small additional expenditure will certainly help in achieving following:

(i) Semi - automation of main system;

(ii) Water - level and flow - control and hence, equity in water distribution;

(iii) Increase in productivity depending upon availability and use of other inputs;

(iv) Less number of complaints from farmers;

(v) Possibility of forming water users organisation.

6.9.4. Rough estimates and probable achievement presented here certainly establish techno-socio-economic pre-feasibility of semi-automation proposed. Detailed economic feasibility study, however, can be taken up after assessment of costs of hydromechanical gates.

Annexure - 6.1

Salient Features of Nirgudi M.I. Project:

Village : Nirgudi Tq.: Khultabad Distt. Aurangabad

State: Maharashtra, Long: $70^{\circ}13'$ Lat. : $20^{\circ}7'$

* **Storage** MM^3

Gross	2.427
Dead	0.203
Live	2.224

* **Canals and Distributories :**

Particulars	Main Canal	Dy-I	Dy-II
Length (km)	2.43	4.7	1.9
Discharge at head cumec (cusec)	0.36 (12.54)	0.17 (6.2)	0.13 (4.5)
Bed width at head (m)	1.2	0.8	0.6
F.S.D. at head (m)	0.6	0.45	0.4
Bed gradient	1:2000	1:1500	1:1500
Rugosity coefficient	0.03	0.03	0.03
No. of outlets	4	27	12

* **Command Area :** ha

Gross	1007
Culturable	990
Irrigable	547

(Annexure 6.1 contd)

* Project and Proposed Cropping Pattern :

Sl.No.	Crop	Project(%)	Proposed (%)
1.	Two seasonals	31	Nil
2.	Cotton	10	30
3.	Groundnut	9	Nil
4.	Maize	5	Nil
5.	Paddy	5	Nil
6.	Rabi Seasonals	40	70
	Wheat		10
	Jowar		35
	Gram		25
7.	Kharif Hybrid Jowar	Nil	30
		100	130

* Communication :

Service road along the canal and distributories and approach road to dam are not provided.

* Field Channels :

FCs are in poor condition and can carry 9-12 Lps discharge only.

Table - 6.2: Average Yields Vs Expected Yields:

Sl. No.	Crops	yields obtained (Q/ha)		Expected yield (Q/ha)	Remarks
		Average	Range		
	KHARIF				No irrigation is used for Kharif crops
1.	Bajara	4.47	1.75-10	20	
2.	Jawar	12.37	2.5-26.67	40	
3.	Cotton	4.52	1.25-12.0	25	
4.	Pulses	2.84	0.875-7.80	12	
	RABI				
5.	Jawar	6.76	1.67-17.5	20	
6.	Wheat	6.18	0.5-12.50	35	
7.	Gram	3.78	1.67-12.50	12	
8.	Sugarcane	462.50	200 - 850	1000	

Table - 6.3: Equipment Proposed at Control Points :

Control	Main Canal:Head	Dy - I: Head	Dy - II Head	Outlets	Remarks
	Refer Fig. 6.5 for Arrangement of Equipment Fig. 6.6 for HEADLOSS CHART			Refer Fig.6.2 for location of outlet & selected falls	
1	2	3	4	5	6
I. WATER - LEVEL CONTROL:					
(i) Equipment	High head AVIO*	Low head AVIO	Low head AVIO	15 cm humps on falls to create sufficient head for outlets U/S of falls.	* To be speciall designed Not available in Neyrpic Brochure
(ii) Discharge (Lps)	400	200	150		
(iii) Max. head (cm)	850 (Required)	90 (gate design)	90(gate design)		
(iv) Min. head (cm)	6 (Required)	2.5 - do -	1.5 -do -		
(v) Constant d/s water level to be maintained (cm) from canal bed for Distributor	52	52	52		
(vi) No. of equipment	1	1	1	11 on Dy-I 3 on Dy-II	
(vii) Comments	Now proposed.	Additional Expenditure Reqd.		Already proposed by Deptt. No additional expenditure.	

(table 6.3 contd...2...)

(table 6.3 contd..)

II. FLOW CONTROL :

(i) Distributor	XX/360	XX/180	XX/150	XX/15**
(ii) Max. Constant Discharge (Lps)	360	180	150	15
(iii) Compartments with discharges (Lps)	10,20,30,60,60,90 90	10,20,30,60, 60	10,20,30,30,60	15
(iv) Discharge (Lps)/cm width	2	2	2	1
(v) Crest height (cm)	25	25	25	7.5
(vi) Normal head (cm)	27	27	27	32.5
(vii) Comments	Now proposed. Distributors maintain desired constant discharge and hence, take care of flow measurement as well. Expenditure to be incurred for measurement devices be utilised for distributors. No additional expenditure involved.			Under renovation plan, I.D has proposed to replace old outlets by new screw-type-gate-outlets. Expenditure to be incurred for this replacement be utilised for module-type outlets. Saving on measuring devices. No additional expenditure.

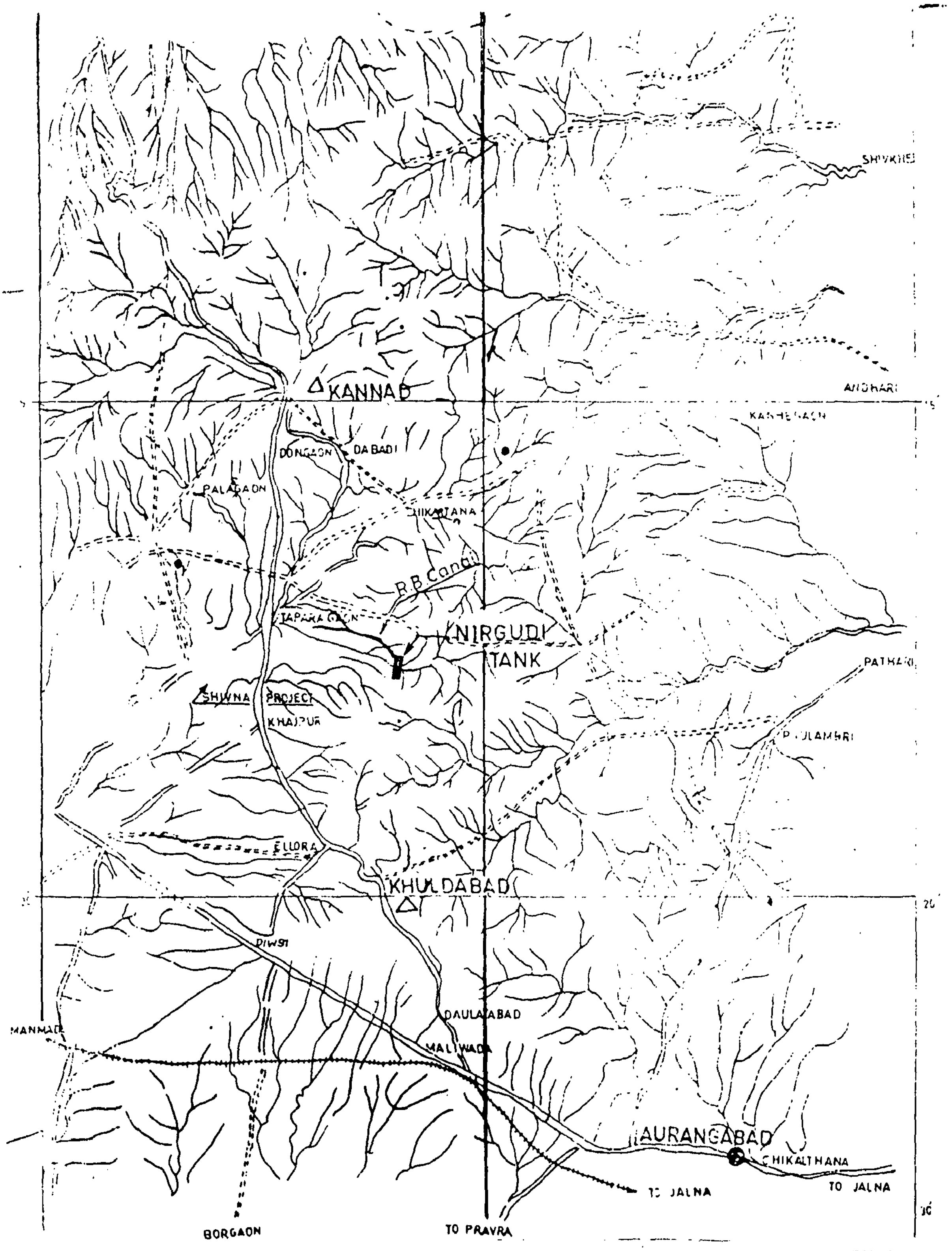
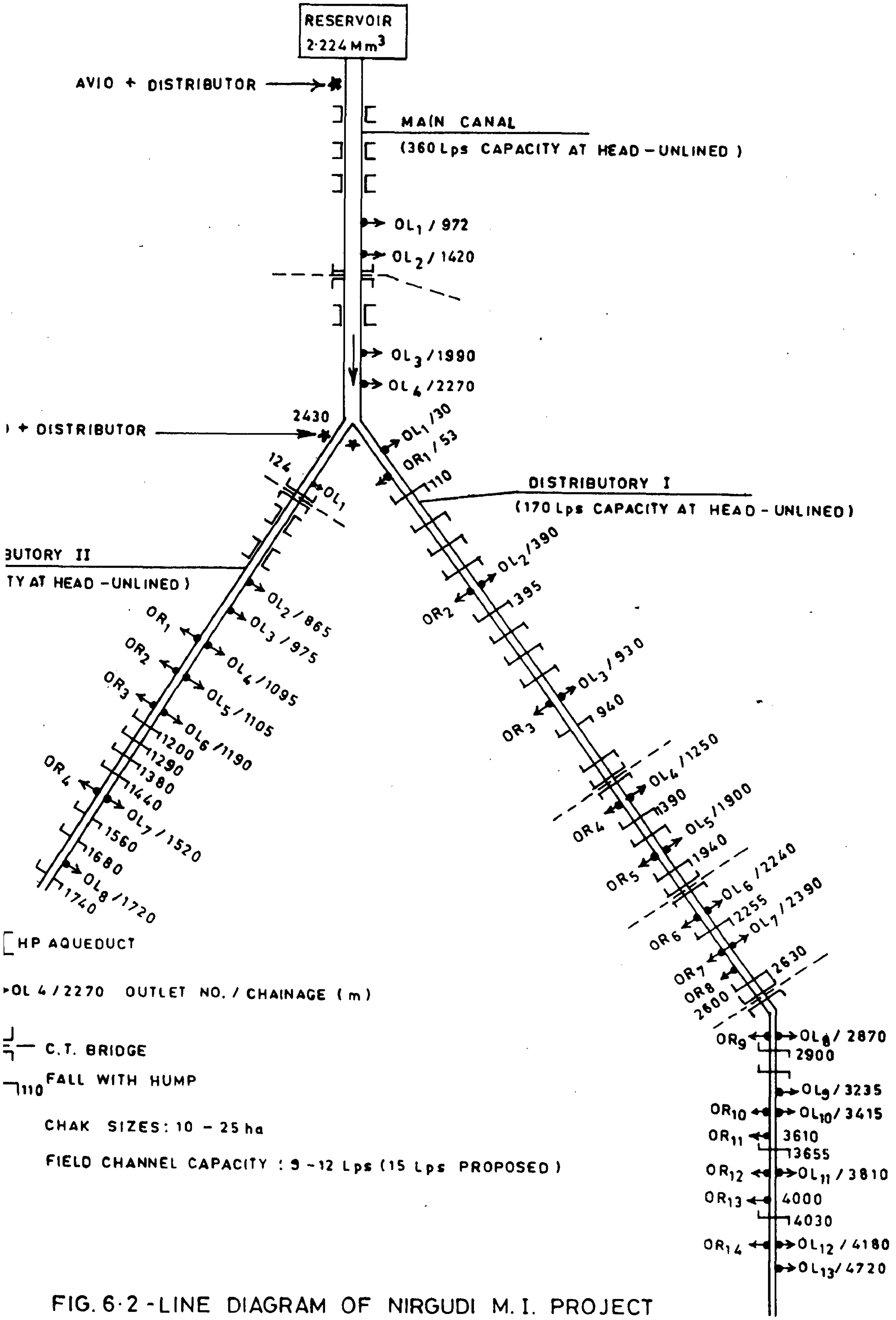


FIG 6·1 INDEX PLAN
NIRGUDI MINOR IRRIGATION
SCHEME
Taluka : Khultabad , District : Aurangabad .



CHAK SIZES: 10 – 25 ha

FIELD CHANNEL CAPACITY : 9 – 12 Lps (15 Lps PROPOSED)

FIG. 6·2 - LINE DIAGRAM OF NIRGUDI M. I. PROJECT
(NOT TO SCALE)

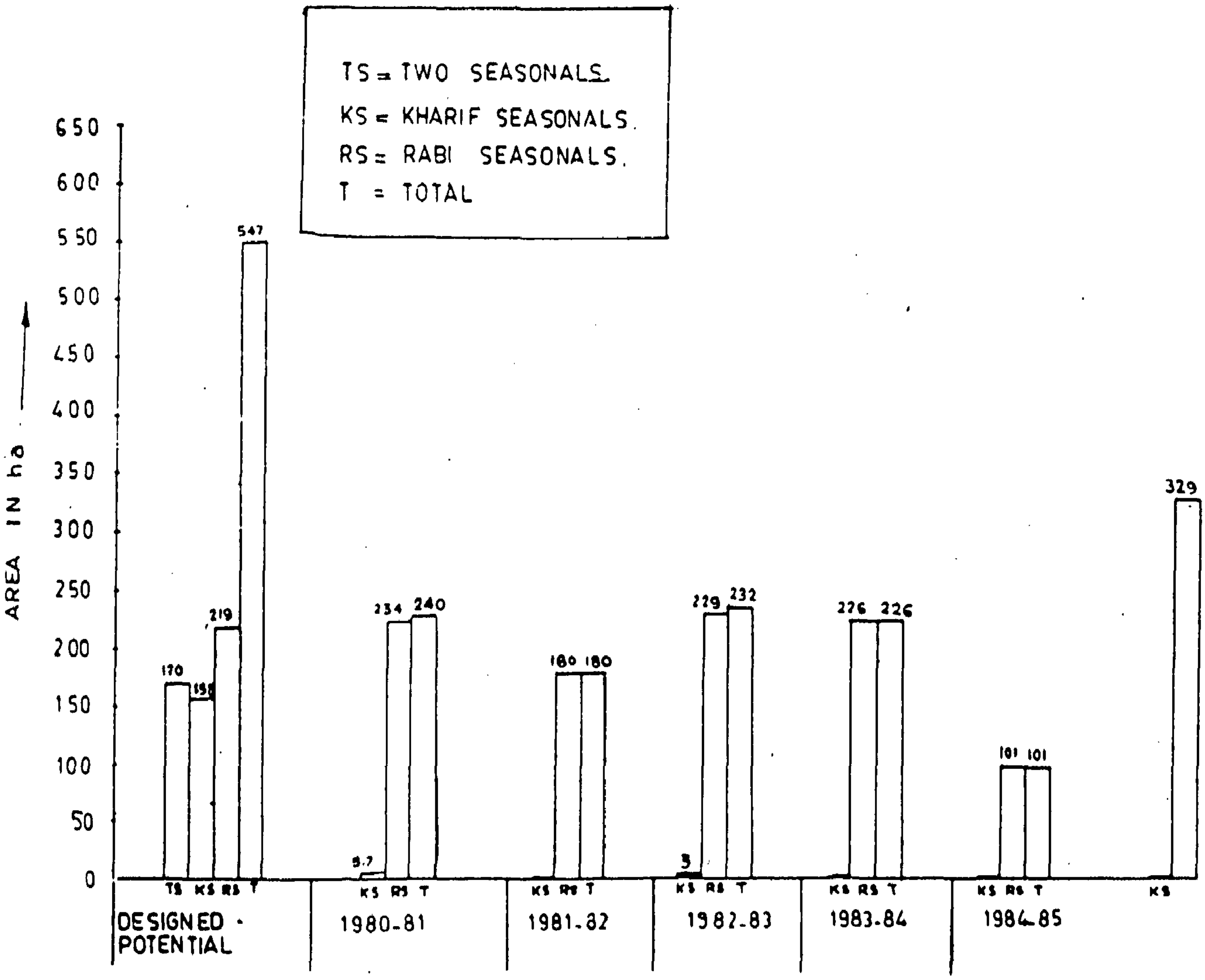
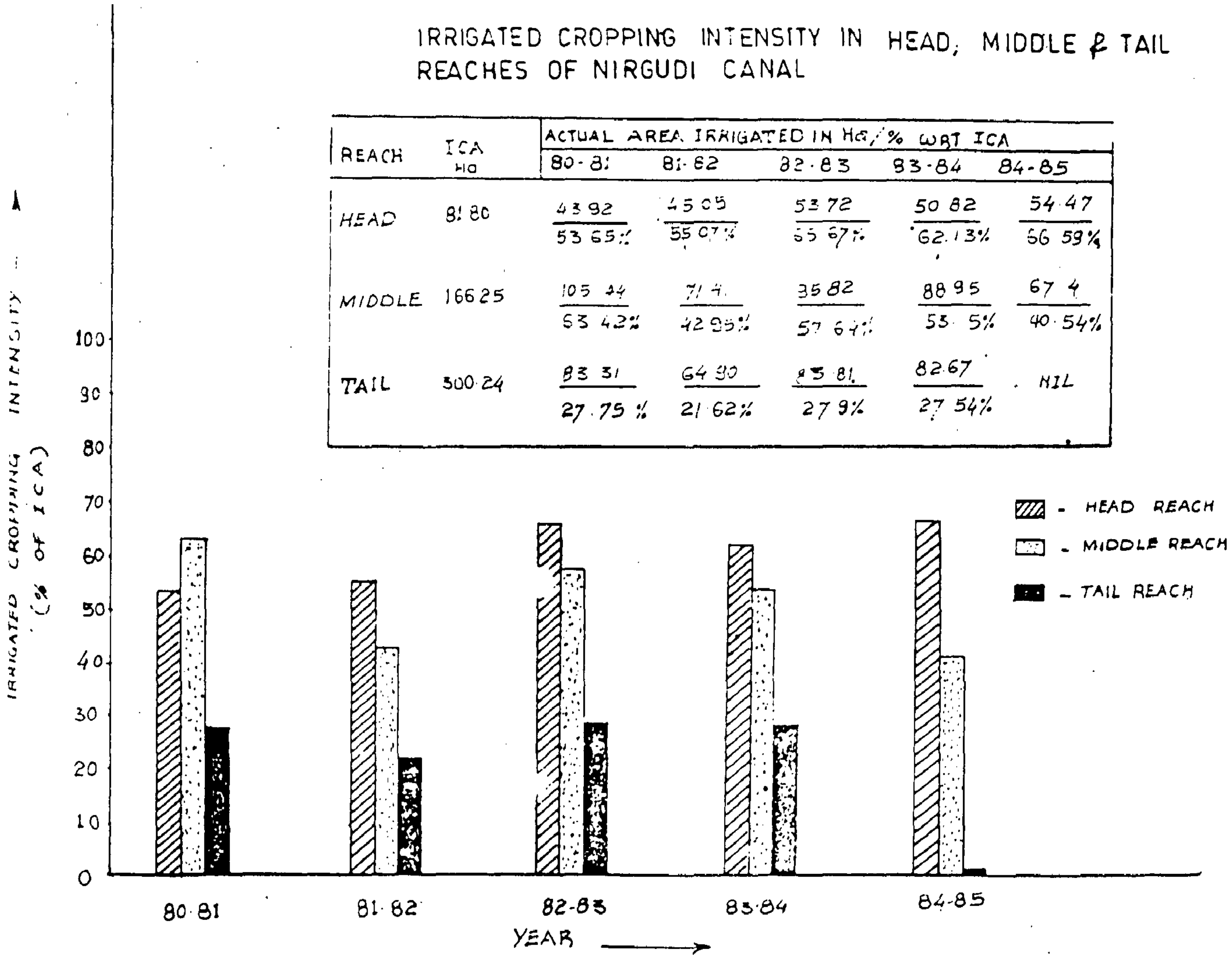


FIG. 6.3: YEARWISE UTILISATION OF POTENTIAL (NIRGUDI M.I. SCHEME)



IRRIGATED CROPPING INTENSITY IN HEAD, MIDDLE & TAIL REACHES OF NIRGUDI CANAL

REACH	ICA Ha	ACTUAL AREA IRRIGATED IN Ha/% WRT ICA				
		80-81	81-82	82-83	83-84	84-85
HEAD	81 80	43 92 53 65%	45 05 55 07%	53 72 65 67%	50 82 62.13%	54·47 66 59%
MIDDLE	166 25	105 44 63 42%	71 4 42 95%	95 82 57 64%	88 95 53· 5%	67 4 40·54%
TAIL	300·24	83 31 27·75 %	64 90 21 62%	83 81 27 9%	82·67 27 54%	NIL

Fig 6·4

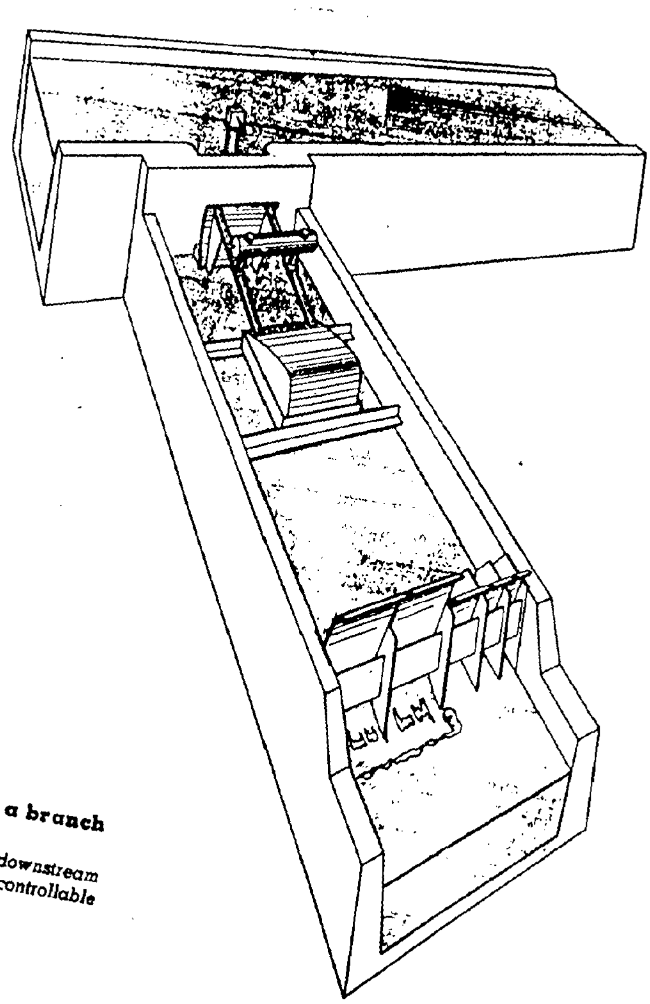
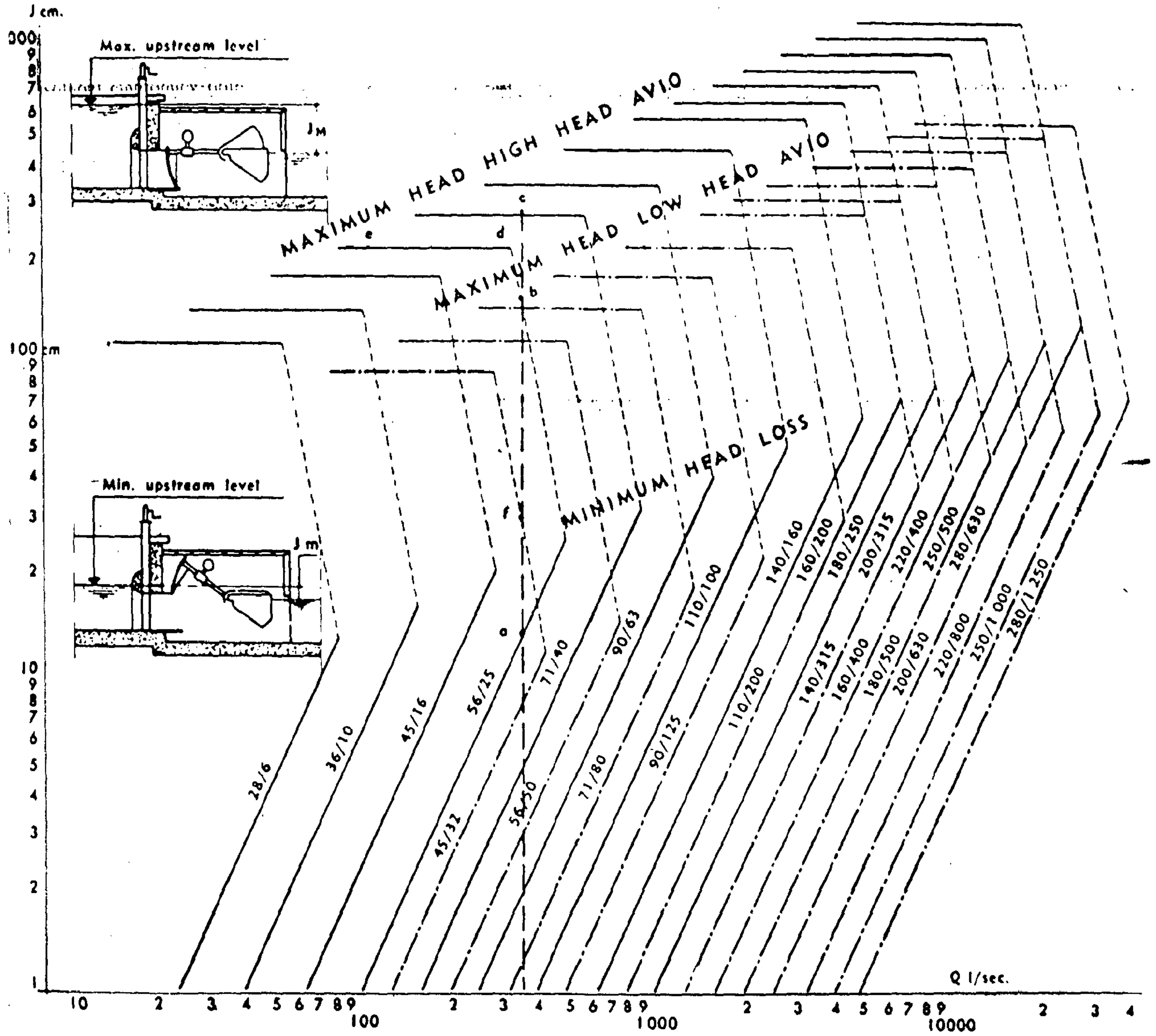


FIGURE 6·5

AVIO gate at the head of a branch canal.

If a set of distributors is installed downstream of the gate, the result is a fully controllable constant-flow offtake.

FIG 6-6 **Head loss diagram**



Note : The Operating points for a gate (Q, J) should *never* lie to the right of its characteristic line on the chart.

CHAPTER - VII

CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS :

7.1.1. Compulsions of Indian Irrigation:

Any decision regarding feasibility of Automation of Irrigation Channel in India must and should be taken giving due serious thought to the following well-known compulsions of Indian Irrigation :

- Scarcity of water and need to distribute shortage of water among large number of small farmers.
- Necessity of extensive irrigation to provide protection against famine.
- Need for positive discrimination in favour of large number of small farmers.
- Need to check unauthorised irrigation within reasonable limits.

7.1.2. Water Distribution Methods :

Considering compulsions of Indian Irrigation it appears that for surface irrigation with open channel flow 'Rotation' is the only W D M that can be thought of in India at least for existing irrigation projects. This is true for distribution system in general and below outlet in particular.

Main canal however need not be always operated strictly on Rotation basis. Principles of demand method can conceivably be incorporated in main canal operation. Upstream controlled Dynamic Regulation and Combination control are some of the ways to achieve this.

7.1.3. Canal Regulation Techniques :

Rotation method is possible only with either upstream control or at the most combination control. All irrigation systems in India have been designed and constructed for upstream control. Now switching over to another concept/technique would need conversion of existing systems which may be impractical and costly.

Various degrees of automation of either upstream - or combination - control can be achieved through the use of different Control Equipment.

Dynamic Regulation (combining essentially upstream control) can also be conceivably possible only for main canal of very big projects having assured water availability.

Any proposal for automation of only main canal would improve its own operation and thereby may help in improving operation of distribution system which would be under manual control.

Zimbalman's algorithm and CARDD hold promise for simple and workable solutions for main canal operation. However their field - verification reports are need to be studied in detail.

7.1.4. Control Equipment :

Upstream control, combination control, and upstream controlled dynamic regulation can be implemented by using one or the other control equipment either singly or in combinations.

Solution 'A' :

Out of the control equipment discussed, weirs (particularly diagonal, duckbill), hydromechanical gates (particularly AMIL, AVIS, AVIO) and modules offer a relatively low-cost, low-technology solution (say, solution A) for upstream and/or combination control. It does not require external energy and skilled manpower. These equipments have been in use since last 5 decades in at least 20 countries (not in India) and their performance is believed to be very good.

Solution 'A' will be particularly appropriate for minor and medium irrigation projects and for distribution system of major irrigation projects which otherwise will remain under complete manual control because electromechanical gates and computer controlled canal operation will not be feasible there because of cost considerations and complexities involved (scattered and numerous control points, social problems etc.)

Weirs are easy to design and construct. Neyrpic module for outlet has already been developed at MERI, Nasik and it is being tested in the field. AVIS, AVIO, AMIL gates are at present not manufactured in India but can be manufactured either by making some collaboration or by importing their know-how, if such policy decision is taken. Automation of irrigation systems does call for development of Irrigation Industry.

Solution 'B' :

Electromechanical gates and computer controlled real-time operation (say, solution - B) provide upstream controlled Dynamic Regulation or combination control. Solution 'B' will be most appropriate for main and branch canals of major irrigation projects. Solution - B is a high - cost, high-technology solution. It does make special demands such as realiable power supply and/or standby arrangements, skilled manpower, special and prompt attention towards maintenance and repairs, and most important of all, an efficient, proven, workable Control Software.

Computer controlled automatic systems have been successful in industry. Computers are not only being increasingly used but also manufactured in India. Development of sales/repairs service and skilled manpower appears to be only a question of time. Even alternative arrangement/sources for energy requirements should not be a very serious problem. However, development of control software is going to be a difficult and time consuming task. It calls for sustained efforts by interdisciplinary teams comprising of Irrigation Manager, hydraulic engineer, professional computer modellers and programmers.

The hydraulic problem of control software however needsa real break-through.

7.1.5. Canal Operation Hydraulics :

As far as solution 'A' is considered, though unsteady flow is involved in canal operation, the gates automatically get adjusted as per flow conditions. The canal operator himself does not have to do unsteady flow computations to adjust the gate positions. The point is solution 'A' for its implementation and operation does not necessarily require unsteady flow computations. That makes it more attractive, simple and immediately workable in existing set-up witn least demands on manpower and its skill.

In case of solution 'B' however gate positions and over all canal operation have to be controlled in Real - Time by computer through control software. And control software does necessarily require some unsteady flow considerations directly or indirectly.

State-of-the-art hydraulic simulation models consider unsteady flow conditions in direct manner aiming at complete solutions of Saint Venant's equations. In the process they become cumbersome and don't remain simple, understandable and workable for canal operation in Real - Time.

Simplified/empirical hydraulic simulation models help in the development of simple and workable Control Software.

This control software in itself does not contain solution of unsteady flow equations but it depends upon constant updating of actual hydraulic data through electronic equipment and its analysis by statistical procedures. Thus, it includes unsteady flow condition indirectly. It aims, and very rightly so, at simple and workable canal operation. Reportedly, it achieves its aim too.

7.1.6. Case Study :

In case of Minor Irrigation Projects, like Nirgudi, factors such as limited availability of water, steep bedslopes and small existing capacities of conveyance and distribution network, non-remunerative seasonal crops, etc. limit the choice of automation techniques. In such cases, the solution 'A' (hydromechanical gates and modules) will be more appropriate.

7.2. RECOMMENDATIONS:

(i) Semi - Automation of Irrigation Channel using hydromechanical gates (AMIL, AVIS, AVIO) and Neyrpic modules may be tried on some minor irrigation Project.

(ii) Possibility of manufacturing hydromechanical gates and modules in India may be explored.

(iii) Research efforts may be concentrated on the development of control software for Real - Time canal operation using simplified/empirical hydraulic simulation models.

(iv) Subject of Automation of Irrigation Systems including some practical aspects of Unsteady Flow and Control System Engineering may be introduced in Post Graduate courses on Water Use Management.

(v) Design and Construction procedures of Controlled Volume Concept, being tried on Narmada Canal, may be made available to researchers.

(vi) A study group may be formed at appropriate level to formulate a comprehensive policy on Automation of Irrigation Systems and coordinate the work and research on Automation in India.

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