REMODELLING OF UNLINED IRRIGATION CANALS AND STRUCTURES

A REVIEW

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Certified that the dissertation entitled "Remodelling of Unlined Irrigation Canals and Structures" which is being submitted by Shri P.Venkata Rao in partial fulfilment for the award of Degree of Master of Engineering in Water Resources Development of the University of Roorkee, is a record of the candidate's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or Diploma, to the best of my knowledge.

This is to further certify that he has worked for a period of over one year and one month for the preparation of this dissertation from October 1975 uptill now.

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SYNOPSIS

Many major irrigation canal systems in India were built long ago when engineering technology was little known. These systems are suffering from inadequacies of supplies due to ever-increasing demands on account of changing cropping patterns apart from the variety of defects in design of canals, headworks and related structures. To fulfil the national objective of increased agricultural production, the improvement of irrigated agriculture is to be achieved not only by construction of new projects to harness the supplies to provide facilities to newer areas but also by increasing the efficiency of the old systems through suitable remodelling to fit in with the changed demands duly rectifying the defects also.

The need for modernisation of existing systems arise from changed conditions in respect of cropping patterns to increase the level of service and water use management within the command. The object is to optimise the benefits of agricultural production with the supplies available in the system taking advantage of the modern concepts of design and those of irrigated agriculture. It envisages improvement of water use efficiency and level of service through suitably remodelling the system.

In some cases, existing systems are remodelled with increased supplies to meet the large increases in demand due to inclusion of vast areas and contemplation of intensive irrigation. In such cases, additional supplies have to be arranged either from a storage or from other basins. The problems are different from those in modernisation.

Consequent on remodelling or modernisation of the systems, the structures are also to be remodelled to be safe against revised operating conditions, apart from their defects and deterioration on account of their long lives.

In this dissertation, an attempt is made to review the problems in the existing systems causing the necessity of modernisation or remodelling of canals and their structures, the different methods that can be adopted to solve such problems and the decision making process to select the best alternative plan. The discussion is concluded with the few case histories of remodelling works and, findings and recommendations of the author for future study.

CHAPTER 1

I N T R O D U C T I O N

1.1. Development of irrigation for agriculture.

1.2. History of Development of irrigation.

1.3. Irrigation systems.

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CHAPTER 1

I N T R O D U C T I O N

1.1. DEVELOPMENT OF IRRIGATION FOR AGRICULTURE

Irrigation is the art and science of artificial application of water to land for the purpose of raising the crops successfully.

Seventy per cent of India's population depends on agriculture directly for their living. The population of India is increasing at the rate of 2 per cent per year and at present rate of growth it is expected to be 90 crores at the end of 20th century. To meet the demand of food production for the growing population, agriculture is to be developed in India.

The rainfall in India is precarious and scanty. Its distribution is variable in amount and space and is not adequate to meet the requirements of crops. Considerable parts of India are often subjected to drought and famine conditions. Failure of crops due to drought conditions is common. The problem cannot be handled without means of irrigation. Therefore, irrigated agriculture is to be developed.

Luckily, India has got most thirsty tracts of lands of about 81.7 million hectares in which irrigation potential is proposed to be created before the end of 20th century.

The utilisable surface water resources are 66.6 million hectare metres and the utilisable ground water resources are 20.36 million hectare metres according to approximate estimates as per Report of Irrigation Commission, 1972.

1.01.2. History of Development of Irrigation

Irrigation in India is contemporary with the dawn of civilization. When man started settling down in groups or communities, he started practicing agriculture. In India, the earliest settlements were along the banks of rivers like the Indus, Ganga and their tributaries where the flood plains along the river course were irrigated by 'Sailab' or inundation annually during the flood season.

In due course small and then larger inundation canals were built in order to draw off the flood waters for irrigation of areas further in land from the river bank utilising suitable creeks or arms of the river for the purposes.

With the passage of time, a number of these early canals came to be enlarged and developed into fairly large inundation canal systems which to this day irrigate and protect hundreds of thousands of acres of land against scarcity and famine, as for instance, the inundation canals of the Multan, Muzaffargarh and Dera Ghazikhan districts of West Punjab and numerous large inundation canals in Sind (now in Pakistan).

In the alluvial plains of North India and the coastal belts of Southern India where the country is flat, it is not possible to form the tanks to collect the rain water. The flat nature of the country is ideal for carrying water over ~~large~~ long distances by means of canals for flow irrigation.

The deep and porous alluvial soils were also found to hold plentiful supplies of under-ground water at moderate depths, which could easily be exploited for the purpose of irrigation. Well irrigation was practiced using indigenous water lifting devices.

In Central and Southern parts of the country, it is not easy to construct wells where the underlying sub-strata is hard usually rock. Hence, number of storage tanks and reservoirs have been practiced in these regions from earliest times to this day. Wells alone account for nearly 30 per cent of the total irrigated area and tanks for another 17 per cent.

In a few comparatively small areas particularly in Assam where rainfall is abundant and almost assured few small irrigation works were constructed. In the rest of the country, artificial irrigation is necessary for protection against scarcity and famine although irrigation has been widely practiced all over the country from the earliest times. It is only during the last 150 years or so that great strides have been taken towards harnessing mighty rivers and exploiting on a large scale the under-ground water resources in order to develop irrigation for agricultural production.

Thus, we see that in the early times and right upto the end of 18th century, the emphasis in India was on irrigation from inundation canals or from wells and tanks. The Grand Anicut in the Cauvery River Delta in South India built in the 2nd century A.D. and some canals with temporary head works in the Punjab and Uttar Pradesh built by the Mohammedan Rulers, were however, exceptions.

In the early 19th century, the British ventured to construct large irrigation canal projects and they made a start with improving and enlarging three existing canals which had earlier fallen more or less into disuse via Western Yamuna canal in the Punjab and the Eastern Yamuna Canal in Uttar Pradesh and Cauvery delta system of canals in Tamilnadu.

These early projects proved successful. Based on them, a number of bigger projects utilising the run-of-the river supplies such as Upper Ganga Canal, Upper Bari doab canal, the Godavari Delta Canals, the Sirhind Canals etc. were undertaken.

In the case of early canal projects no permanent head works were constructed. These temporary diversion bars across the river bed were washed away during the flood season in the case of Western and Eastern Yamuna Canals, Upper Ganga Canal and Upper Bari Doab Canal.This led to the construction of permanent diversion blocks later on.

In due course with greater experience, several improvements were effected in the design of diversion works leading upto the modern river barrages which give complete control over the regulation and flow of river supplies.

In 20th century, many irrigation projects were taken up. Most of them were productive works. Some were meant for the protection against famine also. Some among the productive works were

1. Tribeni Canal Project in Bihar
2. The Godavari Canals
3. Pravara canals and Nira Right Bank Canal in Maharashtra
4. Sarada Canal Project and Wein Ganga Canals in Uttar Pradesh.
5. Mahanadi Canals in Madhya Pradesh.

After Independence in 1947, it was recognised that expansion of irrigation for agricultural production is essential to make the country self sufficient in food production. It gave birth to the concept of irrigated agriculture. Some of the main projects that were taken up in the three Five-Year Plans to achieve this objective are:

1. Bhakra Nangal Project
2. Rajasthan Canal Project
3. Chambal Project, and
4. Nagarjunasagar Project.

~~1.0~~1.3. Irrigation Systems

Irrigation systems can be broadly classified as

1. Gravity systems
2. Pumped systems.

In case of irrigation from gravity systems, water to the land to be irrigated is through gravity canals or water courses. This is accomplished either from storage or/and diversion works. In gravity systems, regular or seasonal supply of water is provided. Such systems are sub-divided into the following three types:

i) Inundation systems

ii) Perennial systems

iii) Seasonal systems.

i) Inundation irrigation canals are non-perennial canals where irrigation is done by direct flooding of land for moisture retention in the soil to grow the crops in the area. These floods may contain rich alluvial soil or silt; only during flood season, this method can be adopted with advantage.

ii) When water is made available for both the crop periods, it is called perennial system. The cost of irrigation is less in this case as water is supplied with smaller operation and maintenance, cost. In this method water-logging may result owing to excessive use of water and so drainage facilities have to be provided as an integral part of the overall scheme. In Northern India where the rivers are perennial due to augmentation of supplies from snow-melt during dry weather from Himalayas, All irrigation canal systems are perennial gravity systems whether from diversion or storage. In South India where rivers are non-perennial many reservoirs have been constructed for stabilising the flows in non-monsoon season to provide perennial irrigation systems.

(iii) In the perennial rivers where the diverted waters meet the demand for raising crops in both seasons, there may be supplies still available in the monsoon period. The supplies can be utilized for constructing seasonal canal systems to serve the additional areas in Kharif season. Where ground waters are harnessed or can be harnessed, these systems can provide possibilities of recharge to provide additional ground water resources.

In case of pumped systems, water is lifted up from the source (river, or canal or tank or ground water) and then taken in channels. Pumps and other devices are to be operated and maintained. Thus, irrigation from pumped schemes is more expensive and requires more labour and time.

1.4. DESIGN OF IRRIGATION SYSTEMS

The main factors governing the design of an irrigation system are:

1. Supplies available
2. Needs, and
3. Structures needed for implementation.

The demand is fixed after studying various alternatives of possible cropping patterns likely to develop. While arriving the supplies available for utilisation, the constraints such as existing use, prior rights, inter-state compacts and inter-national treaties are kept in view. Various alternative methods or combination of methods are then considered to utilise the available supplies for meeting the projected demand. The alternative which maximises the benefits and meets the objective best is selected. The aspect of selection of suit-table alternative is dealt with in the foregoing chapters.

The changing conditions which affect the future irrigation needs have to be considered and provision has to be made to cater for the future development possible. If consideration is not given to flexibility of demands at the time of planning, remodelling ofthe system may often be necessary due to increased demands at a later stage.

1.5. SCOPE OF THE DISSERTATION

The main object and scope of this dissertation is to present a review of methods of planning and selection of methods or combination of methods for remodelling the irrigation systems.

The situations under which remodelling is contemplated are brought out in Chapter 2 citing the practical examples wherever possible. Various methods of remodelling the channel sections are reviewed in Chapter 3 which includes introduction containing the various theories of design of channel sections to appreciate the scope of various methods. In Chapter 4, the problems in the modernisation of existing systems and the methods of modernisation are discussed. In Chapter 5, the problems in remodelling of irrigation systems with increased supplies with the solutions are dealt with. The generation of various alternatives and procedure for selection of the best alternative has also been studied in Chapter 5. The design of structures on the canal is a vast subject & has been only introduced as Chapter 6 in this review to give an outline of the required remodelling works. In Chapter 7, some case histories are included for better understanding of the methods. Chapter 8 gives the summary, conclusions and recommendations along with the areas where further work can be taken up.

CHAPTER 2

NEED FOR REMODELLING

2.1. General

2.2. Demands and their pattern.
Increase in scope - High yielding varieties of crops - Intensive irrigation and multiple cropping-water management.

2.3. Technological problems.
Design of channel - Design of structures - Conjunctive use of ground and surface waters - Lining of canals and provision of drainage system as integral part.

2.4. Other problems.

CHAPTER 2

NEED FOR REMODELLING

2.1. GENERAL

To achieve the self-sufficiency in food production for the growing population, the government is providing facilities of irrigation to the farmers to increase the agricultural production. Government is also giving incentives for the same. Therefore, demands of water for agriculture due to increased areas coming under cultivation and change of cropping patterns, are increasing on the existing canal systems and remodelling of existing systems has thus become necessary to cater for increased demands.

Use of improved water management and better agricultural practices have also dictated the need for modernisation of systems.

Many existing irrigation systems suffer from variety of problems such as inadequacies in design of canals, their head works and other structures due to limitations of technology at the time of their construction. There has been great advancement in technology in recent years which can be adopted to advantage to remedy the defects in existing systems and to render them safe under all operating conditions. Further, the adoption of method of conjunctive use of ground water and surface water has made possible increased use of water resources. Also increased supplies become available from lining of the canals and water courses. All these factors have also necessitated remodelling of canal systems in many cases.

2.2. DEMANDS AND THEIR PATTERN

2.2.1. Increase in Scope -

The scope of some of the existing canal systems may increase due to

i) inclusion of waste lands and reclaimed saline and water-logged areas within the gross command

ii) provision of pumped canals with pumping plants for lifting water from the gravity canals to provide facilities to higher lands in the gross command or in adjoining areas,

and iii) extension of the canal systems to provide irrigation facilities to newer areas which were not envisaged originally. In such cases, remodelling becomes necessary to cope up with the increased demand.

For example, the original scope of the Krishna Delta canal system has changed from 6 lakh acres of irrigation area to 12.25 lakh acres in a period of about 100 years and hence remodelling of the canal system had been contemplated from time to time.

2.2.2. High Yielding varieties of crops -

Due to advancement of agricultural research in recent times, high yielding dwarf varieties of crops have come on the scene. These dwarf varieties require more frequent waterings than the indigenous varieties. They cannot however sustain drought-conditions as the indigenous varieties can, and therefore constant supply is necessary in their case. Though the crop period and the total requirement of water may somewhat be reduced, assured water supply through the canal system is necessary for the successful growth of these crops. Thus, the introduction of these varieties require remodelling of system.

2.2.3. Intensive Irrigation and Multiple Cropping

In the earlier irrigation systems constructed in pre-independence era before 1947, the schemes were to pass the productivity test for financial feasibility which implied the concept of protective irrigation. These systems have extensive commands and catered for the intensity of irrigation seldome exceeding 100% of culturable command area. In view of the objective of irrigation having changed after independence to increased agricultural production for self-reliance, the present trend is in favour of the maximisation of the benefits by adoption of intensive cropping patterns with multiple cropping. Intensities upto 150% of culturable command area and more are now being considered. This intensity of cropping can be achieved with more irrigation facilities and greater use of chemical fertilisers and other inputs.

In almost all the ancient irrigation systems in India, the entire command area within the main drainage lines is already covered by the canals and there is little scope of further increase in command area. Where the supply position can permit, intensive cropping patterns with multiple cropping alongwith the use of high yielding varieties of crops can only be adopted. This can be achieved with increased water supplies from storage reservoirs or diversion from other basins. For example, in Sarda Sahayak Project, the non-monsoon flows of Ghaghra River are diverted into Sarda River and extensive irrigation at the tail end and intensive irrigation under old Sarda Canal system are contemplated. The existing canals are remodelled as follows:

1. Daryabad branch canal 2 to 242 cumecs
2. Barabanki branch canal 11 to 36 cumecs
3. Haidergad branch canal 31 to 165 cumecs
4. Raibareilli branch canal 13 to 30 cumecs
5. Purwa branch canal 34 to 147 cumecs.

Possibilities of exploitation of ground water resources for conjunctive use with surface water are to be examined in such cases.

2.2.4. Water Management -

In certain systems, the above problem of land has further been coupled with the limited surface water resources. In such cases, the water use efficiency has to be improved. The solution lies in economising the use of water resources by adoption of better water and crop management practices and also in reducing the transmission losses in the unlined canals which are about 30 to 50% of head discharge of the canal. The water so saved can be utilised for intensive cropping pattern with multiple cropping. To achieve it, remodelling and lining of canals and water courses becomes necessary.

For example, the Krishna Delta Irrigation Canal system has limited water resources of 181.2 T.M.C(as per award of

Inter-State River Water Dispute Tribunal) and available land is only (12.25 lakh acres) which can not be increased further. Therefore, there are constraints of both land and surface water resources. The water use efficiency of the system is proposed to be increased by adopting water and agricultural management practices and lining the canals. High cropping intensity with multiple cropping is recommended by the water management Division, Ministry of Agriculture, New Delhi for adoption as follows:

	Low level areas	High level areas
1st crop	Paddy	Paddy
2nd crop	Paddy	Irrigated dry.
3rd crop	Pulse/Fodder	Pulse/Fodder.

2.3. TECHNOLOGICAL PROBLEMS

2.3.1. On account of advancement in technology, the concept of planning and design has drastically changed necessitating the remodelling of canals as follows.

2.3.2. Design of Channel

When modern theory of alluvial channels were unknown in the 19th century, Sir Proby Cautley took up the construction of Ganga Canal system in Northern India and Sir Arthur Cotton took up the construction of Cauvery, Krishna and Godavari Canal systems in Southern India. The design of canals have undergone significant development. It was in 1895 that Kennedy published his classic empirical equation correlating the mean velocity in regime channel with the vertical depth D. It was Lindley, who in 1919, introduced the width of a channel as a regime variable and thus made a valuable advance in regime theory. In 1929 Lacey evolved classic equations for the design of a regime channel. Two major attempts to develop a more rational theory have been made in U.S.A; one based on a stable bed at the threshold of moti8n and other on a live bed condition. The former has been developed by U.S.B.R. commonly referred to as "The Threshold Tractive Force Theory", while the later based on Einstein's bed load equation has been used by Wing Chein to determine channel dimensions, given the discharge, slope, bed material and sediment load.

The design of a channel section, according to the present concept, not only depends upon the discharge, silt load, topography and type of soil but also depends on the problem of silting or scouring or silting and scouring encountered in each case. The channel section may have to be remodelled to mitigate these problems.

2.3.3. Design of Structures

There has been technological advancement in the concept of design of masonry structures. Based on Khosla's seepage theory of uplift pressures and exit gradient derived on "Principle of independent variables", the use of sheet piles for cut off has made it possible to design the regulating structures safe against piping and consequent undermining. Due to advancement in soil mechanics, provision of reverse filters on the downstream side of structures has helped to reduce the chances of scour on the downstream of structures such as barrages, regulators, cross drainage works and drops. The development of concrete technology and advent of colcrete and other special concretes resulted in improvement of technology for laying concrete under water. Raft foundations are being adopted for the barrage floors in certain structures. Rational devices for dissipation of energy of flowing waters downstream of barrages, weirs, drops, regulators etc. have been evolved to avoid the possible danger of damage. Now, more knowledge is available to control entry of silt into the canal. The technique of still pond regulation at the barrages has also made it possible to control the entry of silt into the canal. Further, silt excluders, silt ejectors, desilting basins etc. have come into use to handle the silt problem. The evolution of these new techniques has changed the concept for design of structures.

The structures which had been constructed long time back with the inadequate engineering technology available at the time of their construction or have outlived their life have to be remodelled or reconstructed suitably based on present day standards of technology.

The structures originally designed for a particular discharge have also to be remodelled to provide for the increased discharge which the canal may now cater.

2.3.4. Conjunctive use of surface and ground water

Conjunctive use of ground and surface water is being advocated for existing as well as new systems for the following reasons:

1. Use of ground waters in conjunction with surface supplies for increased supplies and stabilised flows.
2. Availability of increased use due to recirculation of supplies.
3. Possibility of artificial recharge of aquifers during high surface flows for use in lean periods.
4. Reduction of drainage and water logging problems due to lowering of the water table.

The ground water can be exploited by means of:

1) Open well
2) Shallow tube wells, and
3) Deep tube wells.

Open masonry wells using mechanical and man power by the farmers are on increased use to supplement canal supplies in North India as well as South India. In South India, it is being adopted for growing sugar-cane. In Cauvery, Krishna and Godavari Deltas, privately owned shallow tube wells (locally called filter points) have been constructed on a large scale with a view to raise the seedlings early in June before the canal system is opened and also use them whenever necessary. These can be independently planned without mixing the ground water and canal water. But, deep tube wells can be planned independent of canal system or to augment the canal supplies by constructing tube wells along the bank of main canal or distributories to mix it with canal water. In Western Jamuna canal system in Haryana State, deep tube wells have been constructed along the canal (100 Nos. of deep wells with total capacity of 5.6 cumecs.)

Where ground water is brackish, saline ground water can be used after mixing it with good and sweet canal water as recommended in West Pakistan Study and as adopted in U.S.A and Isreal.

Thus, the conjunctive use of ground and surface waters has changed the concept of planning and may often require remodelling of the canal for increased discharges or changed cropping patterns.

2.3.5. Lining of Canals and Provision of Drainage System as Integral part.

(a) Lining of Canals - As per old concept of planning, lining of canals is mainly intended to reduce the seepage losses in porous sandy soils and fissured rocky cuts. Now, lining is being provided in many canal systems linked with conjunctive use, water management and drainage based economic use of water resources.

When ground waters are of low quality consequent upon high intensities of irrigation on systems of long standing problems of drainage and water-logging may become paramount. In such cases, lining is very helpful.

(b) Drainage - As per the old practice, drainage facilities in the command area were not provided along with the construction of canals. The problem of drainage was dealt with as and when the problem arose.The inter relation between irrigation and drainage was seldom thought of at the time of construction of irrigation projects. The present day concept is that drainage is an integral part of irrigation project planning.

Due to inadequate drainage facilities in some existing systems, the water table has risen sometimes to an extent that it encroaches upon the root zone of the crops leading to water-logging and thus reducing the crop yields and sometimes making it impossible to raise the crops.

2.4. OTHER PROBLEMS

The canals which were constructed long ago may not cater the needs in the command area originally envisaged owing to defects in the aligmments, channel designs or non-provision of lining in highly pervious portions of channels.

When the first great canal projects like the Western Yamuna Canal, The Cauvery Delta Canals, the Upper Ganga Canal or the Upper Bari Doab Canal were undertaken during 19th century the designers and builders had no experience or precedents to guide them in their mighty undertakings. They are pioneers in their respective fields of endeavour and they learnt by trial and error as they went along.

The original alignments of canals, their bed slopes and designs of canal falls had to be revised subsequently in order to rectify the defects which became apparent when the canals started functioning.

Faulty aligmments of canals which passed through depressions led to water logging and malaria in the surroundings and thrown some areas outside the command. To rectify these defects, the aligmment has to be changed.

The channel section originally designed is found to be inadequate now to pass the discharge contemplated due to adoption of lower value of coefficient of rugosity 'N' or incorrect value of Lacey's silt factor f. Some of the canals designed in the rocky cuts of South India have failed to carry the envisaged discharge due to lower value of 'N' then 0.03 to 0.05 for rocky cuts. Thus, the canals are redesigned and remodelled accordingly.

Similarly, channel, shallow and/or with flat slopes had been provided in some cases, which resulted sluggish velocities of flow. There is a problem of weed growth in these canals, specially in case of canals with seasonal supplies of clear water.

In some of the old canal systems lining was not provided even in the reaches where it was indicated due to abnormal percolation and seepage losses. As a result of this, the proposed discharge did not reach the lower reaches and the canal could not meet the demand. In such cases, remodelling of the canal has become necessary with the provision of lining. For example, in Kurnool, Cuddapah canal in Andhra Pradesh which takes off from the Tungabhadra River, the transmission losses in the Ist reach of 75 miles [120.7 km] are found to be 1000 c/s [28.3 cum] out of the head discharge of 1500 cusecs [42.45 cumecs] i.e. 2/3 of the head discharge. The canal runs throughout in a tract where the subsoil is shale and slate in layers badly fissured horizontally and vertically. Hence, the remodelling of the canal was contemplated.

CHAPTER 3

METHODS OF REMODELLING THE CANAL

3.1. Theories for design of Canals

3.2. Different approaches.

- 3.2.1. Increasing the bed width
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3.4. Lining of the channel.

3.5. Construction of parallel channel.

3.6. Situations for preference of a particular method.

CHAPTER 3

METHODS OF REMODELLING OF THE CANALS

3.1. THEORIES FOR DESIGN OF CANALS

Knowledge of various theories in vogue for design of channels is necessary to appreciate various methods of remodelling canal sections for revised design discharge to cater for the demands. Theories of design of canals have therefore been reviewed here.

The theories that are applicable depend upon the classification of soils and the problems encountered.

Based on classification of soils, the channels can be broadly classified into 2 categories:

1. Channels in alluvial soils
2. Channels in non-alluvial soils

In alluvial channels, depending upon the fluctuation of velocity of flow, the canal gets silted up during the period of low velocities and scoured during the periods of high velocity of flow. That means the bed is moveable. Therefore, the aim of the designer is to provide a stable channel for a particular designed discharge allowing the non-silting and non-scouring velocity of flow.

In the case of non-alluvial soils, thebed of the canal consists of harder strata and is resistent to scour. Higher velocities than in the alluvial soils which can be provided without scour of bed and sides, can be allowed.

Based on the type of problem to be encountered, the channels can also be classified into 3 types as follows:

1. Channels in which there is a problem of scouring without silting.
2. Channels in which there is a problem of silting due to objectionable sediment deposits, and
3. Channels in which there are problems of scouring and silting also.

In the first type of channel, the problem arises when water containing little or no sediment flows in an unlined canal system in alluvial material. Such water may collect sediment by scouring and cease to be sediment free. This situation can be met with canals taking off from storage reservoirs.

In second class of channels, the problem may commonly occur when sediment laden waters from diversion head works enter a canal with lined section or having scour resistent bed.

In the third case, the canals in alluvial soils getting the supplies from diversion works fall into this category.

The following main theories of design are prevalent:

1. Kennedy's method
2. Laceys method
3. Design of non-~~silting~~ Scouring channels.
4. Design of non-silting channels.

The first two are applicable for channels in alluvial soils. These are based on empirical formulae derived after studying various channels in alluvium.

The third is developed in U.S.B.R. by Lane where the problem of scour is commonly encountered due to supplies from reservoirs constructed by them. The main principle is that the scour commences when the forces acting on the particle on level bed or bank are sufficient to cause its motion. It is based on tractive force theory.

The design of non-silting channels is based on rate of transport of bed load in a channel. The main principle is that part of the sediment gets deposited on the bed mostly in head reaches if the coarser sediment (bed load) enters the canal at a rate greater than its carrying capacity. Various equations have been suggested for determining the rate of bed load transport. The most widely used equations are:

1. Mayor Peter equation is based on experimental work carried out at Federal Institute of Technology, Zurich.
2. Einsteins Equation is rationally derived on principles of ~~statistics~~ statics and also involves a number of assumptions.

The use of the above design practices can be approximately generalised as follows:

1) Lacey's formulae are applicable to regime channels in alluvial soils with moderate quantity of solids

passing through the canal as bed load. Lacey's regime channels are found to transport about 15 to 30 P.P.M of silt in most cases. Where the conditions of silt charge are widely different, Lacey's equations can not apply. Lacey's channel is shallow with flat slope. Therefore, it is to be used where the ground slope is flat and when commendability is difficult.

2) Kennedy's equation and Chezy or Kutter or Mannings equation can be used in alluvial as well as non-alluvial soils.

3) When there is no problem of silt and prevention of scour is the only criterion, Lane's method of design of non-scouring channel is to be adopted.

4) When the bed load to be transported is more than 30 P.P.M, sediment transport formulae are utilised to design the channel section. Meyer Peter's and Einsteins equations may give different channel dimensions and slopes to carry the same charge and sediment load. It may be noted that the sides of a channel may start scouring due to higher velocities. Therefore, the channel sections using these formulae are designed with a provision of stabilisation of the slopes.

If the silt concentration is high, it may not be possible to adopt the steep slope worked out by using these formulae as the ground slope is flatter. In such cases, a silt ejector or a silt excluder at head may have to be provided such that the silt entry into the canal is reduced to the level equal to the silt transporting capacity of the channel at the available slope.

3.2. DIFFERENT APPROACHES

The discharging capacity of the existing channel can be increased by different methods. Each method has got certain advantages as well as disadvantages. Therefore, careful selection of the method to increase the carrying capacity of the channel is essential keeping in view the economics and the suitability with reference to the actual problems in a particular case. The following are the usual methods of adjustment of canal section:

1) Increasing area without change of surface slope:
   a) Increasing bed width
   b) Increasing full supply depth at the same or lowered bed level.
   c) Increasing both full supply depth and width of channel
2) Increasing area with change of surface slope.
3) Lining of the channel.
4) Construction of parallel channel.

The improvements to the structures will also be necessary consequent on the increase in discharge of the canal. The magnitude of the improvements to be carried out to the structures will depend on the method of remodelling the canal section.

3.2.1. Increasing the bed Width

By adopting this method, the B/D ratio increases. In portions where the existing alignment passes through an area with high subsoil water table and where further increase in the level of water table may create the trouble of water logging, it is better to widen the canal instead of increasing full supply depth in the canal. In case of substantial increase over existing discharge, this method is not preferred as B/D ratio will then become unfavourable for a good discharging section. It would not serve the purpose to improve the commandability or to improve the sediment transport capacity.

Example - In the phased programme of the Nagarjuna Sagar Left Canal, it is planned to increase the first phase discharge of the Bonakal branch canal by widening the canal. The alignment passes through stiff black cotton soils with high water table and the topography of command area is flat.

3.2.2. Increasing the full supply depth at same or ~~lowed~~ lowered bed

Increase in full supply depth without increasing the bed width will result in slightly higher velocity of flow in the canal and thus scope of its adoption is dependent on the type of soil through which the canal passes. If bed level is unaltered and full supply level is increased, it may improve the commandability of the channel and is adopted where new inclusions of ayacut are contemplated in remodelling or in situations where there is difficulty to command the existing culturable command area. Higher full supply level increases the percolation losses and seepage losses especially where there are embankment reaches and creates favourable conditions for water-logging. Therefore, it can be adopted with increase of full supply level where the water table is low and where there is little possibility of water logging depending on the type of soils in the command area and slope of country. However, the available head is high and there are more chances of wastage of water. When the increase in discharge is substantially more, the channel section becomes narrow as B/D reduces to a value less than that prescribed for a good discharging section. Hence, it is not applicable insuch cases.

As the channel to be excavated is narrow compared to depth, the width being unaltered, the sediment to be transported per foot width of the canal generally increases. Further, the slope of the canal not being changed, the design of non-silting channel may not be possible with these constraints.

In Nagarjuna Sagar Project, it is proposed to increase the first phase discharge of Left Main Canal by allowing higher full supply level without changing the bed width and surface fall in the second phase of the project vide table 3.1. The canal is aligned along contour and passes through non-alluvial soils such as gravel, soft and hard disintegrated rocks. The topography of the command area is hilly. The water table is low. The maximum increase in discharge in second phase is about 9% of the first phase discharge.

Increase in the full supply depth by lowering the bed level is just a modification of the method described above to reduce the seepage losses and consequent water-logging, if any. It can be applied in special cases; but it suffers from the disadvantage of negotiation in the bed levels at the existing structures. A transition is to be given in the bed which may result in silting up of the bed. A recurring annual expenditure is to be incurred at the structures of cross regulators, syphons, bridges and falls.

3.2.3. Increasing both full supply depth and width of channel

The methods described above are applicable only when the difference between the present discharge and the revised discharge is small. Otherwise, the channel section will become either shallow or narrow. Therefore, to maintain the desirable width/depth ratio, the channel section has to be altered to accommodate greater discharges keeping in view the commendability of the channel.

This method is useful for both alluvial and non-alluvial channels and permissible velocities can be allowed. The hydraulic efficiency of the channel may also be satisfactory.

This method will necessitate major remodelling of the structures.

This proposal is to be finalised after consideration of water table conditions and command to be served by the canal.

Example 1: In Nagarjuna Sagar Right Main Canal, the first phase head discharge of 11,000 cusecs is proposed to be increased to 2nd phase discharge of 17,000 cusecs by widening the canal and increasing the full supply depth. The original and revised channel sections are shown in Table 3.2. The proposed increase in discharge is about 65%.

Example 2: This method was also utilised in Kurnool-Cuddapah canal where the existing canal system is not able to command the localised ayacut fully. Here, the command of the canal was increased from 1,03,000 acres to 2,78,000 acres. As the canal runs through arid region and the topography is steep, inspite of provision of higher full supply level, no water logging is anticipated and it helped to improve the command.

3.3. INCREASING THE AREA WITH CHANGE OF SURFACE SLOPE

Change of bed slope to increase the discharge results in changing all the parameters. This means designing the channel section as a new one for which the normal procedure of design can be adopted. If properly designed, there may be no defects in function because all the aspects for a good channel section can be considered freely with no constraints. The slope of a canal can be made steeper or flatter in case of ridge canals. Where the problem of scour is experienced due to steep surface falls, flat slopes can be adopted in remodelling and additional falls can be provided. Steeper slopes can also be adopted, if ncessary, by dismantling some of the existing falls.

In case of contour canals, it may not be possible to alter the slope of the canal in consideration of command.

However, the structures on the canal require major remodelling or sometimes even reconstruction and the cost of remodelling the structures may be high.

3.4. LINING OF THE CANALS

By providing lining to the existing canals, the coefficient of rugosity 'N' reduces. Thereby, the discharging capacity of a canal increases. The seepage and percolation losses can be reduced and more water can be conserved to utilise it for extending the scope of the canal system, if possible. If there is no scope of increasing the command area, the water so saved can be utilised for intensive irrigation. The lining of the canals is advantageous not only to reduce the seepage losses in high embankments, but also to prevent water logging in the flat topography of the command area where the water table is just a few feet below the ground level. This method is expensive though good for adoption in delta areas and alluvial plains.

Where conjunctive use of ground water and surface waters are planned, consequent on lining the canals, the recharge to ground water reservoir may be effected due to reduction of seepage and percolation losses. In such cases, the resource is also affected by lining and planning has to take this aspect in account.

Lining of canals may therefore not be justified in the case of seasonal Kharif canals fulfilling the object of artificial recharge of ground waters as well for reuse during the rabi season with the provision of tube wells.

Example - Pochampad Project is a major irrigation project in Andhra Pradesh. The canal is unlined in the first phase, with a section of 124' x 12.75' [37.80 x 3.89 M] at the head with side slopes of 1½:1 and surface fall of 1 in 10,000 to carry 5370 cusecs [152.1 cumecs]. The same section when lined is designed to carry the required discharge of 8600 cusecs [243.5 cumecs] in the ultimate phase with an full supply depth of 14 ft [4.27 M] where there is no conjunctive use of ground water on large scale.

3.5. CONSTRUCTION OF A PARALLEL CHANNEL

The discharging capacity of a canal system can be increased by excavating a new channel parallel to the existing canal for the additional discharge.

In this method, there are few constraints in design of the canal section and a best discharging section can be designed freely. The problem is whether to provide a common bank for both the canals or separate banks with sufficient distance in between the channels which will depend upon the safety requirements under all operating conditions as also need for drainage of areas between the channels, if any.

There will be no or little disruption of supplies to the existing command area during the construction periods of remodelling. At the position of outlets openings may be necessary.

In the case of contour canals passing through the infertile lands where the cost of land is low, the parallel channel may be excavated on the higher side of the existing canal. This will not only save the cost of land but also reduces the cost of outlets.

In well developed areas the cost of land is high. Further, the extent of land to be acquired for the excavation of the canal is more than that required for other methods of remodelling, thus increasing the total cost of remodelling.

The total number of additional structures to be constructed on the parallel channel are almost equal to those on the existing system. This involves huge expenditure.

Therefore, final decision on the adoption of this method may be taken after weighing all the factors such as cost of land acquisition, cost of structures etc. in this case compared with the other methods.

For the phased programme of Sarada Sahayak Project in Uttar Pradesh twin channels have been adopted for the maincanal in the head reaches with less disruption of existing arrangements and for realisation of benefits to start early.

3.6. SITUATIONS FOR PREFERENCE OF A PARTICULAR METHOD

The merits and demerits of each method have been dealt in the preceding paragraphs. It is not possible to generalise the adoption of the above methods. However, the following are few of useful guidelines for use in selection of the methods, economic aspects will often govern the selection:

1. Methods described in 3.2.1. and 3.2.2 are suitable when the increase in discharge is small.
2. When the increase in discharge is substantial, methods given in paras 3.2.3 and 3.3 are applicable.
3. Method 3.3 is feasible in case of remodelling of canals where the problems of silting or scouring are to be mitigated.
4. Method 3.4, lining of the canals may be adopted to prevent percolation, seepage, water-logging and scour as also part of overall system when conjunctive use of ground water and surface water is planned.
5. While fixing the full supply levels, the commandability and the problem of water-logging should be kept in view in all the methods.

CHANNEL SECTIONS OF NAGARJUNA SAGAR LEFT MAIN CANAL

.	Roach	PHASE			ULTIMATE		
		Section.	Disch-arge.	Velocity	Soction	Disch-orge.	Velocity
)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ch.62.00 to 78.50	46.00'x 22.24'	11000	9.60	46.00'x28.84'	12000	9.24
	Ch.78.50 to 153.65(Tunnel)	32' Ø	11000	12.90	32'Ø	12000	14.81
	Ch.153.65 to 286.00	40.00'x 30.24'	11000	7.86	40.00'x 31.37'	12000	8.00
	Ch.186.00 to 1214.40	95.00'x 21.00'	11000	4.14	95.00'x 22.10'	12000	4.23
	Ch.1214.40 to 1631.00	90.00'x21.20'	10643	4.12	90.00'x22.10'	11643	4.23
	Ch.1631.00 to 2429.22	85.00'x 20.70'	9631	4.02	85.00'x22.10'	10631	4.15
	Ch.2429.22 to 2970.50	86.00'x20.40'	9398	3.88	88.00'x22.10'	10398	3.95
	Ch.2970.50 to 3254.00	80.00'x20.40'	8674	3.84	80.00'x22.10'	9674	3.99
	Ch.3254.00 to 3786.26	85.00'x19.70'	8674	3.84	85.00'x21.60'	9674	3.95
.	Ch.3786.26 to 3821.74	66.00'x20.00'	6703	3.49	66.00'x21.60'	7703	3.63
.	Ch.3821.74 to 3935.52	41.00'x20.53'	6703	7.13	41.00'x22.04'	7703	7.52
.	Ch.3935.52 to 4050.20	85.00'x17.00'	6703	3.364	85' x 18.50'	7703	3.69
.	Ch.4050.20 to 4131.60	82.00'x 17.00'	6424	3.62	82.00'x 18.50'	7424	3.70
.	Ch.4131.60 to 4190	35.00'x23.15'	6424	7.23 / 6.80	35.00'x24.83'	7.424	7.9 / 7.28
.	Ch.4190 to 4473.27	82.00'x17.00'	6424	3.62	82.00'x18.50'	7424	3.70

TABLE No. 3.2

NAGARJUNASAGAR RIGHT CANAL: CHANNEL SECTION FOR DIFFERENT HEAD DISCHARGES IN NORMAL REACHES

S. No.	Reach.	11000 c/s at Head (Phase)			17000 c/s at Head (Ultimate		
		Discharge Des./Req c/s	Section with side slopes of 2:1	Velocity fps.	Discharge Des./req. c/s	Section with side slopes of 2:1	Velocity fps.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	M.0-0-00 to M.4-4-00	Head reach designed and executed for ultimate phase head discharge of 21000 c/s.					
	M.4/4 to 17/0 (bed fall 1/8000)	21000	241'x11.8'	3.68	17000	250'x15'	4.18
	M.17/0 to M.21/0	Buggavagu reservoir, F.R.L. = 474.09; M.W.L. = 475.58					
	M.21/0 to M.30/4	11000	177'x15.7'	3.37	17000	198'x19'	3.80
	M.30/4 to M.34-2-640	10110	167'x15.4'	3.32	15946	187'x19'	3.78
	M.34-2-640 to M.41-3-410	10050	170'x15.2'	3.30	15946	187'x19'	3.78
	M.41-3-410 to M.49-5-000	9221	163'x14.9'	3.24	15161	175x19'	3.76
	M.49-5-000 to M.52-5-165	8600	157'x14.5'	3.19	14409	166'x19'	3.74
	M.52-5-165 to M.57-0-475	6392	136'x13.2'	2.98	12249	139'x19'	3.67
	M.57-0-475 to M.80-7-000	3947	261'x12.7'	2.79	9749	114'x18.5'	3.53
	M.80-7-000 to M.103-2-84	3346	72'x12.7'	2.72	9186	105'x18.5'	3.50
	M.103-2-84 to M.116-4-375	2998	63'x12.7'	2.68	8713	100'x18.5'	3.48
	M.116-4-375 to M.126-0-60	2833	62'x12.7'	2.67	8636	100'x18.5'	3.48

CHAPTER 4

MODERNISATION OF EXISTING SYSTEMS

4.1. General

4.2. Command area and field irrigation requirements

- 4.2.1. Particulars of command area
- 4.2.2. Climatology
- 4.2.3. Soil and land classification
- 4.2.4. Land use
- 4.2.5. Drainage
- 4.2.6. Cropping patterns and irrigation use
- 4.2.7. Field irrigation demands
- 4.2.8. Water use management.

4.3. Appraisal of Resources

- 4.3.1. General
- 4.3.2. Surface supplies
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- 4.3.4. Conveyance losses

4.4. Decision on methods

- 4.4.1. General
- 4.4.2. Modernisation methods

CHAPTER 4

MODERNISATION OF EXISTING SYSTEMS

4.1. GENERAL

As already discussed in Chapter 2, modernisation of the existing system may become necessary in view of the changed conditions in the command area or to remedy the shortcomings of the system for meeting its needs.

The aim of modernisation is to optimise the benefits of agricultural production within the command with the supplies available in the system taking advantage of the modern concepts of designs of canals and structures and those of irrigated agriculture. The modernisation will include:

1. Remodelling of head works
2. Remodelling of canals with lining and drainage as integral part of system
3. Modern practices of water use management for irrigated agriculture.

Almost all the diversion head works which were once considered as typical examples of weir and barrage constructions, have since been replaced by modern structures based on latest theories of design and control for feeding the canals. This aspect is beyond the scope of this dissertation. Similarly the aspect of irrigated agriculture through inseparable from the need of remodelling has not been discussed in detail here. Only, remodelling of the conveyance system has been described and studied.

The changed cropping patterns based on the ever increasing needs and to suit climatology and soil and land classification require additional supplies for increased agricultural production.

The modernisation of the canal system envisages improvement of water use efficiency and level of service by it through suitably remodelling the canal system. It can be achieved by overcoming the defects in designs, by increasing the conveyance efficiency through reduction of conveyance losses in canals and water courses through proper channel design and provision of lining and by better use of land through provision of drainage facilities. It can further be helped in stabilisation of the supplies through provision of conjunctive use of ground and surface waters.

The channels requiring modernisation may have problems of silting, scouring or both, of incorrect alignments, of weed growth and of inadequate sections or the structures. Sometimes, the structures may have outlived their life and may have been damaged or likely to be damaged due to severe operating conditions and may require remodelling or reconstruction.

The percolation losses may be high and the channel may need provision of lining to reduce the losses. It is more important in cases where ground water exploitation may not be possible or return flows may be poor in quality for further use. Sometimes, only special reaches in high porous strata may need treatment. Water courses account for substantial losses of supplies at outlets and thus may need lining to an extent it may be desirable based on their period of use.

In all cases of modernisation, the first step is evaluation of the existing conditions in the command area. It involves collection of data such as characteristics of command area including climatology, soil and land classification, land use, and water table and drainage. Statistical data about prevalent cropping patterns, agricultural practices, irrigation facilities and irrigated crops with areas has also to be collected.

Surveys are conducted to know the problems of canal and their structures and to collect the data to consider the measures necessary to rectify the defects or to increase the supplies.

The data so collected is useful to evaluate the demand and other problems in the existing system. For example, from the particulars of land use, it can be seen whether there is any scope for increased agricultural use or for reclaiming water logged areas or saline lands. The possibilities of exploitation of ground water without or in conjunction with the surface waters can be examined based on the recharge concept and quality of ground waters. The knowledge of existing cropping pattern, the soil and land classification, and prevalent agricultural practices is useful to decide upon a realistic cropping pattern likely to develop. The observations of the crop water requirement under existing conditions in the command area, climatology and efficiency of application at the field help to know how far supplies are to be arranged. Where there is possibility of conjunctive use the lining of canals along with drainage facilities are planned as integral part of the overall system.

The next step is appraisal of the resources including ground water potential. It is ascertained to what extent the supplies that reach the field are sufficient to meet the demand. In these proposals, the possibilities of diversion of supplies from other basins are not considered. The problems in that case would be different as discussed in Chapter 5.

Based on the existing conditions, the problems in the system are identified and form the base for taking a decision on suitable method for modernisation.

4.2. COMMAND AREA AND FIELD IRRIGATION REQUIREMENT

4.2.1. Particulars of Command Area

Knowledge of the physiography of the canal command is necessary to have a general idea about the irrigation methods as also about the systems that may be adopted. Information about the topography whether it is flat or undulating or the terrain comprises hills, the alluvial plain or delta. The data also reveals possibility of better agricultural practices of land levelling and soil management. The data about the natural drainage of the command regarding their pattern, sizes and shapes of their catchments is also required. Extent of agricultural development, settlement and distribution of population and their occupations, and socio-economic background are to be ascertained. Position of employment is to be known. All these factors influence the trend of development and thus establish the demands.

4.2.2. Climatology

The water needs of a plant primarily depend on meteorological parameters. Water loss by plant is governed by weather parameters such as temperature, radiation, humidity, wind velocity etc. The rainfall supplies part of the consumptive use by the crops. The climate in the command area has a great influence on the crops that are grown with or without irrigation facilities. The following data is, therefore, collected:

1. Monthly rainfall and its distribution.
2. Pan evaporation and evapo-transpiration.
3. Temperature, wind velocity, radiation, humidity etc.

If adequate network of meteorological stations for collection of the data do not exist in the command, new stations are set up and observations are continued.

4.2.3. Soil and Land Classification

The cropping patterns depend upon classification of soils and their interpretations. These interpretations also help to establish requirement of land development, appropriate methods of applying water, problems of drainage and salinity etc.

For this purpose, comprehensive soil surveys are conducted, if not available. Information about terrain, water table and drainage are also needed for land classification.

These surveys are carried out as per standard procedure indicated in the Soil Survey Manual (Revised Edition 1970) of the Water Management Division, Ministry of Agriculture, New Delhi.

4.2.4. Land Use

The statistical land use data regarding the gross command area which is usually defined by the two drainages on either side of the canal, is compiled. The area under forests, barren lands, land on use for non-agricultural purposes is collected. The particulars of land under pastures and tree crops, culturable waste, fallow land and total sown areas are obtained. The extent of irrigated land under the existing system with particulars of single cropped area and double cropped area is also ascertained. This information indicates the possibilities of increase in cultivation, cropping patterns and their intensities.

4.2.5. Drainage

Information has to be collected about water table and drainage outlets. Adequate drainage facilities are to be provided in the command area to drain areas quickly in case of excessive rainfalls and to safeguard against water logging resultant from the introduction of intensive irrigation, as also to reclaim water logged areas for culturable use.

The crops are adversely affected by submergence or by water-logging due to rise of ground water table and therefore, both surface and sub-surface drainage facilities are needed.

In planning modifications of existing systems, adequacy of the existing drainage facilities has to be ascertained. If these are not adequate, additional facilities are provided to take care of the problems of drainage.

4.2.6. Cropping Pattern and Irrigation Use

The statistics of existing cropping pattern and area under various crops in different seasons as also of the extent of irrigation being practiced for various crops are collected for few years to know the present and forecast the future trends. It reveals the attitude of the farmers to crops depending on their utility and market value. It highlights the deficiencies in water use and provides guideline for the principal crops and revised cropping patterns likely to develop. It also gives an indication to what extent the irrigation can develop.

4.2.7. Field Irrigation Demands

When data in regard to present cropping patterns, irrigation use and practices is studied in the context of characteristics of command area, it is possible to forecast the cropping patterns and intensities of irrigation likely to develop with the assistance of specialists such as irrigation engineers, water management engineers, soil scientists, agronomists and economists.

Losses occur in application of water due to unequal distribution of water over field, deep percolation and waste at borders. These depend greatly on the water use and accounted for in the assessment of the field irrigation requirements for which the system is to be remodelled.

4.2.8. Water Use Management

The application efficiency represents the percentage of water stored in the root zone of the soil for use by plants, to the water delivered to the field. To obtain the increased efficiency, it is necessary to use proper methods of irrigation to suit the soil and land characteristics, and topography and to adopt better water management and agricultural practices. Water use efficiency increases greatly also in the face of command area development activities such as land levelling, soil management, provision of adequate field channels and drainage. The provision of facility of free technical knowhow to farmers for alignment of field channels is a necessary corollary.

Scheduling of irrigation as per requirements with respect to types of crops and the soil limited by available supplies will be helpful. But it requires control on the cropping patterns. In absence of such arrangements, introduction of turn system on the lines of Wara Bandi system in Punjab or Osra Bandi System in Uttar Pradesh is helpful. Provision of adequate telecommunications on the canal for operation of system and enforcement of volumetric supply of irrigation water from outlets controlled with locking arrangements too promotes economic water use.

Provision of facilities for supply of new improved varieties of seeds, fertilisers and agricultural impliments to farmers will encourage adoption of improved methods of agriculture. Above, alongwith creation of facilities to educate the farmers and train them to take to improved varieties of seeds, greater use of fertilisers, better impliments and tools to improved agricultural practices through demonstration farms and audio-visual media and free advice through extension workers will promote economic water use.

4.3. APPRAISAL OF RESOURCES

4.3.1. General

Appraisal of available water resources is the basic requirement for planning to examine whether the demands can be met by the available supplies. Both surface and subsurface water resources are accounted for planned utilisation.

In assessment of water available, it is important to ascertain not only the total quantity within a certain period of time, but also the distribution of the available quantity with respect to both area and time. The quality of water is also equally important.

The pattern of supplies of a river may undergo drastic changes consequent on construction of new irrigation works on the upstream side of the existing head works. Similarly, the recharge of ground water may increase consequent on introduction of irrigated agriculture. In view of these changes, latest data is to be collected before remodelling of any system is contemplated.

The actual utilisation of these resources is to be estimated to decide upon harnessing of available supplies and to remodel the existing system.

4.3.2. Surface Supplies

The supplies of a canal system may be available either from a dimension head work or a storage reservoir. In case of diversion canal system, the discharge data must be collected for sufficient long period. Adopting a suitable dependability, the dependable supplies are computed. The supplies may be surplus in certain periods and can be considered for utilisation in remodelling proposals.

In the case of reservoirs, where stream flows during the period of abundant supply are stored for releases during the period of deficiency, the yield of a reservoir may change in face of modified requirements for changed cropping patterns. This aspect must be considered in finalising the proposals.

Other supplemental means of irrigation in the command area such as tanks, surface pumping plants ffom rivers etc. are also considered.

4.3.3. Ground Water Supplies

When ground water is available at reasonable depths, it may constitute an important part of the total resource.

Because ground water is a part of the hydrologic cycle, it should be regarded as a renewable natural resource. Thus, consideration is important in developing ground water supplies and in planning for long term utilisation of basin aquifers. The primary concern is the physical feasibility of exploitation which depends on "safe yield".

The data regarding ground water use is compiled from the statistics regarding open wells and tube wells including those for augmentation of supplies in canals. Regarding tube wells, their number, average yield per hour and total hours of working are ascertained. Similar data is collected for open wells also. The monthly distribution of ground water utilisation is computed from the above data.

The samples of ground water are to be analysed in laboratory to find out its fitness for the purpose of irrigation.

The utilisable ground water for irrigation purposes is assessed from a study of fluctuations of water table and annual rainfall in the area. For this purpose water balance studies are made.

4.3.4. Conveyance Losses

Losses occur in the canals and water courses during conveyance from the head to the field due to percolation and seepage. It is denoted by the term "conveyance efficiency" which is the fraction of water delivered to the field to the supplies harnessed.

The quantum of water to be supplied from the source or sources is inclusive of these losses. This has been engaging the attention of irrigation engineers as early as in 1882-1883. Kennedy conducted experiments on the Bari Doab Canal in Punjab (vide Report of the Indian Irrigation Commission 1901-1903 appendix page 60) and the following losses were found for every 100 cusecs of head discharge.

Losses in main canals	= 20 cusecs	
Losses in distributaries	= 6 cusecs	
Losses in water courses	= 21 cusecs	
Other losses at the field	= 25 cusecs	
Total	= 72 cusecs	

Thus, the efficiency of the system is only 28%.

The losses constitute major part of the canal discharge and may still on many systems be as high as 66 percent or so. Excessive losses have been the causes of failure of Kurnool Cuddapah canal system in Andhra Pradesh. Therefore, estimation of these losses and adoption of measures to reduce them in face of even increasing demands and limited resources is of paramount importance.

Observation of losses in the existing system is helpful in assessment of gross irrigation requirement.

4.4. DECISION ON METHODS

4.4.1. General

After evaluation of demands and appraisal of available water resources, the next step is the selection of a suitable method for modernisation. This depends on the problems and issues involved in each case. Apart from the problems arisen due to the defects in the initial planning, these arise mainly from change in pattern and consequent increase in demand. The defects in the canal are identified by conducting the hydraulic surveys for selection of appropriate methods. The surveys are conducted in case of problems pertaining to the demands also but the methods or combination of methods to solve the problems are different. Remodelling of the structures is considered along with the proposals for the canals. If damages exist or are likely to occur, the causes are studied and the decision includes their consideration.

4.4.2. Modernisation Methods

Longitudinal section with cross sections of the canal at regular intervals along the alignment are prepared after conducting the hydraulic surveys. For clear visualisation, sections as per original designs are also plotted on the same long sections for comparative study. The history of the channel as designed originally and subsequent changes is collected from the records. Interpretations are then made to identify the reaches having problems of silting, scouring or both, defective alignments, loss of command, erosion at bends etc. In these cases suitable changes in canal sections and surface slope and in the alignment may become necessary and are considered.

Some of the existing systems which were initially designed as seasonal systems for irrigation in rabi or kharif, may be required to provide facility in both seasons and may thus require remodelling. It may become necessary to remodel the canal due to changed pattern of demand due to increased requirements also. If the pattern of supply from existing source is adequate to meet the demand under changed conditions in different reaches of the canal to carry revised discharges to fit with the demands sometimes, the supplies are augmented from drains, ponds etc. also in the command, if possibilities exist.

If ground waters are of proper quality, their exploitation is possible and conjunctive use of ground water with surface waters is considered. In case of poor quality ground waters, it will not be possible to harness them. Their mixing with surface waters may in some cases, be ~~possible~~ adopted depending on possibilities.

Use of surplus surface supplies of storing them underground and using them along with surface waters to fit in with the demand is attempted wherever possible. Many methods of recharge are in vogue. Situations may, however, exist in some areas, where ground water is being exploited on large scale which may ultimately result in depletion of aquifers. One of the methods can be construction of Kharif channels with rice irrigation for building up of the supplies in the acquifers.

Lining of canals is one of the main alternatives to conserve supplies for meeting demands at the field. Lining of canals is a best proposition where the following problems are predominent:

i) Problem of drainage.

ii) Problem of salinity and alkalinity due to intensive irrigated agriculture.

iii) Inadequate supplies at tail end from heavy percolation losses, and

iv) Frequent damages at the high banking reaches.

All the possible and feasible alternatives as explained above are examined and selection of one or combination of more than one method is made depending on the prevalent conditions in the command.

If problems of agricultural development arise in face of limited water resources and there is no scope for increasing the command area, a mix of methods of conserving the supplies, of conjunctive use of ground waters and surface waters, and of lining of canals is adopted. Decision is based on keeping in view the drainage requirements and problems of water logging, percolation losses, quality of ground water and its economic exploitation.

CHAPTER 5

REMODELLING OF CANAL SYSTEMS WITH INCREASED SUPPLIES

5.1. General

5.2. Problems and issues.

5.3. Alternatives.

5.4. Evaluation of alternatives

5.4.1. General

5.4.2. Measurement of Benefits

5.4.3. Measurement of Costs.

5.5. Criterion for selection.

CHAPTER 5

REMODELLING OF CANAL SYSTEMS WITH INCREASED SUPPLIES

5.1. GENERAL

In the previous Chapter, the modernisation of the existing systems is dealt with. In this case, the supplies available within the system are utilised to meet the increases in demands. Sometimes it is difficult ~~to cope up with large increases~~, without consideration of additional resource from outside the command, to cope up with large increases in demand on account of extensions of the canal systems to include newer areas and/or to provide intensive irrigation facilities. In such cases additional supplies have to be arranged either from the storage on the upstream of diversion site or augmented from other basins. The problems of remodelling are also different from those of the modernisation.

The possible cropping patterns likely to develop in the existing as well as new areas are predicted. The demand and the intensity of irrigation likely to develop are evaluated. An appraisal of the existing and additional supplies likely to become available their pattern is then made, and capacity of canals at different points to meet the demands is fixed. In this case, for the structures to be safe under the revised operating conditions, their large scale remodelling also becomes necessary.

In case of modernisation, the collection of particulars of command area described in 4.2 is restricted to existing area of the system. In case of remodelling, particulars are also required for the entire area which is proposed to be included.

After collection of the data, an idea about the possible cropping patterns and intensities of irrigation is obtained after consultation with specialists. The demands are then evaluated and economic analysis is made to select the alternative of remodelling that must be adopted. In such analysis, the field application efficiency as would obtain in the changed conditions is accounted for.

5.2. PROBLEMS AND ISSUES

While in case of modernisation, the increased demands are met within the command by reduction of conveyance losses by provision of lining etc. and by conjunctive use of ground and surface waters, remodelling may need adjustment of canal section to cater for additional supplies as well.

The methods indicated in para 4.4.2 are applicable in this case as also the major remodelling of the canals that may be inevitable and for which the guidelines explained in Chapter 3 govern. The remodelling of the structures will also be necessary as described in Chapter 6.

5.3. ALTERNATIVES

Based on various methods of modernisation or remodelling of canal systems discussed previously, all the possible alternatives are listed out.

In the case of modernisation, the probable alternatives are adjustment of sections with or without lining and with or without conjunctive use of ground and surface waters. The drainage facilities are included as they vary in magnitude in each case.

In case of remodelling with increased supplies, the scale of remodelling is decided after studying the various cropping patterns and canal capacities. Balancing of supplies and demand are kept in view. All the factors mentioned in the modernisation are also considered. In these cases stage remodelling may also be taken into account.

In cases, where conjunctive use of ground waters and surface waters is planned, the following different systems will be considered.

A. <u>In Case of Good Quality Waters</u>

1. Exploitation of ground water by private tube wells managed by the farmers and/or public tube wells dispersed in the canal command using separate or same water sources as supplimental facility.
2. Exploitation of ground waters through high capacity deep public tubewells serving as feeder wells for augmentation of supplies in the main canal. The system may also have exploitation through private tubewells as well for supplimental irrigation.
3. Exploitation of ground water through public tube wells dispersed in the command to serve as feeder wells in the distribution system with or without large feeder wells and private tube wells.

B. In Case of Poor Quality of Ground Waters

By mixing ground water supplies through public feeder wells limited by quality and pumping for drainage is contemplated to keep down salinity. Exploitation through private tube wells may not be possible in such cases. Some of the alternatives may not be feasible and can be ruled out by study of the existing conditions in the command area. At this stage, approximate estimates may be enough. Once the choice is reduced to few promising alternatives, then benefits and costs are evaluated in detail for selection of final plan.

5.4. EVALUATION OF ALTERNATIVES

5.4.1. General

It is likely that no single method for modernisation or remodelling of the existing systems discussed earlier may suit and a combination of technically feasible methods for large benefits to accrue to the people, may be suitable. Therefore, it is essential that a large number of possible and feasible alternatives are considered.

It is necessary to determine the relative economy of the various alternatives in the programme. The costs and benefits for each alternative are evaluated and the scale of development is fixed and the best alternative is selected based on the economic evaluation by comparison of benefits and costs. All the benefits and costs are translated to a common basis as to time adopting a suitable rate of discount and period of analysis (economic life). The choice is generally in favour of the alternative which maximises the net surplus gain. The social aspects are also considered in final selection.

The economic analysis is simple when the benefits in each alternative plan are predetermined. In case of modernisation, the cropping pattern and its intensity of irrigation is generally known in view of the existing conditions in the command area namely soil and land classification, climatology and agricultural practices and therefore, the selection of the best alternative is simply based on comparison of annual costs only while in situations where remodelling for increased supplies is contemplated, different cropping patterns are considered along with feasible alternatives and selection of the alternative with appropriate canal capacity is made.

5.4.2. Measurement of Benefits

In economic analysis, the primary benefits which can be evaluated in market place and can be assigned monetary value are accounted for. Benefits in the discussion here denote net positive benefits after allowing for adverse or negative benefits.

These benefits represent the value obtained from the sale of project produced goods and services and also the benefits accuring from physical effects of the project on the user as contrasted with effects transmitted through market transactions. In the case of remodelling, the primary benefits are, therefore, the net annual agricultural income from farm produce before and after remodelling.

The secondary benefits from increased activities of processing, manufacturing and trade from the increased employment opportunity from new jobs created to construct, maintain and operate the project may be important; but do not appear in the computations.

Intangible benefits are extra market benefits that cannot be assigned a monetary value. These benefits include greater stability and welfare of community, strengthened security, better diets and health new opportunities for settlement, employment, and savings in earnings of foreign exchange by reduction of imports and increasing the exports of agricultural production. These will only influence choice indirectly.

The farm costs required to prepare the land for irrigation, convert to a new cropping pattern and purchase of machinery required by the new crops is also considered.

5.4.3. Measurement of Costs

In case of remodelling with increased supplies, the costs cover the modifications to canals and structures, provision of lining and installation of tube wells, if any. Drainage facilities may be required in the command when intensive irrigation is contemplated and is also taken into account.

The costs comprise not only capital cost but also operation and maintenance charges, which include annual repairs, maintenance and operation of works, power charges etc. apart from modifications to canals and structures, provision of lining, installation of tube wells etc.

5.5. CRITERION FOR SELECTION

Economic efficiency is generally the criterion for selection of the scale of development. The annual costs, annual benefits and net social benefits are calculated. No alternative where the benefits do not exceed the costs is selected. The alternative where marginal benefits equal to marginal costs is adopted in case the resource is scarce and the scale of development is considered upto a point where the benefit-cost ratio is again unity.

The same general criteria will govern decision on the scale of remodelling.

CHAPTER 6

REMODELLING OF STRUCTURES ON CANALS

6.1. General

6.2. Problems and Methods.

6.3. Decision on Methods.

CHAPTER 6

REMODELLING OF STRUCTURES ON CANALS

6.1. GENERAL

At the time of original construction of structures on the old canal systems, the designs might be based on the then prevalent knowledge of engineering technology. In the face of great advancement in the technique of design and construction of structures, regulating structures such as falls, regulators, cross drainages etc. may now appear to suffer from inadequacies of designs and may require remodelling to render them safe. Such situations can arise as follows:

(i) Inadequate length of floor and downstream cut-off from consideration of piping for the structures on permeable foundations which can cause undermining of the foundations due to steep exit gradients and the structures may remain in perpetual danger of damage due to "piping".

(ii) Insufficient length of floors with and without provision of friction blocks and end sills from considerations of dissipation of energy at the falls and regulators which may result in erosion of loose apron and block protection or damage floor or create scour holes in bed.

(iii) Insufficient thickness of downstream floor from consideration of uplift pressures on foundation floors and unbalanced head due to formation of (standing wave) hydraulic jump which may cause cracks in the floor.

(iv) Insufficient depth of cut-off walls on the upstream and downstream of the structures with respect to scour, which may result in damage to the floor and in formation of the scour holes.

(v) Incorrect assumption in design, with respect to retrogression on account of which the tail water levels may be lower than asumed and may create unfavourable conditions for formation of the hydraulic jump resulting in damages to the floor and protection works.

Investigations may have been insufficient or the possible operating conditions might not have been visualised at the initial stage which may also lead to inadequate design, and

(vi) Provision of structures on the soil foundations comprising more than one type which can cause cracks in the structure due to unequal settlement.

The structures may not be able to withstand the loads under the designed conditions due to adoption of improper methods of construction not conforming to the standard specifications, and damages may occur in the structures that may need strengthening or reconstruction.

The structures that may have outlived their normal life and are showing signs of deterioration may require remodelling or reconstruction. In the later case, it may be necessary to build them at a new site when foundations may have been rendered unsafe. The structures may also require remodelling if increased supplies are contemplated to meet the changes in pattern of demand and require modification of operating conditions. Many structures may not remain safe under the revised operating conditions. The uplift pressures and the exit gradients increase on regulating structures and the energy dissipation arrangements are rendered inadequate. The conditions become severe if the structures have been suffering from inadequate designs.

In all cases of remodelling, data has to be collected to study the problems, frame the issues and select a suitable method of remodelling such that the structure is safe under all operating conditions.

6.2. PROBLEMS AND METHODS

The problems can be broadly classified into two categories, the one relating to the structures having inadequate designs or improper construction, or in various states of deterioration or damage and the other relating to structures in canals where increased supplies are proposed.

In the former case data is to be collected to know the particulars of design and construction in respect to original works and subsequent modifications. The detailed history of operation of the canal, its discharge and losses and performance of the structures are studied. All such information is useful to identify the problems and to arrive at the appropriate methods.

If the problem is due to piping it can be solved by provision of deep cut-off with or without extending impervious floor. The details are worked out after analysis of uplift pressures and scour depth.

If the downstream floor or protection works are inadequate suitable energy dissipation devices with or without extension of the floors are provided to dissipate the excess energy of flow and bring the velocities within normal limits in the canal section. If the dissipation of energy cannot be achieved on the downstream floor bars in the bed or other arrangements are considered.

Inadequacies in thickness of downstream floors are handled by replacement of stone masonry and brick masonry topping by plain or reinforced concrete to make the floors stable against uplift and unbalanced pressure in the hydraulic jump trough.

Increase of insufficient cutoffs on the upstream and downstream floors new cutoffs are provided to the desired level to make the structure safe against scour. This may need strengthening of the floors.

If the inactness has resulted from improper methods of construction strengthening or replacement of the various components is necessary.

If damage has already occured reconstruction with all the above precautions using modern concepts of design is the solution.

In case of increased supplies, remodelling will cover most of the structures on the canal system and accordingly all data as in the former case as well as for future conditions will be required.

If the increase in the carrying capacity of the canal is small, little remodelling of the structures may be needed. If however, there is substantial increase in capacity of canal, the structures may require large scale strengthening or reconstruction. It will not depend on the total supplies but on the discharge capacity to be provided in the canal dependent on the method of meeting the demands as indicated in Chapter 3. Sometimes, flumming of canal at the structures may be possible.

For large increase in discharges, the canal is usually remodelled by increasing the width of canal as well as full supply depth often without changing the surface slope. If increase in depth by raising the full supply level is contemplated the structures are required to withstand more adverse operating conditions. If deepening of bed is proposed, suitable transitions in the bed are to be provided to negotiate the difference in bed levels at the structure. The foundations may need strengthening in this case. If flumming is feasible at the structure, transitions in the width of canal are also necessary. The velocity of flow increases at the structure and therefore, provision of revetment or lining may be found necessary. If flumming is not possible, then the width of the canal is also proposed to be increased at the site of structures, dismantling of abutments atleast on one side and their reconstruction is required.

The methods applicable to various regulating cross drainage, bridges and outlets in different situations have been described below.

1) Regulating Structures

(a) Regulators

These fall into three categories namely;

i) Cross regulators
ii) Offtake regulators
iii) Escape regulators.

The principles of design are similar in all cases though the operating conditions are somewhat different.

In case of cross regulators the bed level on the upstream and downstream is generally the same unless a fall may have been constructed with it: whereas the bed level of offtake or escape regulators is dependent on its cross section.

The escape regulators are operated to release the surplus waters in emergencies only and thus are subjected to less severe conditions.

The operating conditions for offtake regulators are more severe as head regulators operate with varying discharges and may be closed when there is no demand or for repairs. This is accounted for in design by selection of suitable allowable exit gradient.

The piers, abutments and gates are stressed to maximum when the gates are closed and water is upto top of gates and no water on downstream side. The uplift pressures and exit gradients are also maximum under these conditions.

Accordingly increase in bed width is taken care of by extension of waterway, by provision of additional spans.

The existing abutments and wings on one side or both sides are to be dismantled and reconstructed.

But in case of full supply level, strengthening of abutments, wings and piers are necessary. Modifications to gates in respect of height and sizes of its components are essentially required. Depending on the discharge, the type of energy dissipation arrangements i.e. cistern, friction blocks and cill etc. are decided keeping in view the economics also.

The length and thickness of impervious floor are increased in view of exit gradient and uplift pressures. The depth of cutoff walls and their foundations are modified suitably based on scour depth, exit gradient and type of soil to suit the revised operating conditions. Suitable alterations to protection works are also suggested if required.

(b) <u>Falls -</u>

The principles of design for regulators are applicable to falls as well. The difference is that the falls are subjected to lesser severe operating conditions in view of lesser fluctuations as compared to regulators which may require heading of water on their upstream or due to regulation of offtakes.

2) Cross Drainage Works

(a) Drainage Syphons

In case of drainage syphons the loading on all members of drainage barrels, arch or roof slab, the abutments and piers, and the floors depend on the depth of flow in the canal. The worst condition may occur when the drain is empty and the canal runs at full supply level.

If change in full supply level is not contemplated, though the canal be depressed on either side of the structure, the remodelling of the structure will require extension of barrels to accommodate changes of width. Dismantling and reconstruction of drainage wings and extension of masonry floor, block protection and launching aprons may be necessary. In cases where increase in full supply level is proposed, the problem will not remain simple when the members are subjected to higher stresses than permissible values. Then the strengthening is needed to bring the stresses in permissible limits by adopting appropriate methods.

(b) Canal Syphons

In case of canal syphons, the structural members will be stressed to maximum when the drain is running at maximum flood level and the canal is empty and therefore, the increase in discharge of canal does not govern their structural design except in case of substantial increase in depth of canal.

Additional barrels on one or both sides of the existing barrels to accommodate the increased discharges have in any case be provided. If reconstruction of barrels ~~often~~ is not necessary, the extension may often be done with the side of existing barrels. The approach and exit transitions are to be dismantled and reconstructed to suit the new bed width of canal.

(c) <u>Aqueducts</u>

In aqueducts, flumming of canal is usually resorted unless there is substantial increase in canal discharge is envisaged in remodelling, when parallel aqueduct is provided.

In case of remodelling flumming is contemplated on upstream and downstream and the structure is strengthened. If aqueduct rests on arches over the drainage vents, there is greater scope for remodelling.

Nandrai aqueduct on Lower Ganga Canal which was originally designed to carry a discharge of 4000 cusecs [113.2 cumecs] was remodelled in sixties to accommodate 8000 cusecs [226.5 cumecs] with increased depth of flow in the trough. Now for additional increase, a parallel aqueduct is envisaged.

(d) <u>Inlets</u>

If remodelling of the canal is decided by deepening without changing the full supply level, the remodelling of inlets is not needed.

If full supply levels are proposed to be raised in remodelling, the present inlets may not function when the canal runs at full supply level. The F.S.L. will be higher than the sill level of the inlet, creating the submerged conditions of flow and may cause water-logging.

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Nandrai aqueduct on Lower Ganga Canal which was originally designed to carry a discharge of 4000 cusecs [113.3 cumecs] was remodelled in sixties to accommodate 8000 cusecs [226.5 cumecs] with increased depth of flow in the trough. Now for additional increase, a parallel aqueduct is envisaged.

(d) Inlets

If remodelling of the canal is decided by deepening without changing the full supply level, the remodelling of inlets is not needed.

If full supply levels are proposed to be raised in remodelling, the present inlets may not function when the canal runs at full supply level. The F.S.L. will be higher than the sill level of the inlet, creating the submerged conditions of flow and may cause water-logging.

3) <u>Bridges</u>

In case of increased gauge of canal at the site of structure the free board may be reduced. It is verified whether the free board under changed conditions will be adequate. If it is not adequate the superstructure may be dismantled and reconstructed unless in case of slabs which can be raised. The piers and abutments may also be strengthened and raised to proper heights.

Extension of required spans will be necessary to accommodate the additional bed width. In such cases the end abutment will serve as thick pier.

If the width of the canal is increased without changing the F.S.L. at the structure the free board will be sufficient and only provision of additional spans modifications to upstream and downstream transitions will be needed.

4) <u>Outlets</u> -

The outlets are generally pipes provided in the banks to supply water to the water courses. The discharge varies from 1/2 to 1½ cusecs and the diameter from 4" to 1 ft. Head and tail walls may not be provided for small water courses. Sometimes controlling arrangements are also provided. If cropping pattern is proposed to be changed on outlet the pipe will need replacements with larger diameter pipes.

These outlets can easily be refixed to suit changed supply levels in canals being simple structures.

6.3. DECISION ON METHODS

The decision on the methods of remodelling of structures is generally governed by the type of problem encountered in each case, feasibility of method as per site conditions, structural soundness of the existing members, case of construction in remodelling and relative economics. Principle of least cost subject to sound structure will govern.

CHAPTER 7

CASE HISTORIES OF REMODELLING

CHAPTER 7

CASE HISTORIES OF REMODELLING

7.1. GENERAL

The case histories of the two remodelling works in Andhra Pradesh namely 'Modernisation of Krishna Delta System" and the other "Remodelling of Kurnool Cuddapah Canal" are described in this Chapter to give an appraisal of the problems met and solutions adopted in each case.

The proposals for the former project are under preliminary stage of project-formulation. For collection of data and to suggest a detailed plan, an organisation called Modernisation Cell Comprising of a team of Engineers, soils and Agricultural Scientists and Statistical officers has been constituted by the Government of Andhra Pradesh State.

The latter project had many defects of design and operation in the old system, originally constructed in 1866. Its remodelling has been completed in 1960 to remedy the defects.

7.2. MODERNISATION OF KRISHNA DELTA SYSTEM

7.2.1. Particulars of Command Areas and the System

7.2.1.1. Head works and canals

Krishna is one of the major rivers in India and the biggest river in Andhra Pradesh. It originates from Western Ghats and drains an area of ~~1,60,000~~ 256000 sq.km. It carries an enormous flow during monsoon period. British Engineer, Sir Arthur Colton built the delta irrigation canal system including the headworks at Vijayawada in the year 1859 to harness its supplies. It is mainly due to this sytem that the Andhra Pradesh is known as Rice Grannery of India. It was originally contemplated to provide Irrigation facilities to an extent of (6 lakh acres) 2.43 lakh ha.

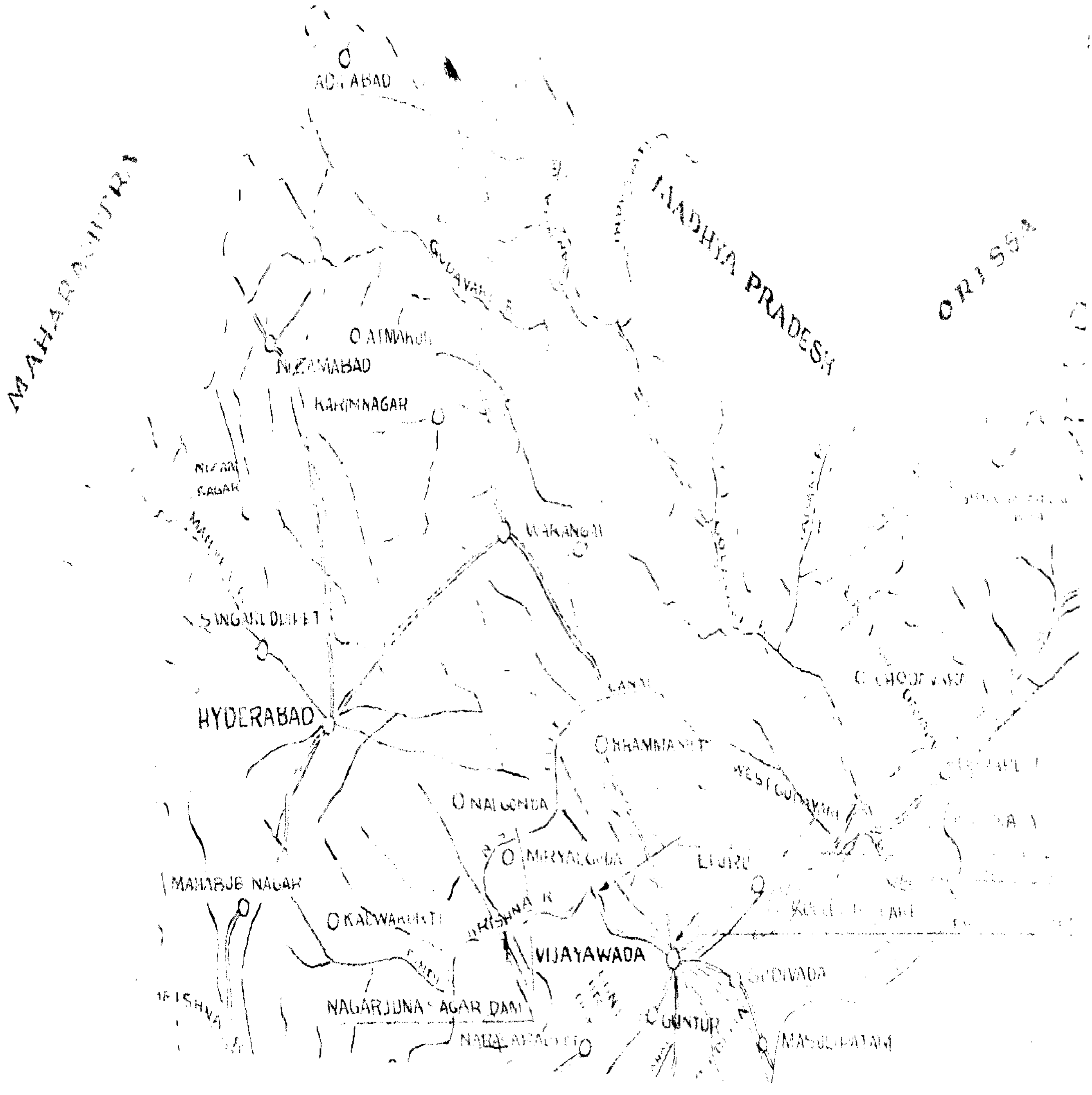
As Krishna is a non-perennial river the flows in the system did not have, during December to May, adequate supplies to meet demands in Rabi season. After the construction of Nagarjuna Sagar dam on upstream side, the situation has improved and stable supplies are now available in the system from the reservoir in lean periods.

Original weir after serving for 93 years was damaged in 1952. A modern barrage called "Prakasam Barrage" was built almost at the dam site in 1954 to 1958 with a higher pond level to make possible drawal of larger quantities of water during the critical period of crop growth namely transplantation and flowering season. The canal systems on both sites were also remodelled to extend the irrigation facilities to (12.5 lakh acres) 5.06 lakh ha.

An index plan of Krishna Delta and another plan showing the canal system are appended vide Fig. 7.1 and 7.2 respectively. Most of the main canals and some of the branches of Krishna Delta system are both irrigation-cum-navigation canals. The head discharge of the left and right side canals are (11,000 cusecs) 311 cumecs and (8000 cusecs) 226.5 cumecs respectively.

FIGURE 7.1

INDEX MAP OF A.P. STATE



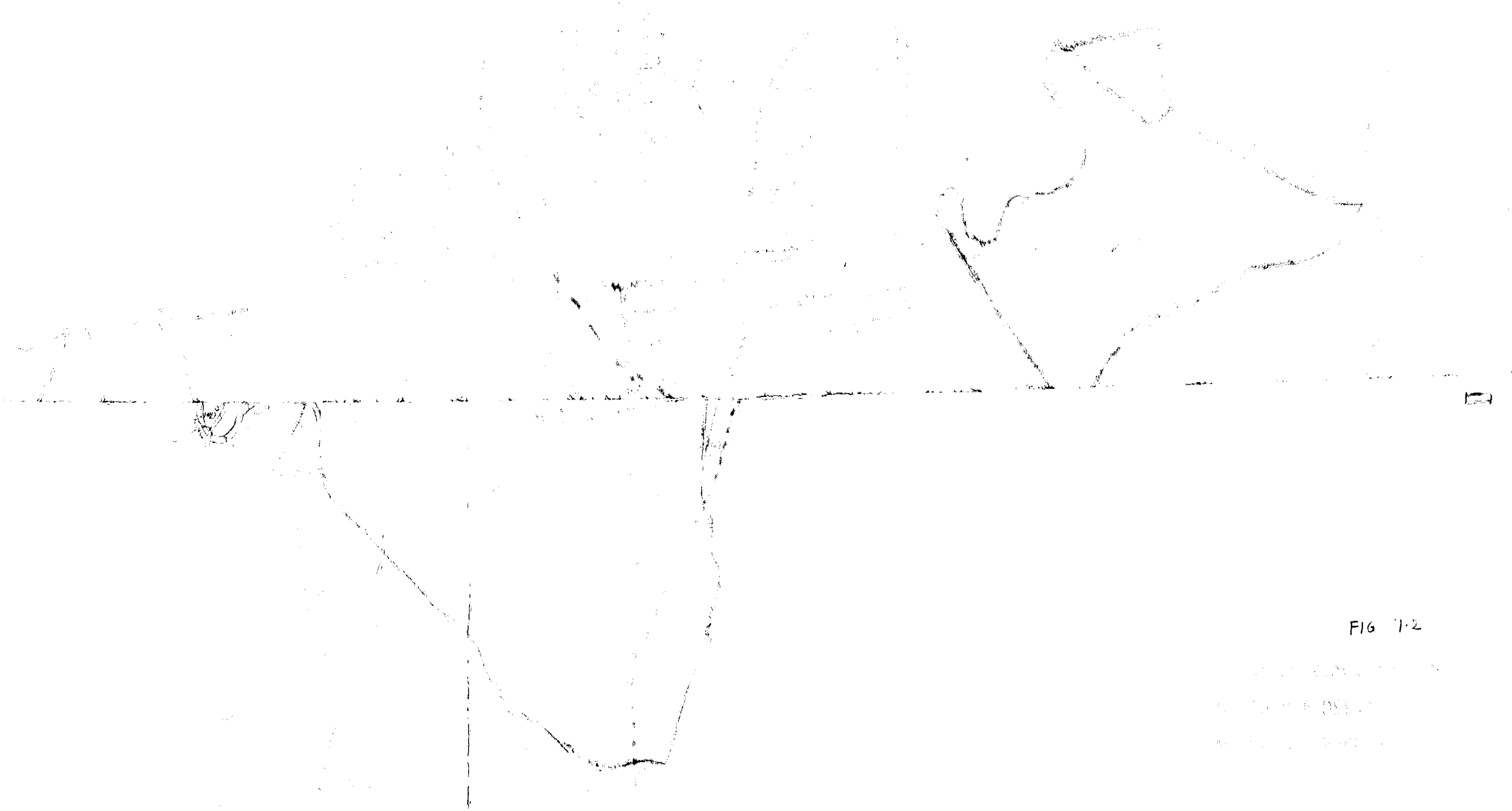


FIG 1.2

7.2.1.2. Command Area

The command area comprises of rich alluvial deposits. The topography is very flat with a slope of about 1 in 5000 at head to 1 in 10000 at the tail end, the command being situated in the delta area along the coast of Bay of Bengal. The area is thickly populated and agriculture is the main industry in this area. The average rainfall in the area is (41.47 inches) 1054 mm. The rainfall pattern varies widely over the command area. The coastal taluks are subjected to active north east monsoon (Oct.-Nov.) whereas the interior upland areas are served by South-West monsoon (Jun to Nov.). The temperature in the upland area is more than at the sea coast. The annual pan evaporation figures at Gannanaram and Masulipatnam are (115.04 inches) 2921 mm and (96.81 inches) 2460 mm respectively.

There are wide differences in soil classification as well in the command area. The high level delta between (40 ft contour to 10 ft) 12.19 m to 3.05 m contour is mostly black cotton soils. The soils between (10 ft and 2 ft) 3.05 m to 0.61 m contour are varying from black cotton, light loam, saline with sandy patches. Considerable areas are subject to water-logging. The soil classification for the area is as follows:

Black clayey soils		3.64 lakh ha
Light loams		1.02 "
Sandy		0.40 "
	Total	5.06 lakh ha.

Rice is the predominent crop in the delta and covers 95% of the command. Farmers have gained much experience in growing rice crop. Perennial garden crops of sugar cane and turmeric are the other secondary crops. Pulses green manure, and fodder crops such as Dainche, Pillipesare and Sunhemp are being grown with the residual moisture in the area in Rabi season or in summar in low lying areas. At present, there are 3,900 filter point wells (shallow tube wells) in the command to supplement the requirements of perennial crops when canals are closed. The farmers are using high yielding varieties of crops and chemical fertilisers in addition to green manure. The use of machinery and improved agricultural impliments has not yet caught up. The method of application of water is usually wild flooding and field to field irrigation is in practice which results in wastage.

The actual irrigation particulars are as follows. The net command area is (12.50 lakhs acres) 5.06 lakh has

	As per cropping pattern		Actual irrigation	
	Lack acres.	Lakh ha.	Lakh acres.	Lakh ha.
Kharif				
Paddy Ist Crop Jun-Nov/Dec.	12.00	4.86	11.77	4.75
Perennial crops such as sugarcane, turmeric plantains etc.	0.50	0.20	0.26	0.11
Total	12.50	5.06	12.03	4.86
Rabi and Summer				
2nd crop paddy Dec-Apr.	2.40	0.99	2.50	1.01
Cotton Dec-May	0.40	0.16	0.05	0.016
Ground nut Jan-Apr.	0.50	0.20	0.20	0.08
Pulses, Fodder, Manure etc. Dec-Feb.	4.00	1.61	6.20	2.51
Total	[illegible]	[illegible]	[illegible]	[illegible]

7.2.2. Problems

7.2.2.1. Growing Demands

Though improvements to the canal system have been implemented from time to time, the supplies are not commensurate with the tremendous increase in demands consequent on introduction of high yielding varities of crops and multiple cropping pattern. As observed from the particulars of irrigation, the intensity of irrigation is about 168%. As the pattern of demand has changed, it is found difficult to supply water at proper time and in proper quantities during critical periods of crop growth in transplantation and flowering stages.

7.2.2.2. Limited Water Resources

The use of surface water resources is limited to (181.2 T.M.C.) 5114 ~~m.cu.secs.~~ million cum as per the award of Inter-state River Water Dispute Tribunal.

The quality of ground water in the delta area is saline and brackish and unsuitable for irrigation. However, the ground water in the upland area is of good quality and can be exploited for irrigation.

At present, the supplies for the rabi period are released from Nagarjunasagar Reservoir pending development of ayacut. Future problem of supplies may arise in rabi as the source is a non-perennial river.

7.2.2.3. Difficulties of Operation

In operation of the system, the farmers in the head reach are utilising more water and are over-irrigating.

The transplantation in the low lying areas is thus delayed. These areas are rather subjected to heavy flooding and submerssion due to the cyclonic depressions in the Bay of Bengal. The tillering phase of the crop growth is effected and consequently the yields are less. Therefore, properly planned roster of water supplies to meet the demand by staggering the transplantation is necessary, in this low lying area, to avert damages from inadequate supplies.

7.2.2.4. <u>Need for Drainage</u>

As there are occasional heavy and wide-spread rainfalls in the area under the influence of cyclonic depressions in the sea and the topography is flat, the surface runoff is slow and sluggish creating severe drainage congestion and causing damages to crops. There is big natural depression in the command area called ~~Kolkru~~ Kolleru Lake which is also causing drainage problem due to peripheral submersion of about 1 lakh acres.

7.2.3. <u>Proposals</u>

After the studying the characteristics of the command the trend of the farmers etc., the Water Management Division, Ministry of Agriculture, New Delhi suggested a multiple cropping pattern with a cropping intensity of 232%. While calculating the water requirements of crops, two alternatives were suggested: one with a high system efficiency (Paddy 76.5%, and other crops 63.8%) ~~with the following~~ and the other alternative with a low system efficiency (paddy 67.5% and others 56.25%). The losses asumed in both the cases are as follows:

	High Efficiency System.	Low Efficiency System.
Transmission losses.	15%	25%
Field losses for paddy.	10%	10%
Field losses for other crops.	25%	25%
Deep percolation in high level.	0.12"/day (3.05 m/day)	0.12"/day
Deep percolation in low level.	Nil	Nil

For the purpose of calculating the water requirements, the entire area is divided into three zones:

(a) High level delta above (10 ft.) 3.05 m contour occupied by black cotton soils covering roughly (7.5 lakh acres) 3.04 lakh ha. in which intensive irrigation can be contemplated.

(b) Low level delta of mixed soil partly saline, water-logged characterised by N.E.monsoon also covering roughly (4.0 lakh acres) 1.62 lakh ha. suitable for late paddy followed by early paddy and partly pulse or fodder.

(c) Coastal sandy area covering (1 lakh acres) 0.4 lakh ha.

The suggested cropping patterns and the demands are shown in Table 7.1. The demand for the high system efficiency is (220.86 T.M.C.ft) 6257 million cubic metres which is proposed to be adopted.

It is felt that transmission losses of 15% is practicable for lined canals. However, field losses of 10% for paddy and 25% for other crops is on low side. Hence, it is suggested that the field losses of 30% may be adopted and the corresponding demands are incorporated in table No.7.1. In view of limited resources, it is proposed to meet the balance demand of (41 T.M.C.ft) 1160 Million cubic metres partly by utilising the ground water resources in the upland area, partly by conserving the water by preventing the losses in the system through lining and partly by economic utilisation of surface water through reduction of field application losses making use of better water management, crop management and soil management techniques.

As the canals are unlined at present, the conveyance losses are found to be appreciable in sandy soils at the tail end reaches and high embankment reaches. Now water is being utilised liberally and wasted in the head reaches. Therefore, there is great need to educate the farmers in proper water and soil management techniques. Though the farmers in this area have already contributed much to the national effort of increasing the agricultural production, it helps further improvement if they are trained and guided at field in the modern agriculture. ~~Area~~ Hence extension service is proposed to be created.

The mixing of sweet canal waters with saline ground water is also under active consideration. The reuse of the drainage water by providing lift systems is also contemplated to augment the supplies. Filter points (shallow tubewells) are proposed to be increased to utilise the effluent seepage from the canals.

When the ayacut under the Nagarjunasagar will fully develop, it will be difficult to supply water to the delta system for Rabi crops as the pattern of supplies available at headworks is not sufficient to meet the demand. Hence, a reservoir called "Pulichinthala Reservoir" across Krishna River in between the Nagarjunasagar dam and Vijayawada is being investigated to meet this situation.

Properly planned time table for regulation of supplies to advance the agricultural operations in the low lying areas is proposed to be enforced to prevent the damage due to the submersion of the rice crop immediately after the transplantation in the tillering phase of its growth, on account of cyclonic depressions in the sea. For this purpose, the entire command is divided into 3 zones:

<u>Zone I</u> - comprising of low lying and submerssible areas where severe drainage congestion takes place from August onwards under the influence of South-West Monsoon.

<u>Zone II</u>- comprising of normal areas which are less susceptible for drainage congestion.

<u>Zone III</u>- comprising of lands commanded by high level channels and lift canal schemes which are least susceptible to flooding and drainage problems.

It is planned to prepare and implement the operational programme so that transplantation is completed before end of June in Zone I, and before end of 21st July in Zone II and before end of July in Zone III.

It is very difficult to implement this programme unless the irrigation officers are vested with compounding powers to deal with the offenders. The draft irrigation Bill under circulation in Ministry of A.P.Government will provide such powers.

Regarding drainage problems in the area, the government of India constituted an expert committee under the Chairmanship of Sri A.C.Mitra to suggest comprehensive drainage plan for the entire delta. Action is already taken in this regards.

The other items of work to rectify the defects in the canal system, the remodelling of damaged or outlived structures, additional bridges, infrastructure facilities with extension service are also planned.

The proposals of modernisation of agricultural pattern are taken up by agricultural department.

7.3. REMODELLING OF KURNOOL-CUDDAPAH CANAL

7.3.1. Particulars of the system and command area

7.3.1.1. Head works and canal system

Tunga and Bhadra Rivers rise in the western ghats which join at Kundali village in Mysore State. The combined river is called Tungabhadra river which is a tributary to Krishna River. It drains an area of (24,985 sq.miles) 63,960 sq.kilometres before it reaches Sunkesule anicut site. The Kurnool-Cuddpah canal takes off from the Sunkesule Anicut which was originally constructed in 1866. It was constructed by a private irrigation company called "The Madras Irrigation and Canal Company Limited". The work was started in 1863 and completed in 1870.

No flows are available in the river at Sunkesule anicut from November to May. But regulated flows from the Tungabhadra dam which is situated at about (145 miles) 232 kilometres upstream side, are available.

The total length of the canal is 190 miles 304 km. The ayacut localised in 1935 is (102466 acres), 41466.61 hectares. The ayacut was proposed to be increased to (2,78,000 acres), 1.122 lakh hectares after remodelling the canal. A plan showing the canal system is enclosed vide Figure 7.3 and 7.4. The irrigation is direct from the main canal general and no bigger distributaries are provided.

7.3.1.2. Command Area

The topography of the area is undulating and hilly at the head reaches. The people are not industrious. The average rainfall in the area is (29.56 inches) 749.3 mm. The area is often subjected to severe famines as the rainfall is precarious and scanty. The predominant soil type is the deep silty clay loam to clay followed by deep clay loams. The silty clay loams to clay and clay loams put together cover about 90%

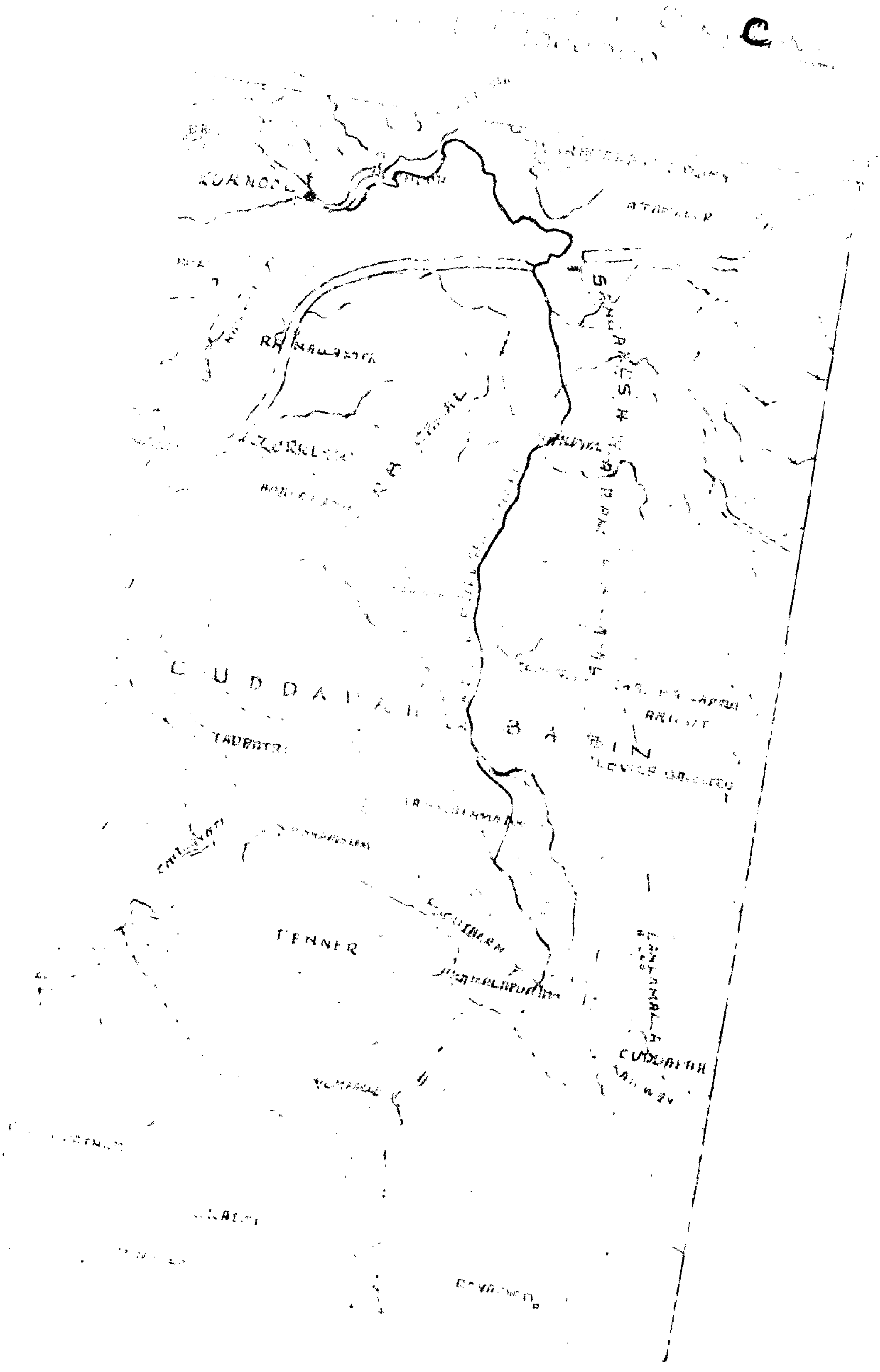
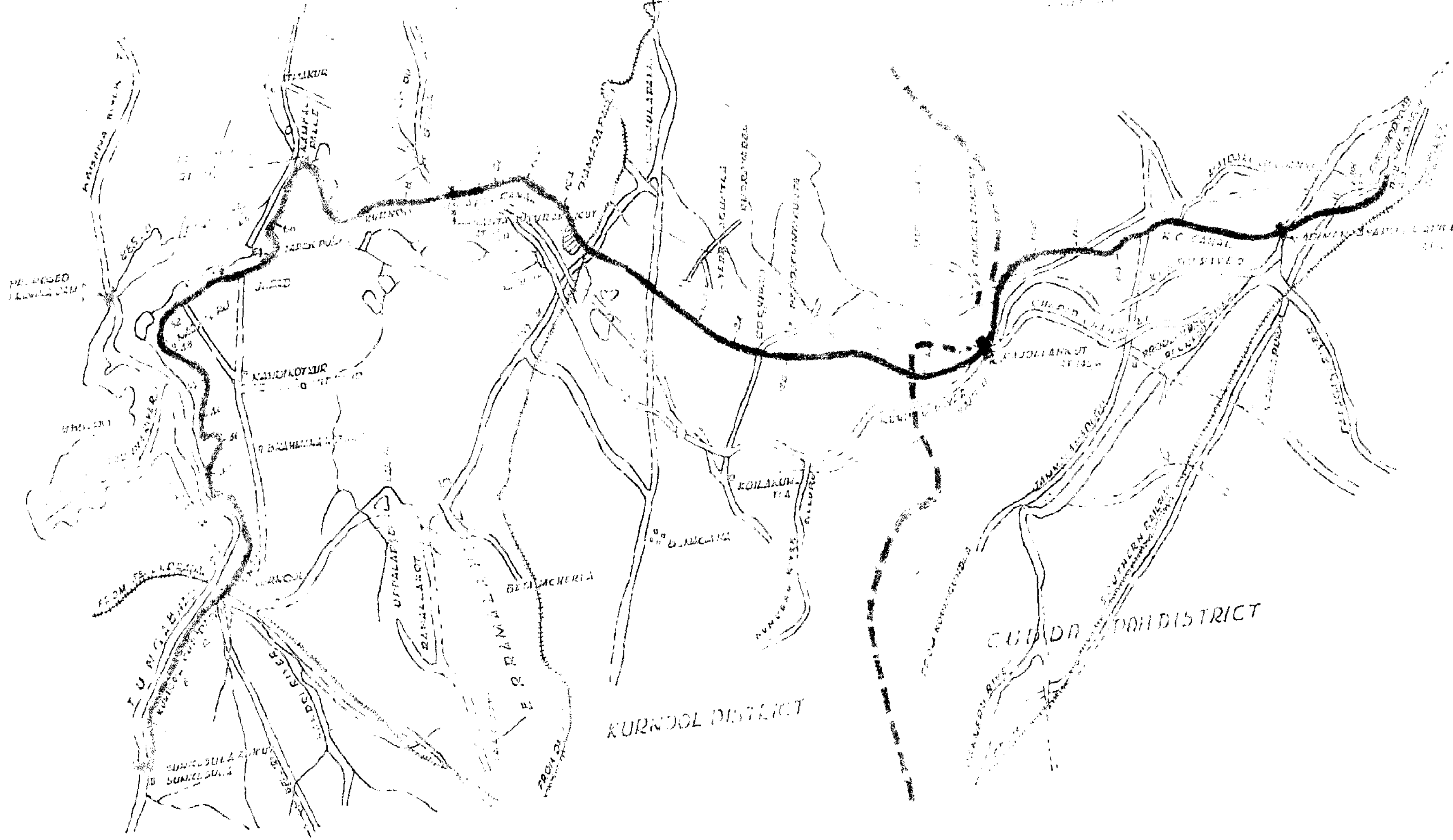

C
KURNOOL
C U D D A P A H
CUDDAPAH

FIGURE 7.4

KURNOOL - CUDDAPAH CANAL



of the area under K.C.canal. The other types of soils encountered are sandy loam, loam and sandy clay loam. Before remodelling, paddy was not popular though the narrow strip of land on right side situated in between the canal and the river was good land and two crops were raised. Where paddy was grown, seed beds were raised only after the canal water was let out from 2nd week of July and late plantation was done in August or September. The garden crops raised were plantains and betal leaves in Kurnool and turmeric in Cuddapah district. Sugarcane was largely grown in Nandyal taluk. The dry crops raised were paddy, cholam, chillies, garlic, onions, cotton, ground nut, ragi, korra, gingelly and horse gram. The farmers were backward. Improved agricultural methods, or use of fertilizers in large scale or improved seeds were not prevalent in the area. The cropping pattern before remodelling was:

1. Double wet (1923 acres) 778.20 hectares.
2. Single wet (25,347 acres) 10259.42 hectares.
3. Systematically irrigated dry (55,791 acres) 22578 hectares.
4. Occasionally irrigated dry (19405 acres) 7852.89 ha.

Total = (1,02466 acres), 41466.61 ha.

Single wet area was given water for paddy in Kharif season only. Double wet area was supplied water for paddy in both Kharif and Rabi seasons. Lands irrigated in 3 years out of 5 were classified as systematically irrigated dry and others are occasionally irrigated dry. The discharged was based on duty and not on rational method of crop water requirement.

For wet crops in Kharif and Rabi seasons, duties of (60 acres per cusec) 757.1 ha. per cumec and(50 acres per cusec) 714.1 hectares per cumecs were adopted. For dry crops in all seasons a duty of (100 acres per cusec) 1428.2 hectares per cumec was used.

7.3.2. Problems

1. The K.C.Canal was originally designed and executed to carry (3800 cusecs) 85 cumecs with a full supply depth of (8 ft.) 2.44 m in head reaches. The anicut (weir) was breached 5 times in 1864, 1866 Oct., 1868, July 1882 and 1885 Oct. In view of the frequent breaches, the crest of the anicut was lowered by 0.9 metre (~~from 947.81 to 944.81 ft~~) in March 1886. The full supply depth was reduced to (7 ft) 2.13 m and the discharge to (1600 cusecs) 45.3 cumecs.

2. Further, there is a problem of silting at head as the head regulator was situated in a unfavourable location.

3. The main problem in this system was that the irrigation potential created was not utilised even after a number of years due to the poverty, laziness and backwardness of the people, and the farmers are also allowed to exercise optional irrigation i.e. they need not pay water charges if they did not use the canal water. Consequently the canal was forced to draw low supplies as there was no demand for several decades. This led to the silting of the canal section.

4. The canal in the first (75 miles) 120 kilometres runs throughout in a tract where the subsoil is shale and slate in layers badly fissured horizontally and vertically. It was found by gaugings that the seepage losses were very abnormal being as much as (1000 cusecs) 28.3 cumecs in (1575 cusecs) 44.62 cumecs of head discharge i.e. about 2/3 of the head discharge. This has resulted in the stagnation (starvation) of ayacut in lower reaches.

5. Problems of operation also arose due to the defects in localisation on account of mixed cropping pattern under the same outlet.

6. The cultivators showed interest after 1952 to take up wet cultivation on large scale (after formation of Tungabhadra Reservoir on upstream side). The situation has improved to quicken the pace of development with stabilised supplies.

7.3.3. Proposals

The head works were remodelled to remedy the defects. The weir was strengthened. The location of the head regulator was changed and reconstructed based on model experiments.

The optional irrigation exercised previously was not allowed, associated activities to develop the command area were implemented.

The Seepage losses were reduced in the canal with a provision of lining in the first reach of 120 kilometres.

Relocalisation was duo in 1955 taking into account the operative problems as woll as the improved situation due to the construction of Tungabhadra Reservoir on the upstream side. A new cropping pattern was proposed as follows:

1. Sugarcane = (13,930 acres) - 5597.20 ha.
2. Double wet = (10,001 acres) - 4047.30 ha
3. Single wet = (1,63,447 acres) - 66145.00 ha.
4. Irrigation dry (90,412 acres) - 36588.73 ha.

Total (2,77,790 acres) - 12378.23 ha.

The mixed cropping pattern under the outlets is modified oither to complete wet or complete dry to mitigate the operation problems. The stabilised flows that could be made available from Tungabhadra Reservoir were taken into account in suggesting tho new cropping pattern. The canal system was now improved after carrying out all the above remodelling works.

TABLE 7.1.

Demands for Krishna Delta with various system efficiencies.

Season	Crop.	High efficiency paddy 76.5% and 63.8% for other crops. Transmission losses=15% Field losses for paddy = 10% " " on others = 25% Deep percolation losses =0.12/day		Low efficiency Paddy = 67.5% others 56.25% Transmission losses = 25% Field losses for paddy 10% " " for others 25% deep percolation losses: 0.12/day		Efficiency of 59.5 for all. Transmission losses = 15% Field losses for all = 30%		Soils
		Area in lac acres.	Demand in TMC ft.	Area in Lac acres.	Demand in TMC ft.	Area in lac acres	Demand in TMC	
Kharif.	Paddy(140 days)	8.00	85.24	8.00	92.72	8.00	100.80	High level
	Paddy(165 days)	4.00	31.96	4.00	35.46	4.0	41.16	Low level
Rabi	Paddy	4.00	59.40	1.00	17.09	1.0	19.38	Low level
	Cotton	0.50	9.03	0.50	10.24	1.0	9.69	High level
	Ground Nut	0.50	7.85	0.50	8.89	0.5	8.41	" "
	Sunhemp	2.50	11.15	2.50	12.69	2.50	11.95	" "
Summer	Pulse	4.00	6.84	4.00	9.56	4.00	7.80	" "
Annuals	Sugar Cane	0.30	5.99	0.30	6.79	0.30	8.57	" "
	Banana	0.10	2.33	0.10	2.64	0.10	2.50	" "
	Turmeric	0.10	1.07	0.10	1.21	0.10	1.14	" "
	Total	24.00	220.86	21.00	197.29	21.00	211.40	
Unirrigated Residual Moisture	Pulses or Fodder	5.00	-	5.00	-	5.00	-	High and Low level
	Total	29.00	220.86	26.00	197.29	26.00	211.40	

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1. Summary

8.2. Findings

8.3. Recommendations.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1. SUMMARY

The object of this dissertation is to present a review of the problems in the existing canal systems causing the need of modernisation or remodelling of canals and their structures, the different methods that can be adopted to solve such problems and decision-making process to select the best alternative plan.

The need of modernisation arises from changed conditions in respect of cropping patterns, extensions of facilities and water use management within the command. The object is to optimise the benefits of agricultural production with the supplies available in the system taking advantage of the modern concepts of design and those of irrigated agriculture. It envisages improvement of water use efficiency and level of service through suitably remodelling the canal system.

The channels requiring modernisation or remodelling may have problems of silting, scouring, or both, incorrect alignments, weed growth, loss of command and inadequate sections and structures. These problems are identified by conducting the hydraulic survey of the canal. In these cases, suitable changes in the canal sections and surface slope, and in the alignment may be considered. The problem of inadequacies in design of canals, head works and other structures due to limitations of technology at the time of their construction are handled by making use of the recent advancement in technology to remedy the defects and render them safe under all operating conditions.

In modernisation some of existing systems which were initially designed as seasonal systems for irrigation in Rabi or Kharif may be required to provide facility in both seasons and may thus require remodelling due to changed pattern of demand. The canal sections in different reaches are remodelled to carry the ~~required~~ revised discharges. Existing supplies are considered alongwith augmentation from drains, ponds etc. If ground waters are of proper quality, conjunctive use of ground waters with surface waters is considered. In case of poor quality ground waters, it will not be possible to harness them. Their mixing with surface waters may in some cases, be possible and is planned. Use of surplus surface supplies by storing them underground and using them along with surface waters to fit in with the demand is attempted whenever possible.

Situations may, exist in some areas where ground water is being exploited on large scale which may ultimately result in depletion of aquifers. One of the methods can be construction of Kharif channels with rice irrigation for building up of the supplies in aquifers.

Lining of canals is one of the main alternatives to conserve supplies for meeting the demands at the fields. It is a best proposition where the following problems are predominant:

(i) Problem of drainage.

(ii) Problem of salinity and alkalinity due to intensive irrigated agriculture.

(iii) Excessive loss from heavy percolation losses, and

(iv) Frequent damages at the high banking reaches.

The discharging capacity of the existing channels can be increased by suitable adjustments in their bed widths, full supply depths with or without changing the full supply level of its canal, or surface slope of the canal or more than one of these parameters. The magnitude of remodelling of the structures in case of substantial increase in discharges on canal is also influenced by the selection. Lining of canals and construction of parallel channels for additional discharge is also resorted. The feasibility and adoptability of any method depend on the problems in the canal such as silting, scouring, commandability, drainage and water-logging, availability and cost of the land etc. as also the extent of remodelling and comparatives on economics of different alternatives. Therefore, careful selection of the method need not be emphasised.

In case of remodelling with increased supplies, there is an additional problem to evolve an economic cropping pattern and the intensity of irrigation. This is decided after studying the various cropping patterns and the corresponding canal capacities including their economics in consultation with the specialists. The modern trend is to keep down the demands itself adopting water use management, soil management and crop management.

All the possible and feasible alternative plans making use of ~~the~~ any single method or combination of the above methods are generated to determine the relative economy by economic analysis. The annual costs and benefits are evaluated and translated to a common basis as to time adopting a suitable rate of discount and period of analysis. Economic efficiency is the general criterion for selection of the scale of development.

Along with the canal, the structure on it are also to be remodelled. The structures on the canal constructed long time back with the prevalent knowledge of engineering technology at that time may now appear to suffer from inadequacies in design such as inadequate length of downstream floor, inadequate depth of cut off walls, inadequate thickness of downstream floor, improper energy dissipation arrangement, insufficient protection works, incorrect assumptions in design, insufficient investigations etc. These structures require remodelling in face of advancement in technology. The structures may also not be able to withstand the designed loads due to adoption of improper methods of construction not conforming to specifications. These structures may need strengthening or reconstruction. Some of the structures may have outlived their normal life and may have to be remodelled or reconstructed. Also when remodelling with increased supplies in canal are contemplated, the structures may not remain safe under the revised operating conditions requiring thereby their large scale remodelling.

For small increases in discharges as in the case of modernisation, little or no remodelling may be needed.

For large increases in discharges, when raising of full supply level is contemplated the structures are required to withstand more adverse operating conditions. However, in case of ~~the~~ no rise in full supply level, the remodelling is comparatively less. In all cases of remodelling, dismantling and reconstruction is inevitable to some extent and strengthening of some components of the structure. The magnitude of remodelling depends on the method of improvement to the canal section to convey the additional discharge and the structural soundness of the components. Various types of structures require various methods of remodelling as described in Chapter 7. The decision on the methods of remodelling of the structures is governed by the type of problem, feasibility of method, ease of construction and relative economics.

Modernisation of Krishna Delta Canal System is being contemplated in Andhra Pradesh. The main problem in this case is increase of demands due to introduction of high yielding varieties, development of multiple cropping and limited water resources. The chances of exploitation of ground water are meagre because of their poor quality. This is proposed to be solved by economising the water use through water and agricultural management and reduction of conveyance losses through lining.

In the remodelling of Kurnool Cuddapah Canal, the system was suffering from inadequacies of supplies due to excessive seepage and percolation losses and the canal was lined to remedy the defects and to some other problems also.

6.2. FINDINGS

To achieve the national objective of maximisation of agricultural production, not only it is necessary to take up the newer irrigation projects but also to make better use of available supplies in the existing systems, through remodelling to fit in with the changed conditions.

The modernisation of the existing systems improves the efficiency and at the same time also takes care of the inadequacies and defects. In this case, better water management, soil management and crop management are the powerful tools to effect economy in water use. Lining and conjunctive use of ground and surface waters also improve the water use efficiency. The optimal system with or without lining, conjunctive use of surface and ground waters and drainage are to be considered.

The selection of the method of increasing the canal capacity must be based on the present problems in the canal (such as silting, scouring, commandability, drainage and waterlogging, the magnitude of remodelling of structures, relative economics etc.

In older systems, conjunctive use of ground waters and surface waters was not planned. In view of the advantages, it should be implemented wherever possible to increase water use efficiency in the face of limited water resources.

Lining of canals was earlier mainly considered to reduce the seepage losses in porous sandy soils and fissured rocky cuts. Now, the concept has changed; lining is now provided in many canal systems linked with conjunctive use of ground and surface waters, water management and drainage based on overall economic use of water resources.

8.3. RECOMMENDATIONS

1. This review covers the unlined canals only. A further study of the remodelling of the lined canals is necessary to know the general problems encountered in such cases.

2. Regarding the design of structures, a simple outline is given in this study. Problems of remodelling and reconstruction of head works have not been discussed. A detailed review of the design procedures and methods under various conditions for different types of structures including head works should be made.

3. In this study, the methods of remodelling are only described. Planning aspects and methodology should be developed for basin planning for agricultural production by construction of inter-linked systems of canals.

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