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In the first article of this issue Er. P. K. Vedanayagam, B.E., Retired Chief Engineer (Irrigation), P.W.D., Tamil Nadu has brought out a note on Coachella Valley Project situated in the state of California, U.S.A. This project is an achievement of the California State Water Development in the maximum use of water in an area where there is hardly any rainfall in an entire year. The author has explained the salient features of the project and the arrangements for distribution of water for maximum utilisation with minimum quantity. The author is of the opinion that Tamil Nadu which has almost utilised its water resources could try out similar methods, though not in full, by having lined Canals and distributaries.

The design of a surplus structure is fully dependent on the correct estimation of the maximum flood discharge. Certain guidelines have been prescribed for fixing the value of 'C' in the Ryves formula which is commonly used in Tamil Nadu for arriving at the maximum flood discharge. In the article "The Eluding value of 'C'—Tamil Nadu Experience" Er. A. Mohanakrishnan, B.E. (Hons.), M.Sc., M.I.E., Senior Deputy Chief Engineer (Irrigation), P.W.D., Tamil Nadu and Er. G. Elumalai, Assistant Executive Engineer, P.W.D. have narrated a few instances where the actual flood realised had been at wide variance from the theoretical flood computed.

Since independence the irrigation potential in Tamil Nadu has been increased manifold mostly through storages in large reservoirs and by canals taking off these storages. Since almost all the surface water resources in the State have been utilised, modernisation of surface irrigation systems and improved water management have to be thought of for further development of irrigation. In the third article of this issue "Water Management of Tank Irrigation System in Tamil Nadu, India" by Er. B.A. Jeyapalan, B.E., Chief Engineer (Investigation), Public Works Department, Tamil Nadu is a paper presented during December 1978 at the Second Afro-Asian Regional Conference, Manila, Philipines. The same is reproduced in this issue for the benefit of readers. This explains in detail the measures contemplated in the tank modernisation programme which is the first attempt to improve the lots of the neglected farmers whose command areas and their distribution system have not seen any improvement for many centuries of their existence.

Finally in the article "Remote Sensing for Hydrological Studies" the author Er. S. Parasuraman, B.E., stresses the advantages of sensing technique over conventional methods for Hydrological studies.

In conclusion, the Editor thanks all the authors of the articles published in this issue for their valuable contribution and kind co-operation. In this regard, all the other Engineers are kindly requested to send as many articles of technical importance as possible and help the noble cause.

EDITOR.

A NOTE ON COACHELLA VALLEY PROJECT

By

Thiru P. K. Vedanayagam, B.E. *

The Coachella Valley Project is an achievement of the California State Water Development Department in the maximum use of water in an area where there is hardly any rainfall in an entire year. The Coachella Valley situated south of India in the State of California receives hardly 5 inches of rainfall annually and has naturally a soil with a very high percentage of salts in it., so that apart from cactae and tubble weed, natural vegetation is not to be seen. Into this valley water from Nevada State has been brought by the All American Canal from the Imperial dam and from the 40th mile of the All American canal the Coachella Canal 123½ miles long takes off to bring water to the Coachella Valley. The capacity of the canal is 1300 cusecs. The last 30 miles of the canal is lined and the section is 40' X 12'. Lining the head reaches is also being contemplated.

The important feature of the Coachella Valley is that water being a very scarce and costly commodity, the distribution of it has been done in such a manner that the maximum utilisation of it can be achieved. Water is given at every 40 acre point and at this point it is measured through water meters which apart from recording the quantity of water delivered have also the facility of checking the rate of flow through the meter. The entire area is connected by undergoing pipes about 500 miles long through which water flows from the canal by a system of valves and turn outs with necessary regulators to control the maintenance of water level in the canal which would ensure adequate flow of water into the pipes at various off-takes. Automatic regulation is done at off-take points to maintain F.S.L. Though the project in the earlier stages carried out the regulation of supply manually, now a high standard of sophistication has been arrived at by a system of telemetry by which the regulation of the watersupply either to the pipes or in the canal is operated from a central panel in the offices of the Coachella Valley headworks.

The notable points which would be of great interest are first that the quantum of water required for the crop is to be requested for by the ryot giving atleast 24 hours advance notice. The period of supply and the quantity of water required are given by him and the officers of the Coachella Valley Water District then apportion the supply of water to each individual ryot.

The pipe systems are designed only to take about 1/3 of the requirements of any area commanded by it and this necessitates the supply of water in rotation so that economy is ensured in utilisation and the cost of construction is also the minimum.

When the total requirement of the ryots in an area is more than what can be supplied through any particular pipe, then, the ryots are requested to settle them amicably between themselves the period of supply to each pipe point failing which a contingency plan of distribution already worked out by the Valley authorities and which is conversant to all the ryots is put into operation so that the available water is equitably distributed according to the size of the farms and the requirements of the crops.

The ryots can ask for the water supply either by wireless telephone or in writing at the office and at the site. (*vide* copy of the water request Form Annexure I). The distribution of water in the 40 acre block is still done mainly by the ditch riders equivalent to our Lascars.

Mostly furrow irrigation is used and sprinkler irrigation in this area is very little.

In as much as the water delivered has to pass through water meters, the water from the main canal is filtered by rotary and stationery filters and this is one of the costly portions of the maintenance but it pays off in giving longer life to the water meters.

Complete maintenance crew, workshops, spare parts, etc., are available with the Authority Headworks for maintaining the canal and the machinery. Another interesting feature is the provision of small ponds in many farmers' area where the farmer stores water that has come to him within the period of supply and he makes his own water supply arrangements so that if necessary he could deliver more water to his crop instead of the rate at which he receives supply. This corresponds to our Periyar-Vaigai-System where a certain extent of reforming is achieved by the use of existing tank in the ayacut.

At the very end of the canal a reservoir called Cahuilla has been built which can hold 1/2 day's supply from the canal whenever it is not fully utilised and the reservoir is so constructed that flow into it and out of it to the ayacut is by gravity. The cost of construction of this reservoir is £ 1.56 million. It is a soil cement lined reservoir about 12' deep having capacity of 1,500 Ac.ft. The bottom of the lake has been sealed with 6" of compacted soil cement.

As mentioned earlier, the soil is full of salts, and farmers are advocated to lay their own drainage pipes 8 ft. below the ground level. About 35,000 acres are provided with drainage by 1,000 miles of on-farm drains. The drainage flows are conveyed through a drainage networks of 163 miles of pipe and 20 miles of open ditches to the salton sea which is at the end of the Valley and which acts as a drainage sump. The Salton sea is a natural depression and is an inland sea 35 miles long 15 miles *wide* and 40 feet deep.

The lake is used for boating, swimming, water skiing, fishing, camping picknicking and other general recreational use by the public on a fee basis. The lake is getting increasingly saline year after year and steps are being contemplated to reduce the Salinity by with drawing

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* *Retired Chief Engineer (Irrigation), Tamil Nadu, P.W.D.*

125,000 acre-feet of water annually from the sea and replacing this by relatively fresh drainage water entering the sea and diluting it.

The irrigation project is managed by the Coachella Valley County Water District which has a governing board of five elected members. The District is involved in six water-related field of service-irrigation, urban water supply, storm water protection, Rauch drainage waste water reclamation and water conservation. Rules and regulations for the delivery and use of water Establishment of Raw Schedules, and collection of charges are approved and modified periodically by the Board of Directors. The ordinances Nos. 958 and 1072 are reproduced in Annexure II and III.

The Coachella Valley Project with hardly any rainfall in the locality has successfully brought out a variety of crops from grapes, orchards, vegetables, cereals, etc., to cotton and this has been done with the minimum quantity of water because of certain factors—

(1) The volumetric supply of water to each farmer for which he is billed.

(2) The requirement of water for farms is judged by the farmer and based on his need, the supply is made.

(3) Considerable savings in transmission is done by provision of a net work of underground pipes for supply to each 40 acres outlet.

(4) What is normally considered as unproductive soil is being turned into useful orchards and other crop growing area by the system of underground drainage which leeches the salt away and makes the soil workable.

(5) Highly sophisticated telemetry system and control is maintained by electronic equipment which reduces the manual labour.

Tamil Nadu, which has nearly fully utilised its water resources could try out a method of this type, though not in full, by having lined canals and distributaries. This has been attempted in the Parambikulam–Aliyar Project where precious water is imported from other basins. Still there is wastage in this system as the water is supplied without any measurement. The ryots should be made to realise that they are the ones who are to ask for water and if they are made to pay for the water based on their requirements, a greater amount of conservation of water would be feasible. This may be against the present method of revenue collection, but it is necessary that in the interest of higher conservation of water the supply of water is measured probably in a simpler form than water meters, e.g.,by Parshall Flumes, etc., (2)supply of water to the fields is based on the requirements of the ryots. Even if our ryots do not apply for their requirement of water the Government could give the crop requirement judged by the agricultural department and this could be arranged to be measured and (3) the supply at turn-out is restricted to the period of utilisation in a day by the ryots.

ANNEXURE I.

C.V.C.W.D.

WATER REQUEST.

Owner, Tenant or Agent..........................

Date......................Requested by............

Hour..............................

Zanjero Run : 1 2 3 4 5 6 Taken by:

Phone..............in person

Radio............ Other......

Lateral................Zanjero ackn................

or by....................

Turn ON..........(C.f.s.)	From Change To	Meter No.

Effective ON Date

Remarks :

C.V.C.W.D., 488, Rev., 12—76,

RULES AND REGULATIONS.

COUNTRY WATER DISTRICT

for the Delivery and Use of Water Establishment of

Rate Schedules,
and Collection of charges.

Approved by Board of Directors
June 9, 1964.

COACHELLA VALLEY COUNTY WATER DISTRICT.

Coachella, California.

ANNEXURE II.

Ordinance No. 958.

COACHELLA VALLEY COUNTY WATER DISTRICT

An Ordinance of the Coachella Valley County Water District relating to the delivery and use of District Water, providing for the establishment of rate schedules from time to time, for billing and collecting pursuant to said rate schedules and for other purposes.

SECTION I.

INITIAL APPLICATION FOR WATTER.

(*a*) Before any water is delivered by the District, each landowner must fill out, sign and file with the District an "Application for Water by Land Owner", for each parcel of land for which he desires water. This application shall indicate the particular land or lands owned by the applicant which are to receive water and shall also designate the name or names of those persons who will have authority subsequently to place water orders under the application. The required application form may be procured at the District Office.

(*b*) Whenever the person or persons who are to have authority to place water orders under an application are to be changed or whenever ownership of a parcel of land is changed, a new application for water must be filled out, signed and filed with the District.

(*c*) The landowner shall provide a right of way for access road to meter and valves for operational and maintenance purposes.

(*d*) Water will be delivered only through District approved service connections.

(*e*) there shall be installed by the landowner prior to any delivery, an adequate overflow or constant head stand approved by the District.

SECTION 2.

DEPOSITS.

In case of Public lands under lease or lands held by desert entry, entrymen recognized as such by the United States Bureau of Land Management, an "Application for Water by other than Landowner" may be received and may be granted in the discretion of the Board upon the precedent condition, however, that a deposit shall be made with the District to guarantee all tolls and charges ; deposit shall be returned upon termination of water service, less any amount then due and owing. The amount of deposit to be made will be sent by the Board at time of approval of application for water.

SECTION 3.

WATER ORDERS.

(*a*) All water orders must be placed with the Office of the Water Department of the District during normal business hours. The District assumes no responsibility for errors arising from orders which are not submitted in writing.

(*b*) Water orders may be placed only by an authorised person and must include the following information :—

(1) Meter number.

(2) Name of landowner.

(3) Name of authorized person placing the order.

(4) The quantity of water and the period of time during which said order is to be effective.

(c) On the day upon which the order is to be put into effect, the zanjero will turn water on or off or make changes at the time when he passes the point of delivery on his regular scheduled run for that day.

(*d*) Delivered water as ordered will run continuously day and night until ordered off. Water orders will not be accepted for runs of less than twenty-four (24) hours, and must be in multiples of 24 hours. Requests for cancellation which are placed after normal business hours on the day preceding the day upon which an order is to become effective will be received and honoured only as an unscheduled change.

(*e*) Where the demand for water exceeds the capacity of the facilities, water shall be delivered in sequence to water users pursuant to orders received at the maximum rate of flow available or as much there of as the water user shall order. Twelve days shall be the maximum period of time for a complete cycle during which all effected water users are served. The amount of time allotted to each water user shall bear the same ratio as his acreage bears to the total acreage involved, provided that the shortest length of time for a given delivery shall be one day. Should all of the water users involved in a rotation water schedule agree among themselves to a schedule other than above and submit such schedule in writing, the Board of Directors or the General Manager may approve the same if it does not conflict with existing rules and regulations.

(*f*) Where the demand for water exceeds the available water supply within the canal, water orders may be delayed two days, however, all orders will be honoured within that period of time except those water users who are on a rotation schedule, except under emergency conditions as determined by the District.

SECTION 4.

UNSCHEDULED ORDERS.

In addition to the current water tolls, there shall be a special service charge made for each unscheduled order amount of charge being setforth in Rate Schedules as referred to in Section. Unscheduled orders are generally defined as follows :—

(*a*) When a turn-off or decrease order is placed with the Water Department after normal business hours of the day preceding that in which the order is to become effective and prior to the time the zanjero begins his regular work on the lateral which the order affects.

(*b*) When a turn-off or decrease order is placed with the Office of the Water Department after the zanjero has commenced work on the lateral, or the order affects a lateral which has already been "set-up".

(*c*) When a turn-on or increase order is placed after normal business hours and prior to the time when the zanjero begins his daily work, or has already commenced work on the lateral on which the delivery is to be made.

All unscheduled orders are subject to the availability of water in the lateral involved and the ability of the District's personnel to perform the additional work.

SECTION 5.

RATE SCHEDULES.

All charges for water furnished to a water user will be made as set forth in the Rate Schedules established from time to time by the Board of Directors of the Coachella

Valley County Water District. Copies of these Rate Schedules are available for inspection at the District Office.

SECTION 6.

BILLING/DELINQUENCIES.
TERMINATION & RENEWAL OF SERVICE.

(*a*) During each calendar month the District shall mail a statement covering charges for all water delivered during the preceding calendar month which charges shall be due and payable immediately. If such charges are not paid by the last day of the month in which billed, two per cent (2%) penalty shall be added to the amount of the bill and an additional two per cent (2%) shall be added for each month thereafter that the bill remains unpaid. If charges billed are not paid by the 10th day of the month succeeding the month in which billed, they shall become delinquent, following which the District shall, without further notice, discontinue service until such charges are paid in full. Whether or not the statement coveirng charges, as in this Section provided, is actually delivered to the person responsible for the payment thereof is not controlling, the amount of said charges being due and owing to the District whether or not the statement therefor is actually delivered.

(*b*) Any applicant whose application for water is filed pursuant to Sections 1 and 2 of this Ordinance, which application is accepted by the District and under which application water is furnished by the District as provided herein, becomes liable for payment under the appropriate rate schedule for all water or services so furnished by the District, as provided herein, subsequent to the date stipulated on the authorization and until such time as the applicant makes proper request to the District to cancel the authorization. It is understood that the District delivers water through its works and meters and charges for all water delivered through each meter. In the event that water service is interrupted or discontinued by the District because of the failure of the applicant or the water user to pay the charges therefor, said service shall not be restored nor shall water again be delivered through the meter or to the land involved unless and until all charges which are delinquent have been paid in full. Change in ownership of land shall in no way cause a modification hereof, it being the intent and purpose of the provision that once delinquency has occured no further water will be delivered through the involved meter to the concerned land, even though ownership of the land has changed, unless and until all delinquencies have been paid in full.

SECTION 7.

USE OF RIGHTS OF WAY,
PIPE LINES AND STRUCTURES.

According to easements granted by landowners for construction of laterals and turn-out structures on or across their property, the land owner has the right to farm all land over District laterals ; however, permission is not granted to operate this land in any manner which might injure the pipe lines therein. No fences or other obstructions should be contructed which would interfere with normal operation and maintenance of main laterals. This should not be construed as giving permission to farm, fence or make installations of any kind on the right of way along the open canal which might interfere with the travel of maintenance equipment along same.

The roads on the main canal are not public roads, but are to be used only for the operation and maintenance of the canal system.

Swimming in any of the water system facilities is strictly forbidden.

The structures and lines of the District system shall not be used for the application of fertilizer or any other uses which might either damage or interfere with the operation of the system. Open irrigation ditches or reservoirs are not to be constructed on top of the District pipe lines.

SECTION 8.

BENEFICIAL USE—WASTE OF WATER.

(*a*) Water is ordered from the District with the express stipulation by the water user that water delivered will be restricted to an amount which can be beneficially used within the confines of the property described in the application. Water will be delivered only to lands eligible to receive and use District water.

(*b*) The District will refuse or restrict water service to any landowner or water user where wasting of water occurs.

SECTION 9.

COMPENSATION TO DISTRICT
EMPLOYEES.

All inspectors, agents and employees of the District, while acting as such, are strictly forbidden to demand or accept any personal compensation for services rendered to a water user of the District.

SECTION 10.

INTERFERENCE BY UNAUTHORISED PERSONS.

No water shall be delivered except through works controlled by the District. No person shall molest tamper or interfere with structures used for the delivery of water.

SECTION 11.

VIOLATIONS OF THE PROVISIONS OF THIS
ORDINANCE.

Except as otherwise herein provided water service may be discontinued without notice upon violation of any of the provision of this Ordinance, in which event service will be restored only upon order of the Board and upon such conditions as the Board may determnei.

SECTION 12.

REPEALS.

Ordinances Nos. 860, 865, 868, 869, and 871, as well as any other Ordinances or parts of Ordinances in conflict with the provisions of this Ordinance, are hereby expressly repealed.

SECTION 13.

EFFECTIVE DATE.

This Ordinance shall become effective on the first day of July 1964.

ANNEXURE III.

Ordinance No. 1072.

COACHELLA VALLEY COUNTY WATER DISTRICT.

An Ordinance of the Coachella Valley County Water District establishing a schedule of water rates, tolls and special charges for Agricultural Water Service to improvement District No. 1.

BE IT ORDAINED by the Board of Directors of the Coachella Valley County Water District as follows :—

Pursuant to Section 5 of Ordinance No. 958 the following rates and charges are to apply for all water delivered, effective July 1, 1976.

Water rates :

Agricultural Water :

85.00 per acre foot, plus $1.00 per day gate charge for each day that water is delivered.

Industrial and Construction Water :

825.00 per acre foot, plus $1.00 per day gate charge for each day that water is delivered.

Special Charges :

Unscheduled orders. In addition to the current water tolls there shall be a special service charge made for each of the unscheduled orders as follows :—

1. When a turn-off or decrease order is placed with the Water District after normal business hours of the day preceding that in which the order is to become effective and prior to the time the zanjero begins its daily work on the lateral which the order affects, the order will be honored, if possible, and a charge of $25.00 made.

2. When a turn-off or decrease order is placed with the Office of the Water Department after the zanjero has commenced work on the lateral, or the order affects a lateral which has already been "set up", the order will be honoured, if possible, and a charge of $30.00 made. The water will be charged for as if it had been delivered as originally ordered.

3. When a turn-on or increase is ordered after normal business hours and prior to the time the zanjero begins his daily work and if the water is immediately available, the order will be honoured and a $25.00 charge made. A $30.00 charge will be made if the zanjero has already begun work on the lateral on which the delivery is to be made and if water is immediately available.

Unauthorized Operations :

The unauthorized operation, changing, molesting, tampering with or interference by the water user or any of his employees or agents with the operation or control of District facilities, including the main turnout valve, canal turnouts, pumps, valves, meters, shall immediately make the water user ineligible to receive water.

Repeals :

All Ordinances or parts of ordinances in conflict with the provisions of this Ordinance, are hereby expressly repealed.

BE IT FURTHER ORDAINED that this Ordinance shall become effective July 1, 1976.

Adopted by the Board of Directors on June 22, 1976.

THE ELUDING VALUE OF 'C'—TAMIL NADU EXPERIENCE

BY

A. MOHANAKRISHNAN[1] & G. ELUMALAI[2].

Synopsis :

The important aspect of any irrigation work is the efficient functioning of its surplus works providing safety to the structure. The design of this surplus structure is fully dependent on the correct estimation of the maximum flood discharge.

Ryves' formula has been mainly used in Tamil Nadu for deciding on the maximum flood discharge while designing Irrigation structures for a long time now. Certain guide lines have been prescribed for fixing the value of 'C' in the formula. Experience has shown that there is no way of precisely specifying the value of 'C' in individual catchments and many a time the actual flood realised has been at wide variance from the theoretical flood computed. A few examples are given to illustrate this.

1.1 Tamil Nadu—Physical features :

Bordered on the west by the high hilly ranges of the western ghats the Tamil Nadu State lies on the eastern side of the southern extremity of the Indian Peninsula. The land has a general gentle slope from West to East and from North to South with all the river systems flowing from West to East generally.

The large plains of the State may be broadly divided as—

(a) Coromandel plains comprising of Districts of Chingleput, North Arcot and South Arcot.

(b) Alluvial plains of Cauvery Delta extending over Thanjavur and Tiruchirappalli Districts and

(c) Southern plains comprising of Madurai, Ramanathapuram and Tiruchirappalli Districts forming the dry rainshadow area and

(d) the hilly north western region extending over the Districts of Nilgiris, Coimbatore, Salem and Dharmapuri and comprising of high undulating country of hard rock areas.

1.2 Monsoons and the rainfall :

The State is served mostly by the North East Monsoon though South West Monsoon has also a marked influence in a few of the Districts close to the western ghats. The annual distribution of rainfall is as under—

January and February—Dry and Cool—Winter.	50 mm
March to May—Dry and hot—Summer.	150 mm
June to September—Rainy—South West Monsoon.	300 mm
October to December—Rainy—North East Monsoon.	450 mm
Annual mean rainfall ..	950 mm

The north-east monsoon is generally accompanied by Cyclonic storms which frequently results in cloud bursts, bringing in unprecedented rainfall and floods in small catchments. Fortunately heavy rainfall in such cases is generally confined to coastal areas.

2.1 Development of Irrigation :

Irrigation has been practised from time immemorial in this State. Irrigation tanks big and small have been created over a long period in the past centuries and they sustain as much as one-third of the irrigated area of the State even now. Creation of anicuts and diversion works to ensure storages in these tanks came as the next stage. Construction of dams and formation of storage reservoirs major and medium began only towards the end of the last century. It will be of interest to know how in all these cases the problem of deciding on the maximum flood discharges to which these structures are to be designed was solved. In general, it was a matter of trial and error, the discretion and the experience of the creator, the engineer, playing the main part.

2.2 Surplus works in old irrigation tanks :

Irrigation tanks in general have a weir surplus on the flanks. They are about 37,000 in number in the entire State among which 10,000 are those irrigating more than 100 acres and hence of capacity 20 M.cft and more. A few of the tanks are quite large as large as to store 2.5 to 3 thousand million cubic feet also. Most of these tanks are so created that the surplus of one runs down to feed the next lower one and so on, thus forming a chain of tanks. It is interesting to study and imagine as to how the artists and creators were able to link these chains so well when even contour mapping was not developed.

The flank surplus is either a broad crested weir, or a bye wash of sufficient length to pass down the surplus with the head generally not exceeding 0.60 to 1 metre. The location in most cases was best chosen.

It is not clear how the probable maximum discharge was computed in those days when even the earliest emperical formula had not been derived. It could have been by force, through sound judgement and trial and error. Instances can be cited where the tank surpluses have been lengthened and new additional weirs have been opened much earlier than even the British Period which should have been the outcome of actual experience. The Mahendravadi tank surplus in the tank in North Arcot District supposed to have been created by Mahendra Pallava, the Chembarambakkam tank surplus in the Chingleput District and the Ramanathapuram big tank surplus in Ramanathapuram District provide visible signs of additional surpluses having been created after the first provisions have proved inadequate.

1. Senior Deputy Chief Engineer, Irrigation, P.W.D., Tamil Nadu.
2. Assistant Executive Engineer, P.W.D., now on deputation for a doctoral research in the Indian Institute of Management, Bangalore.

3. Flood formula :

Systematic studies to relate the maximum flood discharged and the catchment and the rainfall began in the second half of the last century. The emperical formulae derived by Dickens and Ryves for the Indian catchments were the outcome (1865). Since then several detailed and scientific studies and observations have been made and many formulae and procedures derived attempting to fully represent all the characteristics of the catchment and the rainfall.

Confining our discussion to the formulae of Dickens and Ryves they can be written down as—

$$Q = CM^P$$

Where

Q is the maximum flood discharge in cusecs.

C a comprehensive co-efficient to represent the characteristics of catchment and rainfall.

M the area of the catchment in square miles.

P is the index 3/4 as per Dickens.
2/3 as per Ryves.

Dickens plotted a graph relating the Area of a basin in square miles to the depth of precipitation in inches from the data he could obtain for many of the north Indian river basins which varied in size from 1/80 of a square mile to as much as 27,000 sq. miles. He established a relation $I \; 4\sqrt{M} = 1.25$ a constant.

Where I is the precipitation in inches per hour.

$$I = \frac{1.25}{4\sqrt{M}}$$

$$Q \quad \frac{1.25 \quad M \times 5280 \times 5280}{4\sqrt{M} \quad 12 \times 60 \times 60} \text{ in cusecs.}$$

$$= 806\ M^{3/4}$$
$$\text{or } C\ M^{3/4}$$

The following were the guidelines given for choosing an appropriate value of C.

1. Bare catchments covered with precipitous cliffs.	1400 to 2000
2. Catchment with hills on the skirts with undulating country below.	1000 to 1200
3. Undulating country with hard clay soil.	800 to 1000
4. Flat sandy absorbant soil and cultivated plains.	200 to 500

Major Ryves worked on similar lines with the data gathered from South Indian Rivers and gave the formula

$$Q = C.M.^{2/3}$$

and the guide lines suggested for 'C' are

1. Catchment within 50 miles from Sea ..	450
2. Catchments 50 to 100 miles from Sea ..	560
3. Limited areas near the hills	675

Here the distance from Sea is assumed to represent the slope of the catchment which has an effect on run off from the precipitation.

For irrigation works in Tamil Nadu only the Ryves' formula is generally used.

4. Factors that affect 'C'

The guide lines mentioned above are, as we see, too general to decide on the most appropriate value of this all important Constant 'C'.

The maximum flood discharge from a catchment due to a particular storm will depend on the characteristics of the precipitation due to the storm and the characteristics of the drainage basin. It will depend upon type of precipitation, intensity of precipitation, duration of precipitation, distribution of precipitation and the direction of the storm movement with reference to the point of measurement. It will also depend upon the area of the drainage basin, its shape, its slope, its elevation above mean sea level and the density of the drainage network in the basin, viz., the number of streams and sub-streams joining the main stream.

5. Fixing the value of 'C'

The Engineer charged with the responsibility of designing a structure has to fix the value of 'C' properly in the formula to arrive at the Design Flood and while doing so he should have all the above factors in mind while analysing the data on rainfall and catchment. Beyond all these he depends on his sound judgement and personal experience and knowledge of the area.

Over the period of time after a long trial certain values of 'C' have been adopted for different regions of the State and also for certain catchments nearing the hills, etc. These have also been now and then modified through later experience. When heavy floods occur in a basin and the pattern of the storm that has caused the floods is known, an attempt is made to arrive at the value of 'C' that has caused the maximum flood discharge by reverse process and this value of 'C' is thereafter adopted for the said basin.

In some small catchments where stream gaugings have not been made, the maximum flood discharge that might have passed is assessed from the maximum flood marks that might have been left as old marking and from that the probable value of 'C' is assessed.

6. 'C' eludes the engineer :

In spite of all these many situations have arisen when the value of 'C' fixed for a particular project had to be revised based on latter experience for ensuring the safety of the structure. The statement appended gives the Design flood adopted in all the reservoir projects executed in Tamil Nadu and the value of 'C' adopted. Therein changes made in the value of 'C' before a final value of Design Flood is adopted in some of the cases have been shown.

7. Illustrations :

(a) **Cauvery Mettur Project—Mettur Dam**

This is the first major River Valley Project executed in Tamil Nadu in 1930s. A solid gravity type masonry dam was constructed about one mile long between mountains across River Cauvery to create a reservoir of 93 thousand million cubic feet capacity and 120 ft. max. depth. This continues to be the largest reservoir in the State.

The catchment area at the damsite is 42,217 square kilometres. River flow data was available over a long period at Bhavani Bridge about 60 k.m. below the proposed damsite and the maximum recorded flood over a period of 28 years prior to 1910 was seen to be 2,00,000 cusecs recorded on 30th July 1896. Allowing sufficient margin of increase for safety the Design Flood was fixed as 2,50,000 cusecs.

As luck would have it when the project was in the preliminary stages of construction a historical flood carrying a peak discharge of 4,56,000 cusecs occurred on 26th July 1924. The designers were happy to revise their Design Flood as 4,56,000 cusecs.

(b) **Cauvery Mettur Project— Grand Anicut Canal**

Under this project the extension of irrigation was done in the Thanjavur District through the Grand Anicut Canal System a new canal excavated from the Grand Anicut. Several of the cross masonry works had to be designed for which Design Flood had to be assessed.

The area is in plain country fairly close to the Sea. So the first value fixed for 'C' in Ryves' formula was 400. This is also the value recommended in the Tank Restoration Memoirs for the area. But during the execution of the Project, the Chief Engineer decided that 'C' value is to be raised to 1000 based on the experience of run off during heavy rains and taking into account an important factor that the area is strewn with a number of small tanks mostly unkept which may breach now and then and create flood conditions.

When Agniar Acqueduct, one of the major cross drainages in the system was under construction there was a heavy intensity of precipitation of 30 c.m. in a day which made the designers to modify the Design Flood from 48,000 cusecs to 58,300 cusecs.

(c) **Lower Bhavani Canal**

In this Project a 5½ mile long masonry-*cum*-earth dam has been placed across Bhavani a major tributory of River Cauvery to create a reservoir of 33 thousand million cubic feet with 105 feet as the largest depth. The main canal runs to a total length of 125 miles to feed an ayacut of 2,07,000 acres.

In such a large system innumerable cross drainage structures are to be designed and with a view to secure uniformity in design certain charts were made out and furnished to the field officers for obtaining the design flood directly read. A value of 700 was proposed for 'C' up to 70 miles of the canal and thereafter 500 to the tail end since in this length the canal traverses a very dry tract. Small catchments less than 3 square miles were treated on a different footing as seen in the note in the Charts appended.

(d) **Vaigai Reservoir Project**

River Vaigai flows in the southern part of the State draining the districts of Madurai and Ramanathapuram. It also carries the flows diverted from the West flowing river of Periyar through the famous Periyar dam and the long tunnels. The Vaigai Dam has been constructed in the 1950s. across this river to store 6.8 thousand million cubic feet with 71 feet as the largest depth.

Fortunately for this basin, stream flow data is available on a long period. The anuual flood series for 32 years from 1920–21 to 1951–52 were subjected to frequency analysis by Foster and Hazen methods and the hundred year frequency flood was arrived at. The design flood was also computed using Ryves' formula with a 'C' value of 615. From the cross sections of the river and the maximum flow marks available at site the probable maximum flood discharge was also calculated. Thus the Design Flood was decided upon comparing the alternative figures available as below :—

1. By Ryves' formula	56,060 C/s.
2. By Area cross section method using Kutter's formula.	62,860 C/s.
3. By flood frequency analysis using Foster method for a hundred year recurrence.	62,940 C/s.

The dam was designed to pass a flood of 59,170 c/s. over spill way and 13,840 c/s. through River sluices totalling up to 73,010 c/s. as design flood.

(e) **Parambikulam Aliyar Project**

This is a multi-valley multi-purpose project executed in the high ranges of Anamalai Hills with seven reservoirs created in elevation ranging from +1,050 ft. to +3,800 ft. Necessarily different criteria had to be adopted and different values of 'C' fixed for the storage dams located in the diffrent situations.

The Upper Nirar Weir has been constructed at +3,800 ft. and is the highest in the complex with an average annual rainfall ranging from 124" to 217" and a catchment of 75 sq. kilometres.

(i) Maximum flood discharge computed by Ryves' formula ('C' taken as 3,000) is 26,226 C/s.

(ii) Maximum flood discharge computed by the rainfall intensity method assuming 75 per cent excess rainfall over the recorded rainfall due to its high altitude and hilly nature is 22,272 C/s.

However taking into account the high altitude of the place and the heavy intensity of rainfall and in view of the fact that the surplus arrangements are controlled spillways a higher value for 'C' viz., 4,000 was favoured and Design Flood suitably altered during constructions.

Similarly for the Parambikulam Dam which is at a lower elevation +1,825 ft. and has a larger catchment of 228 sq. kilometres where the annual rainfall varies from 21" to 122" the maximum flood discharge worked out on the basis of rainfall intensity assuming 75 per cent excess on the maximum recorded rainfall came to 36,850 c/s. only. But since the catchment was steep, lying between elevation 1,500 to 5,600 and since adequate rainfall particulars were not available, the next adjacent valley, viz., Sholayar valley was studied. In Sholayar valley a hydro electric reservoir was already under construction where they had adopted a 'C' value of 2,500. To cover any possible higher intensities of rainfall in the present catchmen ta decision was taken to fix the value of 'C' as 3,000 only. The Design Flood for this value of 'C' in Ryves' formula worked out to 59,580 C/s. which was adopted.

Thirumurthi reservoir, the last among these group of reservoirs, lies to the east of the western ghats and is also lowest in elevation located at +1,337 ft. The catchment at dam site is 80 sq. km. and is partly hilly. Considering the nature of the catchment and comparatively poorer incidence of rain all the value of 'C' is fixed in this case as 1,500 and the maximum flood discharge worked out as 15,820 cusecs which was adopted as the Design Flood.

8. Conclusion

The value of 'C' in Ryves' formula eludes even the best of engineers and he is to be constantly vigilant and alive to all the aspects of environment while taking the decision on the Design Flood lest he may fall far out from probable reality.

STATEMENT OF DESIGN FLOOD ADOPTED IN TAMIL NADU RESERVOIR PROJECTS.

Serial number and name of reservoir.	Catchment in sq. miles.	As originally assumed in project reports, etc.		As finally adopted.		Spill way vent size.	Year of completion.
		Value of 'C' in Ryves' formula.	M.F.D. cusecs.	Value of 'C' in Ryves' formula.	M.F.D. Cusecs.		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. Mettur Reservoir	16,300	(389)	2,50,000	(708)	4,56,000	Ellis Saddle 16x60' x20' 'F' Saddle 810' long.	1934
2. Bhavani Sagar	1,621.5	(884)	1,22,000 (observed in 1930).	(1034)	1,42,750	9 x 36' x 20'	1956
3. Manimuthar Reservoir ..	62.4	(3814)	60,000	(3814)	60,000	7 x 40' x 15'	1958
4. Amaravathi Reservoir ..	324	3000	1,42,000	3000	1,42,000	9 x 36' x 25'	1958
5. Vaigai Reservoir	870	(689)	62,860	(800)	73,010	7 x 40' x 15'	1959
6. Krishnagiri Reservoir ..	2,180	900	1,47,400	900	1,47,400	8 x 40' x 20'	1959
7. Sathanur Reservoir	4,180	771	2,00,000	(771)	2,00,000	9 x 40' x 20' 11 x 40' x 15'	1958
8. Vidur Reservoir	501	1000	63,000	1000	63,000	9 x 36' x 15'	1959
9. Gomukhi Reservoir ..	113	1000	23,426	1000	23,426	2 x 40' x 15'	1965
10. Chittar Dam I	8.5	2000	8,300	3000	21,000	2 x 40' x 15'	1971
11. Chittar Dam II	10.1	2000	9,350			6 x 20' x 4'	1971
12. Manimukthanadhi Reservoir.	187	1000	32,700	1000	32,700	3 x 30' x 15' (Regulator).	1969
13. Manjalar Reservoir ..	46	900	11,700	900	11,700	4 x 26' x 10' (Radial).	1966
14. Chinnar Reservoir	239.72	500	20,040	850	27,200	3 x 4p0 x 15 (Regulator).	1976
15. Marudhanadhi Reservoir ..	20.60	900	6,763	2000	14,830	2 x 25 x 20	1977
16. Karuppanadhi Reservoir ..	11.33	1750	8,850	2,500	12,660	2 x 30 x 15	1976
17. Ponnaniyar Reservoir ..	33.60	675	7,028	75	7,028	2 x 31 x 10	1974

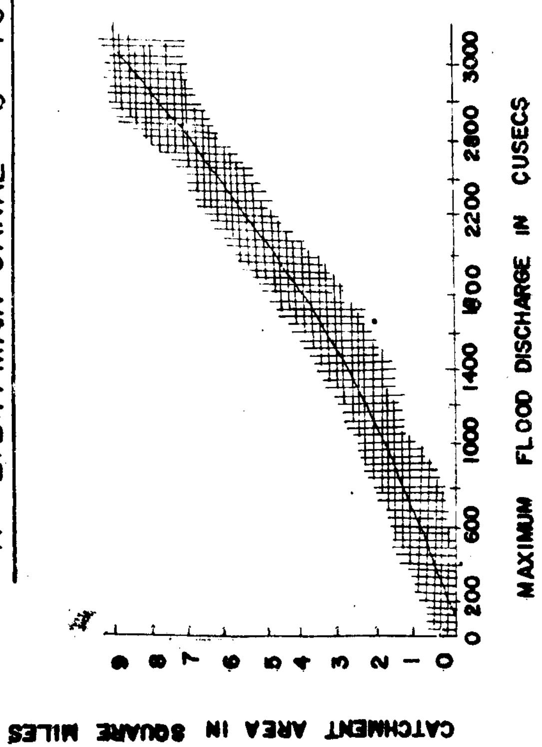
STATEMENT OF DESIGN FLOOD ADOPTED IN TAMIL NADU RESERVOIR PROJECTS—*cont.*

Serial number and name of reservoir.	*Catchment in sq. miles.*	*As originally assumed in project reports, etc.*		*As finally adopted.*		*Spill way vent size.*	*Year of completion.*
		Value of 'C' in Ryves' formula.	*M.F.D. cusecs.*	*Value of 'C' in Ryves' formula.*	*M.F.D. cusecs.*		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
18. Pilavukkal Scheme—							
(*a*) Periyar Dam	13.90	1750	10,120	1,750	10,120	1 x 40' x 20'	1976
(*b*) Kovilar Dam	9.57	1750	7,880	1,750	7,880	1 x 40' x 15'	1976
19. Kodaganar Reservoir ..	645	750	45,000	..	..	....	..
20. Parappalar Reservoir ..	28.14	900	8,300	(2,832)	26,200	3 x 32' x 15'	1975
21. Palar Porandalar Reservoir	43+57	(591)	7,250	..	19,000	2 x 32' x 22'	..
		(621)	9,200	2,000	+24,000	2 x 28' x 22'	1977
22. Varadhamanadhi Reservoir.	28.6	1000	9,353	(1545)	14,450	Weir 58.8 m ..	1977
23. Vattamalaikarai Odai ..	153	500	14,300	659	18,850	Weir 722'	1978
24. Gunderipallam	27.9	700	6,439	1,150	10,600	Weir 312'	1978
25. Varattupallam Reservoir ..	27.59	700	7,698	1,150	11,000	Weir 518'	1978
26. Kelavarapalli Reservoir ..	10.7 (free). 943 (combined).	900	86,540	900	86,540	7 x 40' x 20'	Under execution.
27. Pambar Reservoir	241.39 (Free). 670.23 (combined).	900	58,690	900	58,690	5 x 40' x 15'	Under execution.
28. Gatana Reservoir	17.94	3815	26,800	3,815	26,800	7 x 25' x 10'	1974
29. Ramanadhi Reservoir ..	6.4	1750	6,050	3,000	10,450	2 x 30' x 15'	1974
30. P.A.P. Group—							
(i) Sholayar Dam	47	3000	39,060	4,000	52,080	3 x 42' x 25'	1970
(ii) Thirumurthy Dam ..	31	1500	14,820 +1,000 from contour canal.	1,500	15,820	5 x 26' x 12'	1967
(iii) Parambikulam Dam ..	88.2	3000	59,580	3,000	59,580	3 x 42' x 27.24'	1966
(iv) Aliyar Dam	2.51	2284	41,000	2,284	41,000	11 x 10' x 30'	1962
(v) Uppar Dam	370	500	25,000	500	25,000	3 x 30' x 18'	1968
(vi) Thunacadavu Dam ..	16.74	1500	14,822	2,000	17,500	3 x 28' x 15'	1966
(vii) Peruvaripallam Dam	6.10						1966
(viii) Upper Nirar Weir ..	29	3000	26,226	4,000	37,760	4 x 32' x 15'	1974

NOTE.—Wherever the value of "C" is enclosed in brackets, it is the derived value of "C" from the Design Flood decided on other factors.

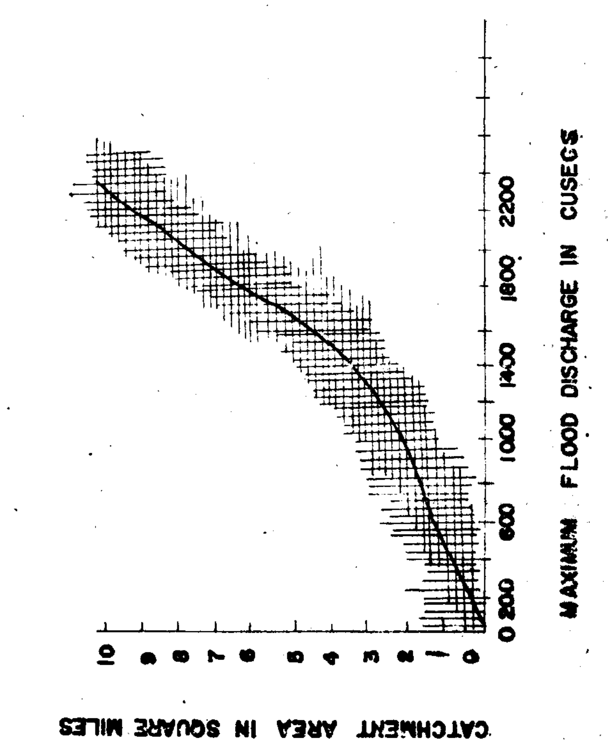
A. L.B.P. MAIN CANAL 0—70 MILES.

1. FOR CATCHMENT UPTO 3 SQ MILES EXTENT DISCHARGES ARE COMPUTED ON THE BASIS OF RAIN FALL 18 INCHES IN 24 HOURS
2. BETWEEN 3 & 6 SQ MILES DISCHARGES ARE READ FROM GRAPH
3. ABOVE 6 SQ MILES DISCHARGES ARE COMPUTED FROM FORMULA $Q=CM^{2/3}$ WITH C=700



B. L.B.P EXTENSION CANAL CROSS DRAINAGE WORKS BELOW M 70.

1. RUN OFF RECKONED AT 18 INCH RAINFALL IN 24 HOURS UPTO 4 SQ MILES OF CATCHMENT AREA
2. RUN OFF CALCULATED BY RYVES FORMULA $Q=CM^{2/3}$ WITH C=500 FOR CATCHMENT ABOVE 8 SQ MILES
3. THE GRAPH GIVES FIGURES OF RUN OFF FOR CATCHMENT OF AREAS BETWEEN 3 & 8 SQ MILES



WATER MANAGEMENT OF TANK IRRIGATION SYSTEM IN TAMIL NADU

By

Er. B. A. JEYAPALAN, B.E.*

The population of the vast continent of India is of the order of 630 millions and feeding this enormous section of humanity has always posed problems. The country passed through a severe period of shortage of food a decade back and imports had to be resorted to on a massive scale. A state of self sufficiency may, however, be said to have been attained now, the production of foodgrains having reached about 115 million tonnes. Cereals form the staple diet of the Indians wheat being popular in most of the States of North India and rice in the Southern States, especially, Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, besides West Bengal and Orissa. The annual production of rice in the country is about 42.5 million tonnes and of wheat 23.3 million tonnes.

1. The Tamils :

The State of Tamil Nadu occupies the south-east part of the Peninsular India. The Tamils have a hoary past and their civilisation extends over a period of over 3,500 years. They have a great cultural heritage and the Tamil language is one of the ancient and complete languages of the World. Their destinies were presided over by a succession of Chera, Chola and Pandiya Kings, who ruled wisely. These Kings were great builders and were responsible for the construction of some of the oldest irrigation structures in the country. The Grand Anicut across the River Cauvery, the gateway to the Cauvery Delta irrigating a gross area of 0.50 million hectares of paddy was constructed by one of the Chola Kings in the 1st Century AD and is still in use. The Veeranam Tank constructed 400 years back by Paranthaga Cholan I irrigates about 20,000 hectares and get its supply from the River Coleroon cutting across an intervening ridge and is perhaps one of the first attempts at an inter basin transfer of water. The Gangaikonda Tank in Tirunelveli District, built by King Rajendra Chola in the beginning of 11th Century AD with an embankment 26 km long, is still serving the area.

2.0. The State of Tamil Nadu :

Tamil Nadu has a land boundary of 1,200 km and a coast line of 900 km and the State can be broadly divided into two geographical regions, viz., the eastern and south-eastern coastal plains to a width of about 80 to 150 km and the western and north-western hilly terrain, which rise up to 2,000 metres at certain places. The climate of the State is trophical, the maximum temperature being 45°C and the minimum 18°C. Climatically, a year may be divided into four seasons as :—

1. Rainy and hot	.. ..	From June to September (South-West monsoon).
2. Rainy and cool	.. ..	From October to December (North-East monsoon).
3. Dry and cool	.. ..	January and February.
4. Dry and hot	.. ..	From March to May.

The eastern plains receive rains from the North-East monsoon and the Central Plateau remains dry and is prone to frequent droughts. The average annual rainfall in the State is about 950 mm, the north east monsoon bringing in 450 mm (47.4 per cent) and the south-west monsoon about 300 mm (31.6 percent). The total precipitation is estimated to be 124 billion cubic metres.

2.0.2. In terms of soil endowment, the State is fairly well placed. The soils may be classified into red loam, laterite, black, alluvial and saline. The red loam is the single largest variety found all over the State and alluvial soil, the more fertile variety, is found in the Cauvery Delta and along the river banks and coastal belts.

2.1. Irrigation in the State :

The net irrigated area in the State up to the dawn of Independence (1947) was only 1.97 million hectares against the net sown area of 4.86 million hectares. Since then, a potential of 2,830 MM³, for irrigating 0.243 million hectares has been created, mostly through storages in large reservoirs and by canals taking off these storages. Currently, the total area irrigated by all sources like canals, tanks and wells, is 2.6 million hectares (nett), out of a net sown area of 6 million hectares, accounting for a percentage of 43. The net irrigated area is covered by different sources comprising canals, tanks and wells, roughly, a third of the area under each category. It may be said that over 92 per cent of the State surface water resources have been utilised. The ground water utilisation is as much as 60 per cent, with the aquifer in danger of depletion, in some areas of the State. Modernisation of surface irrigation systems and improved water management now constitute the mainstay of the State's efforts in irrigation development.

3.0. Tank Formation :

Tanks of varying capacities had been formed across natural drainages or minor valleys from time immemorial. A study of the distribution of the tanks shows a predominance in the eastern belt within about 100 km of the long coast line. Advantage had been taken of the heavy precipitation duing the short north-east monsoon to store up the water for issue as and when required, the rains by themselves, being insufficienct and unreliable for raising a paddy crop, the average precipitation itself being only 450 mm during the north-east monsoon, the requirements for paddy being more than double this quantity. The eastern belt has a very flat slope and though this fact, in turn, has resulted in an appreciable submersion of lands by tank waters, formation of tanks had yet been preferred to a system of cultivation depending solely on the rains. An important limitation in the formation of large tanks had been the lack of expertise in the formation of high bunds of the requisite strength and the imperative necessity to go in for the local soil, whatever be the nature, in the absence of heavy earth-moving equipment. Thus, we find a bund formed with exposed fat clay. Another factor was the need for a tank to feed lands belonging to a particular village only, to get over inter-village factions. Such limitations led to the formation of a large number of small tanks. This may be seen in the fact that there are only 500 tanks each irrigating over 500 hectares. These 500 tanks, however, irrigate as large an area as 25 per cent of the area commanded by the tanks in the State which total 37,400 numbers. Apart from inflow from their own catchment, some of the tanks have additional resources through feeder canals taking off from adjoining river courses. Commandability of these feeder canals in many cases are increased through the construction of bed dams (termed as "Anicuts") across the river.

Chief Engineer (Investigation), Public Works Department, Tamil Nadu, Madras-5 (Paper presented at the Second Afro-Asian Regional Conference of the International Commission on Irrigation and Drainage at Manila, Philippines), during December 1978.

3.0.1. The very factors indicated above which led to the formation of innumerable tanks, appear to have been responsible for the control of the water management by the villagers themselves. While irrigation through canals usually feeding several villages and large extents has been the responsibility of the Irrigation Department of the State, and may be said to have received competent attention to some extent, that through tanks, especially the aspect connected with the water management has always vested with the farmers, assisted by the local officials in-charge of the collection of revenue. No doubt, the maintenance of the tank bund and appurtenant in the case of tanks feeding over 80 hectares each, has been the responsibility of the Irrigation Department (this lower limit has been reduced to 40 hectares recently) but the lack of expertise in irrigation management has been a severe handicap, at least in the case of the bigger tanks.

3.1. Irrigation Practice :

The practices not only in irrigation, but also in agriculture obtaining in the State, are those handed down through the ages, though in the case of the latter there has been improvement in the past decade by way of use of better seeds and fertiliser, resulting in the figures of yield per acre going up. The practice of raising paddy seedlings, preparing the fields and transplanting the seedlings is the popular method, though some of the farmers do not mind taking the risk of sowing a broadcast variety after the break of the south-west monsoon. Normally, tank irrigation provides for barely one crop of paddy by the method of transplantation though under exceptional circumstances when the seeds are broadcast, the farmers do attempt to raise two crops or just one long-term crop depending on the storage in the tank.

3.2. Land Holdings :

Land holdings in the command area of the tanks are small and a typical case of the holdings in the case of the Kambikudi tank is given below :—

Size of holdings.		*Number of holdings.*	*Area. (Hec.)*
(1)		(2)	(3)
Less than 0.20 Hec.	..	494	60.00
0.20 Hec. to 0.40 Hec.	..	338	140.47
0.40 Hec. to 0.81 Hec.	..	247	141.24
0.81 Hec. to 2.02 Hec.	..	114	146.84
2.02 Hec. to 4.05 Hec.	..	21	52.22
Total	..	1,214	540.77

Fractionalisation of land holdings has been a severe handicap in the adoption of machanised cultivation practices, which is so essential for modernisation of farming. Consolidation of holdings, has not been attempted, rather there has been a tendency to further fractionalisation only, the ownership of the lands devolving on the several sons of a farmer when he passes on.

3.3. Data on Tanks :

Lack of data on tanks has been a constraint in planning tank improvements and modernisation. While attempts have been made by the Irrigation Department to investigate the tanks and fix engineering standards and group them, vital statistics like the capacities of the tanks at various periods of time, the number of fillings, figures of the receipt of water in the tank, figures of the issue of water, surplussing details are all lacking. Such a lack of essential information lead us to believe that the farmers by themselves have just not been able to administer the tank irrigation on sound lines.

3.4. Deficiencies in Tank Irrigation :

Irrigation water issues from the tank through sluices and are conveyed through channels to the fields. The sill levels of the sluices are at varying elevations, the lowest sills being near the deep portion. The command area of each of the sluices varies, some irrigating just 3 or 4 hectares and some of the deep sill sluices commanding 200 to 300 hectares, going up to even 1,000 to 2,000 hectares. The areas irrigated by the sluices have not necessarily got contained by natural drains and valleys, even where the terrain is undulating and such divisions are practicable. There is every indication of the command area just getting developed without satisfying the necessary basic requirements of irrigation engineering. Lack of proper layout of irrigation channels and lack of an independent systems of drainage, has resulted in a mix-up of their functions. The resulting deficiencies like waterlogging of low-lying fields, different sources irrigating the same field, etc., would be obvious.

3.4.1. The channels taking off the rear of the sluices are in varying degrees of disrepair, resulting in reduced drawal of water or in lack of command, according as they are silted up or scoured. In the case of the bigger channels, there are controlled off takes, but they are all in a state of utter neglect. There are no specific off takes to feed a specified areas and water is drawn from the channels through openings cut according to convenience. The age-old practice of field-to-field irrigation is in vogue which necessitates continuous flooding and consequent wastage of water. This practice invariably leads to a washing off of the fertilisers. Fields irrigated with drainage water have, on this account, been known to give greater yields than those irrigated with fresh water. Cross bunding of channels to effect an artificial heading up and cutting open the bunds are a frequent necessity. Farmers in the upper reaches of a command get their fields over irrigated resulting in an under-irrigation of those fields lower down. Either way, the yield falls.

3.4.2. The farmers benefitted by the waters of a tank do get a sort of discipline imposed on the use of the waters by a system of unofficial rostering, an arrangement however that subordinate equity to the influence of vested interests.

4.0. The Modernisation Programme :

4.1. The tank modernisation programme aims at overcoming the above deficiencies and is an integrated attempt at agricultural development through improved water management in the command of the major tanks (each irrigating over 200 hectares) in the State. The specific objectives of the programme are—

1. Improvements to and modernisation of the entire irrigation system and command area.

2. Optimum water management by reducing losses and scientific regulation and improved agricultural practices.

3. Stabilisation of existing irrigation of 0.24 million hectares and extension of irrigation by 54,000 hectares of new area by economising on water use.

4.2. The detailed measures contemplated in the programme can be grouped under seven major heads—

1. Improvement of feeder channels to augment irrigation supplies.

2. Improvements to the tank and its appurtenances including sluices and surplussing arrangements to ensure maximum storage against cyclonic storms during monsoon periods.

3. Modernisation of command area through designed and properly aligned sections of main, branch and field water courses and provision of (now totally absent) control structures in the distribution system.

4. Reduction of transit losses in distribution system through lining wherever necessary.

5. Scientific water-regulation management techniques to replace the existing continuous flooding with strictly enforced intermittent irrigation.

6. Adoption of improved agricultural practices creation of requisite agricultural/supporting service and the on-farm works.

7. Improvement in operational efficiency through, control of distribution system by Irrigation Department up to 10 hectares limit, beyond which the distribution by the farmers would be supervised by Irrigation Department officials.

4.2.1. In this Paper, it is not proposed to deal with the measures spelt out in paragraphs 1 and 2 above, which are of a routine nature and paragraph 6, which pertains chiefly to agricultural practices.

4. 3. Command area developemnt—Limitations :

Command area development generally entails land consolidation including—

1. Cadastral survey, topographical survey, preparation of maps and layouts for irrigation, drainage and road systems.

2. Determination of land rights, valuation of different land classes.

3. Preparation of a new plan for the command area including allocation of land for communal purposes (such as field channels and drains, access roads and other public uses like thrashing floors, etc.).

4. Re-allocation of land into compact holdings.

5. Preparation of new land ownership records and maps.

4.3.1. In the Tamil Nadu Project, the lengthy process of a complete reorientation, covering aspects like reforming the command area and preparation of a new plan and re-allocation of the land into compact holdings, will not be carried out, in the absence of necessary legislation in this regard and the immense practical difficulties expected to be met with, though such a process of command area development has been attempted elsewhere in the country with varying degrees of success, especially for high duty crops. It has been considered practicable to limit the modernisation to the irrigation aspect of the system only without changing the existing conditions of location, shape and size of the holdings. Changes in the source of supply will also be made only where essential.

4.3.2. A redrawing up of the system of channels and field water courses, will however be done in the light of topographical surveys of the command area and the entire system of water management re-oriented and modernised. Modernisation programmes generally aim at only a better distribution of water to each field and such programmes are not necessarily made economically viable. A feature of the modernisation of tank irrigation in Tamil Nadu is the attempt at making the project economically viable also, by going in for measures aimed at a reduction of the losses in irrigation and making use of such savings eslewhere.

4.4. Modernisation of Main Irrigation Channels :

The main and branch channels distributing water to the fields will be restored to standards by desilting and adjusting their beds with reference to the existing hard and commandability. It is proposed to curtail unnecessary traversing of channels and distributaries and if necessary, to relay them acquiring some lands. The beds and slopes of all the main channels and distributaries down to the 10 hectare limit will be lined, wherever it would be advantageous to do so, with cement concrete M 150 grade to a thickness of 5 CM. Necessary control structures would be raised in the distribution system for effective enforcement of intermittent irrigation.

4.5. Adoption of scientific water regulation and management :

The salient features of the new irrigation practice to be adopted will be—

(*a*) rotational irrigation.

(*b*) remodelling and regrouping of the command area for better water management.

(*c*) water regulation to be vested with the Irrigation Department up to 10 hectares blocks.

(*d*) provision of field channels (on farm works).

4.6. Rotational Irrigation:

The requirements of water for paddy, both for a long-term and short-term crop are as indicated in the table below —

Duration of Crop-Paddy

Serial number and crop stages.	*105 days.* No. of days.	Depth of water.	*140 days.* No. of days.	Depth of water.	*180 days.* No. of days.	Depth of water.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		CM.		CM.		CM.
1. Nursery ..	25	46	25	46	45	46
2. Preparation of cultivation.	5	20	5	20	10	20
3. Transplanting.	15	30	15	30	75	30
4. Up to heading	30	10	60	28	30	36
5. Heading to harvest.	35	5	35	5	30	5

4.6.1. In general terms, the requirement is given as 112 cm. for a base period of 105 days, 137 cm. for a base period of 180 days, and 130 cm. for a base of 140 days for short, long and medium term crops respectively.

4.6.2. The existing practice of paddy cultivation is to initially raise nurseries in a small patch of land with the help of an early release of tank water on a limited scale, or through ground water sources. While the seedlings grow to a degree of maturity when they can be transplanted, the fields are prepared by soaking them and ploughing. A slushly mass is created, which retains moisture. Green manure is usually applied during ploughing. The seedlings are transplanted on to the ploughed field after about 40 days in the nursery.

4.6.3. The preparatory stage for cultivation, that is, ploughing and the transplantation require a peak input of water, even though the requirements at other times may be much smaller. It is also essential that fields are not allowed to dry up during ploughing and transplantation. The current irrigation practice is to provide a continuous flow during this period from field to field—an arrangement that is unnecessary and wasteful.

4.6.4. Advances in agricultural practices indicate that it is unnecessary to have a continuous flow for paddy; that the yield of grains in fact, increases if over-irrigation is avoided. It is proposed to introduce rotational irrigation, where sufficient supply will be made only every alternate day during ploughing and transplantation and only as and when required, during other periods. The command will be divided into blocks of 10 hectares each for the purpose. Eight days will be allowed for preparation and water will be supplied during this stage to each block every alternate day to a depth of 5 c.m. for 24 hours. There will thus be four such wettings per 10 hectare block. The rate of supply works out to a duty of 171.5 hectares per cusecs (12 acres per cusec) and the field water courses will be designed accordingly. It is also possible to increase the number of wettings to six and allow a correspondingly reduced depth over field, if it is considered more convenient to handle smaller discharges than two cusecs. The period of transplantation in this case will be 16 days and supply ensured on alternate days to a depth over field of 4 cm. in 24 hours.

4.6.5. When the commanded area under a tank sluice exceeds 80 hectares, it is considered necessary to allow for a staggering of irrigation periods from practical considerations of availability of labour, machinery, tools, etc. In such cases, the command will be split into upper and lower blocks and irrigation activities staggered over a period of 20 days, which is the time required for preparation and transplantation. The upper block istelf will be put on turns on alternate days during the period of maximum demand, when both day and night irrigation will be practiced. This process also results in a reduction in the size of the main water course.

4.6.6. After transplantation, water supply for crop sustenance will be restricted to day-light hours, as and when required.

5.0. Water Regulation in main and branch water courses :

5.1. The Irrigation Department will control the supply of water to the command area down to the 10 hectare block. Inside this block, water management will vest with a cultivation committee consisting of the cultivators in the block area, assisted by a Government nominee of the Agricultural or Irrigation Department. The Committee will supervise the implementation of the rotational system, guide the farmer and enlist his co-operation. Issues will be regulated whenever there is a useful rain in the locality. The controlling devices in the main and branch water courses will be operated by the Irrigation Department. These controlling devices will consist of sluices for supply to the field water courses and regulators constructed across the main water courses to shut off or head up or regulate the flow. Shutters with screw gears will be provided to make the arrangements tamper proof. Problems like theft of water, open cuts and uncommandability, will be thus overcome.

5.1.1. The sluices will be designed to draw the maximum quantity of water required with a full supply level in the main water course. They will have to be operated only once every day even at the time of preparation of fields, which is the period of maximum demand.

5.2. Field Water Courses:

The present system of field to field irrigation with attendant deficiencies will be replaced by a system feeding independently and draining each field or a small block not exceeding 4 hectares. The field water course will be located along field boundaries keeping existing shapes of fields undisturbed and will be so designed that they are in banking, with the bed level at the field level. During maximum demand, the field channels will draw a little over 2 cusecs for a block of 10 hectares. The entire quantity will be concentrated to flow through a predetermined gap in the bunds at any one time. These gaps will be constructed with a body wall with the nosing suitably protected and will be provided with shuttering arrangements. There will be 3 or 4 such outlet points in a 10 hectare block and each of them will have a regulating device across the field water course to enable shutting out of supply below the regulating device. The period of suppy through each outlet will be regulated on the basis of the actual acreage fed but the entire block of 10 hectares will be irrigated in 24 hours at the time of peak demand.

5.2.1. Field water courses will be formed at Government expense and also maintained by the Government. This aspect of maintenance is important since the entire system of rotational irrigation is dependent on the proper functioning of the field water courses. The charges for upkeep can be recovered from the beneficiaries on an acreage basis.

6.0. Project Benefits:

6.1. The project is intended to improve irrigation efficiency by reducing losses and introducing scientific water management. It is expected that there will be a total saving of at least 20 per cent in the water utilisation.

The 500 tanks to be covered by the Project irrigate presently in all 0.22 million hectares and since the assumed duty is 86 Hec./MM^3, the present total water consumption will be 2,550 MM^3. The expected saving of water in aggregate works out to 510 MM^3 after meeting the requirements of 0.22 million hectares at a higher duty of 107.25 Hec/M M^3.

6.2. Pattern of utilisation of water saved:

The possible manner in which the additional water could be utilised depends upon field conditions, which vary from one area to another. Field investigation conducted in the command area of eight tanks show four possibilities, viz. (i) filling the existing gap, i.e., the difference between the registered command and actual area under irrigation, (ii) extending irrigation to new area, which presently is used for raising rainfed crops, (iii) increasing the crop intensity and (iv) switching of lands from private source to public source of irrigation.

6.3 One of the important features of the project is its flexibility with reference to financial input and also the benefits realised. Each of the tank schemes is an independent unit of the entire project and the benefits thereof can be realised practically in the same season of modernisation. The constructional phase can also be controlled depending on the availability of funds.

7.0. Project Cost:

7.1. The cost of modernisation including the works of improvements to the different units of the tank like supply channel, bund, surplus arrangement, etc., will vary from tank to tank, and on an average works out to about Rs. 4,000 per hectare (roughly $500 US). The Tamil Nadu Project has been programmed for completion in 8 years and will cost Rs. 105 crores ($124 million US) at the start and Rs, 182 crores ($ 214 million US) on completion.

8.0. Canal, tank and lift irrigation each form one third of total irrigated area in Tamil Nadu State. Lift irrigation is fully taken care by individual farmers with adequate water management. There is practically no effort on the part of Government in such cases, except for subsidised rate in the supply of power for their pumps. Canal irrigation is controlled by the Irrigation Department with adequate expenditure on maintenance of the distribution system. It is the distribution system of the tank irrigation that has been left to fend itself with practically no maintenance either by Government or the farmers, who were expected to maintain the same under the old KUDIMARAMATHU practice. The farmers under the tank irrigation are the poorest among the three categories. Their holdings are small in extent and the irrigation supply is also not assured. This tank modernisation scheme is the first attempt to improve the lots of these neglected farmers, whose command areas and their distribution system have not seen any improvement for many centuries of their existence.

REMOTE SENSING FOR HYDROLOGICAL STUDIES

By

Er. S. PARASURAMAN *

1.0. Introduction :

1.1. Hydrology is briefly defined as the science of water and deals with its occurrence, distribution and movement through the atmosphere, over and under the land surface and eventually back to the sea. It occurs in all the three states of matter, viz., gaseous, liquids, and solids. It occurs as falling rain and water stored in the low pockets of earth crest, flowing streams and under the ground. In solid state it occurs as snow or ice.

1.2. Water stored in lakes, oceans, reservoirs and under the ground evaporates into the atmosphere and forms vapours or clouds. These vapours when condensed precipitate as rain or snow and reaches the ground surface again. The rain water which reaches the ground gets locked up in the low pockets of earth crest. A part of the rain water infiltrates in'o the ground while the excess drains into the sea.

2·0. Informations required for Hydrological Studies :

2.1. The study of water in its various phases of hydrologic cycle requires the following informations:—

(i) Information on evaporation from surface and sub-surface water bodies, transpiration and consumptive uses.

(ii) Information on ground water aquifers and base flow of streams.

(iii) Information on rainfall distribution and drainage basins.

(iv) Information on the velocity of surface water flow, time of concentration of storm flows and the effects of soil cover.

(v) Data on soil cover over large areas.

(vi) Data on the extent of snow cover, moisture content, the rate of snow melt and stream flow production.

(vii) Information on the effect of currents and tidal flows upon harbours and estuaries, the extent of salt water intrusion and the effects of stream flow and waste upon coastal waters.

2.2 For collection of data on these aspects, a variety of instruments are used in hydrology as in other branches of science. Instruments are used in hydrology for measuring, gauging and monitoring hydrologic features and to collect, analyse and transmit these hydrologic informations quickly for use in utilisation of the available water resources and for better understanding of the phenomena of 'hydrologic cycle'. The instruments used in hydrology are classified based on their use, mode of performance and techniques employed in using them. As the technique employed are varied, many a number of instruments have been developed. As the object of this paper is limited to application of remote sensors for hydrologic studies, instruments used for point source data collection or contact measurements such as raingauges, evaporimeters, water level recorders and surface flow measuring devices are not dealt with in this paper.

3.0. Advantages of remote sensors over contact measurement equipments .

3.1. Generally, speaking, it can be said that before the advent of remote sensing as a tool in hydrologic data collection, qualitative observations and quantitative measurements were made by integration of point source data collected by the contact instruments referred to in the previous paragraph. However, it is also possible to get continuous (real time), intermittent and periodic communication of data collected by these point source data collection equipments by linking them by a telemetry net-work. The collection of data either spatially or temporaly through these contact measurement devices eventhough more reliable and fairly accurate, they are more time consuming and expensive in certain cases. Moreover, they have limited application in hydrological observations.

3.2. Research and development has advanced far enough to replace the traditional point source data collection equipments by remote sensing devices. Because of their capability to collect data in *spatial, temporal* and spectral modes they overcome many of the limitations inherent in point source data collection equipments and therefore have wider application in hydrology.

4.0. Development of remote sensing technology :

4.1. Remote sensing in simple terms means viewing and identifying of objects by devises not in intimate contact with them. These sensing devises or equipments are called "remote sensors". The development of this technique is traceable to the latter part of the 17th century when scientists attempted to survey the earth surfaces from Air baloons and until the middle of eighteenth Century remote survey of earth surface was limited to visual observations only. The invention of photography by French Scientist Louis Daguerre in 1839 and making of first aerial photograph by Persian Photogrpher F. F. Tournachan in 1858 are important landmarks in the man's attempt to develop remote sensors to detect things at distances beyond his own senses. Until 1960's remote sensing technique was limited to aerial photography and photointerpretation techniques only. From 1960 onwards, remote sensing technique had developed very rapidly and many non-photographic techniques were developed.

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4.2. Today, a variety of remote sensors sensitive to each of the various regions of the electro-magnetic spectrum are in use for various resources survey of the earth and for various scientific investigation of the atmosphere. The remote sensors include photographic cameras, television camera systems, multispectral scanners, thermal mappers, side looking airborne radars and micro-wave radio meters. Please vide Fig. 1 which shows the energy types, wave lengths, frequencies and spectral regions of the electro-magnetic spectrum to which various type of remote sensors are sensitive.

5.0. Remote Sensing Technique :

5.1. Most of the remote sensors make use of the fact that all bodies on earth emit certain amount of radient energy in different regions of the electromagnetic spectrum and the emittance of this radiant energy is unique for each object dependent on its spectral, temporal or spatial variations. Each object on earth has a finite temperature and radiates energy depending on its temperature, molecular structure, wave length of radiation and surface conditions. So also, the reflection of light incident upon an object depends upon the wave length, the molecular structure of the object, etc. These *spectral variations* in reflectance or emittance from objects are characteristic of the electro-magnetic spectrum and helps us to recognise the objects. *Spatial variation* on an object such as its size, shape and texture provides a contrast in the reflectance of light incident upon it and its background. This characteristic differential reflection of the object and its background enables us to recognise the object. The reflectance or emittance of radiant energy from an object sometimes varies with time and this *temporal variation* in reflectance or emittance are sometimes used for identification of the objects. These informations which let us recognise the objects are called "Signatures" and are characteristic of their spectral, temporal or spatial variations.

5.2. *Types of Remote Sensors :*

Each remote sensor is fabricated so as to record or measure the variations in reflectance or emittance of objects in their spectral, spatial or temporal modes and are named according to which of these techniques is employed in the sensor. "Sensors may be either active or passive" depending upon whether they can sense the objects under natural radiation emitted or reflected by the objects or whether they can sense the objects based on the energy pulses emitted by the sensor itself.

5.3. *Mode of Data Collection by the Sensors :*

The data are collected by using one or more sensors from a space platform which may be a baloon, an aircraft rocket or a satellite. The informations received by the sensors are recorded in the form of films, magnetic tapes or electrical signals which could be transported back to the earth. These films are tapes are then processed and produced either as photographs or thermal imageries or computer classified resource informations.

6.0. Remote Sensor for Hydrological Observations :

Remote sensors used for hydrological observations can be broadly grouped as photographic cameras, spectro-meters, scanning radiometers, radars and other radio frequency instruments. The various types of instruments relating to various wave lengths and frequencies at which they function and their potential value and use in hydrological studies are described in the following paragraphs.

6.1. *Photographic Cameras :*

Photographic cameras operate in the visible, ultraviolet and informed regions immediately aojacent to the electro-magnetic spectrum. Photographic cameras being relatively simple can be made to rigorous standards and can be employed to measure accurately the locations, shapes and sizes of elements of scenes. They are therefore superior to all other sensors in this respect as they see and record all elements in each scene simultaneously. Photographic techniques are classified according to the type of films used in the camera systems.

6.1.1. *Panchromatic Photography.*—Black and white panchromatic film having been the longest in use is the most widely used remote sensing technique because of its availability and relatively low cost. *It is utilised for sensing* stream lines on water surfaces, mapping snow covered areas, drainage mapping and identification of vegetation features associated with ground water.

6.1.2. *Colour Photography.*—Colour Photographs provide an additional and very distinctive factor "hue" to the photos and increases by many times the value of photography for identification of things. It serves as a major tool to hydrologists in many special fields and is sufficiently better for recognition of significant hydrologic features. It is very helpful for aquifer mapping, and detection and identification of glaciers.

6.1.3. *Infrared Photography.*—In infrared photography, reflected sunlight is not recorded as in the visible spectrum, but the radiation emitted by the objects itself is used. Photographs taken in infrared films are of prime value in mapping drainage features and shorelines. Its use in remote sensing is very valuable as an adjunct to standard aerial photography in detecting many ground water features and in identifying species of vegetation on earth.

6.1.4. *Infrared Colour Photography.*—Colour infrared or false colour films are exposed through a yellow filter which blocks the passage of blue light and results in the exposure of green, red and infrared light. This type records in colours, that are not true to nature but are designed to enchance recognition of vegetation condition. It shows differences in vegetation and in soil characteristics more clearly than standard colour photography. It provides higher contrasts for mapping of discontinuities on water surfaces than other types of photography. It is also used to differentiate new snow from ice.

6.2. *Optical-Mechanical Scanning Radiometers*—

6.2.1. Optimal-mechanical scanning radiometers operate in the ultra-violet, the visible, the infrared (solar) and microwave energy regions. They divide the spectral energy sensed through a single optical system into narrow bands, observe the aerial distribution and amplitude levels in each band simultaneously and record the informations for each independently. Energy sensed is translated to electrical energy which may-(1) activate a cathode ray tube or an intensity modulated glow tube which, in turn, may expose film to create a photographic image or (2) be recorded directly on magnetic tapes. These taped records may also be used to create photographic images through cathode ray tubes.

6.2.2. Advantages of scanners for visible wave lengths are based upon the ease of measuring and reproducing recorded values of electrically taped data as compared with the difficulty of attaining uniformity among film emulsions and film processing procedures. As the scanners record the scenes continuously their aerial information is affected by the lack of balance between the speed of the scanning mirror movement which is oscillating in a vertical plane at right angles to the line of flight and the forward motion of the air craft. This results in distortion of shapes of features observed.

6.3. *Thermal—Infrared and Micro-wave-scanning Radiometers*—

6.3.1. Infrared and micro-wave scanners sense temperature at and near the surface, integrating temperatures over distance and depths that are somewhat shorter than their operating wave lengths. The data collected by them are most commonly presented in the form of imagery for identification of features.

6.3.2. Infrared radiometry is very useful for sequential measurements of changes in land and water surfaces because it is a simple measurement technique and data reduction is simpler than for infrared imagery. Infrarred radiometry is routinely used for periodic surveys of near-shore oceanic areas.

6.3.3. Infrared imagery has shown its value as a tool for measuring water surface temperature and as a means of qualitatively differentiating some terrestrial features. It is of some use in mapping ice and snow temperatures.

6.3.4. Micro-wave scanning radiometres sense temperature variations at longer wave lengths-millimeters and centimetres than these of thermal infrared. Because the wave lengths at which they operate are longer, they sense to greater depths than other systems of remote sensors. Passive micro-wave sensores measure the brightness temperature of terrain and water surfaces. The spatial resolution of micro-wave system is lower than infrared systems. They have high utility for detecting underground caverns, measurement of soil moisture over large areas and the water equivalent volume of snow.

6.4. *Radars*—

6.4.1. Radars are active systems that operate at microwave and radio frequencies. They emit pulsed radio signals at predetermined frequencies, polarisations and rates and measure these parametres of the signals that are returned from the ground. Becaues they are active and operate at relatively longer wave lengths, they can be used to obtain terrain information in darkness and in cloudly weather. At shortest wave lengths, surface characteristics are predominant, at longest wave lengths and in dry and cold materials boundary condi tions may also be sensed. Radars may be imaging of non-imagin.

6.4.2. Airborne imaging radars scan across the flight path in a vertical plane which may extend to both sides or may look only to one side of the aircraft. The type that is most commonly used in environmental studies is side looking and is commonly called SLAR (Side Looking Airborne Radar).

The signals received from each scan are converted into electrical impulses that may be recorded on magnetic tapes or excite a cathode ray tube to present a line of data. New lines are added with the forward movement of the aircraft and the cathode ray tube is photographed to produce a continuous strip image. Image paths on the ground may be as wide as 50 miles and data can be obtained as quickly as aircraft can fly.

6.4.3. Radar imagery is especially useful in determining aerial extent of precipitation. SLAR has an all weather capability for coverage of large areas. Its ability to penetrate foliage and accentuate topographic features enhances its value. Water surfaces are excellent reflectors of microwaves resulting in a uniform black tone image. For these reasons, stream drainage systems and water surfaces are easy to identify. Radars are very useful in terrain analysis for ground water explorations. It is of little value in measuring physical chemical or biological characteristics of water, but is useful in locating and mapping areas of open water. It also has some value in mapping snow covered areas. However, it does not give data on water content of snow.

7.0. Geophysical Methods:

A few remote sensing techniques are not related to electromagnetic spectrum but are based on the sensing of acoustic waves or of fields such as gravitational, magnetic and electrical fields of the earth. They are called as geophysical methods' and are used for surface and subsur face explorations. Geophysical methods detect differences or anomalies of physical properties within the earth's crest. Density, magnetism, elasticity and electrical resistivity are properties most commonly measured. Geophysical methods though primarily intended for scientic measurement of physical properties of the earth's crest for investigation of mineral deposits or geologic structures, it has been refined and developed in recent years for application in ground water investigations also. Of all the methods adopted for geophysical explorations, electrical resitivity and seismic refraction methods are widely used for locating and analysing ground water. The gravity and magnetic methods have little application in ground water prospecting. However as the scope of this paper is limited to remote sensors carried on in air crafts and space crafts only, these are not dealt with in detail here.

8.0. Conclusion:

The conventional methods of earth resources surveys are slow expensive and often unreliable. The data obtained are mostly inadequate for efficient planning of development works. In recent times rapid strides have been made in the development of remote sensing technique and because of its varsatile nature it is being widly adopted for resource survey in the areas of Agriculture, Forestry, Oceanography and Geology, etc. In hydrology also, it serves as a powerful tool in hydrologic data collection and mapping of water bodies flood plains and inundated areas and detection of the presence of ground water in various geological formations. Thus, it can play a very important role in hydrological studies enabling optimal utilisation of the water available in the various phases of Hydrological cycle. The adoption of this technique in all the hydrological study of Tamil Nadu is quite relevent in the context that Tamil Nadu had already harnessed more than 90 per cent of its surface waters and depends for all its future needs on the water available in the other forms of hydrological cycle only. Remote sensing technique could profitably be applied in this State for better management of the available surface waters and exploitation of the water available under the ground.

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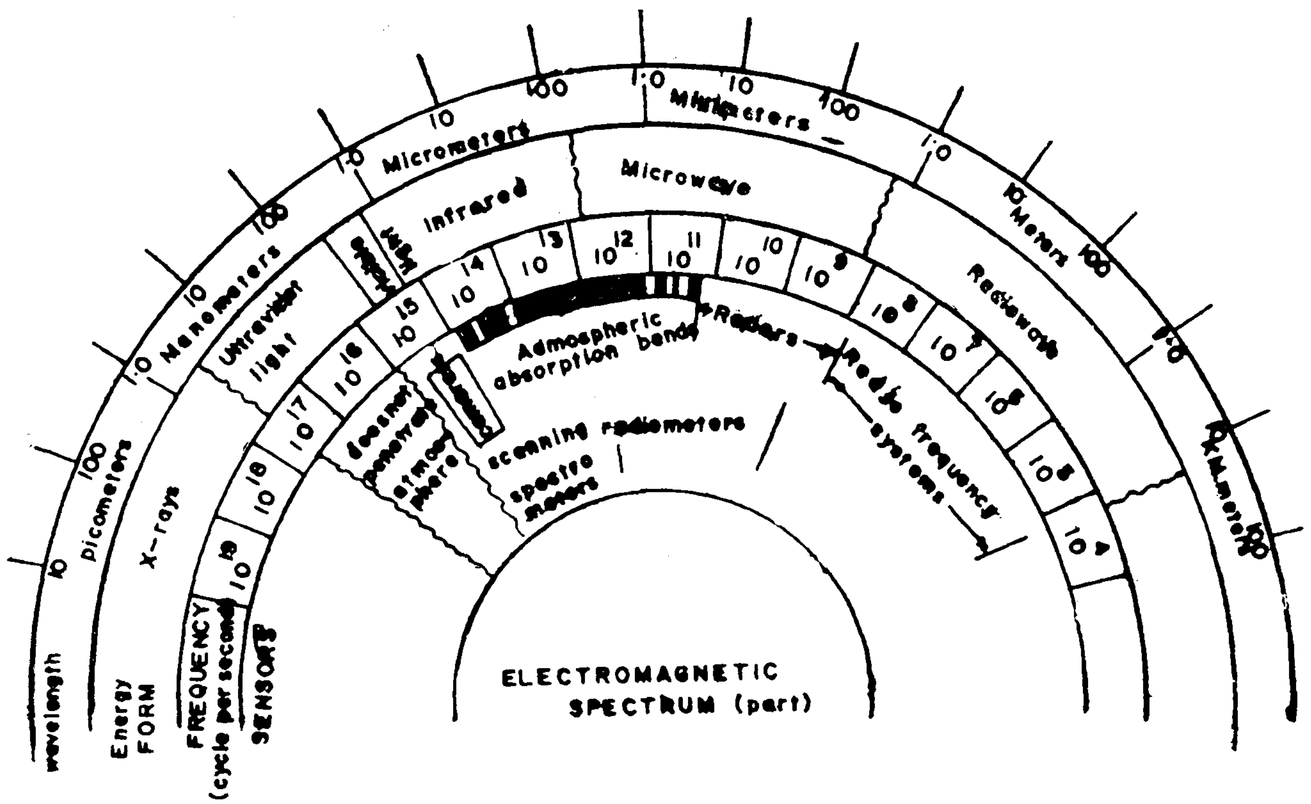

U.S. DEPARTMENT OF THE INTERIOR/GEOLOGICAL SURVEY.

Fig. 1. Diagrammatic representation of part of the electromagnetic spectrum showing energy types, wave lengths and frequents and spectral regions to which airborne and in some cases, spaceborne remote sensors may be addressed. (U.S. Geol. Survey, EROS Program.)

FOREIGN NEWS.

GRANULAR-FILL DAM PROTECTED BY PVC MEMBRANE :*

Design and construction of the Minorca Tailings Basin Starter Dam sets a precedent for the use of plastic membrane for seepage control in the construction of earth fill dams where more conventional methods of seepage control may not be economical. The dam is unique in that it is constructed entirely of granular fill placed in zones of varying gradations within the embankment. Seepage through the embankment is controlled by a 20 mil (51 mm) thick PVC membrane placed on the upstream side of the embankment and covered with a protective layer of granular fill. It is believed that this is the first application of a PVC membrane for a project of this kind.

THE MINORCA TACONITE Development is a new taconite mining and processing facility recently constructed near the City of Virginia in North eastern Minesota. The plant is owned and operated by In land Steel Mining Company which, through mining leases, controls the minerals in approximately 1,800 acres (7,28,000 m²) of land contiguous to the plant. The development has a design production capacity of 2.6 million long tons (2.6 × 10⁹ kg) of pellets annually.

TACONITE INDUSTRY :

The development of the taconite industry has occured in response to the depletion of natural deposits of high grade iron ore in the North Central United States coupled with the growing demand for iron and steel. Taconite is a dense rock of sedimentary origin which may contain as much as 35 per cent iron in the forms of magnetite, hematite and other ferrous minerals. Mineable taconite may contain as much as 25 per cent magnetite which, due to its natural magnetic properties, is the most economically recoverable ferrous mineral in the process of benefication, the crudeore from the mine is crushed and finely ground. After various stages of grinding, magnetite is extracted by magnetic separation. The powdered magnetite is mixed with a bentonite binder and rolled into pellets. The pellets are hardened by firing and shipped to the steel manufacturers.

The material which remains after the magnetite has been extracted is a plant waste known as tails. Tails consist of ground taconite, from which the magnetite has been removed. The size of gradation of the tails is dependent upon the design of the processing plant. The tails produced Minorca are relatively uniformly graded from approximately 10 mm to less than ·005 mm. The Minorca Operation will produce an estimated 200 million tons (180 x 10⁹ kg. of tails during the life of the facility. Currently, the only method of tailings disposal which is considered to be both environmentally and economically acceptable in the North Central United States is on-land disposal in tailings basis and waste stock piles. Due to the large quantity of tails produced by a typical taconite operation, the disposal of the ails in a safe and environment. tally acceptable manner is one of the major problems which must be solved in the planning of a taconite development.

The primary components of the Minorca Development are the open pit mine, the processing plant, the tailings basin and the waste disposal area. Crude ore is transported from the mine to the primary crusher by 130 ton (109,000 kg) trucks. The finished pellets are shipped from the plant to Lake Superior by rail where they are transferred to boats for shipment to the steel manufacturers (See fig. 1.)

TAILING BASIN :

The tails generated by the processing plant are hydraulically separated into two size fractions. The coarse fraction, which consist primarily of particles larger than approximately 0.15 mm, is transported to the waste disposal area or to the tailings basin by truck. The fine fraction which consists primarily of particles smaller than 0.15 mm is slurried and pumped to the tailings basin through a pipeline. The plant will produce an estimated 142 million yd³ (108 million m³) of fine tailings during its anticipated service life.

The primary function of the tailings basin is to produce an impoundment where the slurried tails can be discharged and disposed of in a safe and environmentally acceptable manner. The basin, however also serves a setting pond for the clarification of the slurry water (which is recycled) and as a reservoir in which plant process water can be accumulated and stored. Tailings basins are usually created by the construction of earth fill dams around natural topographic depressions.

In cases where site conditions are suitable for clay upstream blanket—but suitable clay is not available near the site—polymeric membrance may prove an effective and economic alternative to ~~more conventional~~ methods of seepage control.

The location of the tailings basin is determined primarily by the topography of the area in the vicinity of the processing plant and mine. Transportation of crude ore from the mine to the plant and transportation of waste materials from the mine and the plant to the disposal areas constitutes a significant portion of the production cost. Therefore, it is economically advantageous if the mine, the processing plant and the waste disposal areas are located as close to each other as possible. This means that in order to maintain the economic viability of the development, the location of the tailings basin must be largely determined by factors which are relatively unrelated to the dam-building characteristics of the site. Because of this situation, the engineer responsible for the design of the tailings basins dams is often faced with the problem of designing major dams and which are safe, stable and

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economical on sites where the foundation conditions and available construction materials are not well suited for dam construction.

The tailings basin of the Minorca Development is located in the upper portion of the watershed of a small creek on the opposite side of the Laurentaion Divide from the processing plants. The 3,500 acre (14 million M^2) basin was created by the construction of an earthfill dam aligned to follow natural drainage divides across the watershed. In order to provide sufficient volume in the basin to store the accummulated fine tails, plant process water and flood waters, the dam must be ultimately constructed to a maximum height of at least 81 ft. (25 m) and a length of approximately 4·2 mi. (6.8 feet). The initial dam, which is known as the starter dam, was constructed only to a maximum height of 48 ft. (15 m) along a 2·5 mi (4 km) alignment. The height and length of the dam will be increased in stages as the useable storage volume of the basin is depleted by the accumulation of fine tails. Staging of the dam construction in this manner, not only allows the cost of constructing the following stages to be deferred, but allows the coarse fraction of the tails produced by the plant to be used as a construction material.

DESIGN CRITERIA

In order to successfully fulfil its desired function, a tailings basin dam like any earthfill dam must have several important characteristics. The dam must have sufficient freeboard to prevent it from being overtopped by the design flood; the dam must have slopes that are stable under all foreseeable conditions including rapid fluctuations in the level of the reservoir; the dam must not become unsafe or unserviceable due to settlement; the dam must contain adequate provision for the control of seepage through the embankment and the foundation to insure that the hydraulic gradients and potentials on the downstream side of the embankment are maintained within safe limits; and the constructions of the dam must be relatively economical. These characteristics must be considered during the design process by detailed hydrologic, settlement slope stability and underseepage analyses which adequately reflect the conditions of the site. Features which would increase the economy and efficiency of construction without sacrificing safety should also be considered during design.

Typically earthfill dams are constructed with an impervious clay core surrounded by granular shells. If the dam is constructed on a shallow layer of pervious soils above an impervious stratum, see page through the foundation is typically controlled by means of an impervious cu off connecting the impervious Core of the Dam with the impervious stratum. Cut offs may consist of sheet piling concrete, a slurry trench a grout curtain or an excavated trench filled with impervious soils. If the dam is constructed on a previous foundation of great depth, control of under seepage is often achieved by increasing the length of the seepage path by use of an impervious horizontal upstream blanket. In rare instances when the quantity of reservoir water lost by seepage is not an important consideration, a dam may be constructed entirely out of pervious soils. The site selected for the tailings basin of the Minorca Development however, did not lend itself to the economic construction of any of the conventional types of earthfill dams.

SUBSURFACE EXPLORATION YIELD NO IMPERVIOUS SOIL

When the alignment of the starter dam was determined, the foundation conditions along the alignment were explored by a resistivity survey and soil borings. It was found that the foundation materials consisted typically of a relatively thin layer of organic top soil underlain by 1 to 2 (0·3 to 0.6 m.) of sandy clay till on top of dense silty sand. Boulders were encountered at all depths but were more prevalent in the upper most 10 ft. (3 m) and on the surface. In isolated small areas, deposits of peat ranging in depth to 3 ft. (9m) were encountered. Bedrock was found to vary from outcrops on the surface to depths in excess of 76 ft. (18m) and the static water table was found to vary from the surface to depths of 8 ft. (2m). No usable sources of suitable impervious soils were found within 7 mi (11 km) of the site.

Detailed hydrologic, settlement, slope stability and underseepage analyses adequately reflecting the conditions of the site must be considered. The site selected for this particular basin did not lend itself to the economic construction of a conventional earthfill dam.

REVIEW OF ALTERNATIVES

Because clay was relatively expensive due to the 7-mi (11-km.) haul from the nearest suitable borrow area, a preliminary design of a dam was prepared in which the use of impervious soil was minimized to the greatest extent possible. The preliminary design was based on a conventional type of earth dam in which seepage control is provided by a clay blanket on the upstream slope and on the native soils upstream of the toe of the embankment. The blanket contemplated in the preliminary design had a thickness of 3ft. and extended a minimum of three times the hydrostatic head upstream from the toe of the upstream slope. The estimated construction cost of the starter dam contemplated in the preliminary design was slightly over 3 million dollars. However, construction problems associated with the placement and compaction of the clay blanket were anticipated in the areas where the water table was at or near the surface. It was, therefore, decided to investigate the possibility of replacing the clay blanket with a polymeric (i.e.) plastic) membrane.

INVESTIGATION OF POLYMERIC MEMBRANE

The initial step of the investigation of the applicability of polymeric membranes consisted of a review of the durability and relative cost of the membrane materials currently available. The relative cost of construction tecniques which would be required for installation of the membrane was also considered. The results of the investigation indicated that replacement of the clay blanket with 20 mil (.51 mm.) thick polvinyl chloride (PVC) membrane would be both feasible and economical. An additional benefit was that the method would avoid the problems associated with the placement and compaction of clay in areas having a high water table. Therefore, it was decided to base the final design on a dam having an embankment constructed entirely of the pervious soils available on the site and utilizing PVC membrane for seepage control. [See Fig. 2]

Polvinyl chloride (P.V.C.) membrane is subject to deterioration if it is exposed to sunlight and weathering, change. It is also subject to a loss of flexibility due to partial loss, migration or chemical of the plasticizer incorporated into the membrane (which is caused by bacteriological attack). The Interior Department's Bureau of Reclamation has conducted extensive testing of P.V.C. and other membrane materials in the laboratory. The Bureau supplemented the laboratory tests by examination of membranes which had been in service for a number of years as canal linings. The results of this testing programme are contained in Research Report No. 19 Investigation of Plastic Films for Canal Linings, published by BuRec.

The testing programme conducted by the Bureau indicates that P.V.C. membrane should have adequate elongation properties after 35 to 70 years of service under field conditions if membrane is protected from sunlight and weathering by a covering of mineral soil. A study of the rate and manner of tailings deposition in the tailings basin indicated that after a maximum of 20 years of operation, the entire upstream slope of the starter dam would be covered by a fraction of the fine tails, which are smaller than 0.005 mm. and are known as slimes. At that time, which is approximately 15 years earlier than the minimum expected service life of the P.V.C. membrane, the seepage through upstream side of the starter dam would be prevented by the accumulation of impermeable slims—and the P.V.C. membranes on the upstream side of the embankment will no longer be required for the control of seepage.

HYDROLOGIC ANALYSES

The free board of the starter dam and the corresponding crest elevation which could be required to prevent the possibility of overtopping were determined by hydrologic analyses of the watershed. The analyses included evaluation of the response of the impoundment to the precipitation events having a recurrence interval of 100 years, the standard project precipitation and the probable maximum precipitation. The probable maximum precipitation (P.M.P) is defined as the precipitation resulting from the most severe combination of meterologic and hydrologic conditions that are considered charasteristic of the region. Due to environmental considerations, the Minnesota regulatory agencies required that the tailings basin must have the ability to store the runoff generated by the probable maximum precipitation. The P.M.P. for the tailings basin watershed consists of approximately 23 in (58.4 mm.) of precipitation over a duration of six hours.

Since the volume of the impoundment will be continuously decreasing due to the accumulation of tails the rate and manner of tailings deposition were evaluated. Based on these analyses the crest elevation of the starter dam was set so that after five years of operation there would be 3.6 ft (1 m) of freeboard above the pool elevation which would result from the critical precipitation event having a 100 years recurrence interval and 0.7 ft. (0.2 m) of free board above the pool level associated with the probable maximum precipitation. It is currently anticipated that the second stage of construction which will add 10 ft. (3 m) to the crest elevation, will be completed within five years.

STABILITY AND SETTLEMENT ANALYSES

The area along the alignment of the starter dam contained a large number of boulders on the surface, which ranged in size from cobbles to rocks having dimensions in excess of 15 ft. (4.6 m). In most cases the topsoil should be stripped from the foundation area of a dam before construction of the embankment is initiated. This is prudent because a layer of organic topsoil beneath the embankment may constitute a plane of weakness which could be detrimental to the stability of the embankment slopes. In this instance, however, it was anticipated that striping the topsoil in the foundation area of the dam would prove to be extremely difficult and costly due to the large number of boulders at the surface. It was determined by analysis that the protruding boulders would adequately key the foundation soils to the embankment of the dam, thereby decreasing the effect of a weak layer between the foundation soils and the embankment. Therefore, it was decided that it would not be necessary to strip the topsoil. To prevent the possibility of a failure by piping or subsurface erosion, however, it would be necessary to remove any boulders which were nested in such a manner that adequate compaction of the first layer of embankment material and continuous contact between the embankment and the foundation soils could not be achieved.

The design of the starter dam included the initial replacement and compaction of a layer of clean, pervious sand over the foundation area covering a majority of the surface boulders. Once the initial layer of sand was placed, the remainder of the embankment would be constructed by placing and compacting the embankment materials in lifts in the conventional manner. In order to compensate for the possibility that the top soil and the initial layer of sand placed over the foundation area may be more permeable than desirable, an extensive drainage blanket was included along the base of the downstream portion of the embankment to insure that the phreatic surface in the embankment is maintained at a low level, minimizing the potential for piping.

The stability of the starter dam was analyzed with the aid of a computer program which utilizes the Modified Sweedish Circle Method with side forces. Due to the presence of the layer of topsoil and sandy clay till beneath the embankment, the sliding wedge type of failure surface was used in order to ensure that the possible effects of the topsoil and sandy clay till were fully accounted for. The minimum factor of safety against the sliding for an upstream slope of 3.1 was determined to be approximately 1·5 and the minimum factor of safety against sliding for a downstream slope of 25.1 was determined to be 1.26.

Significant settlement of the starter dam is not anticipated due to the dense sands which are the predominant foundation material.

UNDERSEEPAGE ANALYSES

The underseepage analyses of the starter dam was performed with the aid of a computor programe which utilizes the finite element method to compute the piezometric potentials which would exist in a permeable media with respect to a given set of boundary conditions. A finite element model was formulated which incorporated all of the major features of the foundation and the embankment of the section of the dam for which the head differential would be the greatest. The components of the model included the P.V.C. membrane on the upstream portion of the embankment, the embankment material, a two feet thick layer of top soil and sandy clay on the surface of the foundation, the drainage filters with in the embankment, the stratum of silty sand between the surface layer and bed-rock and the bed rock at a depth of 60 ft (18 m) below the ground surface.

The model was used to study how variations in the permeabilities of several of the materials would affect the piezometric potentials in the vicinity of the dam. The parameters varied included but were not limited to, the permeability of the surface layer and the depth to bed-rock from the surface. The underseepage analyses indicated that the piezometric potentials which will exist near the down stream slope of the embankment would be within acceptable limits.

CONSTRUCTION

Construction of the starter dam was initiated in April, 1976, by Johnson Brothers Corporation and was substantially completed by July 1976. Construction entailed the placement and compaction of approximately 1.6 million cubic yard of granular fill and drainage filter material and the installation of approximately 200.000 square yard (167.000 squre metre) of PVC membrane The total cost of construction was approximately. 2.2 million (or roughly two thirds of the estimated cost of the most economical alternative in which impervious soils were used for seepage control).

PERFORMANCE

The performance of the starter dam is monitored by periodic inspection and a system of wells installed to monitor the level of the phreatic surface. The dam has now been in service for over a year and appears to be functioning as anticipated. The slopes of the embankment are stable and to date there has been no evidence of seepage problems. However, due to the drought conditions which existed in northern Minnesota during 1976 and the first half of 1977, the quantity of runo ff and other additions to the reservoir has exceeded the procees water demand only by an amount sufficient to fill the reservoir within 10 ft. (3 m) of the normal operating elevation.

SIGNIFICANCE OF THE PROJECT

A major problem which is inherent in the design of earthfill dams involves the selection of an effective, yet economical, method of controlling seepage through the embankment and the foundation. In instances, such as the Minorca tailings basin, where the site and other conditions are suitable for the utilization of a clay upstream blanket for control of seepage, but suitable clay is not available in the proximity of the site, polymeric membrane may provide an effective and economical alternative to the more conventional methods of seepage control. The feasibility of using polymeric membrane for control of seepage in major earthfill dams, however, will be greatly influenced by the required service life of the membrane and the durability of the membrane materials available.

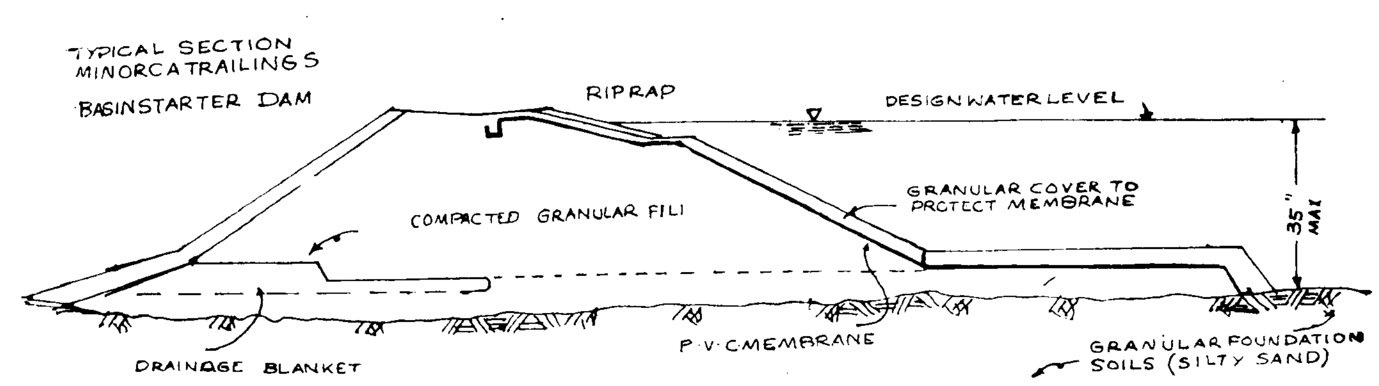
This is believed to be the first major earth dam in which a plastic membrane is used to control seepage through the embankment.

CREDITS

The Minorca Tailings Basin Starter Dam Project was entered in the 1977 A.C.E.C. Engineering Excellence Awards Competition and won the Grand award of the Minnesota Consulting Engineers Council. The project was realized under the direction of the Barr Engineering Company of Minneapolis. Minnesota-General Contractor was the Johnson Brothers Corporation of Litchfield, Minnesota and the more than 200.000 square yard (167,000 square metre of P.V.C. were supplied by the Watersaver Co., Inc. Denvor, Colo.

(Structural design and analysis are the principal responsibilities of Larry Gubbe, who earned his doctorate in structural Engineering in 1973. Some of his major projects have included design of dams, buildings, bridges and various specialised structures such as pipelines, surge tanks, oven towers and ski jumps.)

From "Civil Engineering (ASCE) September 1977".



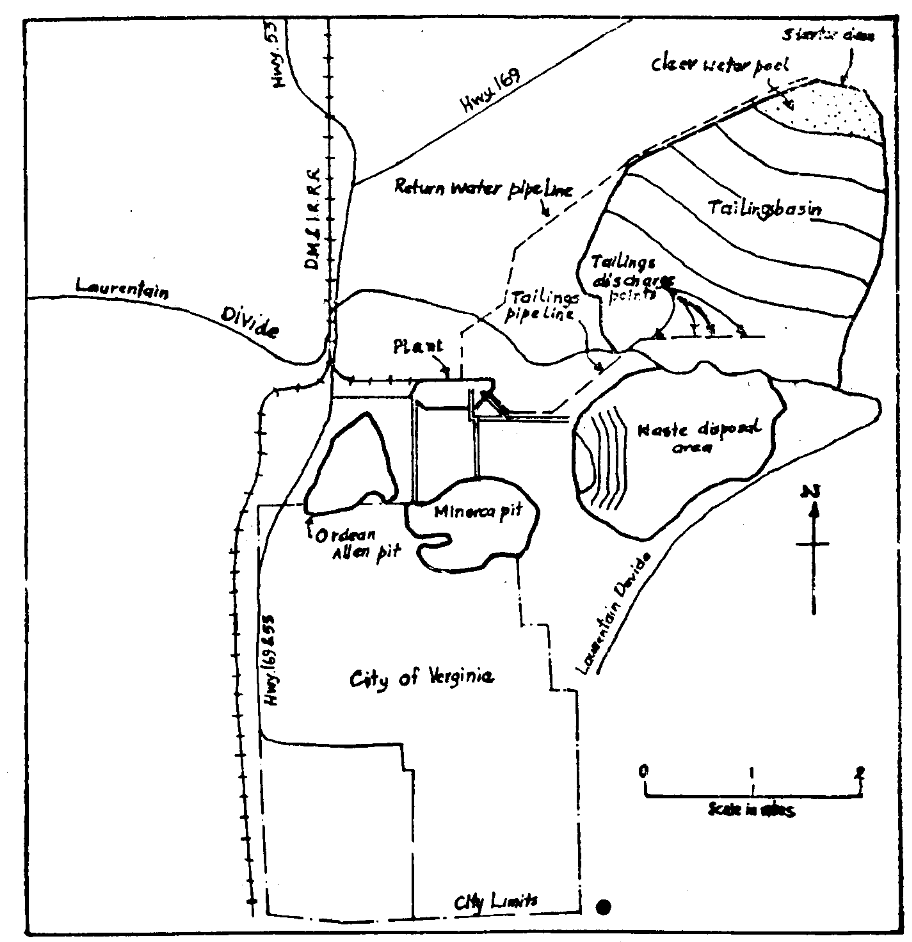


Fig 1. It is economically advantageous if the mine, the processing plant and the waste disposal areas are located as close to each other as possible. The primary components of the Minorca Development are the open pit mine, the processing plant, the Tailing's basin and the waste disposal area. Crude ore is transported from the mine to the waste disposal area by 120-ton trucks. The finished pellets are shipped from the plant to Lake Superior by rail where they are transferred to boats for shipment to the steel manufacturers.

INVITATION TO READERS.

Kind attention of Engineers of Tamil Nadu Public Works Department and other readers of the journal "NEW IRRIGATION ERA" is drawn to the meagre response to repeated requests for contribution of articles to the journal.

As all are aware the objective of the journal is two fold, viz., to promote the interest of Engineers and assisting their specialised work by placing before them the different problems of technical importance and ways and means of solving them and secondly to offer to all Engineers to express their own experience in various fields. It is desired that the Engineering fraternity will come forward in large numbers to utilise this medium to its best advantage by offering their valuable contribution.

The scope of articles to the journal can be mostly on Irrigation, but articles which have direct bearing on subjects as noted below are also welcome :—

1. Technical aspects of Foundation soils and foundation Engineering.
2. Auxiliary works in the fields of Irrigation and other water retaining structures and works.
3. Practical solution to Hydraulic Problems in canals and distribution.
4. Soil erosion problems and conservation and reclamation.
5. Silt problems in Rivers and Reservoirs.
6. Sanitation and Public Health Problems-Possibilities of utilisation of sewage.
7. Inland water ways, Navigation, Fishing Schemes and protection of land against sea erosion, etc.
8. Problem of drainage in deltaic tracts and entrance of rivers into the sea.
9. Run-off studies in catchments and evaporation studies.
10. Other subjects.

The Executive Engineers of the State Public Works Department are specially requested to encourage their Subordinate Officers to come forward with articles and enable the journal to flourish and serve a good cause.

The Engineers of other departments are also requested to contribute articles liberally.

Editor.