EVOLUTION OF WATER RESOURCES PLANNING TECHNIQUES IN SRI LANKA

by

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1.0 Introduction:

The evolution of water resources planning has taken place in Sri Lanka during the last 2500 years. For the convenience of treating the subject of water resources planning, three distinct periods could be identified, the first being the ancient irrigation works done by Sri lankan kings from 500 B.C. to 1200 A.D; then the work done during the British colonial rule and the transition period from 1800 to 1950 and the period after 1950 up to now after taking over the management by local engineers. During the latter part of the present phase, all major development works were financed by outside financial agencies. As a result of this local engineers were exposed to modern technology and terminology than ever before.It should be noted that, due to the comprehensiveness of the subject, it will not be possible for a single individual to cover all these phases and all aspects of the evolution. Therefore, this chapter will be confined to hydrological aspects of water resources planning and it also makes an attempt to fulfill a certain immediate requirement of the younger generation of engineers.In that respect, it is pertinent for the engineers to understand how the British rulers commenced the rehabilitation of the vast ancient irrigation systems by developing simple methodologies to commence the planning and design of water resources at the inception.In the early period of 1800, there were no technical guidelines at their disposal and at that time, tradition and "hit or miss" were the only guiding principles.

2.0 Ancient Irrigation Works in Sri Lanka

Ancient works date back to 500 B.C., where Pandawewa, was the first ever engineering device constructed to store and control water, after the invention of the sluice (Bisokotuwa). According to one of the most outstanding publication "Ancient Ceylon" by Henry Parker, this tank was constructed by King Paduwasdeve and it was probably the first ever reservoir in the world. Then Basawakkulama, the second tank which was constructed by Pandukabaya, the grandson of Panduwasdeve in 300 B.C., is still in working condition. By 1100 A.D. more than 21,000 minor tanks were completed in addition to several major works such as Kalawewa-Jaya Ganga, Minneriya - Kaudulla - Kantale - Giritale and Minipe - Amban Ganga. However, after a very prosperous era of 1700 years, the entire irrigation system went to disuse and administration of the country became weak.

After the arrival of the British in 1776, they took over the administration of the entire country in 1815. They realized the importance of rehabilitating the ancient irrigation system. At the beginning of British rule, all civil engineering works were handled by the Public Works Department (P.W.D) and one notable rehabilitation work done in the year 1887 was Kalawewa.This tank was originally constructed by King Dhatusena in the 5 th century. Today the inscription at Kalawewa reads as follows:

"Kalawewa, deserted and in ruin for many centuries was restored to some measure of its utility, A.D. 1887,in the fifteenth year of the reign of Victoria, Queen Empress. Arthur Hamilton Gordon being then Governor of Ceylon."

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3.0 Challenges to the Irrigation Department

In order to accelerate the rehabilitation of irrigation works, the British government created a separate Irrigation Department on 15 th May 1900. At the time of formation of this new department, though there had been considerable amount of construction experience among the Irrigation Engineers, they did not have any technical guidelines to design irrigation works.

To facilitate the discussion on the subject, four basic issues in the mind of a water resources planner can be visualized as below.

a. Estimation of catchment yield.

b. Estimation of storage capacity of reservoirs.

c. Determination of spillway capacity for safe mitigation of floods.

d. Estimation of irrigation requirement for crop production.

In the early days of the Irrigation Department, the emphasis was on the settlement of people under the existing tanks, where water had been already impounded. Therefore, the last item among the above issues was given priority. The restoration of abandoned tanks was postponed for a later day. However in order to estimate the potential command area under existing tanks, estimation of crop water requirement became an urgent priority.

4.0 Estimation of crop water requirements

J.H.W.Park, in 1909 undertook this task and the only guide line available for this purpose at that time was Bulletin No.46 of the U.S. Department of Agriculture. According to this, for successful plant growth 12% to 20% of soil moisture depending on soil properties reckoned by its dry weight was required. Further, moisture content should not fall below 8% to 14% at any time of the year. Though they were aware of the evaporation losses from the tank water surface and percolation losses in the distributary system, no quantification was possible. However by interpretation of the above guideline, 8 inches of water for a month during the North East cultivation season (Maha) and 10 inches for the South West cultivation season (Yala) were assumed as the water requirement in the Eastern province. The land preparation was entirely done with rainwater and therefore irrigation water was not issued during Maha. For canal losses, 33% was used and 12 inches of water were considered for land preparation during Yala. For free water evaporation, 40 inches were assumed during Yala, but evaporation during the N.E.monsoon season was believed to counter balance the inflow to the tank from the month of October to the month of December. Based on these, deficiency of water during each month was calculated on the monthly basis by comparing the rainfall during the season.The following is an example for the Maha season.

Month	Rainfall in inches	Deficiency below 8 inches	Channel loss
December	19.22	Nil	Nil
January	12.21	Nil	Nil
February	3.08	4.92	1.64
March	Nil	8.0	2.66
	Total	12.92	4.30

Hence, every acre of land cultivated requires 17.22 inches of water during Maha and therefore if the capacity of the tank is 3000 Ac.ft., it was estimated that 2090 acres would have been cultivated with a tank duty of 1.43 ft. Similarly, water requirement during Yala was calculated, accounting for water requirement for land preparation and free water evaporation from the tank surface.

Mr. Balfour in 1911 made some flow measurements at Tissa wewa and Basawakkulama and found that 3 months paddy needed 2.67 Ac.ft. and 3.16 Ac.ft.of water per acre respectively. The rainfall during this particular N.E.monsoon season was 9.0 inches during the cultivation period (December to March) and this quantity should be added to the previous water requirement to calculate the total water requirement for plant growth. To estimate losses from evaporation of the tank, the sluice was shut down during a period where there was no rainfall and free water evaporation was estimated as 6 inches per month. Canal losses were also estimated as 33% for each mile. Run off rainfall ratio was first estimated for Nuwara wewa by the application of water balance principle. It varied from 17.0 % to 21.0% for three years. Then a similar study was done for Labugama tank, which was constructed for the Colombo water supply.

5.0 Estimation of flood discharges

Two of the early flood formulae known to Irrigation engineers were due to Inglis and Dickens. The Inglis formula needed only the catchment area of the basin for the estimation of flood. The formula is,

$$Q = 700 * M/(M+4)^{\wedge}0.5$$

where M is the catchment area in sq.miles.

Dicken's formula $Q = C^* M^{0.75}$

Where C is a coefficient, which depends on the maximum 24 hour rainfall during the storm, denoted by d in inches.

That is $C = 40 * d$

First flood measurement was carried out by Mr.Hedley, Irrigation Engineer, Karachchi, in 1911 across Kanakarayan aru where, the Iranamadu tank was subsequently constructed. His flood estimate was 50,000 cu.secs, but Dicken's formula gave a value of 28,000 cu.secs for the C value of 492 derived from the observed rainfall. With this experience the value of C was then revised to 800 to match the observed flood record. This C value was used by W. Smith, Director of Irrigation, to design the spillway of Iranamadu tank.

The idea of providing a breaching section for village tank bunds was also introduced by Balfour in 1913. This was to limit the length of the breach in case of a disaster.

6.0 Design of Kelani flood protection scheme

Mr. Skelton, Municipal Engineer,Colombo carried out discharge measurements near the bridge of boats in Kelani Ganga (now called Nagalagam) in 1915 to establish a rating curve. This was useful in the design of the Kelani Ganga Flood Protection Scheme, which was based on the 1913 flood. In this design, volume of flood was estimated as the quantity resulting from 8 inches of rainfall during 24 hours, spread all over the catchment above Avissawella.

7.0 Evolution of Scientific Development of Village Irrigation Works

This was originated as a result of the railway disaster that occurred near Medawachchiya in 1923. Prior to this the village irrigation work was regarded as outside the scope of normal engineering duties. The Irrigation Department was entrusted to investigate the safety of some 354 irrigation tanks, both existing and abandoned, which were located above Polgahawela, Mannar and Jaffna railway lines. The Irrigation Department was reorganized in 1923 to handle this special work.Mr.J.S.Kennedy, who took over the major responsibility in this programme said at the inauguration of this work that "Creation of the special unit is analogous to the foundation of a large scale productive laboratory, in which the process of observation and experiment could be carried out systematically. During that process the personnel of the Irrigation staff could be intensively trained."

At that time, the total area under paddy cultivation was 800,000 Acs and this was divided as below.

1. Major Works	- 160,000 Acs.
2. Village Works	- 200,000 "
3. Anicut Schemes	- 170,000 "
4. Rain-fed paddy	- 270,000 "
Total	- 800,000 Acs.

It is interesting to note that during this early period, both seasons were cultivated in the Eastern Province, but only one season was cultivated in the North Central Province.

8.0 Further work on the estimation of yield and storage capacity

An empirical relation was established by Alexander Weir in 1929. He correlated catchment area to the tank storage for the N.E. season. The following is his formula.

$$[(A/X) + (a/Y)] * R * 53.3 = S$$

where, A = Catchment area without tank water spread in sq.miles.
a = Water Spread in sq.miles.
R = Rainfall for Dec. - Mar. in inches.
S = Storage in ac.ft.
X and Y are parameters.

By studying seven tanks in the Eastern Province he calibrated this model. His conclusion was 10 % of the rain falling in the catchment and 85% of the water falling on the water spread of the tank will appear as useful contributions to the tank storage.

9.0 Evolution of scientific development of water resources planning for Irrigation

In this process the following events are important and these events influenced the subsequent planning.

1. Presentation of the paper "Evolution of Scientific Development of Village Irrigation Works" by J.S.Kennedy (D.I. in 1933).

2. R.L.Brohier's authoritative hypothesis of ancient irrigation works in 1956.
(President of Engineering Association in 1956)

3. Preparation of Water Resources Map of Ceylon 1959.

Kennedy's paper 1933

This paper originated as a result of the reorganization of the Irrigation Department to undertake the investigation of 354 village tanks. This paper described the existence, scope and the function of the village tanks broadly and its relevance to the sustainability of the village community. In addition it provided several technical tools for the design and planning for the future. However it is unfortunate to note that the irrigation engineers quickly picked up and adopted these technical tools, but no attention was paid to the social aspects he covered in the same paper. His remarks at the commencement of this special project were as below.

"Science is systematic and formulated knowledge and when the knowledge that has been systematically accumulated on a subject by trained observation and experiment, then the subject becomes amenable to quantitative treatment. In designing a tank, the tradition is the ruling principle up to now. The step to create a new division is analogous to the foundation of a larger scale productive laboratory, in which the process of observation and experiment could be carried out systematically and the personnel of the irrigation staff could be extensively trained."

Regarding the command area under a village tank,he was of the view that benefits of a village tank cannot be quantified mathematically by dividing the volume of water from the tank duty. He said efficiency of village tank is like village cattle and it is too numerous for efficiency. Regarding the concept of replacing several village tanks by a large reservoir in its place, he said that though such concept may appear to be technically feasible, this should not be implemented if village tradition does not allow such change. While highlighting the traditions associated with the village, he said that a good scientist will always respect traditions, but he believed as a scientist that eventually science will prevail over tradition.

Among the several design aspects mentioned in his paper, the following can be highlighted.

(a) Location Map - The system of "Co-ordinates" generally adopted in the Irrigation Department was introduced by him.

(b) Catchment area - It was said that marking the perimeter of the catchment requires a certain amount of experience and judgement, particularly in flat country. Under these circumstances verification of boundaries by field inspection was suggested.

(c) Yield : He recommended to ignore monthly rainfall less than 2 inches during a season, when computing annual rainfall. Among the methods of estimating the yield, the method suggested by Weir in 1929 and Strange's Indian storage reservoirs for bad catchments were in use. This is shown in Fig.1.

(d) Flood Run-Off : By analyzing the river gauging of several catchments, an average value for the Dicken's formula was determined. He recommended the formula to be $Q = 645 * M ^{0.75}$.

where M = Catchment area in square miles.
Q = Flood discharge in cu.sec.

The following C values were recommended by him under different conditions of catchment.

Flat sandy plains-200 to 400
Paddy fields-500
Gentle slopes-645
Undulating hard clay-800 to 1000
Impervious surface-1000 to 1200
Mountainous and rocky-1400 to 2000 p73

Brohier's hypothesis - 1956

Hypothesis of Brohier regarding the evolution of ancient irrigation works in four stages is as given below:

1.Bailing out water from ponds.

2.Minor tanks with Sluices.

3.Large reservoirs to replace minor tanks.

4. Augmentation of large reservoirs by diversion weirs.

It is now argued by some researchers that the minor tank was never at a stage of development as seen by Brohier, but it had been fully developed and matured. Diversion weirs were in existence before the minor tanks. Therefore a revised sequence needs the rearrangement of Brohier's hypothesis.

However Brohier's hypothesis has already influenced the present water resource map due to the prominence given to large reservoirs.

10.0 Preparation of Water Resources Map of Ceylon

The preparation of water resources map for the country was first done by the Irrigation Department in 1959,in the form of printing and publishing a proposed development plan of river basins of Ceylon.This map indicated the average annual yield of 103 river basins and identified all potential large reservoir sites in the country.This gave a conceptual framework for the water resources planners of that time.However some present day planners identify the following drawbacks in the above map.

(a) Acceptance of the sequence of Brohier's hypothesis by giving prominence to large reservoirs.

(b) Consideration of within basin development without studying the transbasin diversion potential.

(c) Non integration of minor tanks in large irrigation systems.

11.0 Transition

Gradual transition of administrative powers of the Irrigation Department to local engineers began to take place after Independence in 1944. However, dependence on colonial technological skills was evident from the foreign consultancies which emerged during that period for water resources development. A good example was the Gal Oya project. Nevertheless, the Galoya project will always remain the greatest contribution made by the Irrigation Department to the agricultural development of our country, irrigating some 120,000 acres. Many illustrious engineers have contributed to the investigation, design and construction of the first ever multipurpose project with special reference to J.S.Kennedy, who selected the site of the dam and W.T.I.Alagaratnam, who was the first to walk into Inginiyagala to commence surveys. Quoting from his own words, Alagaratnam said that "Having risen to the highest rungs of the ladder at the end of my career in the Irrigation Department, it is with a sense of pride I record my personal interest in the Gal Oya project. The first preliminary report of Gal Oya was prepared by me in 1941, when I was an Irrigation Engineer, and head works were completed when I was the Director of Irrigation." Preliminary designs and estimates were prepared by D.W.R.Kahawita,who took the plans to the foreign consultants, International Engineering Company, Denver, Colorado, U.S.A., in 1947.

12.0 Further developments

Further work has been done for better understanding of reservoir planning and design since then.Some of the notable achievements are mentioned below.

In 1946 M.C.Abraham and Shirley Bocks produced yield curves based on annual precipitation by analyzing the river gauging data of 17 rivers. Dr.Robert V.Burns produced flood density curves in a similar manner in 1947 by analyzing data at 18 gauging sites. Figs. 2 and 3 show these curves.

S.Arumugam published a paper, which was re published as a handbook in the Irrigation Department titled "The Development of Village Irrigation works" in 1957. This publication could be considered as an extension to the work done by J.S.Kennedy in 1933. The book was in large demand, similar to the paper by Kennedy. This book also maintained the original approach of Kennedy, while treating all the design aspects of village works. In this chapter the methods of estimating catchment yield and flood run-off as presented in this publication are elaborated.

Three categories of yield curves were considered to represent catchments of different hydrological characteristics, one having no working tanks within the catchment boundary (Strange's curve), another with limited number of working tanks in the catchment (Minneriya curve) and the last one to represent exploited catchments (Kala Wewa curve). Yield curves are a plot of catchment yield expressed in ac.ft. per sq.mile against annual or seasonal rainfall. The Kalawewa yield curve was considered suitable, with the presence of approximately about one tank per square mile in the catchment area. The annexed Table 1 shows the seasonal yields according to above curves based on seasonal rainfalls.

For the estimation of flood discharge from catchments, this publication has recommended the use of Dickens' formula as suggested by Kennedy.It recommended Francis' formula $Q = 3.33 L*H^{1.5}$ for the calculation of flood lift under clear overfall conditions and $Q=2.8 L*H^{1.5}$ under submerged flow conditions, which is applicable to natural spillways. In addition, self detention of the flood inflow due to piling up of water above the full supply level of reservoirs was recognized in estimating flood lift and spill length. Typical spill analysis diagram adopted at that time is given in Fig.4.

Estimation of the potential command area was done on the basis of tank duty, which was estimated from the tank replenishment analysis of working tanks. During that period, 3.0 to 4.0 ac.ft. per acre for Maha season and 6 ac.ft. per acre for Yala season were adopted. These duties were directly compared with the tank capacity on the assumption that evaporation which takes place from the free water surface of the tank during the Maha season,which is from September to February would be compensated by the inflow to the tank during the same period. For the design of anicuts the seasonal yield for the N.E. monsoon was distributed among the months according to average monthly rainfall distribution. Then the monthly yield for the month of February, which was considered as the critical month of the season was used to estimate the flow rate during the month. Having worked out the flow rate, the command area was estimated on the basis of 1 cu.sec. for 30 acs. of paddy.

13.0 Notable events

In 1959, the preparation of detailed designs, specification for Uda Walawe project and the feasibility study of Samanalawewa were entrusted to the foreign firm of consultants, E.C.I., by the Irrigation Department. The U.N.D.P. funded the investigation of Mahaweli Ganga project for hydropower and irrigation development in 1964 and therefore in 1966 the planning division of the department, which was earlier set up in 1953 was revived. The feasibility studies of Kalu,Gin and Nilwala Ganga (three basins) were commenced with E.C.I. assistance in 1966. The establishment of the Engineering Studies Office (E.S.O) with H.De.S.Manamperi as the Head, to commence the Mahaweli Master Plan studies in 1967 was another important landmark. The design of Maskeli Oya Stage III (Canyon) hydro power project was also undertaken in 1974 by the Irrigation Department.

14.0 Recent Development

The book "Water Resources of Ceylon" published by S. Arumugam in 1969 gave very valuable information regarding the design parameters of existing irrigation schemes. Of the 103 river basins in the Island,the book identified 36 river basins which are more than 100 sq.miles. In addition, all existing and potential water resources were identified under each river basin. Parameters of the head works and scope of development including the historical background were also given under each scheme. The book contained average annual runoff in major river basins and also gave an account of ancient irrigation works.

Then "The Design of Head works for small catchments" was published by A.J.P.Ponrajah, in 1982. This was a refinement to the technical guidelines issued by him, when he was the Senior Deputy Director in charge of Design Branch in the Irrigation Department. In this publication, small catchment is defined as a catchment less than 20 sq.miles in extent. The book rationalized and standardized the design procedures and this enabled the professional engineers and students of university level to use it as a standard reference. It is important to mention here that this publication was complementary to the work done by Kennedy and Arumugam and it did not certainly supersede design philosophy of those publications.

To estimate the catchment yield, the book adopted ISO-yield curves derived from river gauging data of major rivers. For un- gauged catchments, having obtained the seasonal yield for a particular location from ISO-yield curves, monthly distribution of stream flow for operation study was obtained by distributing seasonal yield according to the monthly rainfall distribution.

Crop water requirements were estimated according to the guide lines of the Food and Agricultural Organization (FAO) No.24 for different parts of the country, which was already estimated adopting the evapotranspiration of reference crop ETo for Maha Iluppallama. This was due to the non-availability of reference crop evaporation ETo by Penman method for other locations of the country. Effective rainfall, cropping patterns, cropping calendar, crop factors, growth stages etc.' were also taken into consideration in estimating crop water requirements. Determination of reservoir capacity was done by carrying out an operational study for one year, based on the average distribution of monthly inflows to the reservoirs. The operation study was based on the monthly water balance of inflow and outflow. From the operation study, extent of command area was determined to achieve 75 % probability of success.

For the spillway design, the terms such as "return period" and "frequency of occurrence" have been thus introduced to village tank designs by this publication. Rational formula was recommended, instead of Dickens' formula. Probabilistic approach was introduced by introducing depth duration frequency analysis of six different regions in the country depending on the location of the project. This criteria was according to the paper published in the Journal of Hydrology, Amsterdam by V.R.Baghirathan and E.M.Shaw in 1978. After obtaining peak discharge value from the Rational formula, triangular and trapezoidal shapes of inflow hydrographs were assumed for flood routing through reservoirs.

Flood routing is the technique to estimate the flood lift above the full supply level of a reservoir due to the incoming flood wave. This equates the flood run off into the reservoir with the discharge over the spillway and the temporary detention above the full supply level. In this publication, flood routing through the reservoir was introduced in a more rational manner, based on the principle of water balance. This approach superseded the method of spill analysis given in the "Development of village Irrigation works" as shown in Fig.4.

The above mentioned three publications of Kennedy, Arumugam and Ponrajah treated the subject of village works adequately and those design criteria were commonly adopted even in major works, specially in the design of canal systems. The guidelines provided in the above three publications are adopted in the design of village works without any hesitation.

Estimation of reservoir yield was based on the observed river gauging data and operation studies were carried out on a monthly basis to determine reservoir capacities. The method of obtaining inflow flood hydrographs to design of spills of medium and major reservoirs over 20 sq.miles of catchment was first introduced by D.G.L.Ranatunga and A.A.Jayaratna of the Hydrology Division in 1971. There was an unpublished paper by them which is being widely used by engineers.It is titled "Development of unit hydrographs for ungauged catchment using Snyder technique". The Snyder technique of developing synthetic hydrographs was first developed in the Eastern United States and it is a very popular tool all over the world. This paper analyzed river gauging data at several locations in the country and it estimated Snyder's coefficients Ct and Cp for regional applications. In addition, it also described the method of designing a rain storm of desired return period and its application with the synthetic unit hydrograph previously developed by the Snyder technique.

Designs of Uda Walawe, Castlereagh, Maussakelle, Mahaweli, Kirindi Oya reservoir projects and Gin Ganga, Nilwala Ganga flood protection schemes were carried out mostly with foreign assistance. In these designs, flood discharge capacities were estimated from the observed river gauging data instead of synthetic flood hydrographs. Operation studies to determine reservoir capacities and the Unit Hydrograph theory to obtain design flood hydrographs for spillway designs were extensively used. In the design of flood protection schemes, generated flood hydrographs were routed downstream by the application of the classical Muskingum method.

Since 1960, soil properties in the command areas were taken into consideration in the design of cropping patterns in major irrigation projects. The first attempt was made at the Uda Walawe Project in this regard by introducing crop diversification in 1969.

Publication of "Some aspects of water resources development" was made in 1985 as a result of the initiative taken by the National Committee for the International Hydrological Programme. N.M.G.Navaratna and C.M. Madduma Bandara were the editors, and the writer was responsible for the compilation and publication. This book was a collection of 23 technical papers written by specialist in different fields, who were engaged in water resources planning, design, development and research. The publication covered a range of subjects and provided the state of art of water resources and its development, including some case studies. The chapters were grouped around five major themes, Hydrological Networks, Hydrometeorology, Surface Water, Ground Water and Water Management.

An attempt was made by S.Dimantha of the Irrigation Department in 1985 to estimate ETo on a regional basis by adopting both Penman and Blaney Criddle Method. He provided ETo values for 10 different regions of Sri Lanka. An article on "Planning of irrigation to optimize the effect of rainfall" was published in September 1990 by the writer in the journal of the Institution of Engineers (I.E.S.L.). The calculation of crop water requirement in "The design of Irrigation Head works" by A.J.P.Ponrajah was based on the meteorological observations at Mahailuppalama only. In order to regionalize climatic inputs, observations made at different parts of the country were analyzed in this paper to estimate the reference evapotranspiration of different parts of the country by modified Penman method. This regionalization is more appropriate due to varying climatological characteristics of different parts. This article explained the creation of a climatic database and application of a software developed by the F.A.O. to estimate crop water requirement at 17 stations in the country.

As irrigation of crops is not only confined to the climatic conditions of Mahailuppallama, it is more appropriate and logical to use the climatic data available in other parts of the country to estimate ETo.

Climatic data of the following 17 stations were used.

1. Anuradhapura
2. Puttalam
3. Batticaloa
4. Colombo
5. Polonnaruwa
6. Trincomalee
7. Mahailuppallama
8. Kaudulla
9. Kankesanthurai
10. Kandy

11. Nuwara Eliya
12. Chilaw
13. Kurunegala
14. Badulla
15. Matale
16. Hambantota
17. Ratnapura

The table 2 shows the estimated ETo values for 17 stations.

A paper titled "The rainfall frequency analysis of Sri Lanka" published by the writer in the December issue in 1990 of the same I.E.S.L. journal, provided an updated analysis of rainfall frequencies for different parts of the country. This paper made an attempt to update the rainfall frequency analysis done by V.R.Baghirathan and Elizabeth M. Shaw in 1978. The technique of compounding data for regionalization and linear interpolation of rainfall intensities for 3 hour duration to obtain short durations, 1/2 hour and 1 hour, were avoided in the new analysis.

15.0 Computerization of hydrological database

The Hydrology Division of the Irrigation Department was established in 1941 and it is mainly responsible for the maintenance and operation of hydrometric stations in the Island, collection, processing and publication of hydrological data. In addition to the collection of hydrological data, it collects other hydrological information such as rainfall, evaporation and reservoir replenishment data of irrigation reservoirs. After collecting data from the field, primary processing is done in order to publish Hydrological Annuals in a summarized form. Processed data are widely used for planning, design and operation of reservoir projects and for flood forecasting and research.

15.1 Hydrological network

The measurement, collection and publication of meteorological and hydrological data in Sri Lanka is the responsibility of the Department of Meteorology and the Hydrology Division of the Irrigation Department respectively. Historically, the first meteorology stations were set up during the last century and records show over 600 stations to have been in existence, about half of which are in continuous operation today.

Hydrometric stations however, were established at a much latter date and very few records exist prior to 1940. Discharge measurements have been carried out at well over 150 locations. At present there are about 70 stations with continuous operation by the Irrigation Department.

15.2 Data storage

All these records were available in hard copies (Paper Files) and the quantity of available data were estimated as 100 million characters. Due to the advantages of computerization, action was taken to establish a computerized data base in the Hydrology Division. Such computerization ensures easy access to data, convenience in manipulation, processing, retrieval and publication. Above all these aspects, safety against natural deterioration and disasters cannot be over-emphasized. The long overdue dedicated computer database facility at the Hydrology Division of the Irrigation Department was finally fulfilled in 1988.

16.0 Mathematical modelling in water resources planning

Numerical models for simulation of river flows are used in design and real time flood forecasting. Advances in computer technology in mathematical modelling of the processes in the hydrological cycle have recently improved our potential in this field. Water resources planning and design have become very efficient by the application of mathematical models.

With the introduction of micro computers to the market in 1960, the application of mathematical models in water resources planning has become increasingly popular. The ability to do iterative calculations with a high degree of precision is one of the very attractive features of computer application.

Therefore the rest of this chapter is devoted to the methodologies now available in the Irrigation Department for the planning of medium and major water resources projects.

In most cases, when a planner wants to obtain historical stream flow series to evaluate the reservoir parameters such as capacity and spillway capacity of proposed reservoir projects, it is not generally available, but rainfall data for long periods is often available. While it is possible to overcome this problem of non - availability of stream flow series by development of mathematical models, it is very important to note that these models have become increasingly significant, where land use and other changes have affected the hydrologic response of the basin. Under these circumstances there is a certain amount of ambiguity to use historical stream flow data, even if they are available, because they are no longer representative of the basin characteristics.

Therefore in order to design a water resources project to simulate the present hydro climatical and morphological conditions of the watershed, it is desirable to develop mathematical models using 4 to 5 years of minimum number of years of recent records. These models could be either hydrologic or hydraulic. The first type of model could be subdivided into deterministic rainfall runoff models and stochastic models. The deterministic models are again sub divided into black box, regression and conceptual types. For simulation of flows, deterministic rainfall runoff model takes the historical rainfall as inputs, whereas the stochastic model generates data from the observed stream flows itself. However, the stochastic models which will depend only on the flow characteristics of observed flow data are meant for simulation of long periods 500 to 1000 years. Such data generation by stochastic models become relevant in the design of gigantic reservoirs in certain countries, but are not relevant to Sri Lanka. Such generated data are used in operation studies to determine reservoir capacities, estimation of catchment yields and estimation of flood or low flow frequencies.

Water resources engineers use hydraulic models in planning and design of hydraulic structures in river engineering, specially in river regulations and sometimes in flood forecasting too. There are models to represent the steady state of flow and hydro dynamic conditions of natural rivers. While the former type is commonly used in designs of flood protection and structures for river regulations, the latter type is more appropriate for flood forecasting. In addition, morphological models, water quality models and transport dispersion models are also basically governed by hydrodynamic models.

Some more details about models used in the Irrigation Department of both hydrologic and hydraulic types are given in the following sections. Focus has been made here to give an exposure to our transition from traditional physical models to the technique of mathematical models.

17.0 Hydrologic models

17.1 Regression models (Black box)

Some of these models depend on the system theory, whose expression may be obtained by the application of system analyses methods. These models are time invariant and therefore the model outputs do not change with the time of occurrence of rainfall and therefore inherit a drawback. In order to overcome this problem in reality, as time invariant property does not exist in real world, the conceptual models are considered as an alternative. Linear model, linear perturbation model (Nash and Barsi - 1983) and a model based on linear differential equation of ARMA type (Box and Jenkins 1976) are some linear regression models available for use, which can be used for continuous stream flow modelling.

17.2 Hec I model (Black box)

There are many mathematical models in the world for river flow modelling, but many of these models require a high technical skill for both calibration and operation. The HEC I model described here is an empirical model developed by U.S. Army Corps of Engineers in the U.S.A. It consists of two modules, namely the rainfall run off relationship and river routing. For rainfall run off model the synthetic unit hydrographs developed by Snyder, Clark and Soil Conservation Service(SCS) of U.S.Department of Agriculture are used. For river flow routing, methods such as Muskingum, Kinematic wave and Modified pulse are used.

17.3 Conceptual models

The deficiency in the models of the system approach explained earlier, depends on the assumption of time invariant property. But due to non-linearity of catchment behaviour, linear models might fail to provide satisfactory results, specially when the catchment is subjected to prolonged droughts. The discharge of a river at any particular time is dependent not only on recent rainfall, but also on evaporation. Unlike rainfall, the response of evaporation is not immediate. This effect cannot be achieved by a linear relationship between the discharge and rainfall or evaporation. Therefore conceptual models permit the grouping together of the non-linear operations and leave open the possibility of representing the subsequent transformation of the generated runoff by a linear routing component. In this situation, total water balance and the base flow dominate during the drought and therefore antecedent rainfall alone can be correlated to the stream flow without storage effects in the catchment. Therefore, its effect cannot be explained by a linear relation between the river discharge with combined effect of rainfall and evaporation. This problem is overcome in conceptual models when it can be expressed by a series of operations. Among the conceptual models, soil moisture accounting and routing models (SMAR) developed by P.E.O'Connell in 1970 and NAM model developed by the Danish Hydraulic Institute (DHI) in Denmark are used.

17.4 Hydraulic Models

There are models to simulate steady flow conditions in natural rivers and other models to simulate fully hydrodynamic conditions. HEC-2 is a model developed by the U.S.Army Corps of Engineers, which is being used in the Irrigation Department.

Mike II is a microcomputer based hydrodynamic mathematical model developed by the Danish Hydraulic Institute (DHI) in Denmark for simulation of water flows, sediment transport, dispersion and transport of dissolved materials and water quality in rivers. Velocity distribution along and across the river estuary becomes complex due to back water effects from tidal action. Since the development of one dimensional unsteady flow equations by Saint Venant (1871), a vast number of river flow computational schemes have emerged. The most extensively used numerical models for river flow computations are based on the finite difference solution of St. Venant equations.

17.5 Morphological model

These models are capable of simulating steady non-uniform flow and unsteady sediment transport phenomenon. A description of the principles behind the basic equations are given below.

a. Continuity of mass

b. Equation of momentum.

c. Sediment continuity

d. Sediment transport

These equations can be found in standard text books related to the subject. The first two principles are expressed as the Saint Venant equations in hydraulics. The third principle is similar to the first, which deals with sediment balance and it assumes that the total quantity of sediment entering the river reach is equal to the quantity leaving and the change in bed configuration. The fourth one could be expressed as an empirical equation such as Engelund and Hansen for total sediment load or any other formulae.

The first hydraulic solution is found for the first time step and this solution is then used to estimate sediment transport by using the sediment formula. Then, before moving into the hydrodynamic solution of the second time step, the change in the bed configuration due to sediment transport in the first time step is taken into account. Both Mike II model and HEC 4 model are being used in the Irrigation Department.

17.6 Transport dispersion model

In order to understand salt water intrusion to river estuaries, the Transport Dispersion Model in the MIKE 11 package can be used. The Transport Dispersion Model is based on the one dimensional equation of conservation of mass of a dissolved material. It should be noted that one dimensional model cannot simulate the salinity intrusion process adequately as salinity level in the estuary varies with the depth. Therefore two dimensional model is an appropriate tool for this purpose. However only one dimensional model is available at present and it would give some understanding of the process. As the model is one dimensional, it provides an average salinity at each river cross-section though it varies with depth.

Most of these models were calibrated and verified for major rivers like Kalu Ganga and Kelani Ganga, and several publications were made. For illustration, daily stream flow data generated from two mathematical models for Kalu Ganga and Kelani ganga are given in Fig.5 with observed flow data.

18.0 Conclusions

Today, attempts are being made by many to apply modern technology already developed elsewhere on water resources planning. Before embracing the new technology it is prudent to have an understanding of the evolution process of planning and designs, which took place during the past several years. Often present day designers are quite capable of designing components of major water development projects, but fail to understand the design concepts of village works.It is worthwhile to recognize that a tank means a village and a village means a tank. Therefore the village tank keeps the village community intact with social, cultural and economic harmony. Due to this reason, a knowledge of the village works will enhance the understanding of major works as minor work is a major scheme in miniature. Therefore, it is important to understand the different stages of development to improve the present day planning standards. This is not merely essential for water resources planning, but is equally valid for any other development activity. This was explained by an Indian historian, Kosambi in 1965 when he wrote "Great history is written when the historian's vision of the past is illuminated by insights into the problem of the present. To learn about the present in the light of the past also means to learn about the past in the light of the present. The function of history is to promote a profound understanding of both past and present through the inter-relation between them."/14.

19.0 Acknowledgement

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20.0 References

1. Arumugam S. - The development of village irrigation works-1957.

2. Arumugam S - Water Resources of Ceylon-1969.

3. Baghirathan V.R. and Shaw E.M. - Rainfall intensity studies for Sri Lanka - 1978.

4. Brohier R.L. - Ancient Irrigation works in Ceylon-3 volumes- 1934.N

5. Dharmasena G.T. - Some aspects of ancient irrigation works of Sri Lanka-Journal, I.E.S.L., 1988.

6. Dharmasena G.T. - Planning of irrigation to optimize the effect of rainfall-Journal of the I.E.S.L., Sept.1990.

7. Dharmasena G.T. - Rainfall intensity studies in Sri Lanka Journal of the I.E.S.L, Sri Lanka.1990.

8. Dharmasena G.T. - Mathematical model for Kelani ganga floods- Transactions of the Institute of Engineers, Sri Lanka-1991.

9. Dharmasena G.T. - Mathematical models for stream flow simulation in Sri Lankan rivers-Transaction of Institute of Engineers, Sri Lanka-1992.

10. F.A.O. No. 24, Crop water requirements-1984.

11. Henry Parker - Ancient Ceylon-1907.

12. I.H.P. Publication - Some aspects of water resources in Sri Lanka -1985.

13. Kennedy J.S. - The evolution of scientific development of village irrigation works-Transactions of the Association of Engineers,Ceylon -1933.

14. Mendis D.L.O. - Theory, paradigm and crisis in understanding the history of irrigation systems in Sri Lanka-I.A.H.S., Aug. 1988.

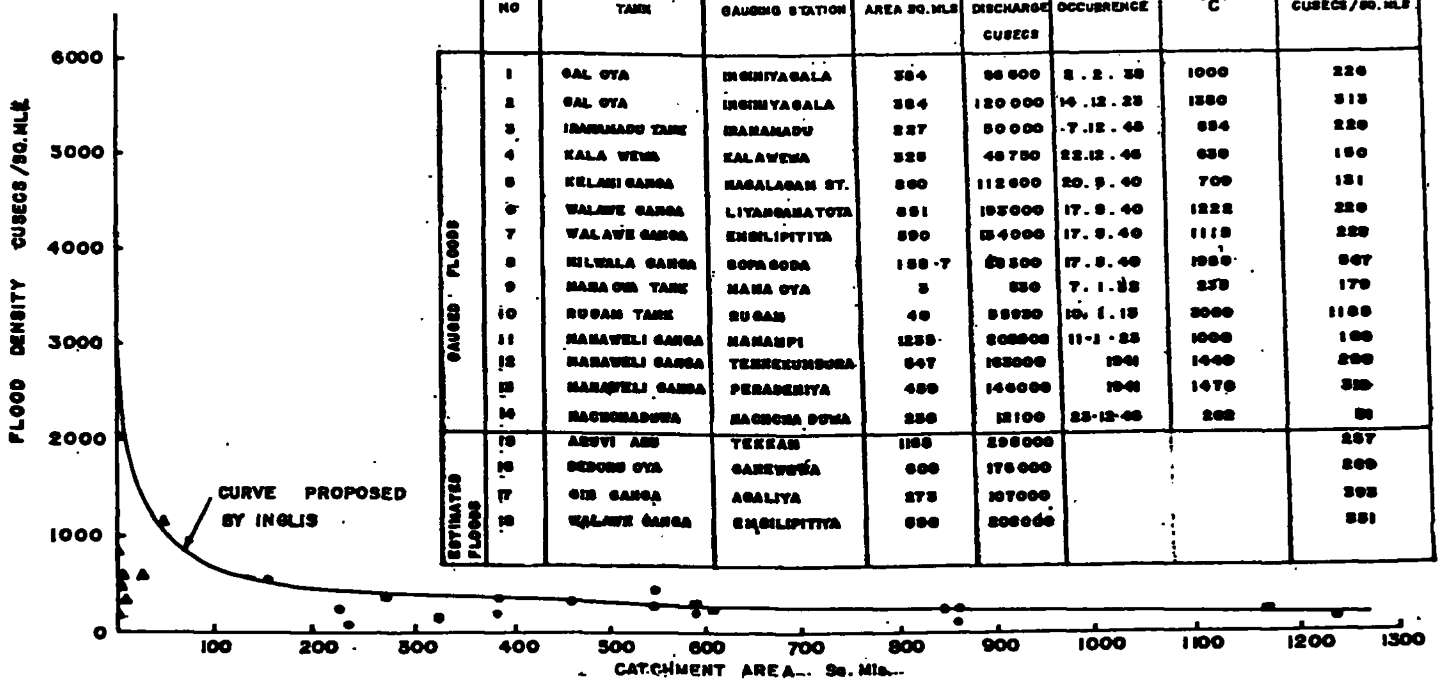
15. Ponrajah A.J.P. Design of head works for small catchments- 1982.

16. Ranatunga D.G.L. and A.A.Jayaratna-Development of unit hydrograph for ungauged catchments - 1971 - Unpublished.

17. Transactions of the Engineering Association of Ceylon - 1909, 1911, 1913, 1929, 1933, 1940, 1946, 1947 and 1956.

FIGURE 1

RELATION BETWEEN FLOOD DENSITY (CUSECS / SQ.MILE) AND CATCHMENT AREA (SQ.MLS) FOR SRI LANKA CATCHMENTS



	INDEX NO	RIVER OR TANK	LOCATION OF GAUGING STATION	CATCHMENT. AREA SQ.MLS	PEAK DISCHARGE CUSECS	DATE OF OCCURRENCE	DICKENS 'C'	FLOOD DENSITY CUSECS/SQ.MLS
GAUGED FLOODS	1	GAL OYA	INGINIYAGALA	384	86 600	2 . 2 . 38	1000	226
	2	GAL OYA	INGINIYAGALA	384	120 000	14 . 12 . 23	1380	313
	3	IRANAMADU TANK	IRANAMADU	227	50 000	7 . 12 . 46	834	220
	4	KALA WEWA	KALAWEWA	325	48 750	22.12 . 46	630	150
	5	KELANI GANGA	NAGALAGAM ST.	860	112 600	20. 5 . 40	700	131
	6	WALAWE GANGA	LIYANGAHATOTA	881	195000	17. 5 . 40	1222	220
	7	WALAWE GANGA	EMBILIPITIYA	590	134000	17. 5 . 40	1118	228
	8	NILWALA GANGA	BOPAGODA	158 ·7	89 500	17 . 5 . 40	1980	567
	9	MAHA OYA TANK	MAHA OYA	3	530	7 . 1 . 38	258	179
	10	RUGAM TANK	RUGAM	48	55930	10. 1 . 13	3060	1188
	11	MAHAWELI GANGA	MANAMPITIYA	1233	206000	11-1 · 25	1000	166
	12	MAHAWELI GANGA	TEMEKUMBURA	647	162000	1941	1440	250
	13	MAHAWELI GANGA	PERADENIYA	450	146000	1941	1470	320
	14	KACHCHADUWA	KACHCHA DUWA	236	12100	25-12-46	262	51
ESTIMATED FLOODS	15	ARUVI ARU	TEKKAM	1156	296000			257
	16	DEDURU OYA	GANEWATTA	600	175 000			289
	17	GIN GANGA	AGALIYA	273	107000			393
	18	WALAWE GANGA	EMBILIPITIYA	590	206000			351

FIGURE 2

RAINFALL RUNOFF RELATIONSHIP

(WATER YEAR - OCTOBER TO SEPTEMBER)

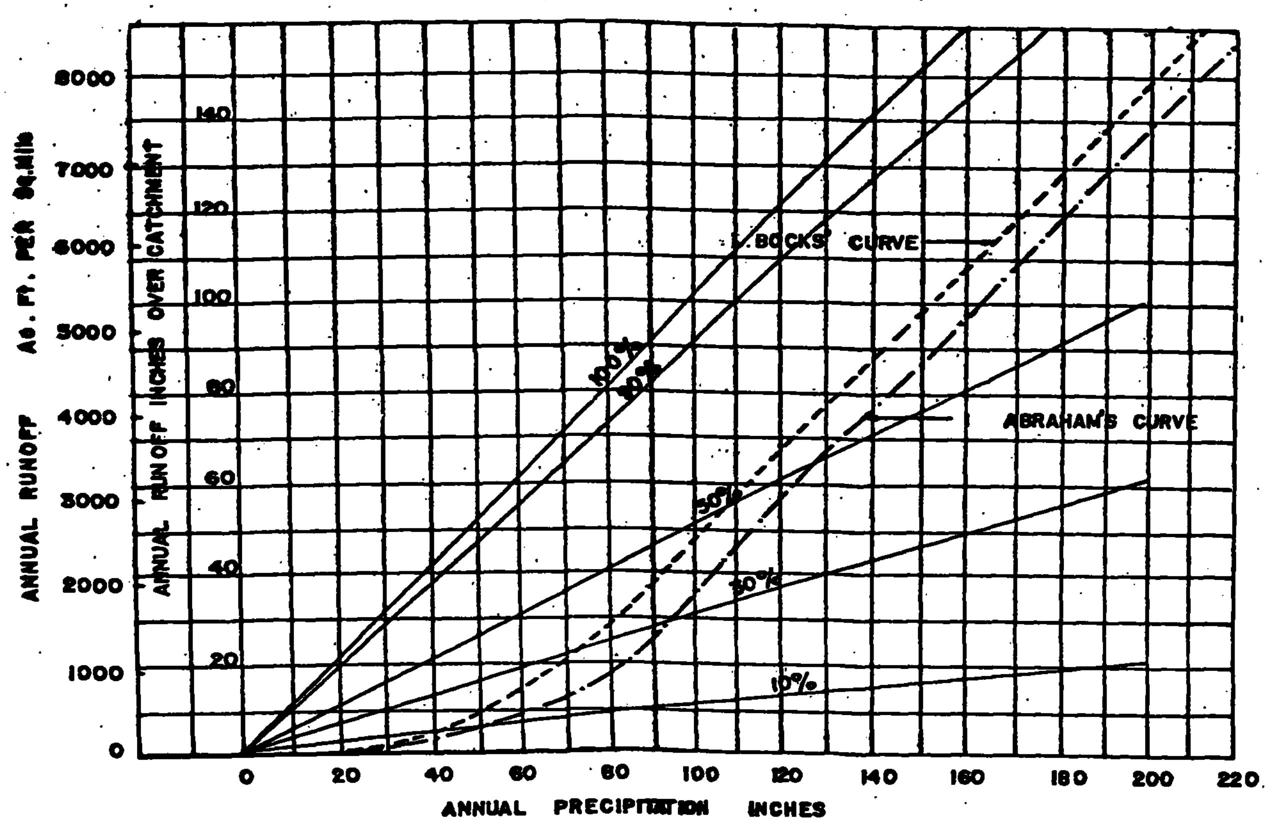


FIGURE 3

ESTIMATION OF YIELD AND FLOOD RUNOFF

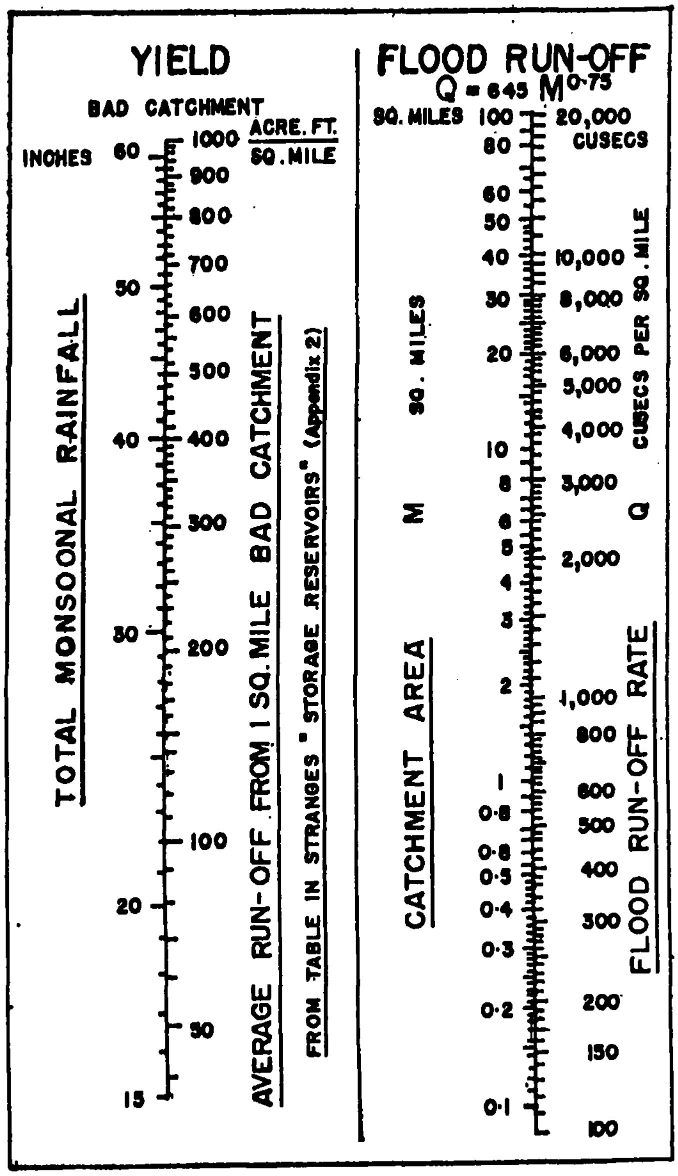
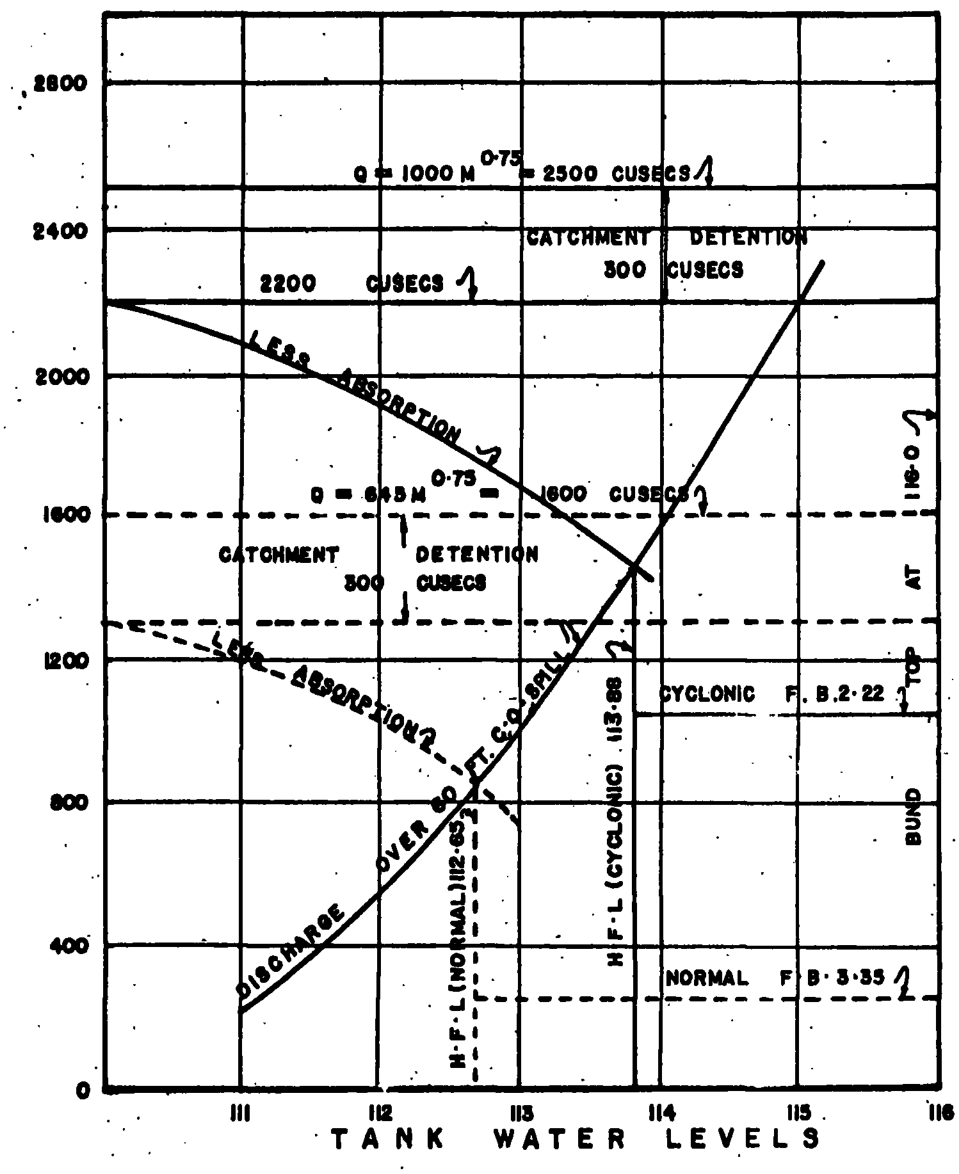
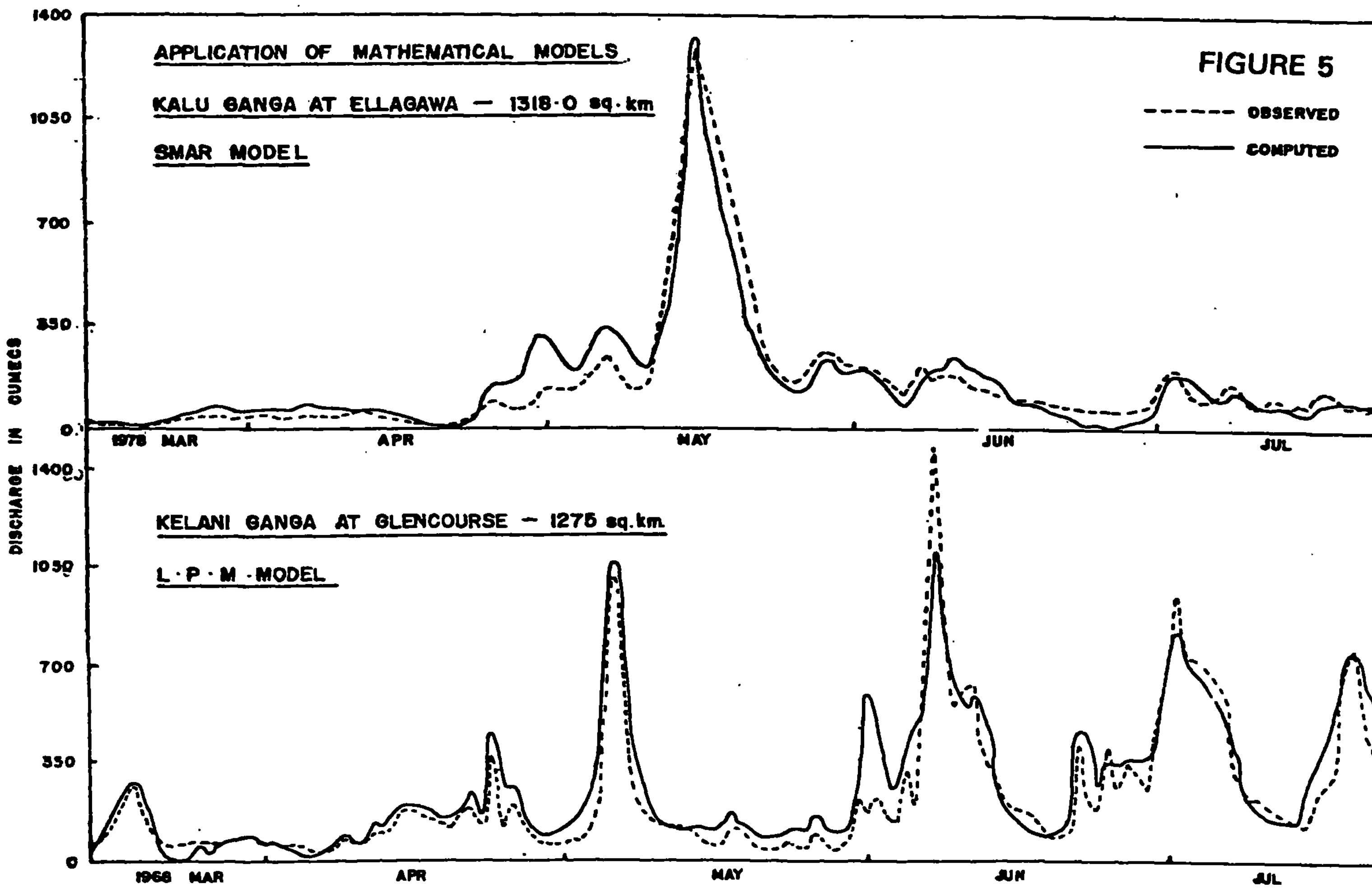


FIGURE 4

TYPE SPILL ANALYSIS DIAGRAM





APPLICATION OF MATHEMATICAL MODELS
KALU GANGA AT ELLAGAWA — 1318·0 sq·km
SMAR MODEL
FIGURE 5
OBSERVED
COMPUTED
1400
1050
700
350
0
1978 MAR
APR
MAY
JUN
JUL
DISCHARGE IN CUMECS
KELANI GANGA AT GLENCOURSE — 1275 sq.km
L·P·M·MODEL
1400
1050
700
350
0
1968 MAR
APR
MAY
JUN
JUL

TABLE — I

CATCHMENT YIELD

YIELD PER SQUARE MILE IN ACRE FEET			
MONSOONAL RAINFALL IN INCHES	STRANGES' BAD CATCHMENT CURVE	KALAWEWA CATCHMENT	MINNERIYA CATCHMENT
30	210	119	145
31	226	130	159
32	243	143	173
33	260	158	188
34	279	175	204
35	298	190	220
36	317	209	239
37	336	230	259
38	358	250	280
39	379	279	301
40	400	302	328
41	422	334	352
42	446	366	380
43	469	400	408
44	493	440	439
45	517	476	465
46	543	524	483
47	568	575	525
48	595	625	562
49	622	880	590
50	651	745	620

TABLE – 2

REFERENCE EVAPOTRANSPIRATION — ETo

	TRINCO	CHILAW	KANDY	MATALE	BADULLA	COLOMBO	KURUGALA	N'ELIYA	BATTICALO	MAHAILU	PUTTALAM	H'TOTA	K·K·S·	MAHIGANA	R'PURA	KAWOULLA	P'NARU
JANUARY	4·51	5·41	4·81	4·30	3·25	4·75	4·52	3·44	4·32	4·28	4·70	5·42	4·57	3·47	4·08	3·00	3·04
FEBRUARY	4·79	4·92	4·75	4·00	4·26	5·06	4·96	4·52	4·70	5·44	5·49	5·91	5·25	4·77	5·10	3·80	3·84
MARCH	6·22	5·38	5·42	5·15	4·60	5·45	5·68	4·93	5·25	5·97	6·02	6·30	5·91	5·28	5·35	4·90	4·98
APRIL	6·28	4·53	4·46	5·20	4·06	5·20	5·08	4·57	5·37	5·70	5·80	5·85	6·53	4·69	4·69	5·10	4·93
MAY	5·68	4·08	4·51	4·26	3·84	5·12	5·47	3·84	5·73	5·16	5·97	5·52	6·23	5·18	4·52	6·90	5·37
JUNE	8·67	3·95	4·15	4·96	4·71	4·98	4·96	3·74	5·48	6·32	6·33	5·85	6·74	5·41	4·18	8·20	7·38
JULY	9·09	4·17	4·72	5·12	4·70	4·91	5·01	3·41	5·45	6·28	5·80	5·54	6·95	6·24	5·09	6·60	5·80
AUGUST	8·15	4·65	4·19	5·64	4·90	4·67	5·20	3·83	5·61	5·65	6·05	6·14	7·00	6·12	4·69	6·50	6·48
SEPTEMBER	8·54	4·48	4·41	6·25	4·15	4·71	5·86	3·20	5·30	6·02	6·07	6·05	6·24	5·74	5·25	6·10	6·20
OCTOBER	7·03	4·13	3·66	4·72	3·37	4·36	4·64	3·24	4·71	5·51	5·34	5·63	6·19	5·21	3·55	5·80	6·09
NOVEMBER	5·04	3·54	3·20	3·56	2·74	4·40	4·01	2·69	4·47	4·19	4·25	4·34	3·33	4·08	4·64	3·40	3·76
DECEMBER	3·90	3·86	3·62	2·99	2·79	4·54	3·85	2·67	4·03	3·78	3·83	3·39	4·12	3·36	3·62	3·40	3·60
ANNUAL TOTAL IN mm.	2369·46	1606·91	1576·63	1709·42	1440·84	1760·52	1801·88	1340·77	1834·73	1830·95	1996·25	2019·67	2112·74	1811·31	1665·62	1937·54	1884·01