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பாசன முறையின் மறுமலர்ச்சி செய்தி

THE NEW IRRIGATION ERA

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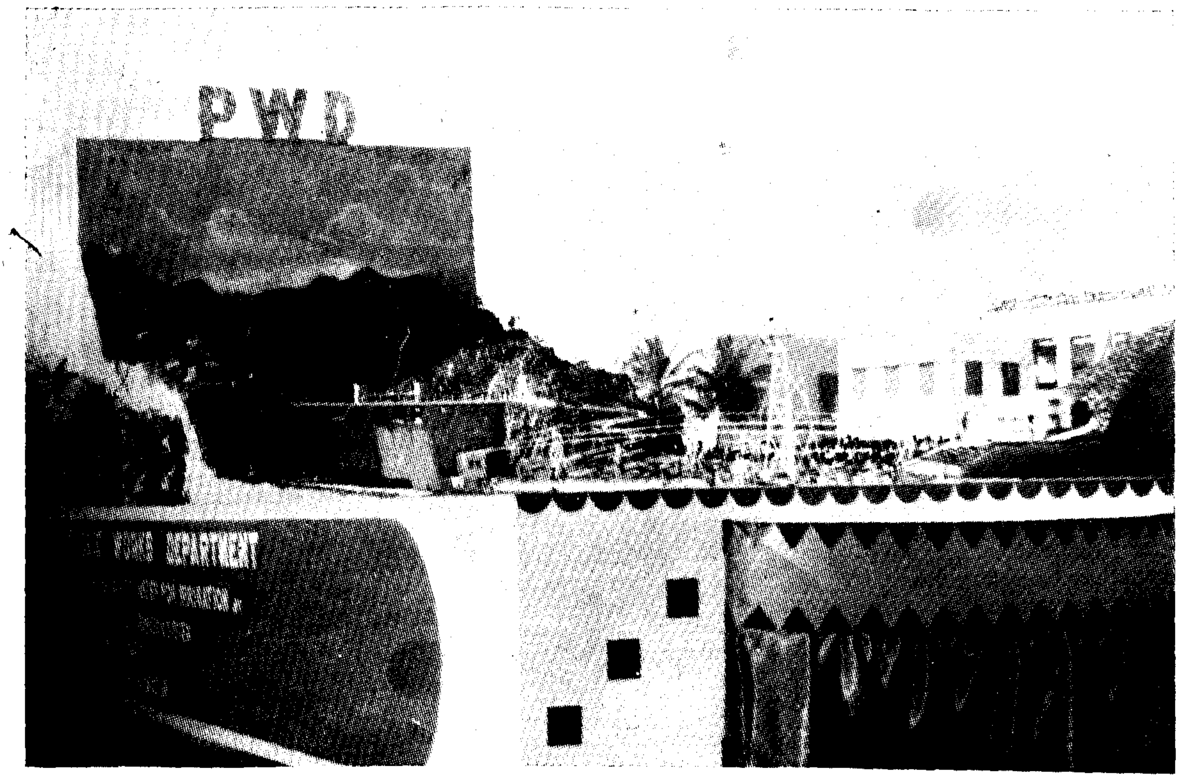

A view of the float put up by the Public Works Department in connection with the Republic Day Pagentry Parade 1977.

Er. P. Sivalingam, Chief Engineer (Buildings and General) addressing the gathering.

Er. C. Sundara, Exe. Engineer, I. H. H. Poondi garlending the speaker.

Er. P. K. Vedanayagam, Chief Engineer (Irrigation) addressing the gathering.

Er. S. P. Namasivayam, Chief Engineer (Retd.) welcoming the speaker

THE NEW IRRIGATION ERA

Volume XV JANUARY 1977 Issue 1

The Editorial Board of New Irrigation Era of Tamil Nadu P.W.D. accepts no responsibility for the views expressed by the authors.

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CONTENTS.

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EDITORIAL

In the first article under the caption "Hydrological prediction Engineering" by Thiru P. Kumaraswamy, the necessity for prediction of Hydrologic variable is stressed. Daily flow through a hydraulic structure across a river is a fluctuating one on account of laws of probability. Accurate prediction of future based on previous records, etc., utilising "information Theory" is possible only if the process is controlled by deterministic laws, prediction of sudden and severe floods is absolutely necessary since money spent on precautionary measures and also for flood damage repairs are more. Similarly prediction of ground water response to accelerated and hap hazaard consumption is necessary in periods of drought. Hence Hydrological prediction Engineering is keenly felt. This has been explained in the above article.

Under the caption "Irrigation, How Much and When" by Thiru R. K. Sivanappan, the desirable methods for irrigation and how much of water is necessary under what soil and climatic conditions, etc., are explained. The depth of water received for any crop has been enunciated by a formulæ and the amount of water required for different type of soil is also mentioned. Water becoming a scarce commodity has to be utilised economically in order to save it. Hence it is necessary to know how, how much and when irrigation is to be done. All the above particulars are detailed by the author in this article.

Thiru G. Ganapathy Subramaniam has explained in the fourth article viz. "Introduction of Electric Digital Computers in activities of P.W.D.". A few suggestions have been put-forth by the author on the above subject. As we are now in the Era of the Computer spectacular changes in our way of life is promising. P.W.D. is an agency incharge of installing, maintaining and maintaining many gauging stations across rivers, etc. Datas are being collected for computing daily, monthly and yearly flow in a river. At present computations are being done manually. A computer programme will not only reduce the time consumed but also has several other advantages. All these aspects have been explained in the above article.

Finally the speech given by Er. R. Gopalakrishnamurthy, Chief Engineer, Andhra Pradesh on "Water Resources of India an appraisal" at the Institute of Engineers Building on 25th October 1976, on the occasion of the fifth Memorial Lecture of Bharatha Rathna Dr. Sir M. Vieswraiyya has been reproduced here.

Again we request all Engineers to contribute more articles for the future issues of the journal and serve a good cause.

HYDROLOGICAL PREDICTION ENGINEERING

By

* Er. P. KUMARASWAMY.

ABSTRACT

The necessity for prediction of hyrologic variables is stressed. The available data base in hydrology is described. The principles of deterministic hydrology are explained besides a narration of the run-off mechanism. various hydrograph methods and system models proposed in deterministic hydrology are shown to be not very efficient in reducing the variance of prediction. Stochastic hydrological principles are applied in the filtering process to isolate the white noise component by systematically removing trend, periodicity and persistence. The probability distribution of the second-order stationery independent random component is derived for use in further correlation work.

Correlation analysis is next done between the white noise components of the rainfall series and flow series and the maximum correlation co-efficents attached to the prediction variables are used in the next stage of multiple regression.

A multiple Regression equation between the white-noise components of the rainfall variables and the flow variable is drived. Through suitable Telemetry systems, criterian variables are transmitted to the Electronic Analog Computer at the Prediction Centre, and by an inverse procedure, the flow variable of the future is predicted.

1. *The Prediction Problem.*

1.1. The hydrological cycle of the planet earth motivated by solar energy is constant and consistent, if considered on a macroscale. However, when one considers a hydrologic time-series at microscale, such as the daily flow through a hydraulic structure across a river, it is observed that the series is a fluctuating process controlled by the laws of probability and any prediction using *deterministic principles* is invariably accompanied with large variance, unaccompanied by any satisfication. Accurate prediction of future events based on past information, utilising 'Information Theory' is possible only if the process is controlled by deterministic laws, to a major extent.

1.2. *Prediction of future surface flows* and subsurface water regime are very essential to the hydrologic Engineer operating large irrigation structures. Release of irrigation waters from a reservoir is dependent on such stochastic elements as future inflows, future water demands and future rains in the ayacut, requiring their reliable prediction. Prediction of sudden and severe floods is absolutely necessary during stormy weather; and since money spent on precautionary measures to minimise flood damages is quite large, more and more accurate flood prediction will be conducive to larger economics in public works expenditure. In periods of severe drought, prediction of the groundwater response to accelerated and haphazard consumption become necessary. The necessity for hydrogical prediction engineering has been keenly felt over the past few decades, specially in the developing countries of the world whose economics depend largely upon agriculture and irrigation.

1.3. Gone are the days when obscurantism held away and its false predictions of weather and hydrology through pseudo-sciences like Astrology, Radiesthetics (Water Divining), etc., creating more calamity and distress both to the superstitious and rational people alike. Science had to take up this enormous challenge of hydrological prediction, and methodologies are slowly but steadily evolving.

2. *Data For Hydrologic Analysis:*

2.1. The following three types of hydrologic data are usually available in small quantities for rainfall riverflows and groundwater levels.

2.1.1 *Historic Data.*—If not observed and recorded initially, this information is lost for ever. Usually daily data is available for rainfall for about 50 to 60 years for a number of rain gauges; daily flow data is available for a number of river-gauging stations, but only for important irrigation structures across large and medium rivers. Ground water levels are available generally at monthly intervals, very sporadically and for few locations only.

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(Lecture delivered on 19 and 20 February 1976 at the College of Engineering, Guindy, Madras under the Maharaja of Travencore Curzon Endowment Lectures in Engineering, 1975-76.)

2.1.2. *Field Surveys.*—Hydrologic data along lines such as river cross sections, or across areas such as ground contours, soils, soil cover, etc., or in space such as extent and location of aquifers, basins, etc., can be obtained by surveys.

2.1.3. *Laboratory and Field experiments.*—Evaporation losses, infiltration rates, etc., can be studied under controlled conditions in a laboratory and their correlation with other parameters like Atmospheric temperature, wind speeds, soil moisture, etc., can be deleted and such data find their use in prediction.

2.2. It should be noted that hydrologic data is not always available as continuous data but only as discrete data by periodical sampling. Some amount of information is unavoidably lost in this discretisation. Continuous data for rainfall river flows, ground water levels, are recently becoming increasingly available.

2.3. Observed hydrologic data have errors in sensing, transmitting, recording and processing. Computed values always contain random or systematic errors, which make the data inconsistent. Data affected by environmental changes due to slow evolution in nature or due to human activity become non-homogeneous data, and also transform a stationary time series into a non-stationary series. Therefore before computing the prediction parameters from past data, all errors, trends, non-homogeneities have to be detected, assessed and removed.

3. *Deterministic Hydrology*:

3.1. Deterministic hydrology attempts to predict surface runoff, purely based on the drainage basin characteristics and the spatial and temporal distribution of rainfall. Deterministic hydrological processes follow physical, chemical and biological deterministic laws and are primarily the results of fluid mechanics and thermodynamic laws.

3.2. *The Run-off mechanisms*:

3.2.1. Runoff is that part of rainfall which appears in surface streams at the outlet of a drainage basin or catchment. The total runoff consists of surface runoff occuring immediately after the rain, interflow a little later to the rain and groundwater flows much later to the rainfall. The run-off cycle comprises of five phases. The first phase relates to the rainless period just prior to the beginning of rainfall. The second phase relates to the initial period of rain. As the rain starts, its amount is divided among channel precipitation, interception by vegetation, infiltrations into the soil and temporary retention in surface depressions. The third phase relates to a continuation of rain at variable intensity. As rain continues, excess rain is transformed into overland flow. The fourth phase relates to continuation of rainfall until all natural storage has been filled up. During this phase, the infiltration rate will approach the rate of water transmission through the zone of aeration of the soil cover. The fifth and last phase relates to the period between the termination of rain and the time when the first phase is reached again. Evaporation and transpiration are active during this phase and infiltration continues.

3.2.2. From the hydrologic point of view, rounoff rate is influenced by climatic and geomorphologic factors. Climatic factors include the form of precipitation, its type and intensity, duration, time distribution and aerial distribution, frequency of occurrence, direction of storm movement, antecedent precipitation, soil moisture interception, evaporation and transpiration. Geomorphologic factors are *basin characteristics* such as size, shape, slope, orientation, elevation, stream density, land use and cover, surface infiltration condition, soil type, geological and topographical conditions such as the presence of lakes, swamps and artificial drainage and channel characteristics including carrying capacities of the channels, their sizes, shapes of cross sections, bedslope, surface roughness, length and tributories of each channel and their storage capacities.

3.3. Deterministic theories have not so far succeeded in predicting future *rainfall*: but a number of attempts has been made to predict *runoff* based on antecedent precipitation. The relations between precipitation and runoff differ with the type of precipitation, the peak volume of runoff and the time distribution of runoff. The concept of Antecedent Precipitation Index (API) has been utilised to discover empirical relationships between precipitation and peak runoff and to predict the output hydrograph from a watershed.

3.4. *The Hydrograph*:

3.4.1. A hydrograph can be regarded as a convolution integral of the physiographic and meteorological characteristics of the watershed. Even though numerous methods have been developed to synthesise a hydrograph, such as the Unit hydrograph, synthetic Unit hydrograph, Instantaneous Unit hydrograph, System models of network of linear storages and linear channels, many of their procedures are arbitrary and have not shown any organic connection to the watershed studied.

3.4.2. Sherman introduced the concept of unit hydrograph for a storm of a specific duration for any given drainage basin, based on the premises that the time of concentration is constant for a basin, and therefore, the time base for the direct runoff hydrograph of all storms of the same duration is constant for the basin. This assumption is not valid since the time of concentration is also a function of the antecedent moisture conditions whose variance in time and space is quite large. Many other assumptions made by Sherman are not realistic.

3.4.3. Snyder's rules and coefficients were derived from data of watersheds in the Appalachian mountain, for developing this Synthetic Unit hydrographs. It is obvious that such an empirical approach has no universality, and cannot be used for prediction with any modicum of certainity.

3.4.4. When an effective rainfall function I (t) of duration to is applied, the ordinate of tne Instaneous Unit hydrograph is given by the Duhamel Integral, which is a liner process. Even though the IUH is independent of the duration of effective rainfall, its determination is numerically tedious and completely overlooks the stochastic nature of the process.

3.5. *System models*: Some system models of net work of linear storages and linear channels have been developed in the recent past by Chow, Kulandaiswamy, Nash, Diskin, Singh and others These models in general consist only of input, output and throughput and the transform operator which converts the input (rainfall) to output (flow) is derived from observed data. In such models the watershed has been treated as a lumped

system, or black box, and the spatial distribution of flow inside the watershed is not considered at all. The models are also deterministic with no probability considerations attached and hence the predictions have large variance.

3.6. Noteworthy is the fact that vital data such as soil moisture, infiltration rates, evaporation rates, precipitation rates at closely packed and numerous locations over a large watershed are impossible to gather economically and effectively for utilisation in such deterministic models. Therefore for practical predictions, stochastic hydrological methods appear more suitable at the present state of the art science.

4. *Stochastic Hydrology*:

4.1. *Discretization of continuous series*.

4.1.1. The majority of sequences of basic hydrologic variables are contiuous series of continuous variables. Discrete sequences are obtained either by averaging values over the time intervals, or by observations at discrete times or distances or by any rule of selection particular values. The accuracy of observation is imposed either by instrumentation, or measuring techniques and data processing, or by appropriate economic analysis.

4.1.2. The selection of the Δ x-interval for the hydrologic variable x is basically a compromise between the accuracy of information and the economics of obtaining the data. As at present, Δx is now decided empirically or through intuition, rather by any optimization analysis.

4.1.3. An observed continuous series has a total information I_c about the underlying stochastic process. As soon as the series is discretized, there is a loss of information ΔI.

The selection of Δt-interval is made by optimizing the function $\Delta I = f(\Delta t)$. Prediction of any hydrological variable involves basically the reduction in its variance as compared to guesswork or to predictions made by more approximate methods. Therefore $\Delta I = (1/\mathrm{var}\,x_c) - (1/\mathrm{var}\,x_d)$ where the subscripts c and d indicate continuous and discrete series. The optimal Δt should always be determined for any important hydrological undertaking of data acquisition and processing. The present practice has been explained in 2.1.1. It should always be remembered that once information is lost by digitizing a variable and a series, it usually cannot be recovered by any reverse procedure.

4.2. *Stochastic Processes*:

4.2.1. Sequences characterised by statistical properties are called stochastic processes. A stochastic process is the mathematical abstraction of an empirical process with its development governed by probability laws. Nearly all hydrologic processes are a combination of deterministic and stochastic processes.

4.2.2. Statistical analysis is used in hydrology where processes are observed and stated in terms of numbers. The purposes are:—

(*a*) Interpretation of observations

(*b*) Search for probabilistic regularities,

(*c*) Extraction of maximum information, and

(*d*) Presentation of hydrologic information in condensed form.

The important objective of applying statistics to hydrology is the derivation of information from the past for making inferences about the future, i.e., for prediction. However, blind application of statistics will result in futile expectation of more information than available in the data, wrong belief that statistical methods can replace scarce or unreliable data and in a tendency to replace judgement and interpretation of physical facts by statistical computations.

4.3. *Time Series*.

4.3.1. Time Series are the main sequences in hydrology for all variables which are observed or recorded in time. sequences associated with two or more dimensions in hydrology are variables either associated with area, or those observed simultaneously in time or along at line. These are multi-dimensional hydrologic stochastic processes.

4.3.2. An ensemble of time series is a set of time series each of size N in the discrete case, or of length T in the continuous case. The concept of ensemble of time series is the basis for definitions of *stationarity* and *ergodicity* in stochastic processes. If properties of time series do not change with absolute *time* they are called stationery (time-invariant). If the properties do not change with the position in a *line or area or over space*, the series are called *homogeneous*.

4.3.3. A sample discrete series of Size N, or a sample of a continuous series of length T is a *realization* of the stochastic process, and is also called a *sample function*. If the means of N discrete values, but taken at various times, converge to the population mean, the series x (t) is said to be stationary in the mean, or *first order stationary*. If the series is stationary both in the mean and in convariance it is *second order stationary*. If all higher moments are independent of t, but dependent only on $\tau_1, \tau_2, \ldots$ the series is higher-order stationary or *strongly stationary*.

4.3.4. If the properties of ensembles do not change from each other's, the process is said to be *ergodic*. For example, the annual rainfall series is ergodic for a given location, but its monthly averages are different for different months and hence the monthly series is non-stationary.

4.4. *Pre-whitening a time series*.

4.4.1. When hydrological processes are both stationary and ergodic, or made such by eliminating non-stationarity and non-ergodicity, further mathematical analysis becomes much simpler. In general, if the subseries parameters are confined within the 95 per cent tolerance limits, the process is said to be self-stationary.

4.4.2. Before attempting to use correlation theory to detect any relationships between various hydrological variables the following steps are taken to isolate the ergodic, stationary random component of the time series, and this is called pre-whitening the series.

4.5 *Removal of Trends.*

4.5.1 Consider the $x_{p\tau}$ series as the original non-stationary stochastic process with $\tau = 1, 2, \ldots\ldots w$, where w is the basic periodicity of discrete series, equal to 365 52 or 12 for daily, weekly or monthly series; $p = 1, 2, \ldots\ldots, n$, and n is the number of years of record. Assume that $x_{p\tau}$ has trends, periodicities and dependent stochastic components. The trends may be in the mean and in the standard deviation. The trends $Tm_{p,\tau}$ and $Ts_{p,\tau}$ may be approximated by Polynomials,

$$Tm_{p,\tau} = Am + Bmt + Cmt^2 + Dmt^3 + \cdots\cdots \text{ and}$$

$$Ts_{p,\tau} = As + Bst + Cst^2 + Dst^3 + \cdots\cdots \text{ in which}$$

$$t = (p-1)\,w + \tau \text{ and } A, B, C \cdots\cdots \text{ are}$$

the coefficients of the polynomial regressions.

4.5.2. A new process $y_{p,\tau}$ is now generated by removing trends in the mean and standard deviation as

$$y_{p,\tau} = \frac{x_{p,\tau} - Tm_{p,\tau}}{Ts_{p,\tau}}$$

4.6 *Removal of periodicity:*

4.6.1. The process $y_{p,\tau}$ may now be represented as $y_{p,\tau} = \mu_\tau + \delta_\tau \epsilon_{p,\tau}$ in which μ_τ and δ_τ are the periodic mean and standard deviation, and $\epsilon_{p,\tau}$ is a dependent stochastic component which may or may not be stationary.

4.6.2 If m_τ and m_y are the sample estimates of and μ_τ, and μ_y and S_τ, S_y are the samplo estimates of and δ_τ, δ_y the Fourier co-efficients Aj and Bj are given by

$$A_j = 2/w \sum_{\tau=1}^{w} (m_\tau - m_y) \operatorname{Cos}\left(\frac{2\pi j \tau}{w}\right)$$

$$\text{and } \; B_j = 2/w \sum_{\tau=1}^{w} (m_\tau - m_y) \sin\left(\frac{2\pi j \tau}{w}\right)$$

and similarly for S_τ

4.6.3. By Fourier analysis, the periodic μ_τ and δ_τ are expressed by

$$\mu_\tau = \mu_y + \sum_{j=1}^{m} \left[A_j \operatorname{Cos}(2\pi f_j \tau) + B_j \operatorname{Sin}(2\pi f_j \tau) \right]$$

in which μ_y is the mean value of m_τ and $f_j = j/w$. By a similar expression, δ_τ can be derived from S_τ

4.6.4. The sample estimates M_τ and S_τ are computed by

$$m_\tau = \frac{1}{n} \sum_{p=1}^{n} y_{p.\tau} \qquad \text{and}$$

$$S_\tau = \left[\frac{1}{n-1} \sum_{p=1}^{n} (y_{p,\tau} - m_\tau)^2 \right]^{1/2}$$

4.6.5. The stochastic process $\epsilon'_{p,\tau}$ is now obtained by removing the periodic mean and standard deviation by the parametric approach,

$$\epsilon'_{p,\tau} = (y_{p,\tau} - \mu_\tau)/\delta_\tau$$

4.6.6. $\epsilon'_{p,\tau}$ may not be a serially independent random component. It may have periodic auto-correlation co-efficients. To detect these, first and entire group of $\epsilon'_{p\tau}$ is normalized by the equation

$\epsilon'_{p.\tau} = (\epsilon'_{p.\tau} - \overline{\epsilon'})/s(\epsilon')$, so that its mean is zero and variance 1.

4.6.7. The auto correlation co-efficient $r_{k,\tau}$ estimated by

$$r_{k,\tau} = \frac{\operatorname{Cov}(\epsilon_{p\tau}, \epsilon_{p,\tau+k})}{\left[\operatorname{Var}\{\epsilon_{p\tau}\} \operatorname{Var}\{\epsilon_{p\tau+k}\} \right]^{1/2}}$$

and through harmonic analysis (as in the case of mean and standard deviation), $\rho_{k,\tau}$ is computed.

4.7. *The Markov model:*

4.7.1. The general m-th order autoregressive linear dependence model or Markov model is assumed for $\epsilon_{p,\tau}$ by

$$\epsilon_{p.\tau} = \sum_{j=1}^{m} \alpha_{j,\tau-j} \cdot \epsilon_{p.\tau-j} + \left[1 - \sum_{i=1}^{m} \sum_{j=1}^{m} \alpha_{i,\tau-j} \cdot \alpha_{j,\tau-j}\, \rho_{|i-j|,\tau-k} \right]^{1/2} \xi_{p\tau}$$

in which $k = i$, if $i < j$ and $k = j$ if $i > j$, with α_j the autoregression co-efficient at the position $\tau - j$

For the first order Markov model, $m = 1$ and $\alpha_{1,\tau-1} = \rho_{1,\tau-1}$

For the second order Markov model, $m = 2$

$$\text{and} \quad \alpha_{1,\tau-1} = \frac{\rho_{1,\tau-1} - \rho_{1,\tau-2} \cdot \rho_{2,\tau-2}}{1 - \rho^2_{1,\tau-2}} \quad \text{and}$$

$$\text{and} \quad \alpha_{2,\tau-2} = \frac{\rho_{2,\tau-2} - \rho_{1\tau-1} \cdot \rho_{1,\tau-2}}{1 - \rho^2_{1,\tau-2}} \quad \text{etc.}$$

Through the above equations, the second order stationary independent stochastic component $\xi_{p,\tau}$ is obtained.

4.8. *Probability distribution of white noise.*

4.8.1. The probability distribution of $\xi_{p,\tau}$ is now found out. Usually in hydrological work, the following points are to be noted, which have been gleaned through experience with vast amounts of data.

(*a*) In harmonic analysis it is sufficient to take up to 6 harmonics only, whatever be the value of w(12,52 or 365). In such cases 70 to 95 per cent of the variance in the original process is explained by the periodicities in mean, standard deviation and auto correlation coefficients.

(*b*) It is sufficient to consider Markow models up to order 3 only. Higher order models are not generally realistic, considering the poor accuracy of observed hydrologic data.

(*c*) The common probability distributions such as Normal, Lognormal, Gamma, Beta and Polynomial-transformed Normal do not fit up $\xi_{p,\tau}$ with χ^2 value as the criterion. Empirical distributions have invariably to be evolved for $\xi_{p,\tau}$ especially for weekly and daily series.

(d) The residual variance left in $\xi_{p,\tau}$ after explaining a major portion through multiple regression, should be atributed to observational errors. non homogeneities, etc.

4.8.2. In the case of weekly hydrological series, the author has observed that piecewise normal distributions fitted up to the white noise component suit admirably from the point of view of expeditious prediction while economically using digital computer time.

5. *Correlation Analysis.*

5.1. An important principle of Information Theory is the transmission of a fluctuating process. In consequence of their random nature, these processes constitute a population of measurement values in the mathematical statistical sense. By the representation of a hydrological series as a time function, a frequency function and a probability function, correlation analysis forms a link between the three disciplines of signal theory

5.2. The correlation function is defined as

$$r = \frac{\overline{xy} - \bar{x}\bar{y}}{S_x \cdot S_y}$$ where x and y are the two variables to be correlated, $\bar{x}, \bar{y}, \overline{xy}$ represent mean values, and the standard deviations of S_x and S_y respectively.

5.3. The auto-correlation function

$$r(\tau) = \frac{\overline{x_i \cdot x_{i+\tau}} - \overline{x_i}, \overline{x_{i+\tau}}}{S_{x_i} \cdot S_{x_{i+\tau}}}$$

5.4. The cross-correlation function

$$r_{xy}(\tau) = \frac{\overline{x_i \cdot y_{i+\tau}} - \overline{x_i} \cdot \overline{y_{i+\tau}}}{S_{x_i} \cdot S_{y_{i+\tau}}}$$

It should be noted that between two time functions of different frequency, there is no statistical coherence, no correlation.

5.5. In stochastic processes in general, the frequencies of periodic elements and their harmonics are not known a priority and hence spectral density techniques are used to detect the fundamental frequencies and their harmonics. However with hydrologic stochastic processes, the fundamental frequencies which are connected with the periods of revolution of the earth around the sun, the period of Self-rotation of the earth, the period of revolution of the moon around the earth and the periods of equator-crossing of the sun are well known, and hence spectral density techniques are not necessary. Straightaway, correllograms can be obtained between two hydrological random variables in the lag domain.

5.6. Usually the variables to be correlated are rainfall series at a number of locations in the watershed and the resultant flow at a gauging site at the outlet of the watershed. If there are n rainfall stations and m flowstations to be inter-correlated, there are $\frac{(n+m)\;(n+m-1)}{2}$ correllograms, to be obtained with maximum lag $\tau_o = w$. After obtaining these correllograms, the maximum values of correlation coefficients between the rainfalls and the flows are used to derive the multiple regression equation, for use in prediction.

6. *Multiple Regression.*

6.1. If $\{x_1\}, \{x_2\} \cdots\cdots\cdots\cdots \{x_n\}$ are the white noises of n rainfall variables to be correlated with $\{y\}$ the white noise of the flow variable the multiple correlation matrix of maximum correlation with y is first computed.

Then $\underline{\beta} = \underline{R}_{xx}^{-1} \cdot \underline{r}_{xy}$ in matrix notation, where $\underline{R}_{xx}$ is the matrix of intercorrelation among x_i, and $\underline{r}_{xy}$ the marginal correlation vector between x_i and y. R^2, the coefficient of determination is computed from the equation.

$$R^2 = \underline{\beta'} \cdot \underline{r_{xy}}$$

The regression coefficients b_i are computed

from $b_i = \beta_i \cdot \frac{s_y}{s_{x_i}}$

and the intercept $e = \bar{y} - \sum_{i=1}^{n} b_i x_i$

The regression equation is finally derived as

$$y = \sum_{i=1}^{n} b_i \cdot x_i + c$$

It should be emphasised once again here that (x_i) and (y) are the $\xi_{p,\tau}$ values for the n+1 variables, respectively.

6.2. The important point to be stressed here, from the point of view of prediction accuracy is that the R^2 value by correlating the white-noise components is always higher than that obtained by correlating the raw original data, and hence the need for the elaborate but essential filtering process described earlier to isolate the second order Stationary independent stochastic components of all hydrological variables, before applying correlation and multiple-regression techniques.

7. *Prediction Technique.*

7.1. Let us assume that yesterday's rainfall, rainfall at n raingauges in the watershed are made available i.e. $(x_i)\tau$ is known for the period τ. Since the parameters $\mu_\tau, \delta_\tau, \alpha_{1\tau}, \alpha_{2\tau}$ ...... etc. are derivable from past historical data, $(\xi_i)\tau$ can be computed. Using the Multiple regression euqation $x = \sum_{i=1}^{n} \xi_i b_i + c$ the white noise component of the flow station is computed. $y_{p,\tau+1}$ which is the value to be predicted is derived from the equation,

$$y_{p,\tau+1} = f\left(y_{p,\tau}, x_{p,\tau}, \alpha_{i,\tau}, \mu_\tau, \delta_\tau\right)$$

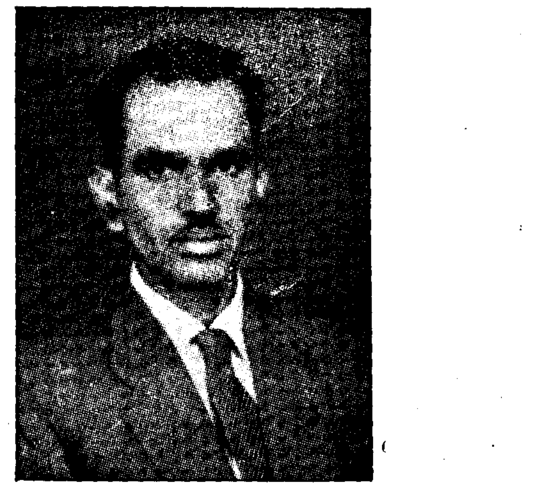
7.2. For real-time prediction for rapidly varying phenomena such as a flood wave in a driver, electronic analog computers using delay elements, multipliers and integrators are to be used. With potentiometer settings to represent the various parameters and with a white noise generator, real-time prediction with speed is possible.

7.3. The delay elements are generally magnetic tape recorders in which lag-time can be varied, either by adjusting the recording and reading heads, or by multiple recording in various tracks and adjusting the lag manually from a master tape. Electronic multipliers are generally used to form the product $x_t y_{t+\tau}$. The integrators are D.C. amplifiers used in standard analog computing equipment.

7.4. The author has developed simple Telemetry equipment to transmit hydrological data over vast distances by using the principles of frequency modulation of V.H.F. electromagnetic waves. These data are directly received at the Analog Computer which processes them and predicts the future hydrologic variables, based on the techniques described above.

IRRIGATION—HOW—HOW MUCH AND WHEN

By Thiru R. K. SIVANAPPAN *



1. *Irrigation.*

Efficient methods of irrigation enables the application of the right amount of water to the crop at the right time and its uniform distribution in the field. Irrigation-how refers to the manner in which irrigation water is applied to the land. It may be applied to the crops on soil surface by spreading or by spraying it over the crops through pipes and nozzles or applying it at a slow rate in drops or trickling in the root zone of each plant. The amount of water to be applied in any method depends on the soil, its water holding capacity, root depth of the crop, the time of application and method of application. The time of application depends on the weather condition, the sensitiveness of the crop, stage of crop, how much water the soil holds, etc. The technology of irrigation-how, how much and when has to be practiced in order to increase the area of irrigation from the available water to produce more for the growing population.

2. *Irrigation-How.*

The desirable method to apply water for the crop is determined by many factors namely, the water supply, its quality, soil depth, its texture, topography and climatological factors. The methods available are *(a)* surface method *(b)* over head or sprinkler and *(c)* Drip or trickle method. The surface method of irrigation includes furrow, border, check basins and the selection depends upon the type of crop grown. Irrespective of the method, the essential requirements in water application are to apply uniformly to wet the root zone to its storage capacity. The various methods are given in figure 1.

Delivering the correct amount is not enough, but distribute it evenly. System design is important for either sprinkler, drip or surface irrigation. In surface method use large streams for flat slopes, long runs, light irrigations and soils which take water rapidly, use small streams for steep slopes, short runs, heavy irrigations and soils which take water slowly.

The correct amount of water which is evenly distributed either in surface or sprinkler irrigation will be as shown in the figure 2. In figure 3, though the amount of water used is the same, but the water has not been distributed evenly. For row crops, adopt furrow irrigation which reduces the water requirement of crop compared to border or check basin. The water applied should go upto the root depth and not more or less. In drip and sprinkler method the depth of water is restricted to the depth, but in sprinkler, the water is spread in the entire area whereas in the drip it is only surrounding the crop space but not for the entire soil surface (see figure 4). In Israel still another method called "pulsed irrigation" is being adopted which is reported as better than drip method.

Irrigation of crops is an age old practice. Improvement if any, in methods and application have been brought as a result of systematic scientific research. There is large scope for improving irrigation method in order to economise the water and to take maximum production per unit quantity of water.

3. *Irrigation-how-much.*

The amount of water to be applied depends on the season when irrigation is done. If irrigation is given to germinate seed, soften a crust, cool the soil, shallow sandy soil condition, light irrigation is enough. Heavier irrigation is needed (a) when the salts are to be leached out of the soil, (b) provide moisture for plant growth, (c) deep and clay soil conditions.

A clay soil will hold more water than a sandy soil. Both soils under normal conditions should have effective root zone of 45 75 cm (average 60 cm) in depth. Therefore a clay soil will hold considerably more water in the 45-75 cm. profile than the sandy types will hold. Generally clay soil hold about 7.5 cm. per 30 cm. or 15 cm. in the root zone depth of 60 cm. It is generally agreed by most irrigaters that irrigation is needed immediately when soil moisture falls to between 50 and 60 per cent of field capacity. When 7.5 to 9 cm. of water is utilised by the plant, next irrigation to fill up the depleted quantity has to be given. The depth of water to be given for any crop can be calculated from the following formula.

$$d = \frac{PW\ AS\ DS}{100}$$

Where d : depth of water applied in cm

PW : Different in SMC at the time of irrigation and at FC ;

AS : Apparant specific gravity ;

DS : Root depth of the crop.

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The table 1, shows the approximate amount of water required to replinish the soil moisture at the time of irrigation taking that 50 per cent of the available moisture is used by the plant if the root depth is 60 cm.

TABLE 1. AMOUNT OF WATER NEEDED FOR DIFFERENT TYPES OF SOILS.

Serial number.	*Soil type.*	*Amount needed in cm to restore root zone water when 50 per cent is receeded.*
1	Clay	7·5
2	Clay loam	9·25
3	Silt	4·50
4	Sand loam	3·75
5	Sand	2·50

In the field, it is difficult to find out the percentage of available moisture for growing crops. Table given below shows a quick method of determining the per centage of available moisture in the soil.

TABLE 2. GUIDE FOR JUDGING HOW MUCH MOISTURE IS AVAILABLE FOR CROPS.

Serial number.	*Available soil moisture remaining.*	*Feel or Appearance of soil* *Light texture.*	*Medium texture.*	*Heavy texture.*
1	25-50 per cent	Appears to be dry, will not form a ball with pressure.	Some what crumbly but holds together from pressure.	Some what pliable will, form ball under pressure.
2	50-75 per cent	Appeats to be dry. will not form a ball with pressure.	Forms a ball some-what plastic, will somehow stick, slightly with pressure.	Forms a ball ribbons out between thumb and forefinger.

Irrigation—When.

To decide when to irrigate, look at the plant and the soil. The sign indicated by the soil and plant will help in deciding when to irrigate. In the case of plant, observe its wilting, colour, growth rate and stage of development. For soil, check for dryness by appearance method.

Some plant at certain growth stages can tolerate to deplete the moisture even upto 0-25 per cent and some others it will affect, its growth if the moisture reduces below 75-50 per cent. Therefore the sensitiveness of the plant and its tolerance limit at various stages without affecting the yield should be studied and irrigation should be given accordingly. But normally irrigation can be given for most of the crops when 50 per cent of the available moistures is depleted.

In some situations the irrigation is to be given more frequently and in other cases it can be postponed for a long period. It depends upon weather, plant and soil characteristics. Figure 5 given below shows how the weather, plant and soil affect the irrigation frequently.

Fig. 5. Effect of Soil, Plant, Weather on Irrigation Timing.

Cool Damp Still out		Weather	Hot Dry Windy	
Irrigate less often	Deep rooted Healthy roots Incomplete ground cover	Plants	Shallow rooted damaged by Diseased roots complete ground cover.	Irrigated more often
	Deep fine textured	Soil	Shallow Coarse textured	

Summary.

Water is becoming a scarce commodity and so we have to utilise it economically in order to save it. Therefore it is necessary to know, how, how much and when the irrigation is to be done. The present practice of irrigation is age old one and it has to be changed in order to conserve and to get more produces per unit area of land per unit amount of water. Irrigation properly applied can make a tremendous difference in the Agricultural Economy. But it must be based on scientific concepts related to agriculture, specially to the diffirent soil type, crops, etc.

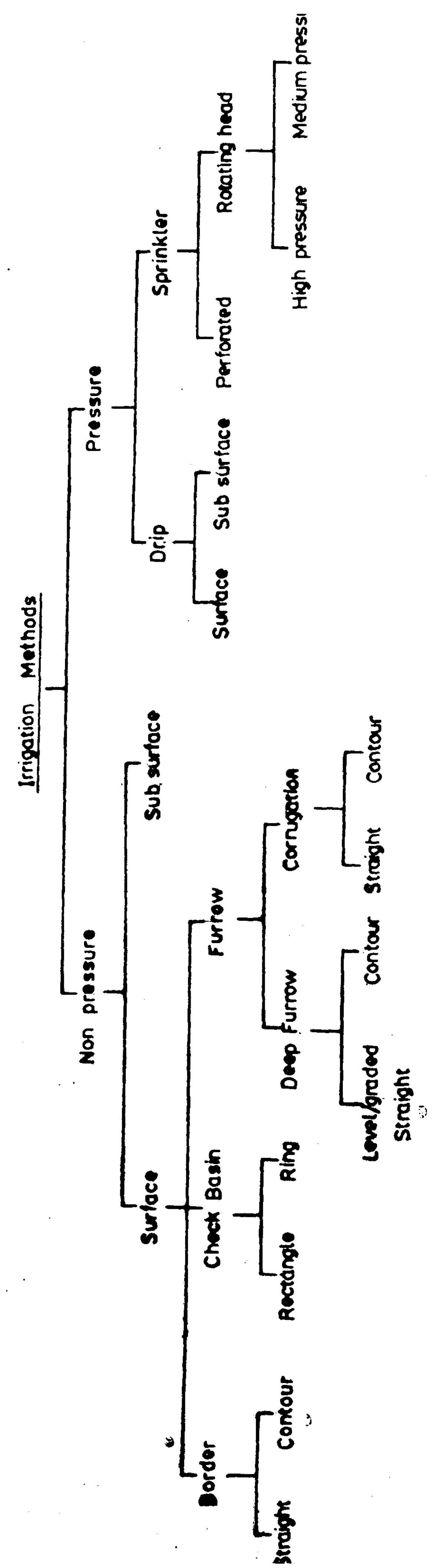

FIG 1. VARIOUS METHODS OF IRRIGATION

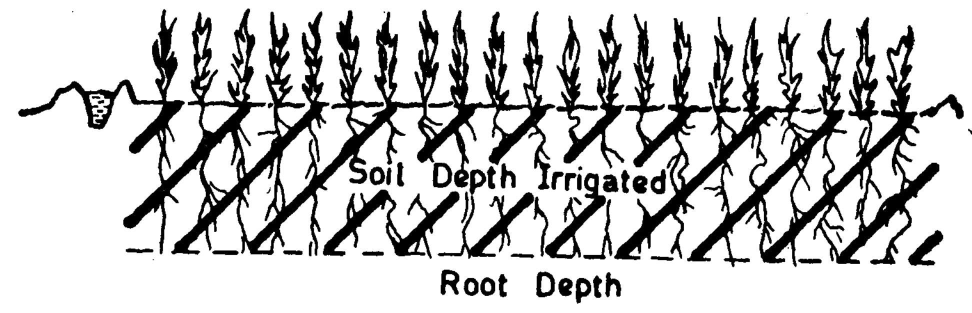

Fig 2. Correct Amount Of Water, Evenly Distributed

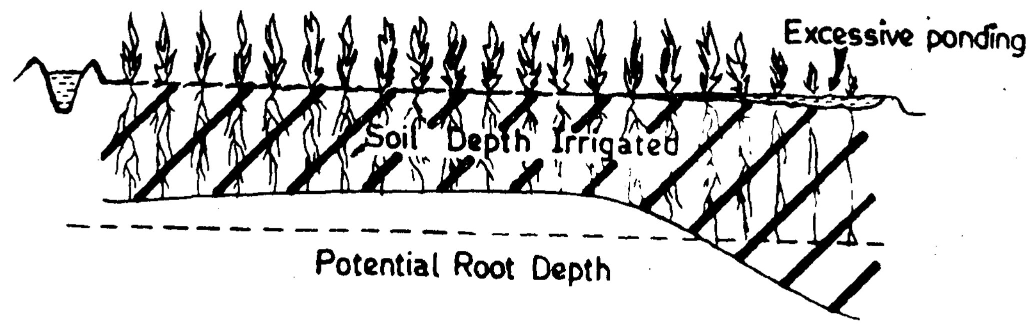

Fig 3. Uneven Distribution With Less And More Water

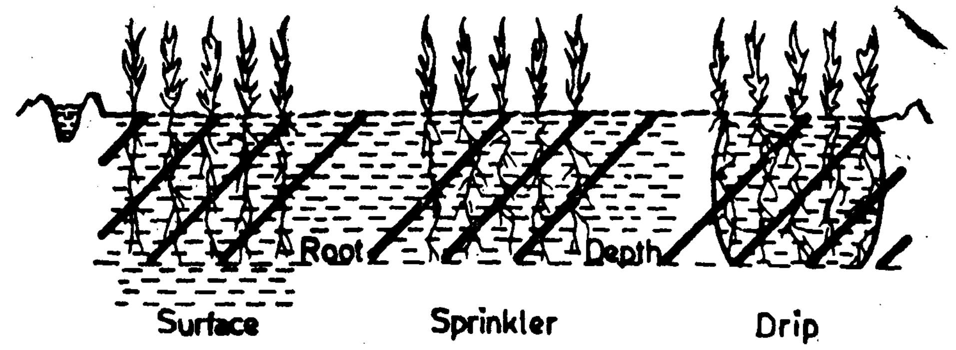

Fig 4. Distribution Of Water In 3 Different Methods Of Irrigation

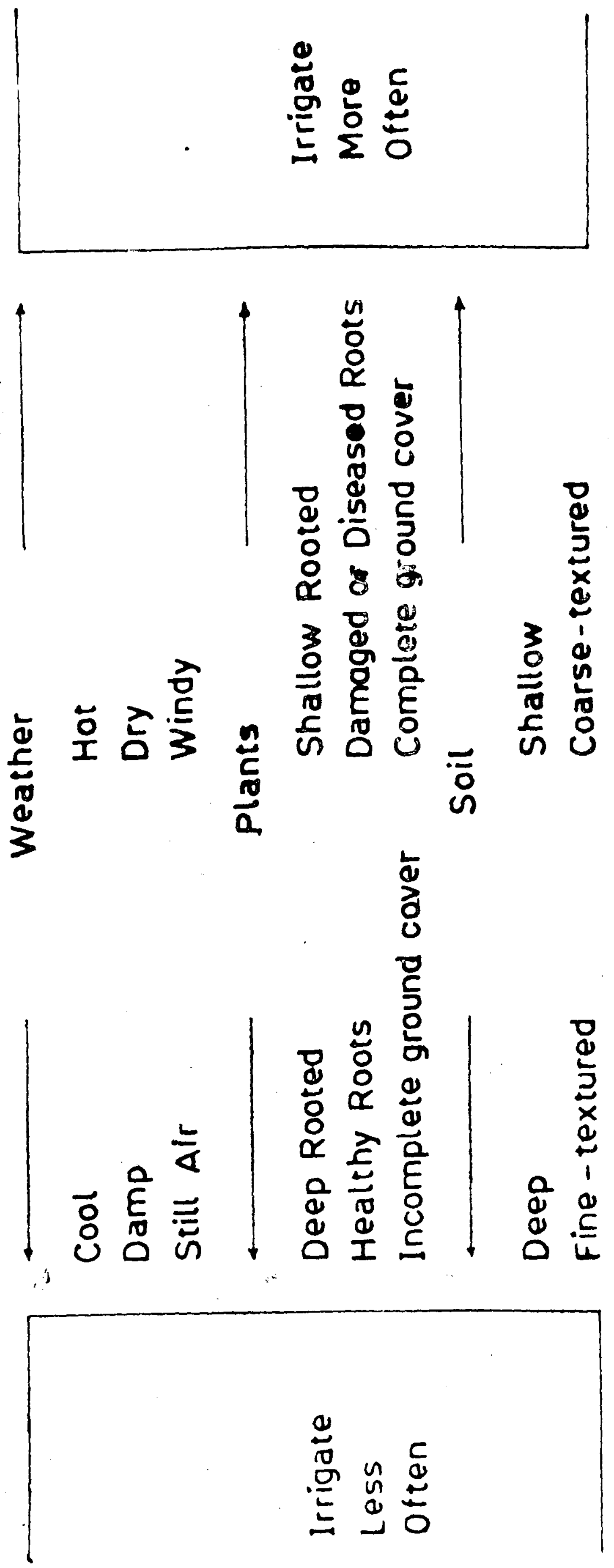

FIG 5. EFFECT OF SOIL, PLANT AND WEATHER ON IRRIGATION TIMMING

INTRODUCTION OF ELECTRONIC DIGITAL COMPUTERS IN THE ACTIVITIES OF PUBLIC WORKS DEPARTMENT (TAMIL NADU)

(Few Suggestions.)

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Man has been making concerted efforts for finding different ways to perform routine calculations automatically. In the days of Yere, abacus was used by Greeks and Romans for simple additions and subtractions, and subsequently in 1642, Pascal developed the first machine for performing all the four basic operations of arthmetic. It was Charles Sabbage in 1802 who conceived the idea of automating the simple calculations. Further activity in the direction of effecting automation, resulted in the present day Electronic High Speed Digital Computers. The modern Computer is perhaps the most versatile piece of machine, man has ever invented.

The Digital Computer is an information processing, and storing device doing logical manipultations. It belongs to the class of machines comprising of discrete action devices. It is an expanded version of an adding machine, doing electronically what the adding machine accomplishes through a mechanical system of gears. We are now on the thresh-hold of the "Era of the Computer", which promises spectacular changes in our way of life. Today the large number of computers which are already in daily use, have penetrated almost all phases of our modern society, from Nuclear-Energy production, down to medical diagnosis processing of business invoices, etc. The use of computers is based on the ability to operate at great speed, to produce accurate results, to store large quantities of information and to carry out long and complex sequences of operations without human intervention.

In this article an attempt has been made to mention a few areas from the broad spectrum of problems now being solved by Public Works Department in which a Digital computer can play an useful and leading part to help the P.W.D. Engineer effectively and also to suggest to set up a soft ware developing unit for this department.

Possible areas of application of Digital Computer in P.W.D.

The Public Works Department is the agency incharge of installing, maintaining and monitoring many gauging stations across the rivers and streams in Tamil Nadu. Every year a large volume of data are being collected for analysis and computations in a centralised office for computing the daily flow, monthly and yearly flow in a river system. At present the volume of data collected is so large, it takes months or sometimes years between the collection of data and transmitting to the centralised processing office and finally recording this data after computing the required quantities for retrieval later. At present such computations are being done manually, or sometimes using Desk calculators The method of computations for similar type of structures is almost the same. The computations are repetitive calculations which could be best done by using a Digital Computer. A computer programme could be developed which could be used for such purposes. The other advantage of using the computer for such bulwork, is, it is accurate, and more reliable than hand computations, besides it reduces the time consumed for such work.

The Design of many water resources projects, however small it can be, may be made using a Digital Computer. In the design of water resources projects a number of parameters are involved, e.g. Spillway design flood, alignment, height of impoundment, type of material earth or masonry, etc. By varying one parameter alone keeping the other parameters constant a number of alternative designs can be made to arrive at the optimum design.

Again for arriving at the structural designs for the various structural Components of a Project, a number of programme packages can be developed which can be readily applied and used. A library of such programmes can be built for the general use of the Public Works Department Engineers. Such programme parameter keeping the other parameters constant. one to study the characteristics of variation of one parameter keeping the other parameters constant. Such a study can best be done by a digital computer since it is bulwork consuming lot of time of the designer. With this Man-machine interaction, a higher level of output can be obtained with a digital computer.

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As far as Structural Engineering as applied to Building Construction is concerned, the digital computers can play a very leading role in the design of multistoried buildings now being executed by Public Works Department.

Electronic Digital Computers have been used extensively in hydrology and hydraulics. One of the applications of Digital Computers is computation of back-water curves in the design of water Resources Projects. The Institute of Hydraulics and Hydrology, Poondi utilised the Digital Computer IBM 1620 at the College of Engineering, Guindy, Madras for working out a number of water surface profiles in the River Cooum to arrive at the maximum flood that could have passed in the year 1943. Such a study could not have been made except with the use of a Digital Computer. Attempts are being done at Institute of Hydraulics and Hydrology, Poondi to make the Research Problems Computer oriented.

In Hydrology and Water Resources planning a number of modern methods have been developed and applied, e.g., systems approach, mathematical models, stechastic principles, etc. These modern tools available for the present day Engineers can be applied for the Water Resources Projects being studied by the Department, which could best be possible with a digital computer.

The Ground Water Directorate has taken a lead to apply the Digital Computer for assessing the Ground Water potential. The data collected by them pertaining to the disciplines like Hydrology, Hydrogeology, Geophysics, Hydro-chemistry had to be checked, for statistical homegenity error analysis, missing data and also for evaluating values of standard deviation, correlation co-efficient, regression co-efficient. For such massive work the digital computers are being applied.

Recently it has been reported, that the Railway Board has now decided to utilise the vast potential available for application of computers to civil Engineering problems. The activities of various computer service Bureau, are being co-ordinated in the Board's office by the Civil Engineering soft ware centre, attached to its efficiency cell. The Centre not only under taken development of computer programmes but also maintains a library of programmes collected from Zonal Railways and from other sources, so that these are readily available to all zonal railways for use. Railway Board expects increased utilisation of computers in the Civil Engineering field to bring about a reduction in the over all cost of construction and maintenance. It also expects that it would not only minimise project costs but also extend the capabilities of professional personnel.

As Engineers, we must be receptive to innovations. A reading of the preceding paragraphs would have shown a subtle but nevertheless an obvious indication of the necessity of application of computer oriented approach for solving the Civil Engineering problems of the Public Works Department. In order that the computer may fulfil its intended role as an innovative tool in the Engineering activities of this department and not relegated as a slide rule replacement, it will be necessary that a significant change in the structure and orientation of the department is made now.

Before suggesting the structural changes in the department, it is necessary to mention here that some of our brother engineers have developed a cynical attitude for any technological innovation in the department, but they mention it only behind doors or in private conversations. They have an aversion for theoretical methods using powerful tools such as computers due to their disinclination and incapability for learning the techniques to use them properly. Therefore it is necessary to explain to them the innumerable advances, both technical and economic, that have been possible due to the computer, from space exploration to evolving new hybrid variety paddy, from diagnosis of diseases to regulating traffic during rush hours, the computer is creating a revolution. The computer makes its presence felt in all walks of life, like quality control, inventory control, resource allocation, travel reservation, etc. The computer is taking over the insurance business, pay roll preparation, examination results processing and infinite other activities. Soon mini and micro computers are expected to invade the field. Under these circumstances, computers must find a place in the activities of the Public Works Department also. To start with a soft ware developing unit can be started for the public works department. This centre can perhaps be attached to the Institute of Hydraulics and Hydrology, Poondi. This soft ware developing unit can be entrusted with the work of exploring the areas of present activities of the Tamil Nadu Public Works Department, viz. Hydrologic and Structural Design activities, collection and retrieval of Hydrologic, Hydraulic data, etc. This soft ware developing unit can also contact other States in India where much work would have been made on the application of digital computer for Civil Engineering problems and collect them, and store them for possible use later in this state.

This unit may comprise experts in each branches of Civil Engineering like, Hydraulics, Structural Engineering, Soil Mechanics and Foundation Engineering, etc. The Unit should also comprise experts in the field of mathematics, statistics also. Young and inaginative officers' of Public Works Department, may be selected, proper training given to them on the application and use of High speed digital computers. The Tamil Nadu Police Department has already taken a in applying High speed digital computers in its activities relating to crime detection, storage of data regarding criminals for retrieval whenever they are required. Also the Finance Department is utilising a digital computer for processing the budget data of Tamil Nadu State. The Public Works Department which is a technical department, should not lag behind other departments in exploiting the capabilities of a digital computer. The software developing unit should also act as a consultative body for all wings of public works department who are in charge of Designs

organisations, Research units, maintenance and operation of storage reservoirs, Design of multistoried structures, etc. This unit shall be head quartered at Madras, so that they can have easy access for the computer available at I.I.T., University of Madras and the Engineering College, Madras. *The staff of this unit shall not be disturbed by applying the usual rules of transfer of Government servants.* In due course the public works department itself can acquire a digital computer, perhaps an IBM 1130 with a plotter, for its work. In this connection it should also be mentioned, that at present P.W.D. is depending on other departments like Technical Education department for consultency services, development of software, etc., on payment of Cost. This can be avoided if a software developing unit as mentioned earlier is set up for Public Works Department.

Since the Designs organisation, investigation of projects, and the Research Units have been brought under the control of one Chief Engineer, it is high time that we make concerted efforts to induct the digital computer into the activities of the public works department.

WATER RESOURCES OF INDIA—AN APPRAISAL

by THIRU Er. R. GOPALAKRISHNA MURTHY,

India is a vast country with a veleidoscopic diversity of Topography, Climate and Vegetation. Its geographical area is 800 million acres out of which 500 millions is cultivable but only 75 to 80 per cent of this is actually cultivated at present. India has a large population of 600 millions to support with the result, the presure on land is great. While it is 25 per square mile in U.S.S.R. and 50 in U.S.A. It is as high as 500 in India. 70 per cent of the population depend upon agriculture directly for their living and therefore Agriculture had always been and in the foreseeable future forms the main industry of India. India being a tropical country, Rainfall is monsoonic and generally capricious in its incidence and variable in its amount and distribution. As a consequence fluction in production, is a dominant feature of Agricultural production. It has truly been said that Agriculture in India is a gamble with the monsoon. In many parts of India, and particularly in the Deccan plateau, the rain-fall cannot be entirely depended upon as both sufficient in quantity and regular in its distribution throughout the crop period for raising crops with any degree of security against failure. Most of the areas are liable to drought. Without irrigation, large arid and semirid tracts of the country would not be able to yield a successful crop ; they remain waste or fallow. Artifical irrigation is not only an insurance against famine and scarcity, but it also augments the crop yields with various inputs such as improved seeds, fertilizers, etc., enabling larger and sustained out puts. That is the reason why, Irrigation had been practised in one form or another since times immemorial. The Vedas considered to be the most ancient documents, refer to wells, canals and reservoirs. Manu Dharma Shastra mentions code of conduct to be followed on water distribution. The Indus and other Riverine Civilizations bear testimony to the great developments and accomplishments in this direction from the far past. Nevertheless we have to bear in mind that, as in other fields of science and technology rapid advances have been made in the science and techniques of Irrigation in particular and water Resources Development in general during recent decades.

Water Resources Development:

The development of water Resources is predicated on

(i) The conception ;
(ii) The design ;
(iii) The construction ; and
(iv) Operation of facilities to control conserve and utilise water.

Water is controlled, as you all know and regulated to serve a wide variety of purposes, Irrigation, power development, Navigation pisiculture and so on. There are three essential functions in this operation ; viz., control of water, utilisation of Water and Management (including quality and environment).

Water Resources Development is essentially a function of civil engineers but the services of other specialised fields are required, such as Geologists Hydro-mateorologists Electrical and Mechanical Engineers and most often scientists from Forestly, Soil Management, Riology, Ecology and also Economists and politicians.

With world population doubling every four decades, the water Resources of the world are becoming one of its most important assets, and its development one of the Chief Resources Development activities of the advanced and advancing nations. Unless it is harnessed, like all elements of nature. Water is a wild element. In this context, it is better to be remined of what Veda Vysa said in Mahabharata:

ANDHAHA BALAM JALAM PRANUTAVYA VICH—CHANAU.

అంధః బలం జలం ప్రణు తవ్య విచ్ఛనః॥

"Water is blind force ; it has to be harnessed with discrimination".

India has substantial Water Resources but their distribution like rainfall is uneven. This is because of the seasonal and regional distribution of rainfall ; Runoff being its consequence shares the same variation

Chief Engineer. Irrigation and Planning (Retired), Andhra Pradesh Lecture delivered for the fifth ***memorial*** *Lecture of Bharatha Rathna Dr. M. Visweswaraiyya on 25th October 1976 at Madras.*

Water Resources:

(*a*) *Surface.*—Unfortunately, a correct appraisal of country's Water resources—their occurrence, present use and future possibilities—is yet to be made. The C.W. & P.C. worked out the surface water resources of different regions during the period 1954-66, according to which in a Normal year like 1960, the water resources of the various basins amounted to 1523 M.A. Ft. (1881 B. cum) as detailed below.

Lone I—West Flowing Rivers.

River Basin.	*Water Potential in M.A.*	
1. River basin of Kerala	30	
2. River basin of Madras and Bombay up to Tapi	247	
3. Tapi Basin	16	
4. Narmada Basin	33	
5. Basin above Narmada	22	
Total ...	248	248.0

Zone II—East Flowing Rivers.

6. Tambraparani and Vaiga river basin	7	
7. Cauvery basin	15	
8. Pennar	6	
9. Basin between Cauvery and Pennar	14	
10. Mahanadi and other basins between Ganga and Godavari	107	
11. Godavari	93	
12. Krishna	47	
Total ...	289	289.0

Zone III—Indus Basin (Indian portion)	64.00
Zone IV—Ganga Basin	446.00
Zone V—Brahamaputra	497.00
Total ...	1,526.00

This is a general approximation and indicates that the Ganga and Brahmaputra together account for nearly 60 percent of the surface water potential of the Indian subcontinent.

(*b*) *Ground Water Resources.*—A scientific assessment of the ground water potential of the country was not undertaken until a few years ago. A very rough assessment of ground water resources has been attempted by Dr. K. V. Raghava Rao and his collegues of the Central Ground Water Board (C.G.W.B.), according which, the net ground water recharge is 219 M.A. feet out of which about 47 M.A. feet is utilised by 27 M. acres under irrigation by ground water leaving 171 M.A. feet for further development.

Utilisable Water Resources:

So far, no systematic study or analysis of the utilisable water resources of the country had been done except for the Indus System. Some preliminary studies have, however, been carried out in respect of the Godavari, the Krishna, the Narmada and the Tapi rivers, according to which the, entire water resources of these basins can be Utilised. The waters of the Cauvery have been fully utlilised. This is broadly summed up as below.

	Utilisable M. A. Ft.	*Total run off in M.A.F.*
1 Godavery, Cauvery, Krishna and other Southern Rivers.	150	(150)
2 The Indus System.	40	(64)
3 The Ganga System.	150	(450)
4 The Brahmaputar System	10	(480)
5 The Mahanadi and other East	100	(100)
6 West flowing rivers excluding Narmada and Tapi.	40	(200)
7 Narmada Tapi	50	(50)
Total ..	540	(1534)

Surface water utilisation which used to be 76 M.A. feet in 1951 is doubled by the end of the 3rd plan and stood at 180 M.A. feet. by end of March 1970. Irrigation potential under Major and Medium Projects is increased from 24 M. acres to 48 M. acres (1970).

From the foregoing, it is evident that the total water Resources of the country are large, but their distribution is uneven, in relation to the Time and Need during the year and in relation to the areas of water demand. This imbalance to a relatively small extent was attempted to be rectified by transfering of water from areas of surplus to the areas of the needy or deticit. The concept of transfer of water is therefore not new in our country. Some schemes have already been implemented in our country during the past decades. Most of these schemes are in the State of Madras itself and are familiar.

(i) Periyar Diversion Scheme.
(ii) Kurnool Cuddapah Canal.
(iii) Parambikulam Aliyar Project.

In North India also, in recent years some transbasin schemes have been taken up, viz.

(i) Rajasthan Canal.

(ii) Beas-Sutlej Link.

(iii) Diversion from Ramaganga to Ganga, and so on.

In this context, our thoughts naturally should go back to the bold thinking and fore-sight of that great wizard, Sir Arthur Cotton:

It is nearly a century ago that Sir Arthur Cotton set forth in detail his scheme for canals for enabling a water transport link over nearly the whole of India, with many intermediate connections.

1. From Calcutta to Kurrachee-up the Valley of the Ganges, across the Watershed of the Jumna and Sutlej, down the Valley of the Indus to Kurrachee. The worst part is already cut, the Sirhind Canal across from the Sutlej to the Jumna.

2. By the line of the Godavari and the Tapti from Cocanada to Surat.

(3) Up the valley of the Tungabudra and the valley of the Kala Nuddee, crossing the watershed near Darwar, which is the worst one, two thousand feet, reaching the sea at Karwar.

(4) By Palghat, abreach south of the Nilgiris up the valley of the Penang and down the valley of Amaravatty, crossing the watershed near Coimbatore on a level of about thousand four hundred feet. Two coast lines would meet at Cape Comorin.

In his public works for India, published in 1881, he elaborates his proposals as hereafter given. These particulars so far as was possible have been indicated on the accompanying map

1. The completion of the coast canals from the Godavari to Madras—380 miles.

2. The completion of the Godavari and Krishna Delta works.

3. The completion of the Upper Godavari and Wurda Navigation to near Chanda on the Wurda 150 miles.

4. The Junction canal from the Tungabudra canal at Cuddapah to the North Coast Canal at Nellore—80 miles.

5. The construction of a great tank on the Tungabudra, west of Bellary, to contain at least 3,000,000,000 cubic yards.

6. The canal from it to the Irrigation Company's Canal 200 miles, irrigation 500,000 acres.

7. The complete examination of the whole system of old tanks perfecting, enlarging etc.

8. A nearly level canal from the great Tungabudra Tank South to the Cauveri, near Seringapatnam, and North across the Kistana and Bheema, passing near Hydrabad to the Godavari 800 miles.

9. Canals leading the water from this main canal to multitudes of old tanks in the carnatic.

10. A canal from the above main canal in Bellary across the Water-shed of the Hagary and the pennair to convey water into the latter river.

11. A bund across the pennair where it leaves the hills forty miles above Nellore with Canals leading North to the Krishna and South through the carnatic to supply old tanks and for irrigation about 400 miles.

12. The extension of the East Coast Canal from the Pallaur, forty miles south of Madras to Cape Comorin 400 miles.

13. The completion of the West Coast Canal from Cape Comorin to Karwar—400 miles.

14. The construction of a canal from Madras through the heart of the Carnatic to Ponany on the West Coast through the Palghat pass of which the canal from the Pennair would form a branch.

15. The continuation of the high level canal from the Kistna anicut south to the pennair at Nellore 200 miles.

16. The construction of the two great tanks on the Peneh and the Kanhan rivers north of Nagpur.

17. A canal from them to the Warda, near chanda, for navigation Irrigating 250,000 acres in Nagpur, and supplying water to keep the Godaveri Navigable and fill the Delta canals in the dry season.

Events have not moved in this direction, even though parts have been implemented. The reasons are obvious and well known.

Waterways, Natural or artificial, function in a variety of ways, supply the Resources necessary for Irrigation, Navigation, Power Development, Recreation Development, Pisciculture and so on; thus they play an important role in the Economic, social and cultural development of a Nation and its people. The water Resources along with Mineral, Forest and Land Resources form an integrated whole and the Developmental activities and planning have to take due note of this ESSENTIAL UNITY OF the resources. It has aptly been said that land, water and people go together. People cannot reach the highest standards of well-being unless there is wisest and integrated use of the Natural Resources, of which water is only an element. Some experiments have been made in this direction by the Tennesse Valley Authority and Domodar Valley Corporation, where the River Valley with all its resources have been treated as an organic unity and dealt with on an unified basis. Meanwhile, water Resources Planning activities themselves have evolved through the years from a single purpose project to multipurpose projects, and a project limited in scope to basin wide conception, basin wide projects to inter-basin projects inter-regional to national projects. For the time being I leave inter-national projects alone.

One important question that arises from the National point of view is the recognition of the uneven distribution of the National Resources in general and the Water Resources in particular. As pointed out, more than half of our. Water Resources are concentrated in Western Ghats and Assam-Brahmaputra regions and find their way unused to sea. At the present time, it is problematic how much quantity can be developed out of this large quantity. There are areas which are prone to frequent flood. Therefore flood control is the main concern. Then there is Indus which has become an International river with the partition of this country. We have derived the water of three eastern tributaries, Beas, Sutlej and Ravi and they are being tapped fully. Ganga in the north is also being tapped in a great measure in the main river as well as its tributaries. This basin has the advantage of a vast natural reservoir in the Snow-melt which is fully utilised for raising sucessful Rabi crops. Having tapped these winter flows, new storage projects and project Assists are being added like Ramganga and Sarada-sahyak etc. Inspite of all these, the demands are so outstipping that schemes of a bigger magnitude and lofty thinking had to be evolved and implemented expeditiously. For, there is the question of resuciating the Ragirath or Hooghly, to keep Calcutta Port alive. Then there is the issue of meeting reasonable needs of Bangaladesh. These are, in one way or the other, inter-linked as to how best we can harness the rivers like Karnali, Kosi, Teesta and other tributaries which rise in Himalayan Kingdoms which are our neighbours. Various other schemes, such as GANGA WATER MACHINE or the project of conjunctive use of surface and underground waters and underground storage of Ganges Water

system are also under consideration. There are also others like Garland Canal, etc. Perhaps for the time being they may appear as Utopian. All these and several others, which are in conceptual stage may find sufficient justification in the coming decades and next century, by which time we might have exhausted conventional methods of planning and usage.

There is very little possibility of utilising the Brahmaputra water on a large scale except through a few medium and lift Irrigation Schemes in Assam. It is roughly assessed that nearly 300 M.A. ft. of Brahmaputra waters will continue to flow annually into the Bay of Bengal. As regards the Ganga, which carries about 450 M.A ft. of water on an average, it is assessed that about 150 M.A. feet can be harnessed for irrigation. According to the present line of thinking, in view of the topography and limited opportunities for storage, the rest of its water will continue to flow into Bay of Bengal, particularly during the monsoon season,

So far as the west flowing rivers are concerned, it is feared that on account of very short distances traversed by them and the nature of the terrain, the possibilities of utilising the water for irrigation are limited. However, potentialities for east-ward diversion of west-flowing rivers must be given top priority. It will be a national waste to allow 160 out of this 200 M.A. feet to flow down to Arabian Sea without a purposeful effort to harness the rivers.

As against this background, we have to view the contemplated utilizations in the east-flowing rivers like Cauvery, Krishna, Godavari, Mahanadi, etc. These rivers are estimated to carry annually about 300 M.A. feet of water. Cauvery, with its annual run-off if 15 M.A. feet had already been committed. Krishna with its flow of 50 M.A. feet is well on the way of commitment. Then there is mighty Godavari or Dakshina Ganga, with its flow running to 70 M.A. feet. You all know, that in the early fifties, when we were in the undivided state, two gigantic projects were planned, the Kistna-pennar and the Ramapadasagar schemes. Both of them could not materialise. The conflicts that have arisen, the disputes that were raised thereafter are well known.

A careful analysis of all these differences and disputes and its impact on the national development in general and regions in particular, reveals the short comings of the past and ensures a possibility of planning the future developments on correct lines.

From a national point of view, we cannot allow any parts to suffer from Drought and Famine and other parts subjected to recurring floods, some regions suffering from excess and surplus while others due to lack of it or its deficit. It is this regional imbalance that has to be corrected and rectified. We all know, that to correct this localised imbalance, developed countries have already started moving water on large scale from places of surplus to places of deficit. Water had been moved from place to place to such an extent that the old adage, " Water is where you find it ", is giving place to *water is where you put it*. In this process, we all know, often State and Regional interests will crop up and complicate what would otherwise be simple from Engineering point of view. The past has a great lesson to teach in this context. It is of *fundamental importance to protect the existing uses as well as the assurance and insurance of the future expansion with in the basin or region before we export or attempt to transport the water elsewhere.* This cardinal principle has to be recognised, but a solution with far sighted balance has to be evolved.

Science and techonology are making great strides. Just as the magnitude of projects now being planned and constructed was beyond the dreams of the planners a few decades ago, it is quite possible that the future will demand and fructify projects on a scale and in a manner not now seriously considered. It is quite possible, that we may develop scientific techniques as to modernise the present irrigation practices, and conserve water. This is being done on a large scale in Israel and other desert areas, where every drop of water is worth more than a pearl or diamond. Conjunctive use of underground and surface water on a large scale, should reveal new potentialities. I congratulate you. You have done well in the field of exploiting underground water, having exhausted surface waters. Till now we are accustomed in terms of gravity canals. Henceforth, we may have to lift waters by several hundred feet. Coastal areas may resort to desalination, waters so released, being used in the higher contours. Who knows, we may succeed in controlling and regulating the Hydrological Cycle, by Cloud-seeding and other devices. Now that we have entered Space Age, we may develop a new technology that has well-meant control on nature. These are all possibilities of the future. Yet in the living present, we can be pragmatic and be realistic as to evolve viable schemes to utilise the available and recurrent run-off for the largest good of the largest number.

Ganga-Cauvery link.

As early as 1963, the then Union Minister for Irrigation and Power has stated in Lok Sabha that:

" One of the other main points of controversy has been the trans-basin utilisation of waters, i.e., diversion of waters from one river basin to another. Objections have been raised to the diversion of Krishna flows south-eastward. While it will be readily agreed that the people in a river valley itself should have their requirements met for the development of irrigation, we cannot afford to be so rigid, as to exclude the adjoining areas, which are equally, if not more, deficient in rainfall and water resources. In such a case, the endeavour has to be to share available supplies for the greatest good for of the greatest number. The inter-linking of rivers is some what analogous to the establishment of power gride ....But even a beginning in the direction grid diversion will enable us to form " River Grids " for the benefit of a much larger number of people........"

Most of the rivers in India flow generally in an Easterly or Westerly Direction. In view of this pattern of the river system of the country, a North-to-South link is a convenient means of connecting a number of Major River Systems. The Ganga-Cauvery link is expected to provide such a connection in the National Water Grid. This Scheme is planned for diversion of the surplus discharge in the Ganga near Patna during the high flow or flood period, allowing a minimum of 70,000 cusecs to flow downstream. It is proposed to lift up to 60,000 cusecs of waters of Ganga from a

Barrage near Patna. Out of this quantity, 10,000 cusecs are proposed to be utilized in southern Uttar Pradesh and South Bihar in Ganga Basin. Fifty thousand cusecs of water pumped for 150 days, will be transferred outside the basin to meet the water requirements of chronically drought prone areas of Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Mysore and Tamil Nadu. In this process water has to be lifted from El. 150 feet to climb Vindhyan range involving a pumping lift of 1,100 to 1,300 feet. Water conductor system follows Sone Valley up to Narmada river either to Bargi Reservoir (El. 1387) or Tilwaragha (El. 1280 feet) on Narmada. From this place, a link is established via Godavari (and its tributaries of Wainganga and Pranhita) Krishna and Pennar to Cauvery. Dropping either upstream of Mettur Reservoir or Upper Anicut on Cauvery. The different alternatives possible, envisage total pump lift of 1,000 to 2,000 feet and conveyor system along rivers and canals ranging from 1,600 miles to 2,200 miles. The expert committee of the UNDP expressed its view that the National Water Grid is a practical proposition.

In fact, a river Grid on a small-scale is already in operation in the North Western Region where the three Punjab rivers, viz., the Ravi, the Beas and the Sutlej, have been effectively inter-linked for the benefit of that region, consisting of Jammu-Kashmir, Punjab, Haryana and Rajasthan.

As components of National Water Grid, there are other components in view.

Brahmaputra Ganga Link.

Brahmaputra carries a discharge of 1.2 to 1.8 lakh cusecs even during the dry summer months and there is conceivably large surplus. A proposal for linking the two rivers Brahmaputra and Ganga envisages construction of a Diversion barrage near Dhubri on the Brahmaputra in Assam and a 200 mile long feeder or link canal tailing off upstream of Farakka Barrage on the Ganga. This link of 40,000 cusecs capacity requires hardly a 35 to 40 feet pump lift. It can provide a navigable waterway and serve Bangaladesh also.

As outlined earlier, the proposed Ganga-Cauvery link in its southward journey, had to traverse the Godavari and Krishna Valleys. Great transformation of these valleys are under way. I have already mentioned that the Krishna is well on the way of commitment. In post-independence decades, gigantic schemes have been built. The Tungabhadra sub-basin has been fully tapped by the Tunga anicut, Bhadra reservoir and Tungabhadra project. Most of the backward, drought and famine affected areas have been protected. A number of schemes on Malaprabha and Ghataprabha in Karnataka as well as Bhima and Krishna in Maharashtra are also under-way. There is the Upper Krishna Project, which is under construction. Down below, the river Krishna enters a gorge and emerges near the head of the delta. The Srisailam Hydro-Electric Project is under construction, while the Nagarjunasagar Dam is already completed. Sharing of Krishna waters had been a matter of dispute since 1956 States Reorganisation, and the Krishna Waters Dispute Tribunal had given its verdict and fixed the quantum that each State is entitled to.

On the Godavari river, the development had in the past been slow, but it is expected that the pace of development hereafter will be rapid. The sharing of Godavari Waters was also a matter of dispute and the matter is before the Godavari Waters Dispute Tribunal. As the process of adjudication by tribunals is necessarily time-consuming, the States concerned under the guidance of the Central Government have thought it fit to enter into an interim accord. This is one of the important developments in recent times in regard to water resources development. *Inter alia,* the State of Andhra Pradesh agree Maharashtra utilising all waters upstream of Jaikwadi while Andhra Pradesh is permitted to utilise the balance waters in its Pochampad Project. As you all know, this project with its P.R.L. 1093 is so situated that it commands quite a substantial area right up to Cape Comorin. But it is ironical that nature has not bestowed sufficient water resources to serve the purpose. However, about 1.5 million acres are proposed to be irrigated under this comprehensive scheme. It is needless that this project occupies a premier position in the Ganga-Cauvery link. It is a question of finding enough water. It is yet to be seen, how much water can be transported from Ganga or elsewhere and if so, when it is going to take place. Another notable feature of the agreement is that the States of Maharashtra, Madhya Pradesh and Orissa can utilise 200 T.M. C.ft. from Godavari and its tributaries downstream of Pochampad dam site for their new projects. The States of Andhra Pradesh, Maharashtra and Madhya Pradesh have agreed in principle for taking up of the Inchampalli project with F.R.L. that is yet to be agreed upon. Andhra Pradesh has proposed a storage at Inchampalli with F.R.L. 390.00 with a gross storage of 550 T.M. C.ft. It is ideally situated below the confluence of Pranhita and Indravati, which contribute 50 per cent of the run-off of the Godavari system This reservoir forms the King Pin of the Godavari Valley Development. The regulated releases can generate 100 M.Ws. of power and Irrigate 4.5 million acres of land. It is again a twist of fate or nature that the level here is so low that it cannot command more extensive areas like Pochampad. Any way, this project also figures in Ganga-Cauvery link.

It is also premature to envisage what the likely develppments would be. But these gigantic projects on Godavari and Krishna have a key role to play in the lives of the people of this region and are National Projects by themselves. It is our good fortune that our generation is lucky enough to formulate and implement these projects. Their potentialities for a glorious future for the region in particular and nation in general are immense, and hence all efforts should be made to complete them as expeditiously as possible.

In passing I may mention that in a relatively short time, the Krishna water is to be available in Madras along with a component of Pennar Water for drinking water purposes.

Trans basin developments in U.S.S.R.

The Soviet Union is the largest country in the world and occupies almost a *sixth* of the inhabited earth, covering an area of 8 M. Sq. miles or 5,000 million acres. Of this, only 400 M. acres in cultivated. The

Soviet Union possesses abundant Water and Water Power Resources. The average annual run off is 3,500 M.A. feet. But over 80 per cent of it is discharged by sparsely populated Siberian rivers. The total Hydel Power potential of these rivers is estimated to be 3,500 Billion K.W. Hrs. Great developments have taken place during the last four or five decades and some of the features is worthy of emulation by developing countries. Volga is the most developed. Waterway in U.S.S.R. It is 2,300 miles long and falls into the Gaspian Sea, the largest inland lake covering as area of 1,30,000 Sq. Mls. Volga trains nearly 8,40,000 Sq. Mls. and annually carries 200 M.A. feet of water which equals the combined flow of all our Eastern rivers of the Deccan plateau up to Mahanadi. Kama is its Chief tributary. Perm, Votinsk and Lower Kama on the Kama; Invankovo, Uglicj Rybinsk Gorki, Cheboksary, Baratov, Kuibyshev, Stalingrad and Lower Volga Hydro technical constructions on Volga harness about 600 feet head along the river by a cascade of Dams. The reservoirs so formed have 130 M.A. feet storage capacity, out of which only a little more than a quarter of this capacity need be used. The installed capacity of the Hydel stations is about 12 M.K. Ws. generating annually 50 B.K.W. Hrs. of energy. The structures involves 500 M. Cyds of earthwork, Earth-filling of 600 M. Cyds. 35 M. Cyds of concrete and R.C.C. and 5 lakh tons of structure and steel equipment. The storage lakes submerge about 12,000 Sq. Mls. or 7½ M. acres. Creation of these works, provided a 2,500 mile long and 10 feet deep waterway for navigation. The length of navigable reaches of various drafts is 12,000 miles. Motor cargoes and Towing vessels of 400 H.P. capacity and Cargo ships and Oil tankers constantly ply the river system up and down. Nearly 100 to 125 million tons of cargo is carried by the fleet in the Volga-Kama system and efforts are being made to increase it by 50 per cent. Volumes can be written about these developments; suffice is to say for the present, that Volga is the Life-line of U.S.S.R. and similar developments are going on, on Angara on Yensei and other Siberian rivers.

One of the peculiarities of U.S.S.R. is the Aral-Caspian basin, which has no outlets and covers nearly 23 per cent of the entire U.S.S.R. Due to various developments, since 1929. Caspian Sea level is swiftly dropping. This drop is expected to increase as the years pass by due to Irrigation abstractions, and other changes in the Hydro-Regime of this vast area. Russians consider that there is only one way of dealing with this problem, and that is to divert from adjacent basins, part of the peripheral flow which is at present wasted, into the open sea in the North. The annual discharge of the Pechora, the Northern Dwina and the Onega, which take off quite close to the Kamal and Sheskana tributaries of Volga but on the other side of the Dividing ridge, carry annually 175 M.A. feet of water. Three Hydro Reservoirs on these streams covering 8,600 Sq. miles of water-spread with necessary diversion channels, permit diversion and thus augment the flow of Volga system to balance the abstractions.

There is also another long range plan which aims at diversion of the surplus flows of the Yensei, Ob and other Siberian rivers to the Desert and Arid areas of the Amu-Darya and Syr-Darya basins of the Arab Basin. These two rivers carry as much as the flow of Krishna and they are fully harnessed by Kara-Kum, Kizhl Kum canals and other works. This mammoth scheme envisages stage development. The first stage of the plan allows for the diversion of some 35 M.A. feet of water annually to the lower reaches of the Amu Darya and Syr-Darya. It would increase the irrigated areas of the region to 52 million acres. During the second stage, the irrigated areas would expand to 80 million acres taking in western Turkmenia and the north of the Aral Sea. 25 M. acres would be fed by local water resources and 55 M. across by the Siberian rivers. Finally, the irrigated area will be expanded to 85 M. across by including the middle reaches of the Amu Darya. The waters have to travel thousands of miles enroute crossing the Turgai Mountain ridge, from the confluence of Angara and the Yensei. It is expected that Ob and Yensi can spare about 60 to 65 M.A. feet of water to the Aral-Caspian basin. It is proposed to be diverted, as already discussed in three stages. Giant canals and matching dams, vast reservoirs and Giant Hydel stations and pumping stations will be built. The flow ensured is about 1 lakh cusecs. The canal is 2,000 miles long, 1,200 feet wide and 40 to 50 feet deep—an unprecedented canal structure. Nature has earlier in geological times built rivers of this order and magnitude and now chance is given to man to plan and build such large waterways. "Re-shaping the land" "Re-distribution of River Flow" "Anti Rivers". It is these new terminology that the Russians proudly use these days, "All these operations are so spectacular that it will hardly be possible to carry them out within the life time of one generation. We are launching a Scheme that will be completed by our Descendents" they proudly say.

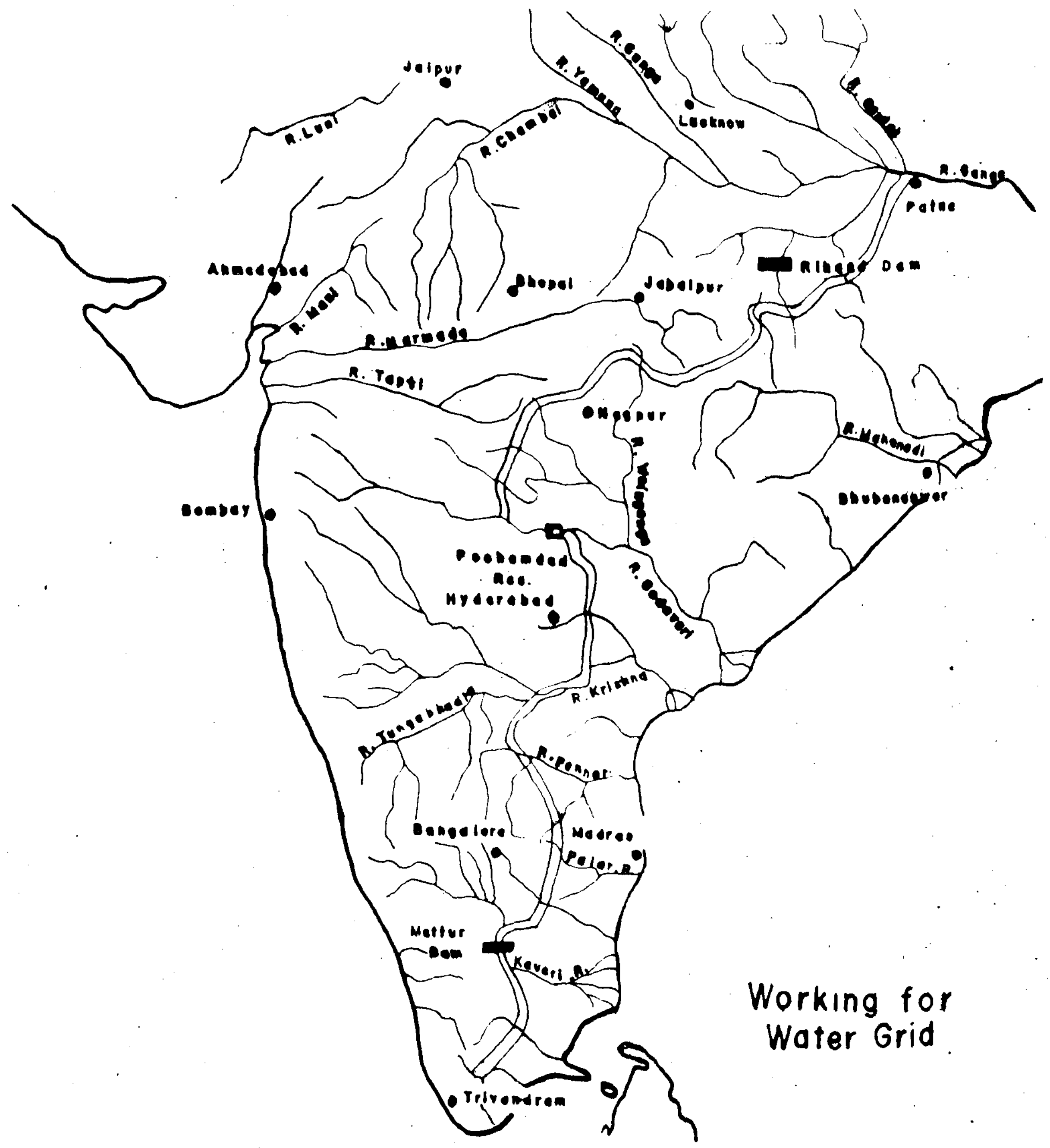
In our country there is an adage, "well-begun is half done". Let us also think in a big way and plan for a Glorious Future for our motherland". Let the poet's song

सुजलां सुफलां मलयज शीतलां
सस्य श्यामलाम्।

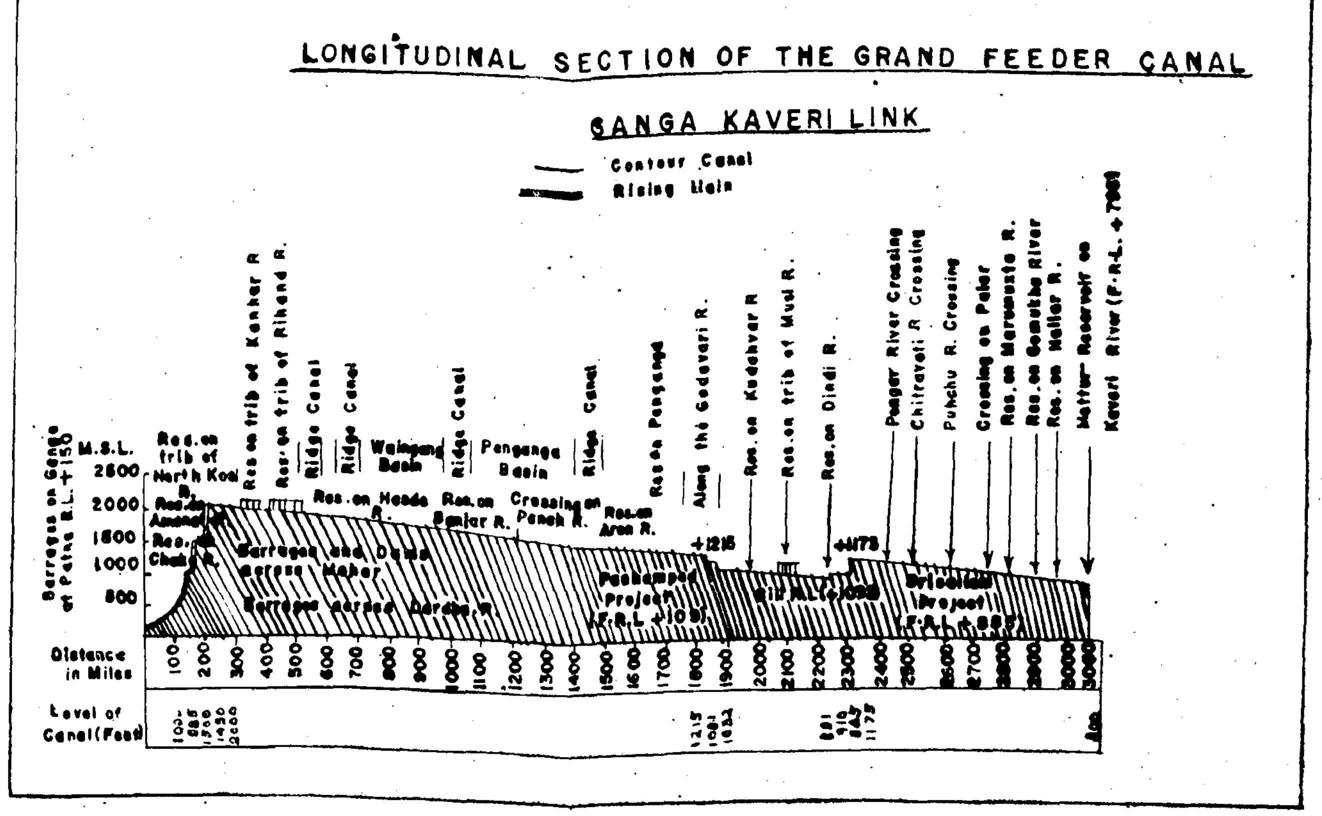
"Sujalam, Suphalam, Malayaja Sithalam, Sasya Shymalam" come true. Let the song of Unity:

Gangecha Yamunechaiya (Krishna) Godavari Saraswati Narmada Sindhu, Kaveri, Jaleshmin and Sannidhimkuru.

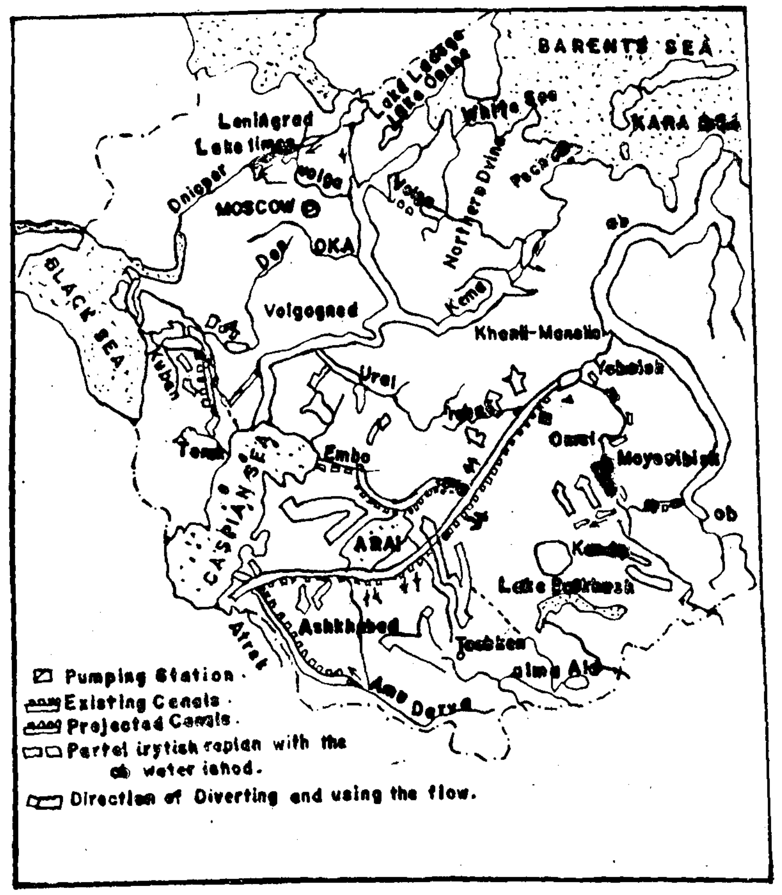
गंगेच, यमुनाचैव (कृष्णा) गोदावरी
सरस्वती नर्मदे, सिंधु, कावेरी,
जलास्मीन, सन्निधिम, कुरु
....

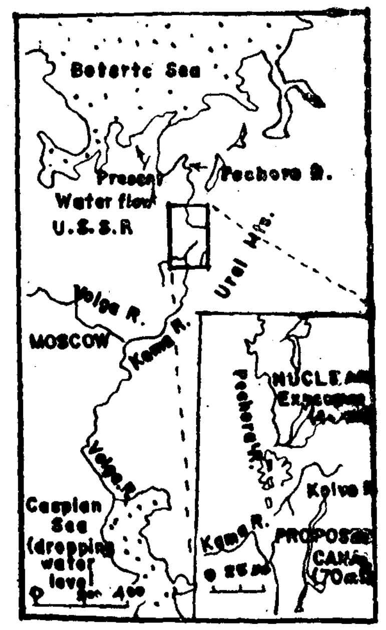


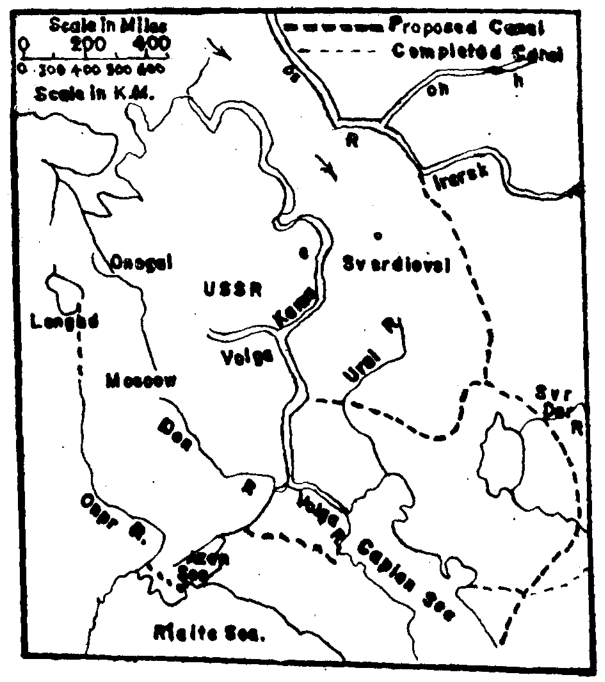
Working for Water Grid



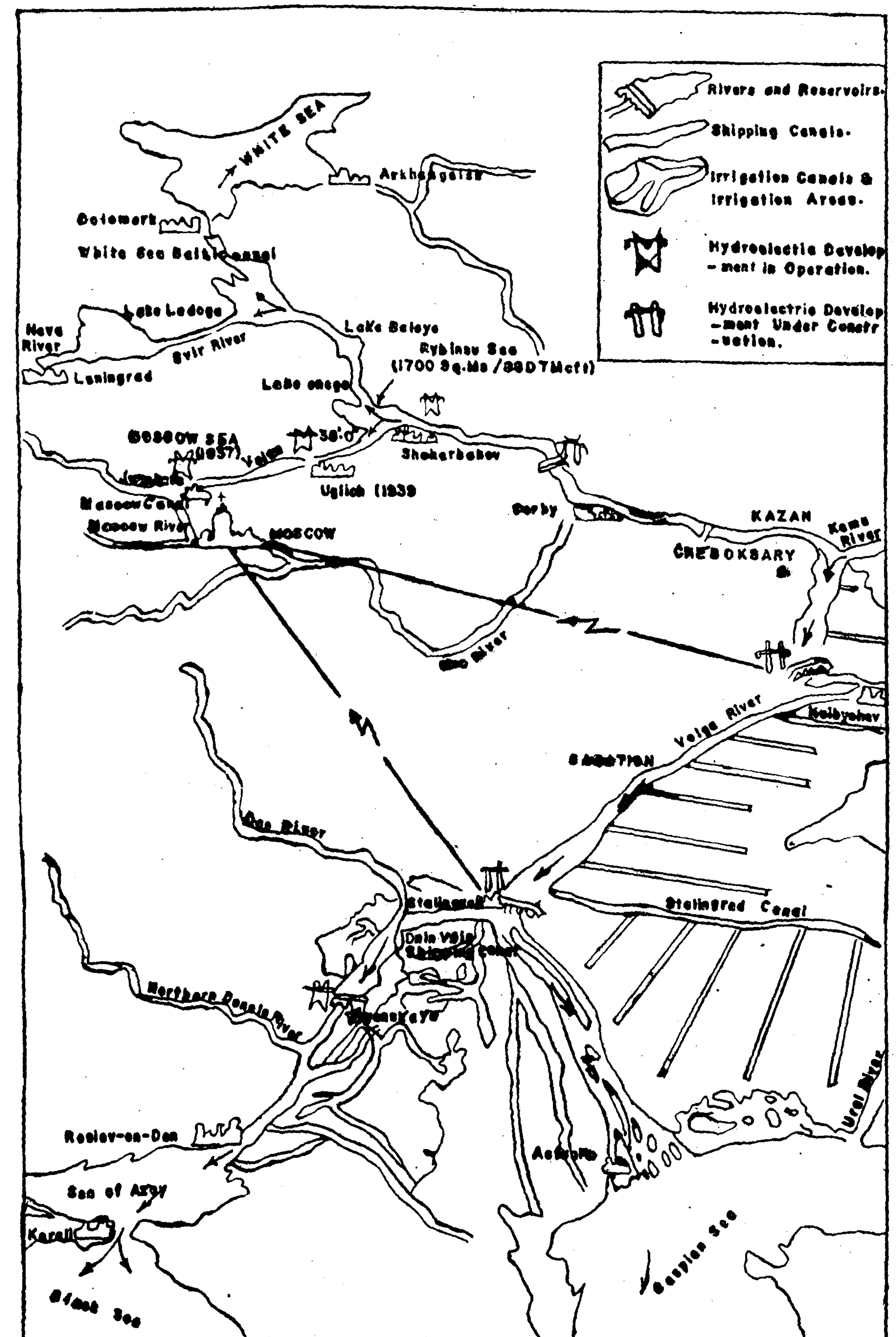
SKETCH MAP OF GRAND FEEDER CANAL
GANGA KAVERI LINK







RIVER REVERSAL



VOLGA WATERWAY

Distinguished gathering attending the Lecture delivered by Er. R. Gopalakrishnamurthy, Chief Engineer, Irrigation and Power (Retd.) Andhra Pradesh on the eve of the Bharathrathna Dr. M. Visweswaraiyya Fifth Memorial Lecture Conducted on 25-10-1976.