Application of streamflow synthesis and reservoir regulation —“SSARR”— Program to the Lower Mekong River

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SUMMARY: This paper has presented the general concepts of the SSARR program, together with highlights of its application to the Mekong River Hydrologic and Reservoir Regulation analyses. The program provides the framework for many future studies of hydrologic analyses of the Mekong River.

RÉSUMÉ : Cette communication présente les concepts généraux du programme SSARR ainsi que les points principaux de leur application dans l'analyse de l'hydrologie du Mékong et de sa régulation par réservoirs. Le programme fournit les bases des études futures des analyses hydrologiques du Mékong.

INTRODUCTION

GENERAL

Early in the consideration of inaugurating a program in Computer Application to System Analysis of the Lower Mekong River, it was recognized that the question of availability of basic data for making studies and analyses was fundamental. One of the major deficiencies in basic data was that of streamflow data with sufficient length of record to constitute an adequate sample for project analysis. It was further recognized that a generalized approach to hydrologic analysis for developing rainfall-runoff relationships, streamflow routings, design flood determinations, reservoir regulation studies, and streamflow forecasting techniques, using computer techniques, would be an important adjunct to the systems analysis training. Accordingly, when Messrs. Nelson and Lewis recommended establishing the training program in system analysis [1], one of the important elements in their recommendation was that of a program of streamflow synthesis. The hydrologic phase of the training was instituted not only for the purpose of training Mekong River engineers in the techniques of streamflow analysis by computer, but also to perform hydrologic analyses of specific river basin in the Mekong drainage for deriving extended periods (15 to 20 years) of streamflow records synthetically from available rainfall data. Such analyses could also be used for deriving design floods, and for various types of flow routing and reservoir regulation studies.

PURPOSE AND SCOPE

The purpose of this paper is to present the general concepts in the development of the “SSAR” Program, computer utilization, illustrative examples of streamflow synthesis in the Lower Mekong Basin, and a discussion of areas of application to hydrologic engineering. It is the intent to present the basic philosophy and use of the “SSARR” Program, without presenting details of the computer program itself.
HISTORICAL DEVELOPMENT OF "SSARR" PROGRAM

The original version of the "SSARR" program presented herein was developed for the IBM 650 computer in 1957, for synthesizing streamflow in the Columbia River Basin. This program was described in the transactions of the American Society of Civil Engineers [2], and was designed specifically for conditions in the Columbia River in Northwest United States. It was developed primarily for simulating snowmelt runoff, and it was used operationally for forecasting streamflow in the Columbia River during the high flow period, as well as for developing design floods for reservoir projects in the area. From experience gained from actual use, further development was initiated early in 1960 to expand upon the program logic, both with regard to hydrologic techniques and machine utilization. This "second generation" development culminated in Computer Program 24.J3.H001, designed for use on the IBM 1920 computer system installed in the North Pacific Division Office of the Corps of Engineers. This program is described in a Corps of Engineers Technical Bulletin [3], and was designed as a general streamflow synthesis model which could be applied to any drainage basin, with no limitation as to basin configuration, hydrologic regime or reservoir system. The program was used extensively for streamflow forecasting, reservoir regulation, design flood studies, and flood regulation studies in the Pacific Northwest of the United States, as well as for streams in Alaska and Canada. It was applied to both rain and snowmelt runoff areas, and, in connection with the Mekong River Systems Analysis training program, it was applied to the Mekong River tributaries.

The computer program described herein is a "third generation" program for streamflow synthesis. It is designed as a hydrologic and reservoir regulation model with application to a much wider range of conditions than the previous version, and it has greatly expanded logic for simulating hydrologic processes, channel routing techniques, and reservoir regulation methods. It is designed to be completely flexible in its ability to represent physical relationships by use of multi-variable relationships in the form of "pre-digested" tables. Such relationships may be linear or curvilinear, derived either from observed or measured physical data or from general functions utilizing empirical coefficients, to synthesize natural conditions of streamflow. For synthesizing the regulation of streamflow by reservoirs, the program may be used to simulate the particular storage and flow conditions for a project as designed or constructed, and the regulation of flow may be specified under various conditions or operating rules, to meet reservoir functional water use requirements.

TRAINING PROGRAM FOR MEKONG RIVER ENGINEERS

The training program on Computer Application to System Analysis, Lower Mekong River, was carried out by the North Pacific Division Office, U.S. Corps of Engineers, during the 18 month period November 1965 through May 1967. Phase I of training program was devoted primarily to hydrologic analysis by computer, and four engineers were assigned, who not only were trained in the application of the SSARR program to the Mekong River, but also conducted countless studies to best define the runoff characteristics of the Mekong drainages. Direct supervision of their work was carried out by Mr. James A. Anderson, Hydraulic Engineer, North Pacific Division Office, U.S. Corps of Engineers, under the general guidance of the author. Preliminary illustrative examples of application of the SSARR program to the Mekong River are contained in a report by Anderson [4]
HYDROLOGIC ENGINEERING CONCEPTS USED IN "SSARR" PROGRAM

GENERAL CONCEPTS

The "SSARR" program is designed to create a mathematical hydrologic model of a river system through use of an electronic digital computer. Streamflows can be synthesized by evaluating the entire hydrologic process of snowmelt and/or rainfall runoff for all significant points throughout a river system.

Drainage basins can be separated into homogeneous hydrologic units of a size and character which can be used as a logical delineation of a major drainage into its component subdrainages. Channel storage can be specified for channel reaches to represent the natural delay to runoff encountered in a complex river system. Storage effects of lakes or man made reservoirs can be evaluated in accordance with free-flow conditions or specified conditions of reservoir storages or withdrawals. Streamflows can be thus developed for all key locations on the main stem and tributary rivers.

The program combines evaluation of various hydrometeorological functions to represent the entire process of streamflow simulation, as described by the standard conceptual model of the hydrologic cycle. It is designed to be completely general in nature, so that streamflow may be synthesized by adjusting the various parameters for a particular drainage basin that affect the evaluation of moisture input (either rainfall or snowmelt); soil moisture; evapotranspiration; depression storage; surface, subsurface, and ground water storage; infiltration to each of the aquifer zones; time delay represented by storage and flow relationships in each zone, and channel storage effects. When these parameters are evaluated for a given basin, they represent the calibration of a particular area or homogeneous unit.

BASIN SUBDIVISIONS

The streamflow may be synthesized digitally from the basin hydrologic model for a series of basin subdivisions. Each sub-basin may be individually represented by its particular set of coefficients and relationships, and there is no limit to the number of such subdivisions that may be made. The computed discharge from all basin subdivisions represent the inputs to the river channel system, through which the inflows are routed and combined to represent the total flow at all specified or desired key streamflow stations or control points. Within the river system, the locations of dams, reservoirs, or lakes may be specified, through which the streamflow may be routed, or operated upon according to particular operating conditions. Diversions from river channels may be accounted for and losses from the stream channels by natural overbank flow into adjacent drainages may be synthesized.

TIME PERIODS

The basic solution of all flow functions are computed as the solution of differential equations successively in small finite time increments. The incremental time period for routing is completely general and it can be specified as desired in a particular case. In general, the time period would vary from three hours to one day. The incremental time period can be varied during the course of a particular run. Input values of hydrometeorologic variables represent any desired time increment for which output data are required. The program is designed to synthesize streamflow in small time increments for whatever total duration of time desired, depending upon the type of study involved. For example, the synthesis may be carried out for representing streamflow variation for a period of a year or more for basin hydrology studies and for streamflow simulations for synthesizing streamflow records from precipitation or snowmelt records. Streamflows
for design floods or for forecasting may be synthesized for a total duration as short as a few days, up to several months in duration.

**TIME VARIABLE DATA**

Hydrometeorological data upon which the program operates are supplied in a number of forms, in order to provide competely flexible methods for handling the large amount of data generally required for parametric simulation. These data may be precipitation records recorded as daily or period values, daily air temperatures, or daily values of hydrometeorological variables affecting snowmelt.

**INITIAL CONDITIONS DATA**

In order to operate the program, it is necessary to provide "initial conditions data" which represent the time, $t_0$, conditions of all time-variable functions. These conditions are provided by special cards for accomplishing this requirement. Thus, the synthesis may be started at any desired point in time, regardless of the hydrologic conditions. Furthermore, provision is made for adjusting the initial conditions data from previously computed values to observed condition at a particular point in time. This feature is necessary for operation of the model in streamflow forecasting on a day-to-day basis.

**ENGLISH AND METRIC UNITS**

The program is designed to be used with either English or metric units. The basic units are rainfall in inches or centimeters, streamflow in cubic feet per second or cubic meters per second, and storage in acre-feet or thousands of cubic meters.

**USES**

The program as designed and developed may be used for any study involving computation of streamflows in a complex river basin, resulting from snowmelt and/or rainfall. In engineering practice, it may be used for design flood studies, reservoir regulation studies, streamflow forecasting, or operational reservoir regulation use. It may also be used to extend short period streamflow data to longer periods, on the basis of known precipitation or snowmelt conditions. Basic studies to determine snowmelt rates, rainfall-runoff relationships, and basin storage characteristics may be developed by use of this program, by trial and error processes through reconstitution studies.

**BASIN RAINFALL-RUNOFF DETERMINATION**

The hydrologic use of the "SSARR" program is primarily in the development of the basin watershed runoff model, which incorporates, rainfall-runoff relationships and simulation of all significant factors in the hydrologic cycle. This paper is limited to discussion only of the simulation of streamflow resulting from rainfall, and while the program incorporates snowmelt runoff evaluation, this segment of the program is not utilized in the Mekong River studies.

The hydrologic model utilized in the "SSARR" program considers the following basic hydrologic elements to be evaluated individually for each relatively homogeneous sub-basin area:

1. **Net Basin Precipitation**, determined as a time variable weighted mean period value of precipitation (after interception) from observed point values or estimated basin values.

2. **Soil Moisture Increase**, determined as a time-variable index of runoff effectiveness to represent the varying conditions of soil moisture which results in a "permanent" loss of precipitation to runoff.
supervision of the Training Program in System Analysis was by Mr. Mark L. Nelson, Chief, Water Control Branch, North Pacific Division Office of the Corps of Engineers, who provided leadership in program development by emphasizing the need for computer simulation techniques for river system analysis. Much credit in the development of the SSARR program is due to Mr. Edward M. Davis, Mathematician and Computer System Analyst, North Pacific Division Office of the Corps of Engineers, who, through his initiative and capability in applying advanced data processing techniques, has been largely responsible for the methods of computer utilization in providing an efficient and workable program.

The development of the present SSARR model was done in collaboration with Messrs. Vail P. Schermerhorn and Donald W. Kuehl of the Portland River Forecast Center, ESSA, U.S. Weather Bureau. Funds for programming the SSARR model were provided in part by the U.S. Agency for International Development.
PERIOD DISTRIBUTION

Each day is divided into eight periods, and the percent of the daily rain in each period is specified by supplying normal or specified distributions for periods within a day. The weighted precipitation per period is then found as follows:

\[ WP = P_d \times DIST \]  

where:

- \( WP \) Weighted precipitation for a given period, in centimeters.
- \( DIST \) The distribution of the daily rainfall for that period, in percent.

It is not necessary to route in 3-hour periods, but the total daily distributions must equal 100%.

SOIL MOISTURE INDEX, EVAPOTRANSPIRATION INDEX, AND RUNOFF EXCESS

The percent of total input for the period available for surface, subsurface and base flow runoff is found from empirically derived relationships of Runoff Percent (ROP) versus Soil Moisture Index (SMI). For a particular basin, this relationship is given to the computer in the form of a table. The total generated runoff per period (RGP) is computed as follows:

\[ RGP = ROP \times WP \]  

where:

- \( RGP \) Generated runoff for the period (in centimeters).
- \( ROP \) Runoff percent.
- \( WP \) Weighted precipitation for the period (in centimeters).

The soil moisture index (SMI) is a measure of the relative soil wetness used to determine runoff. When the soil moisture is depleted to the permanent wilting point, the value of the SMI is considered to be zero. When precipitation recharges soil moisture, the value of the SMI increases until it reaches a maximum value considered to represent its field capacity. This SMI value is calculated at the end of each period as follows:

\[ SMI_2 = SMI_1 + (WP - RGP) - \left[ \frac{PH}{24} \times KE \times ETI \right] \]  

where:

- \( SMI_1 \) Soil moisture index, in cm, at beginning of period.
- \( SMI_2 \) Soil moisture index, in cm, at end of period.
- \( PH \) Period length in hours.
- \( ETI \) Evapotranspiration index, in cm per day.
- \( KE \) A factor for reducing ETI on rainy days, specified to the computer in a table of KE versus rate of precipitation in centimeters per day.

For zero precipitation, \( KE \) is 1.0 and SMI will be reduced during the period by the constant factor \( PH/24 \times ETI \). When the rainfall not contributing to runoff exceeds the adjusted evapotranspiration factor, the soil moisture index will increase. The evapotranspiration index, \( ETI \), is specified as the daily potential evapotranspiration, expressed on a mean monthly basis.

BASE FLOW

That portion of the runoff excess contributing to the base flow component is a function of the base flow infiltration index, \( BII \). A relationship is provided to the computer as a continuous function in the form of a table, to express the percent contribution of the
runoff excess to base flow ($BFP$), as related to the $BII$. The base flow infiltration index computed for each period is as follows:

$$BII_2 = BII_1 + (24 \times RGP - BII_1) \times \frac{PH}{TSBII + PH/2}$$

(6)

where:

$BII_1$ Base Flow Infiltration index, in centimeters per 24 hours, at beginning of period.
$BII_2$ Base Flow Infiltration index, in centimeters per 24 hours, at end of period.
$RGP$ Runoff rate in centimeters per hour.
$PH$ Time delay, $T_s$ (time of storage), for calculation of change of $BII$.

$BII$ may be thought of as an index of depression storage, holding runoff available for deep percolation. The base flow component is computed as the product of the $BFP$ and $RGP$. The input to surface and subsurface runoff ($RGS$) is computed as follows:

$$RGS = RGP \times (1.0 - BFP)$$

(7)

**SURFACE - SUBSURFACE FLOW SEPARATION**

A table of surface runoff input ($RS$) versus total input to surface and subsurface runoff ($RGS$) is specified to the computer for a particular basin. Any relationship may be specified in the table, but the separation commonly used is bases on the following assumptions:

1. The minimum surface component ($RS$) is 10% of the total ($RGS$).
2. The subsurface flow component reaches a maximum ($KSS$) and remains constant for input rates ($RGS$) above 200% of $KSS$.
3. Values commonly used are determined from the following equations:

$$RS = [0.1 + 0.2 \times (RGS/KSS)] \times RGS$$

and:

$$IF RS < KSS, \quad RSS = RGS - RS$$

$$IF RS > KSS, \quad RSS = KSS, \quad and \quad RS = RGS - RSS$$

where:

$RS$ Surface component input rate, in cm/hr.
$RGS$ Total input rate to surface and subsurface components, in cm/hr.
$KSS$ Maximum subsurface input rate, in cm/hr.

**ROUTING OF SURFACE, SUBSURFACE AND BASE FLOW**

Each of the components of runoff excess inputs to surface, subsurface, and base flow are computed as input rates, expressed in cm per period. Each period value is converted to the equivalent inflow rate, in cubic meters per second, based on the drainage area and the length of the period, in hours. Each of the computed component inflows and routed through basin storage, by incremental storage routing, as described in Technical Bulletin 22 [3]. The following diagram illustrates schematically the principle of basin storage routing:

The modification of the inflow to represent the shape of the outflow hydrograph is determined by the number of increments, and time of storage per increment. Routing is
accomplished in solutions of the basic storage equation in finite time increments, as a continuous function, for each increment of storage routing. Generally, three to five increments are used in typical drainage basins. The “time of storage” per increment can be from a few hours to a month or more. Virtually unlimited flexibility in time distribution of runoff can be achieved by the incremental storage routing technique. This type of storage is used to convert basin inflows to an outflow hydrograph, computed as the sum of the surface, subsurface and base flow components. The number of increments and time of storage per increment are specified individually for routing each of the three flow components, and these values are specified individually by sub-basin areas.

DERIVATION OF BASIN CHARACTERISTICS

The use of the “SSARR” program in synthesizing streamflow from rainfall or snowmelt is dependent upon deriving the various coefficients and relationships specific to a particular drainage basin, as discussed in the preceding paragraphs. Some of the relationships are general, and are therefore applicable to many sub-basins within a major drainage. Others are specifically derived for a particular sub-basin area.

A basic concept in the derivation of basin runoff characteristic is the use of the computer program itself in performing repetitive trial-and-error solutions, to obtain the best fit of historic streamflow data. Many of the characteristics are known within certain limits from general knowledge and experience with the use program. With such knowledge, an initial attempt at synthesizing a particular year’s record will reveal differences in computed and observed streamflows, which will form the basis for adjusting the parameters in subsequent runs. This procedure is repeated until an adequate verification of observed flows is obtained, and tested upon independent data. This can be considered analogous to calibrating a hydraulic model by adjusting the channel roughness characteristic. In hydrologic simulation, this basic approach of trial-and-error techniques of model verification would be impractical without the use of a digital computer. Also, it should be
pointed out that the efficiency of carrying out adjustment procedures is dependent upon
the judgment and skill of the engineer, in evaluating the inter-actions of the various
parameters. Conversely, the knowledge that the engineer gains in evaluating successive
trials in verification studies can add significantly to the overall understanding of basin
hydrologic characteristics.

The ranges of some of the values are known from experiments and analyses carried out
under so-called "Scientific hydrology" programs. Soil moisture capacities and potential
evapotranspiration rates are known within certain limits. The relationships between
measured point precipitation and mean net basin precipitation are fairly well defined
when there are adequate data. In nearly all studies of relatively large basin areas, however,
(1,000 to 10,000 square kilometers or more), the density of precipitation gages is generally
completely inadequate to define rigorously the precipitation over the area. For this
reason, the precipitation term in most applications of the SSARR program is more nearly
an index of basin precipitation. In a similar sense, the definition of the three aquifers
(surface, subsurface, and ground water zones) is not ammenable to physical measurement,
with regard to either flow or storage of water. Conceptually, however, if this flow
separation helps to explain the variations in flow rates from basin storage which are
known to occur. In using the SSARR program, the separation of the flow into its
components is necessary based on arbitrarily chosen functions. It can be shown that such
functions improve the verification of the model. The storage times \(T_s\) values for routing
are also necessarily empirical in nature. Just as in the case of unit hydrograph analyses,
the development of basin storage characteristics are usually based on trial-and-error
procedures.

In summary, the following are the various functions and elements that require definition
to represent streamflow in the basin hydrologic model:

1. Precipitation stations and relative weighting factors for each, to represent basin
rainfall.
2. Soil moisture index \((SMI)\) vs Runoff percent \((ROP)\), expressed as a two-variable
function, in the form of a table.
3. Evapotranspiration Index, \(ETI\), expressed as a mean potential evapotranspiration
in cm per day, in the form of a table of amounts vs month-of-year.
4. Evapotranspiration effectiveness factor, \(KE\), expressed as a function of precipitation
rate, in the form of a table.
5. Base flow Infiltration Index \((BII)\) vs Base Inflow Percentage \((BFP)\), expressed as a
two-variable function in the form of a table.
6. Base flow Infiltration Time-of-storage Delay factor \((TSBII)\), expressed as a single
value, in hours.
7. Surface, subsurface flow separation relationship, expressed as a two-variable
function relating the surface flow input rate to total surface and subsurface input rate,
in the form of a table.
These are expressed as: (a) the number of routing increments (not to exceed eight),
and \(b\) the time of storage \(T_s\) per increment, expressed in hours, for each component of
flow.

It is not within the scope of this paper to discuss the methods used in defining each
element, in a generalized manner. Reference is made to a publication on Generalized
Basin Runoff Characteristics in the SSARR Program [5] developed and written by
Mr. Bolovong Tanovan, Ing. Civil, EPL, a phase I trainee of the Mekong Study Group.
His study indicates the effect of varying the relationship of each element, individually,
on a hypothetical 3600 square kilometer drainage. In connection with the systems analysis training of the program carried out in the North Pacific Division Office of the Corps of Engineers, Basin Characteristics were developed for about 15 tributaries in the Lower Mekong River.

CHANNEL ROUTING

The application of the basic storage equation, in the SSARR program for routing non steady flow through river channels, which applies the law of continuity, is by successive finite storage routings through non-linear reservoirs. This concept is explained in the previously referenced publications [2, 3].

BASIC ROUTING METHOD

The basic routing method relies on solution of the general storage equation:

\[ I_t = O_t + \frac{dS}{dt} \]  \hspace{1cm} (8)

in which \( I_t \) and \( O_t \) are inflow and outflow, respectively, in cubic feet per second, and \( dS/dt \) is the rate of change of storage at time, \( t \). For cases where storage is a function of outflow (as in natural lakes, or for channel storage for short reaches where wedge storage is negligible in comparison with prismatic storage),

\[ S = T_s O \]  \hspace{1cm} (9)

in which \( T_s \) is the proportionality factor between storage and outflow. Differentiating equation \((S = T_s O)\) with respect to time:

\[ \frac{dS}{dt} = T_s \left( \frac{dO}{dt} \right) \]  \hspace{1cm} (10)

Substituting this expression, it becomes:

\[ I_t = O_t + T_s \left( \frac{dO}{dt} \right) \]  \hspace{1cm} (11)

or:

\[ \frac{dO}{dt} = \frac{I_t - O_t}{T_s} \]  \hspace{1cm} (12)

which represents the basic form of the storage equation used in this method. For natural lakes or river channels, the value of \( T_s \) is not constant, but it can be evaluated from the storage and outflow characteristics. This can be done by evaluating the differential of equation 9 with respect to \( h \):

\[ T_s = \frac{dS/dh}{dO/dh} \]  \hspace{1cm} (13)

in which \( T_s \) for a given elevation, \( h \), is given in units of time, \( dS/dh \), represents the slope of the storage-elevation curve, and \( dO/dh \) is the slope of the discharge-elevation curve at elevation, \( h \). From equation 11 it can be shown that with zero inflow, the outflow recession is in the form in which

\[ O_t = O_0 e^{-t/T_s} \]  \hspace{1cm} (14)

\( O_0 \) is the initial outflow at time, \( t = 0 \), \( O_t \) is the outflow at time, \( t \), and \( T_s \) is the proportionality constant previously defined, corresponding to the value of \( O_t \). Equation 14 is the typical decay-type function characteristic of streamflow recession, but with a varying recession coefficient for this method.
In application to natural lakes or reservoirs, equation 8 may be used in the program in small finite increments of time, as shown schematically in figure 2.

![Diagram of lake storage evaluation](image)

**Figure 2. Lake storage evaluation**

The same general equation may be applied to channel storage by reducing the length of the channel reach to the point where "wedge" storage is negligibly small in comparison with "prismatic" storage. By successive routings through many small increments of reservoir-type storage, the time delay from channel storage can be evaluated as shown in figure 3.

In the "SSARR" program, the ability to vary the storage time, $T_s$, with discharge, is accomplished by use of the equation:

$$T_s = \frac{KTS}{Q^n}$$  \hspace{1cm} (15)

where:

- $T_s$ The time of storage for the particular routing increment, in hours.
- $KTS$ Coefficient representing the time delay for a particular routing reach.
- $Q$ Discharge at beginning of period, in cubic meters per second.
- $n$ A coefficient relating the time of storage variation as a function of discharge.

In the Columbia Basin it has been found that time of storage varies inversely with discharge in cubic feet per second approximately to the 0.2 power, ($n = .2$). Preliminary studies in the Mekong indicate the $n$ value to be about 0.4. The total time of storage for a reach may be estimated from physical characteristics of the channel or examination of hydrographs.
NUMBER OF INCREMENTS

The increments may be thought of as representing a series of small reservoirs where the "wedge" storage is small in comparison with "prismatic" storage. Good results were obtained in the Columbia Basin by dividing the reach into increments of about 5 miles and in the Mekong about 10 kilometers.

DETERMINATION OF CHANNEL STORAGE COEFFICIENTS

Coefficients for the channel storage routing in the SSARR program may be determined empirically from streamflow data, or from physical data, where sufficient information is available for defining storage and rate of flow variation with elevation under steady-state conditions for individual segments of the river channel. The $T_i$ variation can be evaluated from physical data by solution of the general equation (13).

ROUTING STREAMFLOW WITH BACKWATER EFFECTS

Normally, the channel routing is solved in the SSARR program for conditions where there is no appreciable variable downstream backwater effect. This, in effect, is based on conditions where there is an unique relationship between river stage and discharge at any location along the river channel. There are cases, however, when discharge is variably affected by river elevations at more than one location. This condition is termed as a variable backwater effect. Examples of such occurrences in river hydraulics are normally in the upper reaches of reservoirs, in river channels immediately upstream from the confluence of a major tributary, and in river estuaries where there are tidal variations in water surface elevations. For cases where backwater effects prevail, in a particular river reach the SSARR program provide for a three-variable relationship between elevation and discharge, for routing streamflow.
The three-variable relationships of discharge can be expressed in the following general forms:

\[ Q_1 = f(E_1, E_2) \]  
\[ Q_2 = f(E_1, Q_2) \]

where:

- \( Q_1 \) discharge at location 1;
- \( E_1 \) water surface elevation at location 1;
- \( E_2 \) water surface elevation at location 2;
- \( Q_2 \) discharge at location 2.

The specific flow relationship for a channel reach or lake outflow may be derived from steady-flow backwater computations, or from empirical data which relate streamflow to river levels at key observational points, from observed data.

**RESERVOIR REGULATION**

The SSARR program provides for routing streamflows through natural or man-made lakes or reservoirs, either on "free-flow" or controlled flow conditions. Free-flow refers to the condition of routing flows through natural lakes, or involuntary storage in reservoirs under fixed outlet conditions. From computed or specified inflows, the program evaluates the outflows continuously in time, together with the reservoir conditions of storage and elevation. Under controlled flow conditions, it is possible to specify either storage increments on a time basis, desired reservoir elevations at given times, or outflows as a time-series. The reservoirs operate within specified upper and lower limits, as established on an operational or design basis, or under free-flow conditions.

**FREE-FLOW ROUTING**

Routing streamflow through lakes or reservoirs on the basis of free-flow conditions may be applied to: (1) Natural lakes where the discharge is uncontrolled; (2) Reservoirs with ungated spillways or uncontrolled outlets; (3) Routing through projects where the relationship between discharge and storage is known, and where combined discharge through outlets and other facilities is controlled by the hydraulic head on the structure. The basic routing method for reservoirs also relies on the law of continuity in the storage equation.

**BASIN CONFIGURATION**

Preceding paragraphs describe basin concepts used synthesizing basin runoff and routing streamflow in lakes, reservoirs, and channels. In a complete system the computer will perform all of the basin routing first and then route and combine streamflow in the downstream order designated by the basin configuration supplied to the computer, through successive channel reaches, reservoirs, and summing points.

**COMPUTER UTILIZATION FOR "SSARR" PROGRAM**

**GENERAL**

The "SSARR" program is written in FORTRAN IV and it is designed basically to operate on the configuration of the IBM 360/50 computer system recently installed in the North Pacific Division Office of the Corps of Engineers in Portland, Oregon. This system
includes, among other facilities, a core memory of 512,000 bytes, random access Disc Storage Drives, and magnetic Tape Units. The program is not restricted to use on this particular configuration of the computer system in Portland, but efficient operation of the program involves use of mass data storage in both disc and tape storage units. The use of the program on other machines requires consideration of memory size and bulk storage modes of the particular machines. The program is being used operationally on the IBM 360/40 system of the Royal Thai Government in Bangkok. The system includes 64,000 bytes of core storage memory, and disc and tape storage units.

It is not in the scope of this paper to discuss the detailed techniques of computer utilization, data input formats, and the myriad of details necessary for the operation of the program. Reference is made to the Draft of Operating Instructions [6] for information of this type.

APPLICATION OF SSARR PROGRAM TO BASIN STREAM SYNTHESIS

In order to illustrate the application of the SSARR program to a Mekong River drainage, a study of streamflow reconstitution for the Se Bang Hieng River is summarized in the previously referenced publication by Anderson [4]. This basin, draining 3,600 square kilometers in Laos, is typical of the relatively high runoff producing area of the western slopes of the Annam Cordillera.

Reference is made to Mr. Anderson’s publication for details of this analysis, together with the definition of the various parameters and relationships used in synthesizing streamflow in this basin. Four years of streamflow records are available for trial-and-error reconstitution in this basin. Precipitation records for Mukdahan, Thailand and Seno, Laos, are available for the 15-year period, 1950-1964. From these data, it is possible to derive streamflow records synthetically for the period 1950-1960, by applying the daily precipitation values to the SSARR program, with the necessary basin coefficients derived from the reconstitution studies.

Figure 4 shows the degree of fit of the computed hydrograph for the Se Bang Hieng Basin, as compared with the observed hydrograph, for the year 1961. This is considered to be a reasonably good fit of data, considering the general paucity of rainfall data in the basin area. The degree of fit is considered to be adequate for deriving the historic streamflow record synthetically.

It is pointed out that refining the basin and channel routing coefficients is a continuing process. The basic framework of the SSARR program provides for improvements in techniques, without the necessity of altering the program structure. The degree to which such refinements can be accomplished in the future, depends upon the increase in availability in basic data, together with the time, effort and ingenuity of the engineers in applying the data to the streamflow synthesis problem.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the work accomplished by the Phase I trainees of the Training Program in Systems Analysis carried out by the Corps of Engineers. These were:

Bolyvong Tanovan
Sompongse Chantavorapap
Pachern Sridurongkatum
Nolasco A. Intong

The work involved in application of the SSARR program to the Mekong River studies was carried out under the direct supervision of Mr. James A. Anderson. The general
supervision of the Training Program in System Analysis was by Mr. Mark L. Nelson, Chief, Water Control Branch, North Pacific Division Office of the Corps of Engineers, who provided leadership in program development by emphasizing the need for computer simulation techniques for river system analysis. Much credit in the development of the SSARR program is due to Mr. Edward M. Davis, Mathematician and Computer System Analyst, North Pacific Division Office of the Corps of Engineers, who, through his initiative and capability in applying advanced data processing techniques, has been largely responsible for the methods of computer utilization in providing an efficient and workable program.

The development of the present SSARR model was done in collaboration with Messrs. Vail P. Schermerhorn and Donald W. Kuehl of the Portland River Forecast Center, ESSA, U.S. Weather Bureau. Funds for programming the SSARR model were provided in part by the U.S. Agency for International Development.
RÉFÉRENCES


