Hybrid Computer Modeling of the Hydro-Salinity Flow System Within a River Basin

Duane R. Jensen
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HYBRID COMPUTER MODELING OF THE HYDRO-SALINITY FLOW SYSTEM WITHIN A RIVER BASIN

by

Duane R. Jensen

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil Engineering

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
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Duane R. Jensen
TABLE OF CONTENTS

Chapter | Page
-------|------
I | INTRODUCTION | 1
II | REVIEW OF LITERATURE | 4
III | HYDROLOGIC MODEL | 7
IV | SALINITY MODEL | 16
V | THE COMPUTER MODEL | 24
VI | THE SEVIER-SIGURD SUBBASIN | 29

Geography 29
Climate 29
Population and Economy 31
Geology 31
Groundwater 33

Aquifer characteristics 33
Piezometric fluctuations 35
Groundwater recharge 35
Groundwater discharge 36
Subsurface outflow 37

Surface Outflow 38

VII | APPLICATION OF THE HYDRO-SALINITY MODEL OF THE SEVIER-SIGURD SUBBASIN | 39

VIII | SUMMARY AND CONCLUSIONS | 47

REFERENCES | 49

APPENDICES | 52

APPENDIX A 53
APPENDIX B 58
APPENDIX C 65
APPENDIX D 68
APPENDIX E 73
APPENDIX F 74

VITA 75
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
</table>
| 6.1   | Sevier-Sigurd subbasin characteristics  
| 6.2   | Well test results                                                                                  | 34   |
| 6.3   | Average aquifer characteristics in the Sevier-Sigurd subbasin.                                      | 34   |
| 6.4   | Groundwater use within the Sevier-Sigurd subbasin.                                                  | 37   |
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Flow diagram of hydrologic and salinity flow systems</td>
</tr>
<tr>
<td>5.1</td>
<td>Hydrologic program flow chart</td>
</tr>
<tr>
<td>6.1</td>
<td>Map of Sevier-Sigurd subbasin</td>
</tr>
<tr>
<td>7.1</td>
<td>Measured and computed outflow rates of the Sevier-Sigurd subbasin 1964-1965-1966</td>
</tr>
<tr>
<td>7.2</td>
<td>Measured and computed outflow rates, 1970</td>
</tr>
<tr>
<td>7.3</td>
<td>Measured and computed salt weight outflow rate, 1970</td>
</tr>
<tr>
<td>B.1</td>
<td>Input listing</td>
</tr>
<tr>
<td>B.2</td>
<td>Typical listing of input data</td>
</tr>
<tr>
<td>B.3</td>
<td>Coefficients set by model verification</td>
</tr>
<tr>
<td>C.1</td>
<td>Hydrologic model computer program</td>
</tr>
<tr>
<td>C.2</td>
<td>Self-verification subroutine</td>
</tr>
<tr>
<td>C.3</td>
<td>Salinity model program</td>
</tr>
<tr>
<td>C.4</td>
<td>Program to calculate statistical analysis</td>
</tr>
<tr>
<td>C.5</td>
<td>Random number generator</td>
</tr>
<tr>
<td>C.6</td>
<td>Subroutines to operate analog computer</td>
</tr>
<tr>
<td>C.7</td>
<td>Analog computer program</td>
</tr>
<tr>
<td>D.1</td>
<td>Hydrologic model input</td>
</tr>
<tr>
<td>D.2</td>
<td>Hydrologic model output, 1964-65-66</td>
</tr>
<tr>
<td>D.3</td>
<td>Hydrologic model output, 1964-65-66 (cont)</td>
</tr>
<tr>
<td>D.4</td>
<td>Hydrologic model input, 1970</td>
</tr>
<tr>
<td>D.5</td>
<td>Hydrologic model output, 1970</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>D. 6</td>
<td>Hydrologic model output, 1970 (cont)</td>
</tr>
<tr>
<td>D. 7</td>
<td>Salt model input (ppm), 1970</td>
</tr>
<tr>
<td>D. 8</td>
<td>Salt model output, 1970</td>
</tr>
<tr>
<td>D. 9</td>
<td>Coefficients set for Sevier-Sigurd subbasin</td>
</tr>
</tbody>
</table>
ABSTRACT
Hybrid Computer Modeling of the Hydro-
Salinity Flow System Within a River Basin

by
Duane R. Jensen, Master of Science
Utah State University, 1972

Major Professor: Dr. J. Paul Riley
Department: Civil Engineering

As demands upon available water supplies increase, there is an accompanying increase in the need to assess the downstream consequences resulting from changes in the upstream hydrologic system and salinity flow system.

Since the burden of water quantity and quality maintenance must be shared by the users, predictions are needed for quantity and quality changes which might result from contemplated development at any specified location within the river system. A close relationship between the hydrologic and salinity flow systems exist, thus making it necessary for an understanding of both systems in order to properly manage the salinity system.

This study reports the development of a hybrid computer simulation model of the water and salinity flow systems. The validity of the model is demonstrated by applying it to the Sigurd-Sevier subbasin of the Sevier River Basin, Utah.

(82 pages)
Chapter I

Introduction

The current rapid growth of a variety of demands on a limited water resource, such as the Sevier River in central Utah, requires a high level of management efficiency from both a quantity and a quality standpoint. In areas where water supplies are short, future demands will need to be met both by importation and improved management of existing supplies. The increased utilization of the existing resource through use and reuse of water for irrigation and industry concentrates and adds non-degradable substances which produce a degeneration of the water quality for subsequent agricultural and industrial uses.

In the irrigation process, water, together with its accompanying salt load, is diverted from various sources and applied to the land. Evapotranspiration losses are essentially salt free, so that the salt load once carried by this component of the irrigation waters remains in the soil to be carried off by the agricultural return flows. Thus, because of the evapotranspiration losses, there is some increase in the salinity level of waters downstream from an irrigation project. A second phenomenon which contributes to increased salinity concentrations under irrigation management is salt loading from the leaching process. As return flows move along both surface and subsurface
routes, increased salt loads are accumulated. This process, then, tends to increase not only the salt concentration in the receiving waters, but also the total weight of salt being carried by the stream. Thus, in every hydrologic system, each upstream use has some effect on the quantity, quality, and timing of flow occurring at downstream points. However, because of the complex interrelations and variable nature of the hydrologic and salinity flow system, proper evaluations of the effects of upstream changes are difficult.

Many of the factors affecting these flow systems are subject to manipulation and regulation, and through proper management criteria, optimum use of the water resource of the basin can be achieved. This report presents a general hydrologic and salinity model which is based on fundamental equations. The various processes which are included in both the hydrologic and the salinity components of the model are linked by the mass balance equation. The model is similar to that used by Hyatt et al., 1970, but in this case it is programmed on a hybrid computer and a self-calibrating subroutine is included. A time increment of one month is used.

To test the validity of the model, it was applied to the Sevier-Sigurd subbasin of the Sevier River basin in central Utah. Verification (calibration and testing) results for the four years 1964, 1965, 1966, and 1970 are presented. Measured mean monthly values of precipitation, surface air temperature, and water and salt inflow rates to the basin
for these years were input to the model. Comparisons are made between the computed and the measured outflow functions for both water and salt.
CHAPTER II

REVIEW OF LITERATURE

Beginning with Bagley et al. (1963) Utah State University has been in the foreground of research involving the computer simulation of hydrologic and water quality systems. Initial simulation efforts were relatively simple with the primary objective being to develop a nonunique model with respect to geography in terms of the basic physical processes which occur in any hydrologic system, and demonstrates the utility of the analog computer. Riley (1966, 1967) developed improved mathematical relationships for describing the various hydrologic processes and programmed these on an analog computer.

Many efforts have involved interlinking the hydrologic system with other dimensions. Packer et al. (1968) linked the hydrologic model to the general economics of the watershed by using the analog computer. From this model it is possible to estimate how changes in the hydrologic system might affect the agricultural economy of the area.

Dixon (1970) developed a digital computer program for the computation of the hydrologic flow system and linked it to the water quality with respect to several ions and other water quality parameters for the Little Bear River Basin.

Hyatt et al. (1970) developed a general hydrologic and water quality model and programmed it for the electronic analog computer.
With this general model programmed on the analog computer, he applied it to the Upper Colorado River Basin by dividing the basin into smaller subbasins and calibrating each of these to his model.

Hyatt's hydrologic model was based on the mass balance principle, using water inflow and precipitation as the basic input functions, and evapotranspiration losses and basin discharges as the outflow quantities. Hyatt modeled only the salinity (total dissolved solids) parameter for the evaluation of water quality. The mass balance principle was also applied to the salinity model using the weight of salt as the parameter modeled. The quality of the outflowing waters in terms of salinity concentration was then estimated by combining the two predicted outflow streams of water and salt.

Using essentially the same hydrologic model as Hyatt et al. (1970), Hill et al. (1970) programmed it on a hybrid computer and applied it to the Bear River Basin of Wyoming, Idaho, and Utah. A significant advance in this study, however, was the development of a self-calibrating subroutine for the model. The model is being used to investigate the hydrologic implications of various water management alternatives within the Bear River Basin.

Other studies involving analog computer modeling in the various areas of water research includes a study of Shen (1965) in which he discusses the applicability of analog models for simulating flood flows. Harder et al. (1960) developed an analog computer program for the routing of flood flows in a particular river system.
Crawford and Linsley (1962) developed a hydrologic model in which interception, depression storage, infiltration, and evapotranspiration were the extracting processes in predicting both surface and subsurface flows. This model was programmed on a high-speed digital computer for fast runoff evaluation. Dawdy and O'Donnel (1965) have developed a similar digital computer model which contains mathematical descriptions of the various fundamental processes of a hydrologic system. Others who have developed various hydrologic models and programmed them on digital computers are Betson and Green (1968), Machmeier and Larson (1968), and Moore (1968).
CHAPTER III

HYDROLOGIC MODEL

Considerable experience in the simulation of dynamic flow systems has been gained at Utah State University (Riley, Chadwick, and Israelson, 1967; Riley et al., 1967; Hyatt et al., 1970). In each of these studies the continuity of mass principle was applied to link the various processes within the system being modeled. Expressed in equation form, this principle states:

\[ \text{Input} = \text{Output} + \text{Change in Storage} \] (2.1)

Through the application of Equation (2.1) an accounting of the physical flows, whether salt or water, is achieved at various points within the system. Utilizing this concept, translation or routing through the system is represented in the proper relationship to space and time.

The model of this study draws heavily on the experience cited in the previous paragraph and utilizes the continuity of mass principle for both water and salt flow. The model is macroscopic in scale, using monthly time increments and large increments of space. Further simplification was achieved by including only the valley bottom lands of the subbasin in the model.

A schematic flow diagram of both the hydrologic and the salinity systems is shown in Figure 3.1. As this figure indicates, the water
Figure 3.1. Flow diagram of hydrologic and salinity flow systems.
inflows to the basin are obtained by a summation of the gaged and ungaged surface inflow, the precipitation over the modeled area, and the ungaged subsurface inflow. Gaged surface inflows of water are available from records of the U.S. Geological Survey and local water users' groups. Ungaged surface inflows are estimated by correlation procedures using available flow records from a stream within the area. The procedure used in this study is given by Appendix A, Equation (4).

For many simulation studies of river basins (Riley and Chadwick, 1967; Riley et al., 1967) the primary water inflow to the basin is precipitation on the watershed. However, in cases where only the valley floor is included in the modeled area, direct precipitation input is generally overshadowed by the magnitudes of the river and tributary stream inflows. Precipitation then becomes important as it affects the evapotranspiration process and as a correlation parameter for estimating ungaged inflows.

Precipitation input to the hydrologic system varies with respect to both space and time, and it is therefore necessary to convert point measurements from climatological stations into an integrated or averaged monthly value over the modeled area. In this study the Thiessen weighting technique was applied to provide an estimate of the average precipitation over the floor of the subbasin.

The form of precipitation is determined by the surface air temperature at the time of precipitation occurrence. If the air temperature is
above 34° F, the precipitation is assumed to be in the form of rain, and if the air temperature is 34° F or less, the precipitation is assumed to be in the form of snow. All rainfall or snowmelt is assumed to go directly into root zone storage, unless overland flow is occurring. Both the complex nature of the process and data limitations prevent a strictly analytical approach to snowmelt. Equation (1), Appendix A is the equation presented by Israelsen and Riley, 1967. The equation has been tested on snowpacks in Utah and Montana and has been found to be reasonably accurate in describing snowmelt on a monthly basis.

Overland flow occurs when the rate of rainfall or snowmelt exceeds the rate which water can enter the soil. Overland flow is described by two different equations, one for overland flow caused by rain (Appendix A, Equation (2) and the other for overland flow caused by snowmelt (Appendix A, Equation (3)).

An estimate of ungaged subsurface inflows in the vicinity of a gaged stream is obtained from general aquifer conditions and the flow rate in the gaged surface stream. Likewise, the ungaged subsurface inflows not near a gaged stream are estimated by correlation procedures with an appropriate gaged stream in the subbasin area. Because time is required for water to move through the subsurface aquifers, estimated subsurface inflows are delayed before being represented as input quantities to the groundwater basin within the modeled area.

Canal diversions profoundly affect the spatial and time distribution of water in a basin containing irrigated agriculture. A portion
of this water is evaporated directly into the atmosphere from water surfaces. A second part enters the soil profile through canal seepage and infiltration on irrigated lands. The remainder returns to the stream as agricultural surface return flow. For this study some canal diversion data were obtained from local records of irrigation companies in the basin. In cases where these records were not available, diversions were estimated from existing water right information. These data are entered into the hydrologic model as a diversion or extraction from the stream.

Evapotranspiration losses are estimated from the modified Blaney-Criddle formula listed in Appendix A, Equation (5). The amount of water that enters the soil through canal seepage or infiltration into the irrigated land is estimated using a factor termed irrigation efficiency. The irrigation efficiency factor used in this study includes both the conveyance and application efficiencies and is not the same as the usual concept of irrigation efficiency. Multiplying total diversions by the efficiency factor provides an estimate of the quantity of water which enters the soil through canal seepage and infiltration. The irrigation efficiency factor is shown in Appendix A, Equation (6). The remainder of the diverted water returns to the stream as surface return flow, and this process is described by Equation (7) in Appendix A.

The root storage zone acts as a storage element in which water is stored. The two soil moisture equilibrium points which are of
greatest interest are the field capacity and the wilting point. The field capacity is the moisture content of the soil after gravity drainage is essentially complete. The wilting point represents the point at which the plants cannot extract sufficient water to carry on photosynthesis and permanent wilting occurs. The difference between these two points is termed the available moisture for plants. Storage of water in the root zone results from infiltration of precipitation and irrigation water, while the abstractive quantities are deep percolation, interflow and evapotranspiration. The soil moisture at any time is given by Equation (8) of Appendix A.

Deep percolation is the vertical movement of water through the soil from the plant root zone into the groundwater reservoir. This movement results from the forces of gravity and the capillary potential field. For saturated flow the gravity force is dominant, while in the case of unsaturated flow the capillary field becomes the important potential. Equation (9) of Appendix A was proposed by Riley, Bagley, and Chadwick (1967) for describing deep percolation rates.

Deep percolation affects the quantity of the stream only after it has filled the groundwater reservoir and the resulting overflow enters an effluent channel. Because of the time required for the water to flow through the soil, the overflow of the groundwater reservoir to the effluent stream will occur some time after deep percolation from the root zone storage.
As previously indicated, potential evapotranspiration rates are computed from the modified Blaney-Criddle equation shown as Equation (10), Appendix A (Riley et al., 1966). As the moisture content of a soil, $M_s$, is reduced by evapotranspiration, the moisture tension which plants must overcome to obtain sufficient water for growth is increased. It is generally conceded that some reduction in the evapotranspiration rate occurs as the available quantity of water decreases in the plant root zone. Studies by the U.S. Salinity Laboratory in California (Gardner and Ehlig, 1963) indicate that transpiration occurs at the full potential rate through approximately the first one-third of the available soil moisture range, and that thereafter the actual evapotranspiration rate lags the potential rate. When this critical point in the available moisture range, $M_{es}$, is reached, the plants begin to wilt because soil moisture becomes a limiting factor. Thereafter, an essentially linear relationship exists between available soil moisture quantity and actual transpiration rate. In this range the actual evapotranspiration rate is expressed by Riley, Chadwick, and Bagley (1966) as the product of the potential rate from the modified Blaney-Criddle equation and the ratio $M_s / M_{es}$. When the root zone storage is equal to or greater than the limiting point, $M_{es}$, the actual evapotranspiration is assumed to be equal to the potential evapotranspiration and is estimated by setting $M_s / M_{es}$ equal to 1.0.

Evapotranspiration by phreatophyte plants is also computed from the modified Blaney-Criddle equation (Appendix A, Equation (5)).
and using an appropriate plant coefficient curve. For this study, phreatophyte acreages within the subbasin were determined by Federal water and land use agencies, such as the U.S. Soil Conservation Service.

The effects of surface storage reservoirs within the study area are represented by taking into account changes in storage in the reservoir during each time increment. As reservoir surface levels fluctuate, changes in bank storage also occur. The changes in bank storage, whether an increase or a decrease, are represented in the model as a function of the corresponding change in reservoir surface storage (Appendix A, Equation (11)).

The total water outflow rate from an area is estimated by translating the various inflow quantities through the system, taking into account abstractive losses within the system, and by summing both the surface and subsurface outflow streams (Appendix A, Equation (12)). As mentioned earlier, appropriate delays are incorporated into the model to represent the various transport times within the system. The subsurface component of the total outflow is estimated as a function of aquifer conditions in the vicinity of the outflow station and is computed from Equation (13) in Appendix A. The surface outflow component is obtained by subtracting the subsurface outflow function (Equation (13)) from the total outflow function (Equation (12)).

The model described by the preceding paragraphs is general in nature, and is applied to a particular subbasin or drainage area by a verification procedure. Under this procedure the model is first
calibrated by adjusting certain system parameters until computed output functions at points of measurement closely approximate observed values in the prototype at corresponding points. For models based on a monthly time increment, it is customary to calibrate over a period of from two to three years, using discharge as the fitting function. The validity of the model is then tested with a set of independent data. The two steps of calibration and testing comprise model verification, sometimes called validation.

As previously indicated, the time increment used is one month. The space boundaries of the model include only the valley floors, with measured and ungaged runoff from the higher surrounding areas and precipitation representing the input quantities to the modeled area.
CHAPTER IV

SALINITY MODEL

Considerable experience in the simulation of dynamic salinity flow systems has been gained at Utah State University (Hyatt et al., 1970). The salinity flow system is dynamic, just as the hydrologic system is dynamic, and routing of the salt movement through the system is achieved by super-imposing the salinity flow system upon the hydrologic system. The two systems are related since the salts are transported by the water, and the rate of salt flow at any point is a function of the corresponding salinity concentration level and the rate of water flow. A schematic diagram of the salinity and hydrologic flow system is shown in Figure 3.1.

As mentioned previously, the confining area for the model of this study is the valley floor. For this reason, inputs to the model are represented as streams which cross the boundary into the modeled area. At these points the concentration of total dissolved solids is measured or estimated. Soluble products from the weathering and decomposition of rock and soil on the watershed surrounding the valley floor are carried by the inflowing waters. Both hydrologic and geologic factors influence water quality. The geology of an area describes the characteristics of the rocks within a drainage area. The hydrology designates to a considerable extent the degree to which these rocks
are exposed to the weathering processes of water. For example, when high runoff rates occur in the spring months, the flows exhibit their lowest salinity concentrations because of the short contact time with the rock and soils of the drainage area.

Regardless of the upstream processes that contribute to the quality of inflow water, for the model of this study salinity concentrations are considered only at the point of entry to the valley floor (model area). It is emphasized, however, that an understanding of the watershed surface geology and hydrology (routes followed by the moving water on the drainage area) is essential to estimating the quality of inflows for which no sampling records are available. For example, salinity levels of groundwater inflows usually are considerably higher than those of surface inflows.

The surface input of salt consists of the soluble salts dissolved within the water traveling over the ground surface and through the tributary channels of the subbasin. The total inflow rate of surface water is made up of two components, namely measured flows and unmeasured flows. The surface salinity flow system also contains these same two components of measured and unmeasured flow rates. Not always do the two components coincide between the water and salinity flow systems. For many areas the number of streams for which water flow records are available exceeds the number of streams that are being monitored to provide water quality data. In other words,
although the streamflow is being measured on all streams for which salinity records are available, the reverse is not always true.

Salinity inputs in streams for which both water quantity and quality records are available are estimated by Equation (14), Appendix A. Salt inflow rates to a given subbasin associated with the unmonitored (from a salinity standpoint) surface waters are estimated by establishing appropriate salinity concentration levels. The unmonitored surface inflow waters are divided into two categories:

(1) Those streams for which measured water flow rates are available but for which quality data are not available.

(2) The total ungaged rate of surface water inflow.

Salinity concentration levels required for these two components of flow were estimated from surface geology information and available salinity records. It was assumed, for example, that all water emanating from areas of similar hydrologic and geologic conditions would exhibit similar quality characteristics. On the basis of this assumption, salinity levels are estimated as required from the records of monitored streams lying both within and outside the particular subbasin under consideration. The subsurface rate of salt movement into the valley floor area of a basin is estimated by assigning an average salinity concentration value to the rate of groundwater inflow. During periods of low flow, much of the water flowing in a surface stream consists of effluent flow from the groundwater basin of the watershed.
Thus, the quality of the base flow carried by a stream is often a good indicator of groundwater quality. In addition, wells frequently provide an excellent indication of groundwater salinity. Precipitation contains minute concentrations of various minerals, dissolved gases, and other elements. However, the amount of salt carried by precipitation usually is negligible, and was not considered in this study. The total salt inflow rate is obtained by summing the surface and subsurface salt input rates to the modeled area.

Irrigation waters diverted to agricultural lands transport salts from the source of supply. Some extractions from this diverted flow occur through seepage losses in the conveyance system. Since the assumption is made that the irrigation water is uniformly mixed, the proportion of salt lost from the conveyance system through seepage is equal to the proportion of the water seepage loss. Further, it is assumed that the salinity of the water reaching the irrigated lands is essentially the same as that at the diversion point.

Evapotranspiration has no effect on the weight of salt in the salt balance model. The water removed from the modeled area by evapotranspiration is essentially pure. The dissolved solids in the soil water solution either precipitate in the soil or remain dissolved in the portion of the water not consumed. Thus, evapotranspiration processes concentrate the original salt load in the soil solution. If these salts are carried out of the soil by deep percolation, a salt balance within
the plant root zone is maintained. When water supplies from irrigation or precipitation do not exceed the field capacity of the soil, deep percolation is limited and salt storage begins to occur within the soil profile. If this increase of salt storage continues, osmotic pressures will increase in the soil solution to the point where plants will suffer. Thus, irrigation practices which do not maintain a salt balance in arid regions by more than meeting evapotranspiration requirements eventually cause the land to become unproductive.

Irrigation return flow usually is considered as being that part of total irrigation diversions which ultimately return to the stream system. The three major components of return flow are overland flow, interflow, and groundwater outflow. Return flows from irrigated areas tend to increase the total dissolved solids load carried by a stream. Often included in this load are quantities of nitrates, phosphates, and pesticides which are added to the irrigated lands to increase crop production.

In this study the surface return flow and interflow components of agricultural return flow are treated as a single identity. The average salinity level of these waters is estimated either from collected data or by considering concentrations and quantities of the diverted water and the relative proportions of the surface runoff and interflow rates to total rates of diversion. Estimated salinity values are tested during the model verification procedure. The rate of salt flow (weight per unit of time) is estimated as the product of the concentration and water flow rates as given by the hydrologic component of the model.
Deep percolation has been previously defined as water movement from the plant root zone into the underlying groundwater basin. Deep percolation is assumed to occur only when the available soil moisture is at field capacity. As water moves through the soil, the concentration of salts usually increases due to weathering. Also a shift in the components of the salts may occur. In clay soils many cations are adsorbed, while anions may move through the soil at an accelerated rate.

When the percolating waters reach the groundwater basin, they increase or decrease the groundwater salinities depending on the relative concentrations. The rate of salt flow moving with the deep percolating water from the root zone is estimated by multiplying an average salinity concentration by the appropriate rate of water flow. The rate of salt flow in deep percolating waters is estimated by Equation (15), Appendix A.

The movement of deep percolating waters through the groundwater basin to the stream is slow. Therefore, a considerable time period might be required for the deep percolating water, now carrying a salt load associated with the salinity of the groundwater basin, to average as effluent flow.

In most Western river basins the total weight of salt added within the basin cannot be attributed to agricultural sources. For example, Hyatt et al (1970) indicate that 50 percent of the total salt outflow from the upper Colorado River Basin originates from natural diffused and point sources within the bottom lands. In many drainage areas
the upper reaches of the main stream within the basin are influent to the groundwater basin while in the lower reaches of the basin effluent flow occurs. The amount of water that interchanges with the groundwater basin by this means seems to depend in a large measure upon flow rates in the main stream which traverses the valley. Hyatt et al. (1970) proposed Equation (16) in Appendix A for computing the rate of water interchange as a function of the surface flow rate in the main drainage channel within the subbasin. It is assumed that water returning to the surface channel as effluent flows carry the salinity concentration of the groundwater basin through which they have passed.

Since the hydrologic and the salinity flow systems are interconnected, the same basic principles underlie movement in both regimes. As with the hydrologic system, the input functions to the salinity system within an area are acted upon by the routing and storage functions of the system. In addition, depending upon concentration levels, salts move in and out of solution and ionic exchanges occur. All of these various processes affect the output salinity function so that concentration levels and mass rates of salt flow at the output may differ considerably from those of the input. Because dissolved solids are non-degradable, the continuity of mass principle described by Equation (2.1) also applies to the dynamics of flow within the salinity system. Thus, the solvent denudation processes within the system frequently produce mass rates of salt flow at the output which are higher than those at
the input. Depending upon the hydrologic inputs and the relative effects of the evapotranspiration and the dissolving processes, average concentration levels may or may not be increased at the outflow point.

The various processes within the hydrologic-salinity system occur with respect to both space and time, and the net result of modifications to the input salinity flow system are reflected at the outflow point as a combination of both surface and subsurface salt outflow. In the model verification process, the rate of salt movement from the subbasin with surface flows is computed and compared with measured values at the outflow gaging stations.
CHAPTER V

THE COMPUTER MODEL

A computer model of a hydro-salinity system is produced by programming the mathematical relationships and logic functions described in the previous two chapters. The computer model does not directly simulate the real physical system, but is analogous to the prototype, because both systems are described by the same mathematical relationships. The model is applied to the particular prototype system by establishing, through a verification procedure, appropriate coefficient values required by the system.

Computers generally fall into one of three general classifications, namely; analog, digital, and hybrid. The computing components of an analog computer execute the basic operations of addition, subtraction, multiplication, function generation, and high-speed and continuous integration. The analog computer is programmed with various mathematical equations by connecting components through a program "patch panel." It is possible to program on the analog computer an electronic model of a differential equation or a series of differential equations which describe the dynamic performance or operation of the physical prototype.

The general purpose digital computer processes information which is reported by combinations of discrete or instructive data, while the analog computer operates on continuous data. While the
analog computer is a "parallel" system in which all equations programmed are solved simultaneously, the digital computer is basically a "sequential" system performing step by step operations or logic controls at high speed.

The hybrid computer combines the memory and logic capabilities of the digital with the high speed nonlinear solution capabilities of the analog. The hybrid computer also is equipped with linkage channels between its two components, allowing data transfers from the digital to the analog and visa-versa. This linkage also serves to operate the analog computer with statements built into the digital computer program.

The simulation model developed in this study was programmed on a hybrid computer. Because the analog component of this particular computer operates within voltage limits of ±10 volts, it was necessary to scale the analog component of the model so as not to exceed these limits. Since the analog computer is a continuous integrating device, time scales must be considered. The time scale chosen in this study was one-tenth of a second of model time equal to one month of prototype time.

Figure 5.1 is a flow diagram of the basic processes in the hydrologic model. This model was programmed on both the digital and analog components of the hybrid computer. The first section of the hydrologic model refers to data input. A detailed description of the procedure for inputting basin data to the computer model is
Figure 5.1. Hydrologic program flow chart.
given by Appendix B. The basic unit in the hydrologic model is inches over the irrigated land, therefore, all hydrologic inputs are converted to this unit.

Most of the components of the hydrologic model are programmed on the digital computer as shown by Figure C.1. Exceptions are the actual evapotranspiration rate, root zone storage, deep percolation rate, ungaged subsurface inflow rate, and inflow and outflow rates from reservoir bank storage which are programmed on the analog computer (Figure C.7).

The salinity model is programmed on the digital computer in a single subroutine (Figure C.3). Necessary hydrologic flow rates are transferred to the salinity subroutine for the computation of salt volume flow rates. The equations discussed in Chapter III are included in this subroutine for routing the salt flow through the system.

The computer program includes a subroutine for identifying the coefficients in the hydrologic and salinity submodels (Figure C.2). The self-calibration subroutine uses the method of comparative runs with particular coefficients being changed at each run. This subroutine uses a random number generation procedure which is illustrated by Figure C.5. The self-calibration subroutine will be discussed in more detail in Chapter VI.

Also included in the computer model is a program (Figure C.4) to compute the statistical correlation coefficient $R^2$ and the summation of the differences squared with respect to computed and measured
surface outflow volumes of water and salt. In addition to the sub-
routines cited, the program also includes two subroutines which are
operational in nature in that they implement control of the analog
computer by the digital component of the hybrid system.
CHAPTER VI
THE SEVIER-SIGURD SUBBASIN

Geography

The Sevier-Sigurd Basin of the Sevier River is located in Central Utah and extends from the mouth of Marysvale Canyon near the town of Sevier, Utah, to Rocky Ford Reservoir Dam near Sigurd, Utah, and contains the Upper Central Sevier Valley (Figure 6.1). The basin is approximately 25 miles long and ranges from two to five miles in width. The valley is in the high plateau section of the Colorado Plateau physiographic province. It is mostly an alluvium-filled intermountain valley bordered on the east by the Sevier Plateaus and on the west by the Pavant Range. The average valley floor elevation is 5,400 feet above mean sea level and slopes toward the north at a slope of fifteen feet per mile.

Climate

The climate of the Sevier-Sigurd subbasin ranges from semi-arid on the valley floor to humid on the nearby mountains and plateaus. In the valley the relative humidity is generally low, and wind velocities are usually less than two miles per hour and rarely exceed fifty miles per hour.

Average annual precipitation ranges from less than ten inches on the valley floor to more than thirty inches or more in the bordering mountains. The crop growing season averages about 120 days in
Figure 6.1. Map of Sevier-Sigurd subbasin.
length. The highest temperature of record is 105° F. and the lowest recorded temperature is -28° F.

Population and Economy

The total population of the Sevier-Sigurd Basin of the Sevier River is approximately 8,000. Most of the residents are engaged in agriculture and related activities, but most of the residents live in towns and villages rather than on the farms. Certain characteristics of the subbasin including land use and the locations of hydrologic gaging stations are indicated by Table 6.1.

Sheep and cattle raising are also an important part of the agricultural economy. In addition, mining contributes much to the economy of the Sevier-Sigurd Basin. Two large wallboard plants utilize gypsum mined in the hills east of Sigurd, Utah.

Geology

The consolidated rock formations exposed in the mountains surrounding the Sevier-Sigurd Basin include many different types of material ranging from Coconino Sandstone of the Permian age to the Sevier River formation of Pliocene or Pleistocene age. The unconsolidated rocks that make up the fill in the Sevier-Sigurd basin are Pleistocene and Recent age. They are the source of practically all the groundwater obtained from wells. Along the axis of the basin, the alluvium depth increases from a feather edge at the mouth of Marysvale Canyon near Sevier, to more than 800 feet at Venice and then decreases in thickness to 280 feet west of Rocky Ford Reservoir.

<table>
<thead>
<tr>
<th>Land Use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage area</td>
<td>476 mi²</td>
</tr>
<tr>
<td>Total crop acreage</td>
<td>37,590 acres</td>
</tr>
<tr>
<td>Wet meadow</td>
<td>5,460 acres</td>
</tr>
<tr>
<td>Phreatophytes</td>
<td>2,150 acres</td>
</tr>
<tr>
<td>Water surface</td>
<td>840 acres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crop Distribution</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>53%</td>
</tr>
<tr>
<td>Pasture</td>
<td>21%</td>
</tr>
<tr>
<td>Grain</td>
<td>18%</td>
</tr>
<tr>
<td>Corn silage</td>
<td>5%</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrologic Inflow Stations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.G.S.* 10-1940</td>
<td>Sevier River above Clear Creek near Sevier, Utah</td>
</tr>
<tr>
<td>U.S.G.S. 10-1942</td>
<td>Clear Creek near Sevier, Utah</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrologic Outflow Stations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.G.S. 10-2050</td>
<td>Sevier River near Sigurd, Utah</td>
</tr>
<tr>
<td>R.C.R.*</td>
<td>Piute Sevier Canal</td>
</tr>
<tr>
<td>R.C.R.</td>
<td>Vermillion Canal</td>
</tr>
<tr>
<td>R.C.R.</td>
<td>Rocky Ford and Willow Bend Canal</td>
</tr>
</tbody>
</table>

*U.S.G.S. - U.S. Geological Survey Record
*R.C.R. - Sevier River Commissioners Report
The subbasin contains two of the largest faults in the area, with the Sevier Fault on the eastern edge of the valley, and the Elsinore Fault along the western edge. The Sevier Fault has a through of nearly 6,000 feet near Monroe to only a few feet near Sigurd. The through of the Elsinore Fault ranges from 500 feet to 1,000 feet. Three thermal springs occur along these faults. Monroe Hot Spring, the Red Hot Spring, and the Joseph Hot Springs.

The Monroe Hot Spring is located near the city of Monroe in the southern part of the basin. It has a flow of 0.06 cfs and a temperature at the surface of 140° F. The Red Hill Hot Spring is also in the vicinity of Monroe. It has a flow of 0.17 cfs and a temperature of 168° F. The Joseph Hot Springs are located one mile southeast of Joseph in the upper part of the basin. It has a flow rate of 0.02 cfs and a temperature at the surface of 140° F.

Groundwater

Aquifer characteristics. The quantity of water which can be developed in an area depends on the hydraulic characteristics of the aquifer, as well as its extent and saturated thickness.

The hydraulic properties of an aquifer are expressed by the coefficients of storage and permeability. The permeability of the aquifer lying beneath the valley of the Sevier-Sigurd subbasin has been observed at the sites of six test wells located throughout the basin. The results of these tests are shown in Table 6.2.
Table 6.2. Well test results.

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Coefficient of Transmissibility (gpd per ft)</th>
<th>Coefficient of Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300,000</td>
<td>0.0001</td>
</tr>
<tr>
<td>2</td>
<td>900,000</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>15,000</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>20,000</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>900,000</td>
<td>0.001</td>
</tr>
<tr>
<td>6</td>
<td>4,000</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Well No. 6 is a water table well; Well No. 1 is an artesian well. Some artesian pressure was present at the sites of the other two wells from which the storage coefficients were determined, but the piezometric heads were not above the earth's surface. Average aquifer characteristics were determined from these data, and these characteristics are shown in Table 6.3.

Table 6.3. Average aquifer characteristics in the Sevier-Sigurd subbasin.

<table>
<thead>
<tr>
<th>Average Thickness of Saturation Aquifer (ft)</th>
<th>Assigned Average Storage Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>340</td>
<td>0.20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area Underlain by Aquifer (acres)</th>
<th>Estimated Recoverable Storage (Acre ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,000</td>
<td>800,000</td>
</tr>
</tbody>
</table>
Piezometric fluctuations. Artesian conditions in the alluvium beneath the valley floor are caused by 60 to 80 feet of silty clay of low permeability which overly permeable gravel aquifers. Recharge areas for the aquifer are situated in the lower slopes of the surrounding mountains. The elevations of the piezometric surfaces vary from 40 feet beneath the land surface to 20 feet above the land surface at some locations. Short-term fluctuations in the piezometric surface of less than 28 days result from changes in surface flow, use of groundwater by phreatophytes, and well discharge. Seasonal, or long-term fluctuations are caused mostly by seepage of water from streams, by diversions of water from streams for irrigation, and by the capping and uncapping of flowing wells. Water table levels usually begin to rise in May in response to increased streamflow, and increased irrigation diversions. The levels continue to rise through August and then decline slowly until the following spring. In the wells which penetrate the shallow artesian aquifers pressures are usually highest in November and December when the wells are capped and flow is stopped, and are lower in July when the wells are allowed to flow. Very little seasonal fluctuation in rates of flow from the deep artesian wells is observed. These are more than 200 feet deep and draw from a large groundwater storage basin.

Groundwater recharge. The principal sources of recharge to the alluvium in the central Sevier Valley are the Sevier River and its tributaries, irrigation canals, and infiltration from irrigated fields.
Recharge from the Sevier River and other streams occur at points of influent flow to the groundwater basin. In addition to these principal sources of recharge, some groundwater moves into the alluvium from the bedrock in the mountains surrounding the valley. The principal sources of this water are direct precipitation and surface runoff. The rocks dip generally toward the valley floor, and the groundwater moves in the direction of the dip.

**Groundwater discharge.** The primary means of groundwater discharge from the alluvium beneath the valley floor are evapotranspiration, wells, springs, seeps, drains, effluent flow to the streams, and some subsurface movement into the next subbasin downstream. In the Sevier-Sigurd Basin, the total river flow is diverted to the 37,590 acres of cropland. Thus, there is a substantial evapotranspiration loss of surface and subsurface water which is estimated to average 121,580 acre-feet per year. Of this quantity, approximately 25,000 acre-feet are being used directly from the groundwater basin by phreatophytes.

Present development of groundwater reservoirs is very limited. Most of the existing wells are used for domestic and stock watering purposes. Although they are numerous, most are small in diameter and shallow in depth (50-200 feet), and their yields are low. However, there are some large diameter deep wells which produce water for public supplies, irrigation, and industrial purposes. Generally, the higher producing wells yield water from depths of up to 800 feet.
Table 6.4 indicates estimated average groundwater use for irrigation and other purposes for the 1931-60 period and for 1964. Because of recent developments the 1931-60 average for irrigation is considerably less than the amount pumped in 1964.

Table 6.4. Groundwater use within the Sevier-Sigurd subbasin.

<table>
<thead>
<tr>
<th>Irrigation Purposes</th>
<th>Other Purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>1931-60 acre-ft</td>
<td>1964 acre-ft</td>
</tr>
<tr>
<td>2,200</td>
<td>6,000</td>
</tr>
<tr>
<td>1964 acre-ft</td>
<td>1964 acre-ft</td>
</tr>
<tr>
<td>3,500</td>
<td></td>
</tr>
</tbody>
</table>

There are a number of springs in the subbasin, and most of these are situated in the lower slopes above the valley floor. The annual discharge from springs within the Sevier-Sigurd subbasin is about 20,000 acre-feet, and most of this water is used for irrigation purposes. The seasonal discharge of water from drains in the center of the valley usually fluctuates directly with the quantity of irrigation water being applied to the land, but the peak drain flow usually follows the peak irrigation period by about seven months.

Subsurface outflow. Twenty-three percent of the outflow from the Sevier-Sigurd subbasin is in the form of subsurface flow. Much of this water flow through the alluvium at the lower boundary of the
basin which is about 280 feet deep. The remaining portion of the sub-
surface outflow is groundwater which flows along the Elsinore Fault
and emerges at Redmond Spring, ten miles below the lower boundary
of the subbasin. The primary source of this flow, however, is ground-
water from the northern Pavant Plateau. Thus, the water does not at
any time enter the area included within the boundaries of the model of
this study.

Surface Outflow

This subbasin is unique in that the total inflow of the Sevier River
is used for agricultural purposes within the Sevier-Sigurd subbasin.
The average annual surface outflow of 57,500 acre-feet results from
tributary flows within the subbasin and irrigation return flows. The
amount of salt that flows out of this subbasin plays an important role
in the subsequent utilization of the water and land downstream.
CHAPTER VII

APPLICATION OF THE HYDRO-SALINITY
MODEL TO THE SEVIER-SIGURD SUBBASIN

The general hydro-salinity model discussed in the previous chapters is applied to a particular basin through a verification procedure, whereby the value of certain model coefficients is established for a particular prototype system. Under the verification procedure the model is first calibrated by adjusting certain system coefficients until computed functions at points of measurement closely approximate observed values in the prototype at corresponding points. Some of the parameters which are established by the calibration procedure represent initial conditions which exist at the beginning of the time period being modeled. Thus, these coefficients will change with different beginning periods for a study. Other coefficients represent fixed basin characteristics and therefore will remain unchanged over an indefinite period.

For models based on a monthly time increment, it is customary to calibrate over a period of from two to three years, using outflow rates as the fitting function. The validity of the model is then tested with a set of independent data. The two steps of calibration and testing comprise model verification, sometimes called validation.
Evaluation of the model coefficients can follow any desired pattern, whether it be random or specified. In the model of this study each unknown system coefficient is assigned an integer number of identification, and upper and lower bounds. The first randomly-selected coefficient is permitted to vary within the specified bounds, while all other variables remain at their original value halfway between the upper and lower bounds. The coefficients are varied within the bounds by taking the value halfway between the original value and the lower bound for the second iteration. For each iteration the value of the summation of differences squared between computed and observed output values is compared with its value in the previous iteration. If a higher summation of differences squared is obtained in the second run, the lower bound is set at the original value and the process is repeated. If lower summation of differences squared is obtained, the upper bound is set at the original value and the process is repeated. When the change in the value becomes so small that it no longer affects the overall summation of differences squared by a predetermined amount, the program leaves the coefficient at its new value and moves on to the next randomly-selected coefficient. The calibration subroutine shown by Figure C.2 and the random number generator of Figure C.5 are the working components of the self-calibration process.

Some problems were encountered by the calibration subroutine becoming held up on local minimums. In these cases, local minimums were avoided by introducing operator input to the model.
Calibration of the hydrologic model of this study was based on three years of prototype data. Figure D. 1 includes lists of the input data for the hydrologic model. Each month is given a number depending on when it occurs in chronological order. The monthly input values shown by the figure include surface inflow, canal diversions, precipitation, mean monthly air temperature, correlation coefficient for estimating ungaged surface inflow rates, subsurface inflow, correlation coefficient for estimating subsurface inflow rates, and change in reservoir storage.

Figure D. 2 includes monthly data on the internal processes that are taking place within the hydrologic system of the subbasin. The first two columns indicate the month number and month of the year for which the following values are computed. The remaining columns respectively are snowmelt, infiltration to the groundwater basin, crop evapotranspiration, phreatophyte evapotranspiration, water surface evaporation, quantity of water entering soil moisture storage, surface return flow, soil moisture content, quantity of water in snow storage, and total water outflow.

Figure D. 3 presents data on monthly outflows from the subbasin. The first two columns of this table indicate the month number and the month of the year for which the following values are computed or measured. The remaining columns respectively are measured surface outflow, computed surface outflow, subsurface outflow, amount of water returning to the stream due to agricultural groundwater, non-gaged
surface inflow, the quantity of water entering the subbasin as subsurface inflow, correlation coefficient for estimating unaged subsurface inflow rates, change in reservoir bank storage, overland flow, and the quantity of water entering the groundwater system below the irrigated lands.

Model output rates for both water and salt from the Sevier-Sigurd subbasin were compared to the measured output rates. A graph of the computed and measured hydrologic outflows is shown by Figure 7.1 for the years of 1964, 1965, and 1966. These model years represent a dry year, a wet year, and an average year.

The second step in the model verification process, namely testing, was accomplished by modeling events for the 1970 calendar year. Graphs of the measured and computed hydrologic outflow rates from the Sevier-Sigurd subbasin are shown by Figure 7.2, and lists of the hydrologic model input and output data for this year are shown in Figures D.4, D.5, and D.6.

Recently Hill et al. (1970) published a report which presents a self-calibrating model similar to the hydrologic model developed in Chapter III. A different approach was used, however, for the self-calibrating procedure. To further test the coefficients established for the Sevier-Sigurd subbasin, the input data were prepared and fed into the model of Hill et al. (1970). The values of the coefficients as established by the Hill model were essentially the same as those found by the model of this study. These results tended to confirm that an optimum calibration was achieved rather than a local minimum.
Figure 7.1. Measured and computed outflow rates of the Sevier-Sigurd subbasin, 1964-1965-1966.
Figure 7.2. Measured and computed outflow rates, 1970.

Figure 7.3. Measured and computed salt weight outflow rate, 1970.
Salinity data needed for proper calibration of the Sevier-Sigurd subbasin model were not available, and it was therefore necessary to establish water quality sampling stations at the inflow and outflow stream gaging points of the subbasin. Weekly samples were taken at these points for a period of eleven months, and the resulting data were used to estimate mean monthly salinity concentrations. These inflow and outflow salinity concentration data are shown in Appendix F. The computer program used to calculate the mean monthly salinity concentrations from the weekly data is shown in Appendix E.

These salinity data were input to the salinity model developed in Chapter IV and calibration of the model over the year 1970 was accomplished. Figure D.7 shows the measured input and output salinity concentrations for the eleven months and as estimated for the twelve-month period. Figure D.8 presents on a monthly basis the salt inflow by weight and salt outflow by weight for the subbasin. The first column indicates the month number. The remaining columns are, respectively, the computed outflow salt concentration (ppm), the measured outflow salt concentration (ppm), the natural salt loading in the subbasin (tons), subsurface salt outflow (tons), ungaged surface salt inflow (tons), salt leaving the basin as a result of groundwater return flow from agriculture (tons), computed salt outflow (tons), measured salt outflow (tons), salt leaving the subbasin as a result of agricultural surface return flow (tons), estimated subsurface salt inflow (tons), and percentage of the inflowing Sevier River that circulates through the groundwater basin and is
associated with the natural salt loading phenomenon. The computed and measured salt weight outflow rates for 1970 are shown by Figure 7.3.
CHAPTER VIII

SUMMARY AND CONCLUSIONS

With increasing demands on our available water resources, efficient planning and management techniques are essential. Any upstream use of water will affect the quantity, quality, and time distribution of the flow at any downstream point. The complex interrelations and variable nature of the hydrologic and salinity flow systems make proper prediction of these changes difficult. However, the advent of modern high-speed computers has made possible the application of simulation techniques to complex systems of this nature.

In this report, a general hydrologic and salinity model is developed and programmed on the electronic hybrid computer. The basis for the model is a fundamental and logical mathematical representation of the various hydrologic and salinity flow processes.

Computer simulation of the hydro-salinity flow systems has many practical applications in the areas of research, project planning, and water management. In research the model is capable of providing clear insight in the functioning and relative importance of various system processes. In practical use, the model can provide rapid evaluations of the effects of various management alternatives upon the entire system. These alternatives might include such variables as watershed treatment, the construction of storage reservoirs, and changes in irrigation practices within a basin.
In this study, the hydrology and salinity model was applied to the Sevier-Sigurd subbasin of the Sevier River drainage in central Utah. The model was calibrated for this basin by adjusting model coefficients until close agreement between computed and measured surface water and salt outflow rates was obtained. A self-calibration procedure was developed and incorporated into the model as a subroutine. Reasonable agreement was achieved between observed and computed output functions of both water and salt. However, the field data available for model verification were very limited, and as further data become available, the model can be improved in terms of accuracy.

The model presented by this thesis represents a particular phase in the development of the simulation model of the hydrologic and salinity flow systems for the entire Sevier Lake drainage. The general applicability and utility of this approach has been demonstrated, and the remaining subbasins will be modeled as more data become available.
REFERENCES


APPENDICES
APPENDIX A

1. Snow Melt Equation

\[ Sm = Ws(I-1) - Ws(I) \]

in which \( Sm = \) snow melt rate

\[ Ws(I) = Ws(I-1) \exp \left( -Ks \left( T_a - 32 \right) \right) \]

\( T_a = \) mean monthly surface air temperature in °F

\( Ws = \) equivalent water storage in the snow pack

2. Rain Overland Flow Equation

in which \( OLF = (P - Pr)Cr; P \geq Pr \)

\( OLF = 0.0; \ P < Pr \)

\( OLF = \) Rate of water entering the stream as overland flow

\( P = \) Precipitation in any one time increment, t

\( Pr = \) Maximum infiltration rate into the soil

\( Cr = \) A constant which represents the area which the precipitation is taking place

3. Snow Overland Flow Equation

\( OLF = (SM - SM_r)Cs; SM \geq SM_r \)

\( OLF = 0.0; \ SM < SM_r \)

in which \( SM = \) snow melt in any one time increment, t

\( SM_r = \) Maximum infiltration rate into the soil;

\( Cs = \) A constant which represents the area which the snow melt is taking place

4. Ungaged Surface Inflow Rate

\[ Q_{ng} = Q_g \left( C_{sc} \right) \]

in which \( Q_{ng} = \) Flow of the ungaged streams for a particular time increment
Appendix A (Cont.)

\( Q_g \) = Flow of some local gaged stream for the same time increment

\( C_{sc} \) = A constant which relates the number unaged streams and their relative size

5. Evaporation Rate

\[ ET_{w+p} = Kc(0.173Ta^2 \frac{P}{100} - 0.314Ta \frac{P}{100}) \]

in which \( ET_{w+p} \) = Evaporation from water surface and evapotranspiration from phreatophytes

\( Kc \) = modified Blainy-Criddle coefficients for water surface or Phreatophytes

\( Ta \) = Mean monthly air temperature

\( P \) = Monthly percentage daylight hours of the year

6. Irrigation Efficiency

\[ IE = 100 \frac{Wdr}{WEF} \]

in which \( IE \) = Water conveyance and application efficiency in percent

\( Wdr \) = Rate at which diverted water enters the soil through seepage and infiltration

\( Wtr \) = Total rate at which water is diverted from the stream

7. Agricultural Surface Return Flow Rate

\[ AR = (1.0 - IE) ID \]

in which \( IE \) = Irrigation efficiency

\( ID \) = Irrigation diversions

\( AR \) = Rate of agricultural surface return flow
Appendix A (Cont.)

8. Soil Moisture Storage at Any Time, t

\[ MS(t) = (F_r - ET_r - G_r - N_r) \ dt \]

in which \( F_r \) = Infiltration rate
\( Ms(t) \) = Water in root zone storage at time, t
\( ET_r \) = Evapotranspiration rate
\( G_r \) = Deep percolation rate
\( N_r \) = Interflow rate

9. Deep Percolation

\[ G_r = \text{WES-ET}; \ Ms(t) = Mcs \]
\[ G_r = 0.0. ; (0 \leq Ms(t) \leq Mcs) \]

in which \( Mcs \) = Maximum moisture capacity of the root storage zone

10. Evapotranspiration Rate

\[ ET_r = \frac{Ms}{Mes} k_c (0.0173 \ \text{Ta}^2 \ p - 0.314 \ \text{Ta}^0)_{100} \ (0 \leq Ms \leq Mes) \]

in which \( k_c \) = Crop coefficient which represents plant physiology and stage of growth
\( Mes \) = Limiting root zone available moisture content below which actual evapotranspiration becomes less than the potential rate
\( p \) = Monthly percentage daylight hours of the year
\( ET \) = Rate of water evaporated or transpired from plants

11. Change in Reservoir Bank Storage

\[ S_b = \frac{1}{C_b} R - \frac{1}{K_b} \int S_b \ dt \]

in which \( S_b \) = the change in reservoir bank storage during time period t to t-1
\( C_b \) = A constant relating the fraction of change in reservoir that goes into bank storage
Appendix A (Cont.)

\[ R = \text{Change in reservoir storage during time period } t \text{ to } t-1 \]
\[ \frac{1}{Kg} = \text{A constant} \]

12. Total Hydrologic Outflow Rate
\[ S_0 = DLF + Q_g + Q_{ng} + AR + Q_{sbng} - Wtr - ET_{w+p} \]
\[ \pm R \pm S_b \]
in which \( S_0 \) = Total hydrologic outflow rate
\( Q_{sbng} \) = Nongaged subsurface inflow rate

13. Subsurface Outflow Rate
\[ S_{B0q} = S_0 \times A(14) \]
in which \( S_{B0q} \) = Subsurface outflow rate
\( A(14) \) = fraction of total outflow rate that leaves as subsurface outflow

14. Salt Volume Inflow Rate
\[ S_{Vgi} = C_{gi} \times Q_g \times \text{CONF} \]
in which \( S_{Vgi} \) = Salt Volume Input rate by gaged surface stream (inches)
\( C_{gi} \) = Measured salt concentration of gaged surface inflow in ppm
\( \text{CONF} \) = A constant relating Tons/inch to ppm

15. Deep Percolating Salt
\[ G_{rs} = Gr \times A(18) \times \text{CONF} \]
in which \( G_{rs} \) = Salt deep percolation rate
\( A(18) \) = Average salinity concentration of groundwater basin through which deep percolation water returns to the stream
Appendix A (Cont.)

16. Water Interchange with Groundwater Basin

\[ \text{PERC} = A(24) \times Qg^{-A(25)} \]

in which \( \text{PERC} \) = Fraction of water in influent channel that interchanges with the groundwater basin

\( A(24) = \) A constant

\( A(25) = \) A constant
APPENDIX B

INPUT DATA SEQUENCE REQUIRED
FOR HYDRO-SALINITY MODEL

Figure B.1

**Input Listing**

I Read Control Card

1 = Yes 0 = No

FORMAT (8I5)

A. Optimize water program
B. Salt program included
C. Optimize salt program
D. Number of months to be modeled
E. Reservoir model included
F. Subsurface inflow correlation to be used
G. Number of water coefficients to be optimized
H. Number of salt coefficients to be optimized
I. Starting integer for random number generator

II Read Subbasin Characteristics

FORMAT (4F10.2)

A. Acres irrigated land in subbasin
B. Acres phreatophytes in subbasin
C. Acres water surface in subbasin
D. Amount of snow storage at the beginning of the period being modeled

III Read Conversion Factors

FORMAT (6F10.4)

A. FAC2  One divided by the largest change in reservoir storage during any one time increment
B. FAC3  One divided by the largest subsurface inflow correlation during any time increment
C. FAC4  One divided by the largest potential E.T. or the largest amount of irrigation water and precipitation during one time increment
Figure B.1 (Cont.)

D. FAC5 One divided by the largest subsurface inflow during any time increment

E. DFSM = MCS The field capacity of the root storage zone

F. VAR The smallest change between integration of summation of differences squared that will be accepted before optimization moves on to the next randomly selected coefficient

IV Read in monthly constants for subbasin

FORMA T (2X, 4F10.2)

A. PDH(1-12) Monthly percentage daylight hours of the year

B. KC(1-12) Kc values for Blainy-Criddle equation for crops

C. KCP(1-12) Kc value for Blainy-Criddle equation for phreatophytes

D. KCW(1-12) Kc value for Blainy-Criddle equation for water surface

V Read Subbasin Input Values

FORMAT (12, 2X, 2F6.2, 9F7.0)

A. MO(1-NI) Month

B. P(1-NI) Precipitation occurring during that month

C. T(1-NI) Mean monthly temperature occurring

D. CDD Canal diversion (Acre-ft.)

E. SINN Surface inflow (Acre-ft.)

F. WOO Surface outflow (Acre-ft.)

G. SCZ Stream correlation stream (Acre-ft.)

H. SBINN Subsurface inflow (Acre-ft.)

I. DEL Change in Reservoir storage (Acre-ft.)

J. SBS Subsurface inflow correlation stream (Acre-ft.)

K. MDD Municipal and industrial diversions (Acre-ft.)

L. MRQ Municipal and industrial return flow (Acre-ft.)
Appendix B (Cont.)

Figure B.1 (Cont.)

VI Read Initial Condition for Groundwater
FORMAT (8F10.0)

A. QGR(1-8) Estimate of Agricultural groundwater for the first eight months (inches)
B. QSB(1-8) Estimate of subsurface inflow for first eight months (inches)
C. QSBIC(1-8) Estimate of subsurface inflow correlation for first eight months (inches)

Only When Optimizing Model

VII Read Coefficient Limits
FORMAT (17F10.4)

A. UP(1-17) Upper limits to be set on the various water coefficients See coefficient list
B. LOW(1-17) Lower limits to be set on the various water coefficients See coefficient list

Only When not Optimizing Model

VIII Read Coefficients
FORMAT (17F10.4)

A. A(1-17) Water coefficients for the model

Salt Model Input

IX Read Subbasin Input Salinity Values
FORMAT (4F7.0)

A. CINC(Month) Salt concentration of surface inflow
B. COT(Month) Salt concentration of surface outflow
C. TC(Month) Salt concentration of nongaged surface inflow
Read in Only When Optimizing Salt Model

X Read Coefficient Limits
FORMAT (8F10.0)

A. UP(18-25) Upper limits to be set on the various salt coefficients See Coefficient List
B. LO(18-25) Lower limits to be set on the various salt coefficients See Coefficient List

Read in Only When Not Optimizing Salt Model

XI Read Coefficients
FORMAT (8F10.0)

A. A(18-25) Salt coefficients for the salinity model See Coefficient List
### Figure B.2  Typical Listing of Input Data

<table>
<thead>
<tr>
<th>SEVIER - SIGURD SUB BASIN</th>
<th>MODEL YEAR</th>
<th>1970</th>
</tr>
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<td>.85</td>
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<td>163</td>
<td>553</td>
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| 60.0 | 1.25 | 1.30 | 0.00 | 800.00 | 600.00 | .175 | .10
Figure B.3  

Coefficients Set by  
Model Verification  

Water Program

A(1) 1/Kg Agricultural Groundwater smoothing coefficient
A(2) 1/Kg Subsurface inflow water smoothing coefficient
A(3) Smoothing function on inflow and outflow from reservoir bank storage, driving function smoothed is change in reservoir storage
A(4) Ks Constant in the snowmelt equation
A(5) Threshold value for overland flow due to rainfall
A(6) Constant associated with the overland flow from rainfall. Relating the amount of land from which overland flow is coming
A(7) Threshold value for overland flow due to snowmelt
A(8) Constant associated with overland flow from snowmelt. Relating the amount of land from which overland flow is coming
A(9) Irrigation Efficiency: The percent of the water from the total diverted for irrigation that enters the soil root zone
A(10) Constant representing the percent of the nongage surface inflow correlation stream which is nongaged surface inflow.
A(11) Constant representing the percent of the subsurface inflow correlation stream that is subsurface inflow
A(12) A Constant relating the rate of inflow to bank storage in a reservoir
A(13) A constant relating the rate of outflow from bank storage in a reservoir
A(14) Percent of total outflow from a subbasin that leaves as subsurface outflow
Figure B.3 (Cont.)

A(15) Time delay (months) on agricultural groundwater
A(16) Time delay (months) on subsurface inflow or subsurface outflow from the basin upstream
A(17) Time delay (months) on subsurface inflow correlation

Salt Model

A(18) Salt concentration (ppm) of Agricultural groundwater
A(19) A factor that relates the salinity of the canal diversions to the salt concentrations of the surface inflow
A(20) The factor that relates the salinity of the surface return flow to the salinity surface inflow
A(21) Salt concentration of overland flow
A(22) Salinity of the groundwater interchange where natural salt loading occurs
A(23) The salinity of the groundwater aquifer through which the subsurface inflow correlation water enters the subbasin
A(24) The intercept of 1 on Log-Log plot to predict the percent of flow that interchanges with the natural salt loading aquifer
A(25) The slope of the straight line on Log-Log paper to predict percent of the flow that interchanges with the natural salt loading aquifer
Figure C.1. Subroutine Submodel.

SUBROUTINE SUBMDL, UTD, E, X, R, Q, W, D, B, S, C, T

C

SUBROUTINE SUBMDL (UTD, E, X, R, Q, W, D, B, S, C, T)

C

SUBROUTINE SUBMDL (E, X, R, Q, W, D, B, S, C, T)

C

SUBROUTINE SUBMDL (E, X, R, Q, W, D, B, S, C, T)

C

SUBROUTINE SUBMDL (E, X, R, Q, W, D, B, S, C, T)

C

RETURN

END

Figure C.2. Submodel Subroutine.

SUBROUTINE SUBMDL, UTD, E, X, R, Q, W, D, B, S, C, T

C

SUBROUTINE SUBMDL (UTD, E, X, R, Q, W, D, B, S, C, T)

C

SUBROUTINE SUBMDL (E, X, R, Q, W, D, B, S, C, T)

C

SUBROUTINE SUBMDL (E, X, R, Q, W, D, B, S, C, T)

C

RETURN

END
Appendix C (Cont.)

Figure C.6. Subroutines to Operate Analog Computer.

C
SUBROUTINE FOR OPERATING ANALOG IF LOW DETECTED
SUBROUTINE SPAM(3)
DIMENSION 44(3)
1 CALL OPLRS (ITEST,IERR)
IF (ITEST .EQ. 1200) GO TO 3
GO TO 1
2 CALL OPR129(N)
4 CALL OPLRD (ITEST, IERR)
IF (ITEST .NE. 1200) GO TO 3
GO TO 4
R CALL OREDR (44, 8, 3, IERR)
CALL OBR (IERR)
RETURN
END

C
SUBROUTINE FOR OPERATING ANALOG IF HIGH DETECTED
SUBROUTINE SPHH(3)
DIMENSION 44(3)
1 CALL OPLRS (ITEST,IERR)
IF (ITEST .EQ. 1200) GO TO 2
GO TO 1
2 CALL OPR129(N)
4 CALL OPLRD (ITEST, IERR)
IF (ITEST .NE. 1200) GO TO 3
GO TO 4
3 CALL OREDR (44, 8, 3, IERR)
CALL OBR (IERR)
RETURN
END

Figure C.6 Subroutines to Operate Analog Computer
Appendix C (Cont.)

Figure C.7 Analog Computer Program
null
### Appendix D (Cont.)

**Figure D.7.**

<table>
<thead>
<tr>
<th>WELL NUMBER</th>
<th>SALT MODEL INPUT</th>
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<tr>
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<td>973</td>
<td>790</td>
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<tr>
<td>3</td>
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<td>436</td>
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<tr>
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<td>243</td>
<td>192</td>
</tr>
<tr>
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<td>752</td>
</tr>
<tr>
<td>6</td>
<td>598</td>
<td>498</td>
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<td>598</td>
<td>498</td>
</tr>
<tr>
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</table>

**Figure D.8.**

<table>
<thead>
<tr>
<th>WELL NUMBER</th>
<th>SALT MODEL INPUT</th>
<th>SALT MODEL OUTPUT</th>
</tr>
</thead>
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<td>1,529</td>
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<tr>
<td>2</td>
<td>973</td>
<td>790</td>
</tr>
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<td>510</td>
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<tr>
<td>4</td>
<td>243</td>
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<td>7</td>
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<td>752</td>
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<tr>
<td>8</td>
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<tr>
<td>9</td>
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<td>752</td>
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<td>498</td>
</tr>
<tr>
<td>12</td>
<td>508</td>
<td>408</td>
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</tbody>
</table>
### Appendix D (Cont.)

Figure D.9. Coefficients Set for Sevier-Sigurd Subbasin

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>1964-65-66</th>
<th>1970</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(1)</td>
<td>1/Kg Agricultural Ground-water smoothing coefficient</td>
<td>0.1900</td>
<td>0.1900</td>
</tr>
<tr>
<td>A(2)</td>
<td>1/Kg Subsurface inflow water smoothing coefficient</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A(3)</td>
<td>Smoothing function on inflow and outflow from reservoir bank storage</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>A(4)</td>
<td>Ks Constant in the snowmelt equation</td>
<td>0.175</td>
<td>0.175</td>
</tr>
<tr>
<td>A(5)</td>
<td>Threshold value for overland plow due to rainfall</td>
<td>3.25</td>
<td>3.25</td>
</tr>
<tr>
<td>A(6)</td>
<td>Constant associated with the overland flow from rainfall</td>
<td>0.5005</td>
<td>0.5005</td>
</tr>
<tr>
<td>A(7)</td>
<td>Threshold value for overland flow due to snowmelt</td>
<td>1.300</td>
<td>1.300</td>
</tr>
<tr>
<td>A(8)</td>
<td>Constant associated with the overland flow from snowmelt</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>A(9)</td>
<td>Irrigation Efficiency</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>A(10)</td>
<td>Constant representing the % of nongaged surface inflow correlation stream that is nongaged surface inflow</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>A(11)</td>
<td>Constant representing the % of subsurface inflow correlation stream that is subsurface inflow</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>A(12)</td>
<td>A constant relating the rate of inflow to bank storage in a reservoir</td>
<td>0.0275</td>
<td>0.0275</td>
</tr>
<tr>
<td>A(13)</td>
<td>A constant relating the rate of outflow rom bank storage in a reservoir</td>
<td>0.0275</td>
<td>0.0275</td>
</tr>
</tbody>
</table>
### Value | Description | 1964-65-66 | 1970
--- | --- | --- | ---
A(14) | Percent of total outflow from a subbasin that leaves as subsurface outflow | 0.110 | 0.110
A(15) | Time delay (months) on agricultural groundwater | 7.0 | 7.0
A(16) | Time delay (months) on subsurface inflow | 0.0 | 0.0
A(17) | Time delay (months) on subsurface inflow correlation | 4.00 | 4.00
ICms | Initial condition on root zone storage (inches) | 6.00 | 4.50
ICbs | Initial condition on rate of inflow or outflow from bank storage | +0.25 | +0.25
ICAG | Initial conditions on the deep percolation waters | 0.00 | 0.0857
ICSS1 | Initial conditions on the rate of subsurface inflow | 0.00 | 0.00
ICsc | Initial conditions on the rate of subsurface inflow correlation waters to the basin | 0.4000 | 0.00
Kgsc | Smoothing function on the rate of subsurface inflow correlation waters to the basin | 0.6187 | 0.6187

**Salt Model**

A(18) | Salt concentration (ppm) of agricultural groundwater | 600 | 600
A(19) | A factor that relates the salinity of the canal diversions to the salt concentration of surface inflow | 1.25 | 1.25
Appendix D (Cont.)

Figure D.9. (Cont.)

<table>
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<th>Value</th>
<th>Description</th>
<th>Value 1964-65-66</th>
<th>Value 1970</th>
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</thead>
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<td>A(20)</td>
<td>A factor that relates the salinity of surface return flow to the salinity of surface inflow</td>
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<td>1.30</td>
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<tr>
<td>A(21)</td>
<td>Salt Concentration of overland flow</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A(22)</td>
<td>Salinity of the groundwater interchange where natural salt loading occurs</td>
<td>700.0</td>
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</tr>
<tr>
<td>A(23)</td>
<td>The salinity concentration of the groundwater aquifer through which the subsurface inflow correlation waters enter the subbasin</td>
<td>600.0</td>
<td>600.0</td>
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<tr>
<td>A(24)</td>
<td>The intercept of 1 on Log-Log paper to predict percent of flow that interchanges with the natural salt loading aquifer</td>
<td>.47</td>
<td>.47</td>
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<tr>
<td>A(25)</td>
<td>The slope of the straight line on Log-Log paper to predict the flow that interchanges with the natural salt loading aquifer</td>
<td>.16</td>
<td>.16</td>
</tr>
</tbody>
</table>
VITA
Duane R. Jensen

Candidate for the Degree of
Master of Science

Thesis: Hybrid Computer Modeling of the Hydro-Salinity Flow System Within a River Basin

Major Field: Civil Engineering

Biographical Information:

Personal Data: Born at Richfield, Utah, July 19, 1947, son of Hal D. and Althalia M. Hatch Jensen; married Cynthia Cowley September 1, 1967; one daughter--Nicole.

Education: Attended elementary school in Antimony, Utah; graduated from Piute High School in 1965; received the Bachelor of Science degree at Utah State University in 1970; completed requirements for the Master of Science degree at Utah State University in 1972.