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Surface water and groundwater interactions in a surficial aquifer in Northwest Iowa

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SURFACE WATER AND GROUNDWATER INTERACTIONS IN A SURFICIAL AQUIFER IN NORTHWEST IOWA

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Surface water and groundwater interactions in a surficial aquifer in Northwest Iowa

by

Hossein Arfa

A Dissertation Submitted to the
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CHAPTER I. INTRODUCTION

Surface and groundwater interaction, in general, is composed of those physical relationships that govern the occurrence, source, quantity, quality, movement and some other cause and effect relations for this phenomenon. More specifically, it is a part of the science of hydrology that measures the circulation of water through the atmosphere, to the ground surface and then to underground layers of the earth. Since the circulation of water through this path (the hydrologic cycle) is so interrelated in time and space, it is not really possible to distinguish a clear division between any two coincident spaces. Therefore, the study of the movement of water in each space necessitates the consideration of other spaces and their interactions with the space of interest.

Water is a very important element for living creatures as well as for industries, and its essence as a scarce resource urges an overall study for allocation among competing uses. Basically, in such a case, scientific, engineering and management studies are conducted to find the best alternative for a specific use of water.

Scientific study includes both field and laboratory observations and their assembly for formulating a verbal explanation or constructing a model to define the interrelated phenomena. In other words, science leads to definition of natural laws.

Engineering attempts include the application of scientific laws so that a particular objective can be achieved. The laws that science provides for a water resource system are used by engineers to achieve some utility or objective. As a matter of fact, the utilization of groundwater requires a solution of hydrologic relationships which define the interaction of surface and groundwater. Engineering studies usually deal with development, transportation, reliability, cost, maintenance and the like for the existing water resources of a region.

Finally, a management study includes the allocation of the resource so that maximum benefit is accrued, or minimum cost is achieved for development and utilization. For example, in the case of groundwater, the management study will define what type of distribution system should be chosen, how many wells are needed, what should be the water quality through treatment, and how an operational system is to be scheduled.

The system of surface water and groundwater interactions is a relatively broad area of hydrology, so that a simple concept may not be capable of covering all elements, yet still keep a reasonable amount of accuracy. Dealing with groundwater alone, many elements are involved, such as surficial aquifers, deep bedrock aquifers, confined or unconfined aquifers, karstic or sandy layers, etc. Each of these characteristics requires specific attention. Therefore, depending on the type of study, it must be stated what the objective of the research is and how far should the researcher go to accomplish the task.

The objective of this research is to evaluate a surficial aquifer and its interaction with surface runoff, with an objective of constructing a general mathematical model to respond to these interrelations. Although this type of work is deterministic in principle, based on the probabilistic laws of the nature, the influence of the natural laws on prediction also has been studied. Therefore, a part of this research effort has been dedicated to this evaluation. To evaluate the application of probabilistic laws to surficial groundwater fluctuations, a study of the sequential variation of rainfall in Northwest Iowa was conducted. Rainfall variations were defined, from dry-dry to wet-wet sequences. Obviously, the interaction between surface water and surficial groundwater is a complicated phenomenon, and a strong tool is needed. The best tool for this situation, to be both practical and reliable, is the use of mathematical models. For this reason, a mathematical model (hydromodel) was adopted, and adjustments and testing of this model in a real basin in Northwest Iowa was accomplished. The basin selected for study is the Floyd River Basin, above Alton, which has the approximate geometry and dimensions of a unit model of interest. Full emphasis is put on recharge concepts of surficial groundwater in the basin, and the capability of the aquifer to withstand temporary mining or overdrafting to meet the beneficial water use requirements of the basin.

The text of this dissertation includes the essential scientific theories and definitions, results obtained, and considers the practical laws of interactions with necessary discussion. Also, in the last chapter, appropriate conclusions, recommendations and advice for continuing the research to reach other goals are presented.

Area Under Study

Regional aspects

The area under consideration for this study consists of 12 counties in Northwest Iowa, as shown on Figure 1 (after U.S.G.S.). This region was chosen as a "water short" area of the state on the basis of hydro-

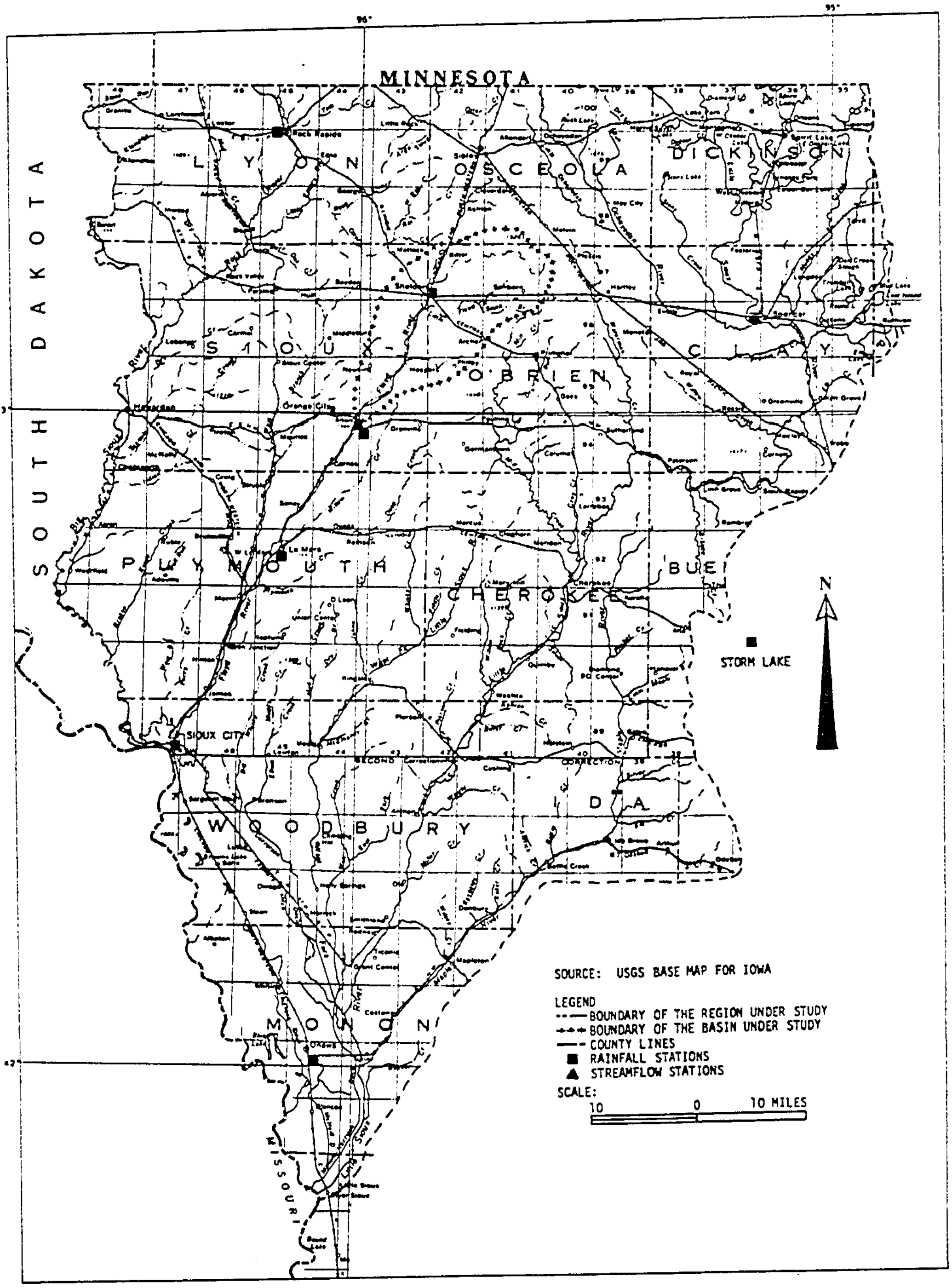


Figure 1. The map of the area under study

meteorological considerations. It does not necessarily comply with the division of the state done by the climatological office of the U.S. National Weather Service. Indeed, the river basin area under study covers 12 counties fully or partially (the eastern counties of the region share the area partially as Figure 1 shows), and includes the areas of Northwest and West-Central Iowa as labeled by the state office.

Although some supplementary meteorological studies were done in this research study for the entire region, research emphasis was given to a smaller area. The basin selected for detailed study is the Floyd River Basin at Alton, Iowa, as listed in the U.S. Geological Survey Water Supply Papers. This particular basin was selected in order to develop a usable model of the hydrologic cycle that would be representative of the region. The intensity of the effort required for such model development necessitated the adoption of a smaller river basin, compared to the 12-county region.

The Floyd River Basin at Alton has a 265-square mile drainage area and is located in the northwest Iowa counties of Osceola, Sioux and O'Brien. Figure 1 depicts the boundary of the basin.

The lack of precise or complete data for treating a complex hydrosystem does not limit the investigation towards the development of a mathematical model, if the model is constructed in terms of variable parameters. The parametric model can be adjusted and "fine tuned" following its initial development in a verification phase, so the output will conform to the data available. Therefore, the research started on the basis of actual field data, using available data for the area as necessary to develop a basic model utilizing monthly data. Once developed, it was then subjected to adjustment.

Information of a general nature will help to identify the area under study, and is presented in the following sections.

Geology

The region under study is mostly overlaid by Iowan drift and partially by Cary-Mankato drift (eastern part of the region). The general stratigraphical features of the region have been reported by the Iowa Geological Survey and the U.S. Geological Survey (78). Of course, some geological discontinuities might exist in some parts of the region. The I.G.S. geological column for the region shows that the Precambrian and Upper Devonian age rocks are found at a depth of about 650 ft below the surface. The Cretaceous Strata extend between the depths of about 640 to 70 ft. At the upper part of the Cretaceous system is the Dakota Formation that extends from the approximate depth of 280 ft upwards to a depth of 220 ft. The Graneros shale overlaying the Dakota Formation, extends from a depth of 220 to 160 ft and mainly consists of dark grey calcareous shale. Greenhorn limestone overlays the Graneros shale and extends from the approximate depth of 160 to 140 ft. Carlisle shale overlays the Greenhorn limestone, extending from an approximate depth of 140 to 70 ft and consists of dark grey, silty hard shale. From the depth of about 70 ft up to the surface, the strata of Pleistocene age occur, consisting of undifferentiated materials which were glacially deposited. This particular formation is of interest in this study because of the presence of shallow alluvial aquifers.

This stratigraphical classification as briefly described herein was researched by the IGS and USGS organizations by means of a natural gamma log obtained near Hawarden in Sioux County (78). This serves as a good representation of the area under study, and specifically for the basin under consideration.

For a precise material classification, appropriate for application in the proposed mathematical model, a more detailed geomorphological and geohydrological study is needed in the future.

Hydrometeorology

Information on climatology and hydrology for the area under study can be found in the climatological yearbooks (U.S. National Weather Service, formerly the U.S. Weather Bureau) and the U.S.G.S. papers (Water Resources Data for Iowa). Some other special publications are available such as "Drainage Areas of Iowa Streams" (75) and "Low-Flow Characteristics of Iowa Streams" (52). The best data base, collected from many sources for Northwest Iowa, is provided by Rossmiller (94). However, it is emphasized again that more precise measurements for refined application of the model developed in this research are needed to improve the verification and estimates made. More information about the input data used in the hydromodel development and testing phases will be introduced later in this text.

Statement of the Problem

Hypothesis

Northwest Iowa is a region which has little surplus water, insofar as surface runoff is concerned. Precipitation varies from 26-28 inches annually, and the annual streamflow is from 2 to 3 inches at most. Therefore, most of the precipitation infiltrates the soil profile and subsequently is being consumed in the evapo-transpiration process. The region does experience good agricultural yields from those soils having good soil moisture retention. The sandy, alluvial soils suffer under frequent drought stress.

The hypothesis being expressed and studied is that the shallow alluvial aquifers lying in the floodplains of the region can provide sustained yields of significant quantities of water _if_ they are temporarily mined (short-term overdraft) during the moderate to severe drought events, which occur about once in 10-20 years. The questions are (1) whether the depth of aquifer is sufficient; (2) is there enough water to supply farmsteads in the valley, regional rural water systems, communities, and also support crop irrigation on these alluvial soils?; and (3) will the shallow aquifer be fully replenished during wet years, e.g., will it recover?

These moderate to severe drought events may be 2 to 5 years in total length, and recovery of groundwater levels will depend on (1) precipitation, followed by infiltration and percolation from these precipitation events, and (2) seepage from the streams into the underlying alluvial sands and gravels. Therefore, the sequence of wet years required to recharge the system after several drought years with large withdrawals is of considerable importance in the planning and management of the water resource. Modeling the surface water and groundwater hydrology and evaluating the groundwater mining stress during drought periods are the major objectives of this thesis.

Objectives, then, are as follows:

1. Evaluate the sequence of wet and dry years on a probabilistic basis, determining moderate and severe drought sequences.
2. Characterize or normalize the valley floodplains and upland land surface areas into a characteristic pattern and size for the river basins in Northwest Iowa.
3. Develop an interconnected hydromodel which satisfies the water balance requirements, includes surface and groundwater hydrology and a groundwater extraction model which will permit testing the stated hypothesis.
4. Evaluate a characteristic river basin, verify the model and then apply the model developed in the study to a variable pattern of demands, including farmstead and community water supply, regional rural water use, irrigation of floodplain lands and possibly industrial use.

CHAPTER II. REVIEW OF LITERATURE

Hydrological Concepts

Historical review

Two schools of research have contributed in development of the theories in physical hydrology: (1) research on the basis of scientific formulation of hydrological phenomena; and (2) research to provide appropriate techniques for measurement of variables.

Fleming (39) has summarized the development of scientific and technological hydrology into four historical areas. These are described below.

First, the era of 3500 BC-1500 AD. This is the period of the early philosophy of primitive measurements and calculations. During this period, man was concerned about natural events. Experience and judgment were the basis for his investigations. This period was based on a "rule of thumb" approach.

Egyptians were possibly the earliest people who started the measurement of annual stages in the Nile River as early as 3000 BC. According to Biswas (13), water resources networks, conveying channels, and some other irrigation installations were developed by Egyptians between 3200-600 BC. The Persians invented the Kanat system which is still in operation in Iran today.

Some philosophers, such as Plato and Aristotle were aware of the hydrological cycle. Romans constructed their famous aqueducts. Hero (65-150 AD) stated the relationship between velocity, discharge and cross-sectional area. During this era, rain gages existed in India (4th century), Palestine (65-150 AD), China (1774 AD) and Korea (1441 AD). In summary, these ancient countries initiated the attempts to develop water works installations in this early stage. In addition to the above-mentioned devices, the Chinese water ladder, a device used for raising surface water to an increased elevation, is a good example of these attempts.

Second, the era of 1500-1800 AD. This is a period for motivation of developments for scientific hydrology. There had been a lack of improvement in the science of hydrology at the end of the previous era (200-1500 AD approximately). By the coming of Christ, human activities were directed toward moral and theological attempts. Therefore, a gap in scientific improvements occurred between the two eras. The motivation for renewal of scientific hydrology can be attributed to the attempts of Leonard da Vinci (1452-1519 AD), who used floats to measure stream velocity. This was an early form of modern flow-measurement techniques. Palissy (1510-1590 AD) and Kepler (1571-1630) consolidated the modern philosophy of the hydrologic cycle. In 1610, Santario introduced a primitive current meter. Later in 1682 Castelli introduced a way to measure rainfall, and in 1639 verified Hero's concept of the continuity principle (Q = AV). The first recording rain gage was introduced by Wren in 1663 and the important idea of a punched tape mechanism for the recording of rainfall pulses was developed by Hooke in 1678. He also introduced an improved current meter in 1683. Parallel to these physical measurement tools, remarkable improvement took place for mathematical calculation devices. John Napier produced a set of log tables in 1614 and his numbering rods in 1617 were an initiative for the modern slide rule. The concept of a calculating machine was introduced by Pascal (1642), and later in 1683 Leibniz improved this type of machine. The science of quantitative hydrology was born in

Europe in the 17th century in the shadow of measurement and calculation techniques. Development of the concept of the rainfall-runoff relationship is very much due to the efforts and experiments of Perrault (1674) and Marriotte (1686). Early concepts of evaporation are due to Halley, who conducted many experiments during 1687-1715, using evaporation meters. The science of hydrology and hydraulics progressed rapidly by the end of the 18th century. Bernoulli (1738) found pressure and velocity relationships; Franklin (1756) investigated oil film suppression on evaporation. Herberden (1769) found the relationship between rainfall and altitude. Chezy (1775) worked out a channel flow formula and Venturi (1797) studied the flow current through constrictions and expansions. The history of the science has recorded many other pioneers in this era. Interested readers may refer to other references.

Third, the era of 1800-1954. This period has significant importance in scientific hydrology. The concept of scale models characterized by Smeaton made a revolutionary development in tools for calculations. This period (19th and the first part of 20th century), was devoted to the improvement of calculation techniques, and a new technique named <u>component hydrology</u> was created. In 1812 Charles Babbage invented a machine to compute mathematical tables. He called this tool the difference machine. Later, in 1833 he modified his machine for more automatic operation by using perforated cards. Scheutz in 1834 followed Babbage's idea and improved the difference machine. In 1939, Aitken of Harvard University used the idea of Babbage and improved the cards developed by Hollerth in 1889 to produce the first form of the digital computer. A primary all-electronic computer called ENIAC, that was called a first generation computer by scientists, was produced by Eckert and Mauchley in 1943. The first memory computer was produced at Cambridge University in 1949 on the basis of the Newman concept discovered in 1946. The invention of transistors by Bardeen and Bratain in 1948 has improved the first generation computers, and the production of commercial computers began about 1951.

It is not possible to enumerate all hydrological tools and their development during the period in this review. However, the following events are important due to their reference to the subject.

Smith (1827) developed a theory considering the geologic principles of groundwater. In 1856 Darcy presented his famous theory in groundwater. Mulvaney, in 1851 presented the rational formula ($Q = CIA$), which is still in use for urban design purposes. Also, Dickens in 1865 introduced a flood formula of the type $Q = CA^n$ which is still in use in modern engineering practice. During this period, statistical methods in hydrology began to spread. Hazen introduced the concept of synthetic streamflow in 1914 as a contribution to stochastical hydrology. Foster applied theoretical frequency curves to engineering in 1924. Gumbel, in 1941, defined the extreme value theory in frequency analysis. Bernard, in 1944 investigated the relationship between meteorology and floods. There are many other scientists who studied and improved the science of hydrology. Outstanding were the efforts of Linsley, et al., for applying electronic techniques to flood routing studies. In 1951 Kohler and Linsley developed the coaxial correlation techniques in hydrology which was very important in the practical approach to flood forecasting, and usable in flood routing. The effort of Manning (1889), for his famous formula on flow in natural channels is well known. Jervis (1836) in snow surveys, Planck (1900) in theory on black body radiation, Harton (1915) and Angstrom (1919) in theories of snowmelt processes and many other researchers made highly valuable contributions to the advancement of scientific hydrology in this period. A part of the progress made in scientific hydrology can be attributed to the efforts of the U.S. Geological Survey, in providing a wealth of streamflow data for analytical work as well as other studies conducted by USGS researchers who applied theories to real world situations.

Fourth, the era of 1954 to the present. This period is named the period of philosophy of interaction of integral hydrology and the computer era. Prior to this period, fundamental techniques in statistics, system engineering and analysis, stochastic and deterministic simulation were formed. Considerable advancement had been made in the knowledge of component hydrology and further progress is being made today. The advent of third generation computers (large high-speed stored-memory) provided an opportunity for the rapid advancement in technology including hydrology. During this period, hydrology as a science was being related to other disciplines, such as economics, the social and political sciences together with some other sciences tied with hydrology. The interaction of different disciplines with modern hydrology opens a new era of scientific hydrology named water resources. That is, for a proper design, operation and forecasting a water system, a multitude of sciences is essential. For more information about historical review on hydrology, one can refer to George Fleming's "computer simulation techniques in hydrology" (39) as well as other publications given in the List of References (13, 50, 79).

Present methods in data evaluation

A water resource study consists of a comprehensive evaluation of sources that contribute to a system. In other words, to design a system, one should consider the most important dominant factors that affect the system. Arthur Maass, et al. (79), state that the methodology of a system design involves four related steps as follows:

1. defining the objective of the design,
2. translating the objectives into the design criteria,
3. making a plan for a particular water resource system on the basis of these criteria, and
4. evaluating the consequences of the plan developed for the system.

Apart from the overall study of a system, data evaluation is a vital part of each study. In engineering as well as management sciences, analysis is based upon the observations of the events. The analyst or engineer should understand the process so that he can make a hypothesis about the system or develop a model for it. Since probabilistic laws govern many hydrologic processes, modeling a hypothesis must involve these probabilistic components. Therefore, the analyst should be familiar with statistics and probability.

In the 18th century, "mathematical statistics" and "descriptive statistics" were developed. The former development deals with the error measurement, and the latter one deals with the tabular and graphical presentation of the data. Later, numerical analysis was used to summarize the processes. From those early days to the present time, as mathematical statistics grew, more powerful techniques for analysis were developed and applied to experimental data. One of these techniques is "statistical inference." Huntsberger and Billingsley (56) state this inference as follows: "As long as we refrain from making generalizations based on our calculated measures, we are only describing what we observed. But as soon as we make an inductive generalization, we have passed beyond description and have entered the realm of inference." Therefore, the statistical inference incorporates mathematical statistics with experimental evidences. This part of statistics is a very powerful technique which is characterized by drawing conclusions about a population or universe based on observed data drawn from it.

There are many theories available such as "set theory," "experiments and sample spaces," "total probability and Bayes theorem," "partitions," "finite sample spaces," "enumeration methods," "Markovian approach," "general sample spaces," and others, that can handle the problem of data evaluation based on a given situation. There is much information about these methods in statistics books and references. In this study, a particular type of enumeration method and the Markovian approach were applied to the precipitation data of northwest Iowa. A general brief description for these two methods (enumeration methods and Markovian approach) follows. It should be added that in the beginning of this research, conditional probability and the Bayes' theorem were attempted, but the results were not satisfactory, and the course of action was diverted to the following methods as will be seen in the body of the thesis.

Enumeration methods   Before representing these methods, a delineation of the nature of probability is needed. Probability is expressed as a ratio. The classical concept states that the probability of a particular event 'E' is the ratio of the number of ways in which that event can occur to the number of possible outcomes. Therefore,

$$P(E) = \frac{r}{n} \tag{1}$$

where: r is the number of ways that 'E' can occur, and

n is the number of possible outcomes.

This is an exact probability which occurs in a short series 'n' of trials. In a long series 'n' of trials, similarly, the relative frequency concept states that

$$P(E) \doteq \frac{r}{n} \tag{2}$$

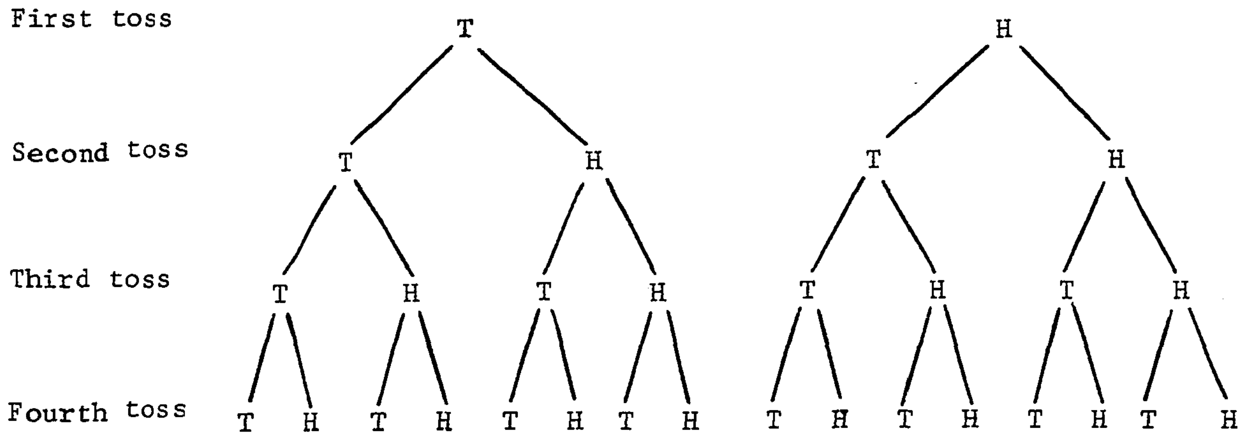
where the $\frac{r}{n}$ ratio is the approximate probability of event 'E' occurring 'r' times. Since $0 \leq r \leq n$, in either case $0 \leq P \leq 1$.

It is not easy to interpret the extremes of the probability range. What do P(E) = 0 and P(E) = 1 mean? The answer to the question depends on the type of concept which we are working with. In the classical concept, P(E) = 0 states that the event is impossible, whereas in relative frequency concept it does not necessarily mean that the event is impossible. In the relative probability concept, P(E) = 0 means only that it has not occurred during the conduct of the experiment. Similarly, in the classical concept, P(E) = 1 states that the occurrence of the event is certain whereas in the case of relative probability concept, we are not sure about the certainty of the event occurring. We can simply say that it has occurred in all of the trials so far. Consequently, in a long series of repeated trials, the approximate probability of an event is the proportion of times that the event can be expected to occur.

The branch of probability (in statistics) originates from the idea presented in the above paragraph. There are many methods elaborated to define, measure and verify the probability in different cases. The science of statistics deals with different approaches and technologies for more advanced cases. In the meantime, the principal work involves the methods by which we should get inquiries about 'r' and 'n.' There are some sophisticated counting schemes to find the value of 'r' and 'n' in an experiment and define the ratio of r/n as possible outcome for a particular event 'E.' Enumeration methods are used in the early mathematics courses. The following methods are used in this procedure, provided the sample space is already understood.

<u>Tree diagram</u> Suppose a true coin is to be tossed four times. All the possible paths for outcomes are shown below. There are $(2)^4 = 16$ possible outcomes, easily obtainable from a tree diagram as follows:

$$\underset{1}{TTTT},\ \underset{2}{TTTH},\ \underset{3}{TTHT},\ \ldots\ldots\ldots\ldots\ldots\ldots,\ \underset{16}{HHHH} \qquad (3a)$$



(3b)

Permutation One way used for enumeration method is permutation. A permutation is an arrangement of definite objects. Permutations differ from each other when the order of arrangements or their contents differ. For example, three objects 'a,' 'b' and 'c' can be arranged 2 by 2 in six different ways as follows:

ab, ba, ac, ca, bc, and cb

In general, from 'n' distinct objects, the permutations of 'r' objects are obtainable from the following formula

$$P_r^n = \frac{n!}{(n - r)!} \quad (r \leq n) \tag{4}$$

Combination Another way used for enumeration method is a combination. A combination is an arrangement of definite objects. One combination differs from another only if the content of the arrangement differs. For example, the combination of three objects 'a,' 'b' and 'c,' 2 by 2, gives only three arrangements as follows:

ab, ac, and bc

The following formula gives the number of arrangements of 'r' objects from 'n' objects:

$$C_r^n = \frac{n!}{r!(n - r)!} \tag{5}$$

Other important procedures in enumeration method are the "multiplication principle" (different sets 'A_k' each of which are arrangeable in 'n_k' different ways), and the "permutation of like objects" ('K' distinct classes of objects with nondistinct objects in each class).

For more information about these methods, one can refer to the mathematics and statistics references. Some of them are given in the list of references in this thesis (18, 54, 56). A special type of enumeration method used for rainfall analysis in this study is discussed in the following chapters.

Markovian approach to probabilistic evaluations The terms of 'probabilistic' and 'stochastic' will be used interchangeably hereafter in this thesis. Hillier and Lieberman (53) state the stochastic process as follows:

> "A Stochastic Process is defined to be simply an indexed collection of random variables (X_t), where the index 't' runs through a given set 'T.' Often 'T' is taken to be the set of nonnegative integers, and 'X_t' represents a measurable characteristic of interest at time 't.'"

One of the strongest tools for analyzing the stochastic process is the Markov Model. A Markov process is a special type of stochastic process having some particular Markovian properties. A Markov chain is a Markov Process with an enumerated (namely, finite or approaching infinity) number of states (26). A set of nonnegative integers or nonnegative real numbers is assigned to the time parameters. Therefore, we may have a discrete time parameter case or a continuous time parameter case. As a matter of fact, the definition of Markovian property is very restrictive, but in the case of a simple condition (discrete time parameter and finite-state space), a stochastic process $\{X_t\}(t = 0, 1, 2...)$ is said to be a finite state Markov chain if it has the following conditions [Hillier and Lieberman (53)].

1. A finite number of states,
2. The Markovian property,
3. Stationary transition probabilities,
4. A set of initial probabilities $P\{X_0 = i\}$ for all i.

A review of science history reveals that the Markov Process is named after A. A. Markov who introduced the concept in 1907 with a discrete parameter and finite number of states. Kolmogorov introduced the initial cases in 1936 and Doeblin improved the concept. Doob performed fundamental work on continuous parameter chains in 1942 and 1945, and Paul Levy in 1951 intuitively drew a comprehensive picture of the field.

Assume a stochastic process $\{X_t, t = 0, 1, 2....\}$, that is, a family of random variables, defined on the space $\mathfrak{X}$ of all possible values that the random variable can assume. The space $\mathfrak{X}$ is called the "state space" of the process, and the elements $x \in \mathfrak{X}$. The different values that X_t can assume are called the 'states.' Consequently, we have the state variable '$\mathfrak{X}$' and the time variable 't.' To have a simple discrete process, the following conditions should be met:

1. $X_o = x_o = 1.$
2. $P(x) = \mathscr{P}\{X_1 = x\}$, with $\sum_{n=0}^{\infty} p(x) = 1.$
3. The conditional distribution of X_{t+1}, given $X_t = j$, is the sum of j independent random variables, each having the same probability distribution as X_1.

A simple discrete process can be thought of as representing the growth of a population (population in this statement may refer to the statistical meaning of the word). That is, the integer valued random variable 'X_t' represents the number of individuals in the population in the generation. In order to study the sequence of X_o, X_1, X_2 .... some expression for probabilities that the population size has in (t + 1)th generation is needed. This expression of probability is thought to be a known population size in previous generations. Hence, we search the conditional probability

$$\mathscr{P}\{X_{t+1} = x_{t+1} | X_t = x_t,\ X_{t-1} = x_{t-1},\ \ldots\ldots\ldots\ X_o = x_o = 1\} \tag{6}$$

The process is called a Markov Chain if the structure of the stochastic process $\{X_t,\ t = 0, 1, 2 \ldots\}$ is such that the conditional probability distribution of X_{t+1} depends only on the value of X_t and independent of all previous values. Therefore, the more precise form of Markov chain is:

$$\mathscr{P}\{X_{t+1} = x_{t+1} | X_t = x_t\ \ldots\ldots\ X_o = x_o = 1\} = \{X_{t+1} = x_{t+1} | X_t = x_t\} \tag{7}$$

As mentioned before, one of the conditions in a finite-state Markov Chain is a stationary transition probability (condition No. 3). The transition probability P_{ij} gives the probability that the process will move from state 'S_i,' to state 'S_j' for every pair of states. As the process moves through any finite number of states, a set of probabilities describes the situation of the process. For the sake of simplicity, the transition probabilities are shown in a matrix form as follows:

$$P = \begin{bmatrix} P_{00} & P_{01} & \cdots\cdots\cdots & P_{0n} \\ P_{10} & P_{12} & \cdots\cdots\cdots & P_{1n} \\ \cdot & \cdot & \cdots\cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots\cdots & \cdot \\ P_{n0} & P_{n1} & \cdots\cdots\cdots & P_{nn} \end{bmatrix} \quad (8)$$

The elements of this matrix show the probability of going from state 'i' to state 'j' in the next step. Each row of this matrix sums to one and the elements of the matrix are positive. Therefore, each row is called a "probability vector" and the matrix itself called a "stochastic matrix." The above 'P' matrix is called a one-step transition probability whereas the n-step transition probability $P_{ij}^{(n)}$ can be found by the Chapman-Kolmogorov equations as follows [Hillier and Lieberman (53)]:

$$P_{ij}^{(n)} = \sum_{K=0}^{M} P_{ik}^{(\nu)} P_{kj}^{(n-\nu)} \text{ for all 'i,' 'j' and 'n' and } 0 \leq \nu \leq n. \quad (9)$$

The equations state that when the process moves from state 'i' to state 'j' in 'n' steps, it will be in state 'K' after exactly 'ν' steps, considering the condition of $0 \leq \nu \leq n$. This $P_{ik}^{(\nu)} P_{kj}^{(n-\nu)}$

represents the conditional probability that starts from state 'i' and the process moves to state k after 'ν' steps and then to state 'j' in $(n - \nu)$ steps. It can be proven that n-step transition probabilities are obtainable from one-step transition probabilities recursively. Consequently,

$$P^{(n)} = P.P.P. \;\ldots.\; P = P.P^{n-1} = P^2P^{n-2} = P^{n-1}P, \text{ etc.} \qquad (10)$$

There are many discussions and manipulations about the Markov chain. This thesis is not intended to provide the comprehensive mathematics of the Markov chain; however, for more information, one can refer to the books exclusively written about the theory and application of the Markov chain. Since this research uses the application of the transition matrix, it is advisable to give a brief description about some more important themes in the Markov chain. The list of references in this paper gives the name of several books related to the subject used for this discussion and useful for reviewing the topic (12, 26, 53).

<u>Derivation of transition probabilities</u> The heart of any Markov Chain model is its transition probabilities, noted as 'P_{ij}' previously. There are two approaches for derivation of transition probabilities: 1) conceptual derivation and 2) statistical estimation. Although in some cases parameters are obtained empirically, it is important to realize that in a mathematical model, the probabilities should be derived theoretically from a probability distribution. The general problem is a lack of suitable data showing individual properties of the variables. In this case, conceptual derivation of the transition

probabilities should be used. Analysis depends upon the criteria available and the ability of the analyst to derive a set of probabilities. Enumeration methods can be of help in this approach.

Statistical estimation is used where a detailed knowledge about the process is not available. In this case, the parameters must be statistically estimated from either aggregate occurrence data or from observations of individual movements between states. In some cases both approaches might be used as were used in this research. Again, the analyst is a decision-maker wanting to apply the best overall statistical method in this contest. The following theories of the Markov Chain are important and have been used for rainfall analysis in this study in certain ways.

First passage time In the Markov stochastic process, it is desirable to find out the number of transitions made by a process to move from state 'i' to state 'j' for the first time. Previous sections gave a discussion of the n-step transition probabilities. The length of time for moving from state 'i' to state 'j' for the first time is called the first passage. In particular conditions where i = j, the first passage is called 'recurrence time' for state 'i,' that is, the first passage time is just equal to the number of transitions until the process returns to the initial state 'i,' i.e., the first passage time is equal to the number of transitions until the process returns to the initial state 'i.' The transition probabilities define the relative frequency distributions of the process. The general equations for the first passage time from state 'i' to state 'j' are as follows (53):

$$\begin{aligned} f_{ij}^{(1)} &= P_{ij}^{(1)} = P_{ij} \\ f_{ij}^{(2)} &= P_{ij}^{(2)} - f_{ij}^{(1)} P_{jj} \\ &\vdots \\ f_{ij}^{(n)} &= P_{ij}^{(n)} - f_{ij}^{(1)} P_{jj}^{(n-1)} - f_{ij}^{(2)} P_{jj}^{(n-2)} \ldots\ldots f_{ij}^{(n-1)} P_{jj} \end{aligned} \tag{11}$$

These are very important equations because they enable one to compute the probability of a first passage time from state 'i' to state 'j' in "n-steps," using a one-step transition matrix. Three important features in Markov Chain probability distributions are:

1. Recurrent state is one where:

$$\sum_{n=1}^{\infty} f_{ii}^{(n)} = 1 \tag{12}$$

   The equation implies that once the process is in state 'i,' it will return to state 'i' again.

2. Absorbing state is one where $P_{ii} = 1$. This condition implies that when the process falls in absorbing state, it will never leave it again. Absorbing state is a particular case of 'recurrent state.'

3. Transient state is one where:

$$\sum_{n=1}^{\infty} f_{ii}^{(n)} < 1 \tag{13}$$

   The equation implies that once the process is in state 'i,' it will never return to state 'i' again on the basis of some positive probabilities.

Like other situations in probability measurement, the computation of '$f_{ij}^{(n)}$' for all n values is not easy, whereas it is relatively simple to compute the expected first passage time. The following set of equations gives the expected first passage time 'μ_{ij}' [Hillier and Lieberman (53)]:

$$\mu_{ij} = \begin{cases} \infty, \text{ if } \sum_{n=1}^{\infty} f_{ij}^{(n)} < 1 \\ \sum_{n=1}^{\infty} nf_{ij}^{(n)}, \text{ if } \sum_{n=1}^{\infty} f_{ij}^{(n)} = 1 \end{cases} \tag{14}$$

The μ_{ij} would satisfy uniquely the equation:

$$\mu_{ij} = 1 + \sum_{K \neq 1} P_{ik}\mu_{kj}$$

In general, when '$j = 1$,' μ_{ij} is called 'expected recurrence time.' If $\mu_{ij} = \infty$, the recurrent state is called 'null recurrent state' and if $\mu_{ij} < \infty$, the recurrent state is called a 'positive recurrent state.'

<u>Long run properties of Markov chain</u> One of the most important properties of Markov Chain is its 'steady-state probabilities.' That is, there is a limiting probability that the process will be in state 'j' after a long number of transitions. This probability is independent of the initial state. To reach the steady-state probabilities, a Markov Chain should be an irreducible and ergodic one. In this case it is possible to show that

$$\lim_{n \to \infty} P_{ij}^{(n)} = \pi_j \tag{15}$$

The following set of equations gives the π_j's [Hillier and Lieberman (53)]:

a) $\pi_j > 0$ (16a)

b) $$\pi_j = \sum_{i=0}^{M} \pi_i P_{ij}, \text{ for } j = 0, 1, 2 \ldots., M \tag{16b}$$

c) $$\sum_{j=0}^{M} \pi_j = 1 \tag{16c}$$

The relation between the steady-state probabilities and the expected recurrence time is:

$$\pi_j = \frac{1}{\mu_{ij}} \forall\, j = 0, 1, \ldots, M \tag{17}$$

That is, the π_j's are reciprocal of μ_{ij}'s. The set of equations for π_j's consist of (M + 2) equations in (M + 1) unknowns. Since it has a unique solution, one equation is redundant and can be deleted. It should be noted that the equation of

$$\sum_{j=0}^{M} \mu_j = 1 \tag{18}$$

is not redundant and should always be considered for system solution.

As has been mentioned already, there are many other properties for using the Markov Chain in handling stochastic processes. Among them the continuous Markov Chain parameter has many applications in mathematical programming, particularly in some queueing models. For a detailed description of the procedures, one should refer to appropriate references.

Other approaches for data evaluations There is a useful approach in mathematical programming to solving a system problem. The controversial "optimization techniques" (an additive term for other approaches for data evaluation) have made a revolutionary advent to conquer the dilemma involved for solution of multivariable problems in systems engineering. Since "systems engineering" is a kind of art and science approach, it depends on the systems engineer to devise a method for the best overall decision-making. "Systems analysis" or "operation research" performs the science part of systems engineering, whereas much of the art does not come from the texts; rather, it depends on the engineer who applies previous experience to obtain the best overall outcome. The term "optimal decision" has a deep philosophy in systems engineering, and it is obtainable through the use of optimization techniques. These optimization techniques can be viewed as a system with hundreds of equations and thousands of variables to be solved. While it may take days or years for a high-speed computer to obtain the best combination for decision-making, optimization techniques will offer the ways by which the same answer will be reached in a few minutes using an appropriate computer algorithm. The technique is based on elimination of many inferior combinations by inspecting the data.

Operations research is a valuable tool in mathematical programming today and has many applications in water-resource engineering. Systems engineers and scientists apply operations research methods such as "linear programming," "transportation programming," "queueing models," "nonlinear programming" models, etc. to solve a water-resource system and evaluate the economical, managerial, engineering, sociological and political consequences of a water-resource system. Since there is no room in this report to define these methods and illustrate their applications, the Appendix A gives a glossary of the important methods in mathematical programming that are in common use in water-system engineering. Also, the list of references presents some important books in water-system engineering (13, 50, 79), and the interested people are directed to the specialized articles written in appropriate journals such as the ASCE Technical Journals, AWRA Bulletin of Water Resources, etc.

Miscellaneous studies of northwest Iowa

In northwest Iowa, like any other part of the state and the nation, hydrologic data acquisition and research studies have been documented by administrative authorities and academic institutions. In the case of state and federal authorities, and the county and state level offices as well as the federal commissions, these programs have been carried out through legal and governmental channels. The results of these studies done by the counties, state (IGS) and federal (USGS, SCS and WB) authorities, contributed measurably to the development of the resources of the region. These agencies contributed in the area of data collection and processing, in addition to practical field research based on development pressures and needs. The results of their investigations are published annually and distributed as open file reports. This study and its model development were accomplished using their data, which were used directly or indirectly to develop the mathematical functions. References Nos. of (7), (20), (21), (27), (70), (74), (93), etc. of the reference list in this thesis give some of the important field research studies accomplished by state and federal agencies. Additional hydrogeological studies in northwest Iowa (78) were done recently by G. A. Ludvigson and B. J. Bunker of the IGS and add to the hydrogeological data base of the area. Their studies cover general geology, geological control on water availability, pumping tests, etc. for this region.

In addition to those published materials (96, 101, 102, 103, 115) given in the list of references in this thesis, an M.S. study accomplished by Michael Meyer (82), for the lower part of the Floyd River basin includes morphological, hydrogeological and hypothetical characterization of the aquifers. His study indicates that the saturated thickness of the sands and gravels within the thesis area (lower part of the Floyd River basin) varies between 0 to 80 ft. An average depth of 30 ft of alluvial material in the flood plain area was selected for the current study of the Floyd River basin. Some other assumptions such as the effective width of flood plain, hydraulic conductivity, etc. made for this study are based on his research report.

Although the current research effort is highly local and specific, the regional study efforts and results of Rossmiller (94) served as the foundation for the hydromodel work. His study includes a broad information base, gathering and processing of data for the region and a general mathematical model (goal programming approach for socio-economical trade-off in northwest Iowa). It can be cited as the initial comprehensive effort for mathematical modeling in the 12-county region. Indeed, this current hydromodel research is a continuation of his initiation of field research in a specific location. As far as academic research is concerned, the existing water and related land-use problems existing in the area along with the desired improvement and development of the area's resources, and hydromodels for defining the hydrologic cycle offer a challenge among researchers who seek appropriate research objectives. If this challenge continues, an expanded level of knowledge will be built up in years to come for this area of the state.

Fundamental Concepts and Equations of Groundwater Movement

Before advancing to the fundamental concepts and equations relating to groundwater movement, it is advisable to give a brief definition of theories involved in estimating soil moisture content. The amount of water existing in the soil profile is referred to as soil moisture. Soil moisture is replenished through infiltration. The term infiltration simply refers to the entry of water through the soil surface and into the soil profile. The dimension of infiltration is volume per unit of time per unit of area (inches per hour, etc.). There are some differences between infiltration, capillary movement conductivity and hydraulic conductivity, so the term infiltration should not be confused with the two latter terms. Infiltration is the sole source of soil moisture which provides the needed source of water to sustain the growth of vegetation through the evapotranspiration process and supplies the groundwater to wells, springs and also contributes partially to surface stream flow. The soil surface separates receiving rainfall into the direct overland flow and into the infiltration process. Some part of the water passes through the soil profile and replenishes the groundwater. The following definitions will help one to recognize some of the most important variables in soil moisture and groundwater movement.

1. Hygroscopic moisture is that of water in soil which is being held tightly on the surface of soil particles by adsorption forces.

2. Capillary moisture is that water in soil which is being held by forces of surface tension as continuous film around particles and in the capillary spaces.
3. Gravitational moisture is that water in the soil profile which can move freely under the gravity force and can be drained out of the soil.
4. Porosity is the percentage of the void spaces relative to the total volume of the soil.

Porosity may be divided into two types such as capillary porosity and noncapillary porosity. The porosity changes with soil structure and texture. To advance the discussion further toward the water movement in the soil, a recognition of soil moisture potential is also needed. The dimension of work per unit mass is used for the soil moisture potential. But the common expression for soil moisture potential is given in terms of the column of water that a given soil potential can hold. Sometimes it may be expressed by equivalent atmospheres of pressure. According to the available literature (99), the following list summarizes soil moisture potentials:

Soil moisture equilibrium point	Tension equivalent to		
	Cm of water	Ergs per gram	Atm.
Ovendry	10^7	$-\ 98{,}000 \times 10^5$	10,000
Wilting point	14,125	$-\ 138.524 \times 10^5$	14.125
Field capacity	501	$-\ 4.9098 \times 10^5$	0.501
Saturation	1	$-\ 0.00098 \times 10^5$	0.001

The following list gives the variation for different types of soil moisture:

Type of soil water	Tension equivalent to		
	Cm of water	Ergs per gram	Atm.
Hygroscopic water	$10^6 - 10^4$	$- 9800 \times 10^5$ — $- 98 \times 10^5$	1000 — 10
Capillary water	$10^4 - 10^2$	$- 98 \times 10^5$ — $- 0.98 \times 10^5$	10 — 0.1
Gravitational water	$10^2 - 1$	$- 0.98 \times 10^5$ — $- 0.0098 \times 10^5$	0.001
Saturation water equal or less than	1	$- 0.0098 \times 10^5$	0.001

5. Specific yield is the fraction or percentage of water which can ultimately be released from storage in a water table aquifer per unit horizontal area and per unit decline of the water table. This definition is used exclusively for discharging conditions. However, in the case of recharging conditions, the same definition is held except that the phrase "added to" and the word "rise" should be substituted for "released to" and "decline," respectively.
6. Coefficient of storage is a dimensionless number which is the ratio of the volume of the water that the aquifer releases from or takes into storage, to the unit volume of the aquifer. The unit volume of the aquifer in this case is a product of unit surface area by a unit decline or rise of head.

7. Permeability is the rate of flow of water in appropriate units (usually gallons per day) under a hydraulic gradient of 1 ft/ft through a cross-sectional area of one square foot at the predominant temperature of water.
8. Coefficient of transmissivity is the product of the coefficient of permeability by the entire thickness of the aquifer ($T = KD$). It is an indication of the capacity of an aquifer for transmitting the water through its entire thickness.

There are more intricate definitions about the naming of the water bearing strata and their classification, properties and boundaries. This study does not present all such definitions. However, the list of references gives some of the appropriate books and papers in this context (24, 55, 117).

Basic Equations in Groundwater Movement

In general, the movement of moisture in the soil is taking place in response to the potential gradient in accordance with the following equation:

$$V = - K \frac{d\phi}{dL} \tag{19}$$

which states that the rate of movement V is proportional to the potential gradient of $\frac{d\phi}{dL}$. In the above equation K is the soil conductivity, ϕ is the existing potential and the L is the distance along the path of the greatest change in potential. The negative sign indicates that movement occurs in the direction of the decreasing potential. A closer look at the above equation reveals the analogy between this equation and those of Ohm's law for flow of electricity and Fourier's law for flow heat. Therefore, to work out the appropriate relationship describing the groundwater movement, a broader knowledge of hydrodynamics and ability of mathematical manipulation is needed. From hydrodynamics, the Bernoulli and continuity equations should be considered in order to provide their application in the groundwater field. From a mathematical point of view, an ability of transformation and application of partial differential equations to the hydrodynamics equations is needed. Although some types of relationship for groundwater movement can be developed mathematically and theoretically, solutions may not be achieved. That is, there may not be a general analytical solution with which to solve the equations. The analyst should then go further and introduce a graphical or a numerical solution to the relationships. For this reason, the use of modern computer technology is sometimes essential, and it will make the numerical solutions practical.

As was mentioned earlier, two fundamental equations of hydrodynamics, namely, the Bernoulli and continuity equations, are widely used in groundwater movement. The familiar Bernoulli equation is

$$\frac{P_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + Z_2 + h_{L_{1-2}} \qquad (20)$$

and the familiar continuity equation as

$$Q = VA \qquad (21)$$

are combined to produce one of the most important and precious equations in groundwater movement called Darcy's equation. Although Darcy's equation is a universal equation in groundwater movement, it has also an equivalent importance in hydrodynamics for computation of the friction factor. Darcy, Weisbach and others have proposed the following equation to compute the friction loss in a flow path:

$$h_L = f \frac{LV^2}{d \cdot 2g} \tag{22}$$

In the Bernoulli equation, the segment $(P/\gamma + Z)$ is referred to as the piezometric head. A combination of Bernoulli and continuity equations leads to the Darcy equation as:

$$q = - \frac{K\gamma}{\mu} \frac{d}{dL} (P/\gamma + Z) \tag{23}$$

for a unit cross section.

Where: K = hydraulic conductivity of the soil, L/T

$\gamma = \rho g$ = specific weight of fluid, M/L^2T^2

μ = dynamic viscosity of the flowing fluid, M/LT.

The variable $(P/\gamma + Z)$ is a useful variable in practical cases because the depth of water in a piezometer is P/γ and Z is the elevation of the terminal point of the piezometer. Therefore, the level of the water in a piezometer is a direct indicator of the piezometric head. The term P/γ can be written in the form of $P/\rho g$ which includes the density of the fluid. In the general form of Darcy's law, ρ can be either a constant or variable. In the case of groundwater, it is usually assumed that ρ is constant.

Application of the Darcy's law to three-dimensional flow of an incompressible fluid through a porous medium with some assumptions and simplications, results in the derivation of Laplace's equations as follows:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \qquad (24)$$

This equation states that the second partial derivatives of the potential with respect to x, y, and z, sum to zero. Also, the Laplace's equation in groundwater describes steady flow in confined aquifers. This condition is frequently assumed in aquifer studies or frequently can be approximated with enough accuracy. Therefore, the condition applies to the situation where piezometric heads are not changing with time. The Laplace equation, which has broad application in physics and engineering works, has been studied by mathematicians and scientists, and sophisticated methods are available for its solution, particularly in the case of two-dimensional forms.

Derivation of Three-Dimensional Groundwater Movement

To derive the basic equation for groundwater movement, in Cartesian coordinates, the principle of conservative of mass and Darcy's law should be applied. The first step, for an infinitesimal volume of mass, say with dimensions of dx, dy and dz, the mass continuity equation is:

$$\int (\rho V) \cdot d\bar{A} = \frac{\partial(\rho S)}{\partial t} \qquad (25)$$

where: ρ = density of fluid, M/L^3

V = resultant velocity vector of directions x, y and z, L/T

$d\bar{A}$ = a vector representing the affected areas through which the flow is passing, L^2

S = volume of fluid existing in the space of dimensions dx, dy and dz, L^3.

Let's separate the V's and dA's into their preassumed directions of x, y and z. Equation (25) becomes as follows:

$$\int(\rho V_x)dA_x + \int(\rho V_y)dA_y + \int(\rho V_z)dA_z = \frac{\partial M}{\partial t} \qquad (26)$$

where: $M = \rho S$ and consequently ∂M will represent $\rho\partial S$ or $\partial(\rho S) = \partial M$.

According to the continuity equation, each element at the left side of Equation (26), produces a flow in the amount of dq. Therefore, in terms of mass:

$$(\rho V_x)dA_x = \rho dq_x,\ (\rho V_y)dA_y = \rho dq_y \text{ and } (\rho V_z)dA_z = \rho dq_z \qquad (27)$$

Considering the fact that flow is a product of velocity by the area normal to flow, we will come up with:

$$dq_x \cdot d_y \cdot d_z = Q_x \qquad (28)$$

Similarly,

$$dq_y \cdot d_x \cdot d_z = Q_y \text{ and } dq_z \cdot d_x \cdot d_y = Q_z \qquad (29)$$

taking into account all planes on the control volume (dx · dy · dz), $Q = Q_x + Q_y + Q_z$. The net rate of mass change would be $Q_{out} - Q_{in}$ or vice versa depending on the desired direction. This net change is equal to $-\frac{\partial M}{\partial t}$ if we desire the flow to be positive when mass is being depleted. In terms of mass flow rate, and for the limit condition, Equation (26) becomes:

$$[\partial(\rho dq_x \cdot dy \cdot dz) + \partial(\rho dq_y \cdot dx \cdot dz) + \partial(\rho dq_z \cdot dx \cdot dy)]$$
$$= -\frac{\partial M}{\partial t} \tag{30}$$

Multiplying the inside and outside of the bracket of the left side of Equation (30) by dxdydz, we will come up with

$$[\partial(\frac{\rho q_x}{dx}) + \partial(\frac{\rho q_y}{dy}) + \partial(\frac{\rho q_z}{dz})]dxdydz = -\frac{\partial M}{\partial t} \tag{31}$$

Inside the bracket, each term is subject to further simplification. That is,

$$\partial(\frac{\rho q_x}{dx}) = \rho\frac{\partial q_x}{\partial x} + q_x\frac{\partial \rho}{\partial x} \tag{32}$$

Since water is considered an almost incompressible fluid, the second term on the right side of Equation (32) is too small and can be dropped from the equation. This simplification will also take care of the barometric influences, so that Equation (32) will be simplified as follows:

$$\partial(\frac{\rho q_x}{dx}) \approx \frac{\partial}{\partial x}(\rho q_x) = \rho(\frac{\partial q_x}{\partial x}) = \rho[\frac{\partial}{\partial x}(q_x)] \tag{33}$$

Darcy's equation states that in a nonhomogeneous, anisotropic aquifer, $q_x = -K_x\frac{\partial h}{\partial x}$. Therefore, combining Equations (31) through (33) and rearranging them, we can come up with

$$[\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial y})] = \frac{\partial M}{\rho dxdydz(\partial t)} \tag{34}$$

The next step is to convert the mass flow into the equivalent value in terms of piezometric head (h). For this arrangement, the relations between volume of water (S), mass flow (M), storage coefficient (S_s) and the piezometric head (H) should be viewed.

The relation between mass flow and applied pressure is as follows (117):

$$dM = (dxdydz)[\phi\rho(\alpha p + \beta)dp] \tag{35}$$

where: ϕ = porosity in percent

αp = pore-volume compressibility factor, $L/M/T^2$

β = water compressibility factor, $L/M/T^2$

dp = pressure applied, M/LT^2

dx, dy, dz and ρ are as defined before.

The relation between applied pressure and piezometric head is as follows:

$$dp = \rho g dh \tag{36}$$

The relation between storage coefficient and the change in volume of water is as follows:

$$S_s = \frac{1}{dxdydz}\,\frac{ds}{dhp} = \rho g\phi(\alpha p + \beta) \tag{37}$$

where: ds = change in volume of water contained in considered unit volume of aquifer.

Combining Equations (35) through (37), we will come up with (considering the limit condition, of course):

$$\partial M = \rho(dxdydz)S_s\partial h \tag{38}$$

and finally substituting Equation (38) into Equation (34), we will get

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} = S_s \frac{\partial h}{\partial t} \tag{39}$$

To obtain Equation (39), another simplification has been taking place. That is, the differential term of $\frac{\partial}{\partial x}(k_x \frac{\partial h}{\partial y})$, for example, has been simplified into the form of $k_x \frac{\partial^2 h}{\partial x^2}$. This is fine, of course, if we had a one-dimensional condition. But in the case of a three-dimensional condition, this simplification can be made for three directions if and only if we have homogeneous media. Of course, from a practical point of view, this simplification is allowed. Consequently, Equation (39) is applicable for homogeneous and isotropic conditions. However, one more simplification allows us to write Equation (39) as follows:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{1}{k}(S_s \frac{\partial h}{\partial t}) \tag{40}$$

which theoretically should be used for homogeneous and isotropic conditions. If we set the left side of Equation (40) equal to zero, i.e.

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \tag{41}$$

we have introduced the Laplace's equation in the groundwater equation.

According to literature available, application of the three-dimensional groundwater equation can be appropriate. Laplace's equation applied to three-dimensional groundwater problems will define the steady flow in a confined aquifer. That is, the replenishment rate is just equal to the outflow rate. Since the relation between S_s, S and b (aquifer thickness) is

$$S = S_s b \tag{42}$$

the differential equation applied to the whole thickness becomes:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S}{kb}\frac{\partial h}{\partial t} \tag{43}$$

and introducing the transmissivity coefficient T = kb, the final equation will be

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S}{T}\frac{\partial h}{\partial t} \tag{44}$$

Equation (44) is the groundwater equation for Cartesian three-dimensional conditions. In some studies it may be needed to derive the groundwater equation for conditions other than the Cartesian condition, i.e., for spherical or cylindrical conditions. The procedure is the same except for the fact that the relevant coordinates must be considered. In many applications the groundwater hydrologists consider the aquifer to be of constant thickness and flow to be horizontal or parallel to the x-y plane. This assumption is referred to as two-dimensional groundwater planes, which is as follows:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{S}{T}\frac{\partial h}{\partial t} \tag{45}$$

Equation (45) describes groundwater movement in two-dimensional space and time. This equation has many applications in groundwater studies.

Furthermore, in nonconfined aquifers like that considered in this thesis (glacial shallow aquifer), we will not be concerned with aquifer thickness only. The height of water in the aquifer also should be considered. That is, instead of thickness, the equation should be derived in terms of elevation of water (H) in the aquifer. Following the differential equation principles and considering two-dimensional condition, the final equation will be (55):

$$\frac{K}{2}\left[\frac{\partial^2 (H^2)}{\partial x^2} + \frac{\partial^2 (H^2)}{\partial y^2}\right] = S \frac{\partial H}{\partial t} \tag{46}$$

which is the two-dimensional differential equation for unconfined groundwater flow under homogeneous and isotropic conditions. As will be seen later, a simpler form of equation (one-dimensional) was used in this study to develop the mathematical model for the system under study.

CHAPTER III. STOCHASTICAL AND PROBABILISTIC STUDIES "METHODOLOGY"

Rainfall-Runoff Analyses

As described previously, the science of statistics provides a way to estimate the probabilities of future hydrologic occurrences, no matter how mother nature creates the events. In other words, techniques available from the science of statistics provide an opportunity to the analyst to choose the best method for analyzing a given situation.

The normal way for treating a probabilistic case is to assume that the chance of an event occurring is known. The analyst then proceeds to define the rules that govern the situation by combining the events, or otherwise considering the results of a particular experiment. This analysis will lead to a conclusion that a certain sequence is more likely to occur than another. According to statistical studies, the relative deviation from the most probable result has a tendency to decrease when the number of trials increases.

Some cases in statistical studies are more or less controllable by conducting an experiment. For example, consider the outcome of tossing a coin or drawing a card from a deck of cards or even in more complex problems such as experimenting with the rate of birth and death in demographic studies. It seems that statistical rules have some types of control imposed on them. But the natural events in hydrology are not necessarily controlled to a high consistency by statistical rules. This difficulty becomes apparent when we realize that the actual data may not fit a theoretical distribution exactly, and it is frequently impossible to trace how or why the differences exist between the actual and theoretical. This is true in most probabilistic investigations. However, this should not discourage the analyst from attempting to obtain the best inference. One hopes to form a reasonable opinion about what is happening with natural events, provided the available techniques are being used in an appropriate way. Since hydrology events are of a random nature that will not be repeated exactly, the best overall results will be obtained if the most appropriate analysis is being used.

Methodology should be in accordance with the principles of scientific hydrology. Consequently, we should not limit ourselves to theoretical statistical consistency and seek a particular confidence limit. Rather, we should rely equally on various outcomes to represent boundary situations, etc. For this reason, in conducting a probabilistic study of the hydrological events included in this study, different ways were tried as far as applicable to this study, and the investigation was stopped when an overall reasonable answer or alternative answers were achieved. Of course, one should realize that the events studied are not the ultimate end. These events will continue along with the progress in hydrology and statistics as well, unless the natural laws in hydrology are defined precisely, which seems unlikely.

The statistical study for this chapter covers the following sections:

1. Stochastic analysis of the rainfall patterns in the region under study.
2. Statistical analyses for rainfall-runoff relationships

including two approaches as follows:

a. Curve number approach and

b. Regression analysis approach.

The following sections discuss the methodology that applies to the conduct of this part of the research. It should be added that these statistical studies led to an overall reasonable conclusion so that the results obtained helped to modify the hydrological mass balance model. This model will be called a hydromodel, and was developed to forecast the hydrological cause and effect behavior of the Floyd River basin at Alton, Iowa. The methodology applied in this research opens the door for further developments in this area that other researchers may pursue and improve. The following section deals with stochastical probabilities, which represent a challenge in the study of hydrological behavior.

Stochastical Study of Northwest Iowa Rainfall Cycles

Data for study

Out of 44 rainfall gaging stations available in the 12-county region under study, eight stations were selected for stochastical study. The ones selected were those that: (1) had the longest duration of record; (2) were evenly distributed over the region; and (3) had other hydrological data available, such as temperature and rainfall intensity. Figure 1, page 4, shows the location of these stations and Table 1 gives the name and the length of available record for them.

Table 1. Name, location, and the length of record for rainfall gaging stations under study

No.	Station	County	Years of record	
			Precipitation	Temperature
1	Rock Rapids	Lyon	82	29
2	Lake Park	Dickinson	62	64
3	Sheldon	O'Brien	23	64
4	Spencer 1N	Clay	21	64
5	LeMars	Plymouth	92	84
6	Storm Lake	Buena Vista	89	29
7	Sioux City WB AP	Woodbury	100	86
8	Onawa	Monona	90	23

Although at some of the stations there were relatively long periods of record, there also were some missing data for some years during the overall period of record. An attempt was made to fill in the missing data; however, the risk of introducing more error was cautiously avoided. That is, if the missing data were located among the first one-third of the record, that early part was dropped from the duration. This is the reason that the length of data which was considered for analysis is not the same as the values given in Table 1.

To choose the most appropriate method for analysis, several methods such as relative probabilities, mathematical expectations, Bayes formula, etc., were attempted. However, none of them were successful for this purpose. Finally, a combination of relative probability together with enumeration methods (see Chapter II) was used.

Method of analysis

As customary in certain statistical analyses, the mean and the standard deviation were selected as statistical variables for comparison. To divide the available data in appropriate groups, the following categories were established from annual precipitation data:

1. The precipitation depth which occurred in the range of (a) mean minus one standard deviation and (b) almost zero (trace), is considered to be dry-dry. In other words, those years experiencing such a depth of precipitations will be categorized as "dry-dry" years.
2. The years having a precipitation depth in the range of (a) mean minus one standard deviation and (b) mean minus one-third of standard deviation will be categorized as "dry" years.
3. The years having precipitation depth in the range of (a) mean minus one-third of standard deviation and (b) mean plus one-third of standard deviation will be categorized as "normal" years.
4. The years having a precipitation depth in the range of (a) mean plus one-third of standard deviation and (b) mean plus one standard deviation will be categorized as "wet" years.
5. The years having a precipitation depth in the range of

(a) mean plus one standard deviation and (b) larger depths (as large as may have occurred), will be categorized as "wet-wet" years.

Figure 2 shows the range of variations for defined limits.

These limits were chosen to provide about the same number of events in each category for the period of record. The results were satisfactory. However, a more extensive statistical study might be conducted to define other limits. Having decided on these limits, some preliminary work was needed for proper arrangement to ease computer application to obtain the transitional probabilities. The use of "SAS" (Statistical Analysis System) package, available in the ISU Computation Center, was advantageous. Since there was not a unique "SAS" program available to perform all needed computations, an additional algorithm was written. This combined program categorizes the precipitation events in accordance with the assigned limits ("dry-dry" through the "wet-wet" ranges) and gives the monthly and annual transitional matrices as well. Due to hydrological data and time limitations, the monthly transitional probabilities were obtained by comparing consecutive months. In the case of annual events, the interannual occurrences were considered.

Computerized Table 2a gives the categorized monthly and annual precipitation values for the Spencer station where: DD, D, N, W and WW represent the "dry-dry," "dry," "normal," "wet" and "wet-wet" categories, respectively. Computerized Tables 2b through 2l give the computed monthly transitional matrices and Table 2m represents the annual transitional matrix for this station. Since there are 84

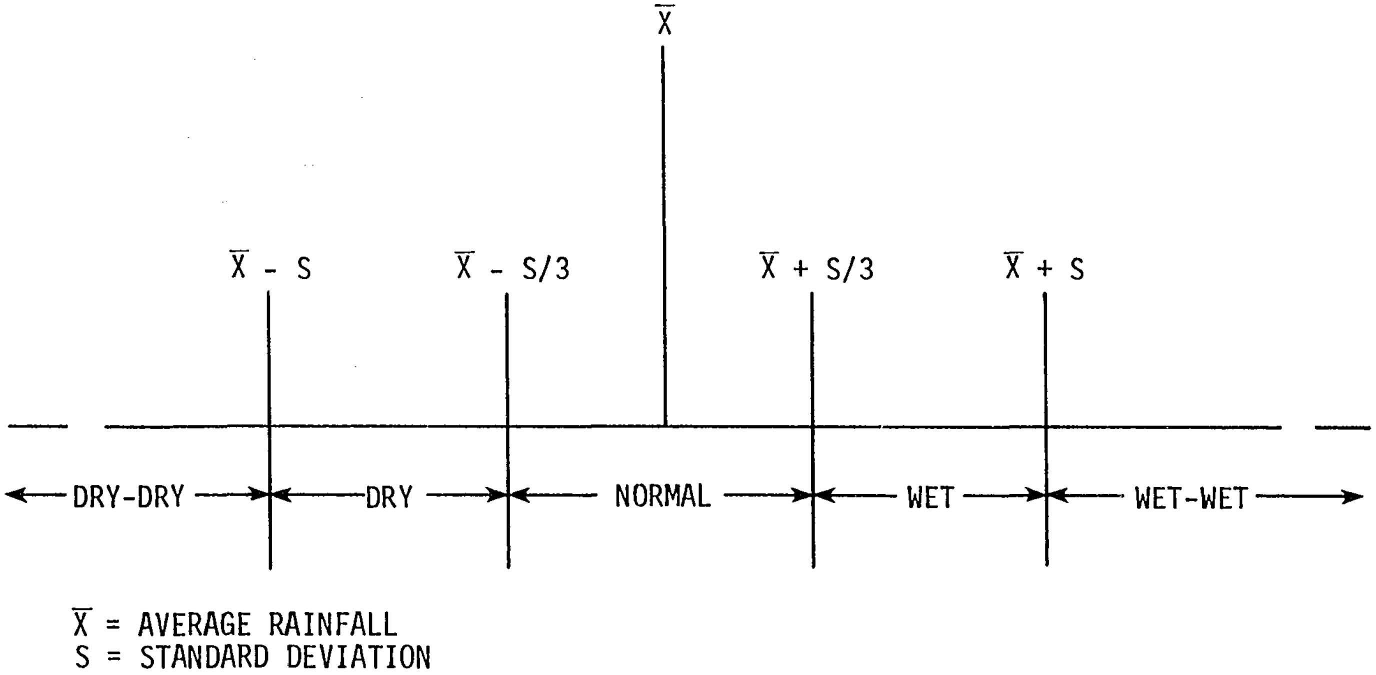


Figure 2. Range of variations for defined limits of the precipitation

Table 2a. The categorized monthly and annual precipitation values for the Spencer station, northwest Iowa

RAINFALL DATA FOR SPENCER NORTHWEST IOWA 11:25 THURSDAY, FEBRUARY 14, 1980 3

OBS	YEAR	M1	JANUARY	M2	FEBRUARY	M3	MARCH	M4	APRIL	M5	MAY	M6	JUNE	M7	JULY	M8	AUGUST	M9	SEPT	M10	OCTOBER	M11	NOVEMBER	M12	DECEMBER	M13	ANNUAL
1	1919	0.30	D	2.60	WW	0.81	D	4.61	WW	3.47	N	6.36	WW	4.17	W	2.06	D	4.09	N	1.28	D	2.90	WW	0.40	D	33.05	W
2	1920	0.42	D	0.40	D	3.20	WW	4.34	WW	3.82	N	2.01	DD	5.55	W	4.83	W	3.57	N	2.12	N	2.18	W	0.85	N	33.29	W
3	1921	0.30	D	1.30	W	0.93	D	2.26	N	5.38	W	2.02	DD	0.75	DD	3.50	N	4.16	W	1.08	D	0.73	D	0.45	D	22.86	D
4	1922	1.10	W	0.40	D	0.76	D	4.17	WW	1.23	DD	1.32	DD	4.95	W	5.55	W	0.96	D	2.15	W	4.15	WW	0.15	DD	26.89	N
5	1923	0.60	N	0.70	N	1.65	N	3.21	W	2.66	D	4.66	N	0.57	DD	5.20	W	4.12	N	1.34	N	0.12	DD	0.72	N	25.55	D
6	1924	0.40	D	0.90	N	2.45	W	0.93	DD	1.46	DD	4.75	N	0.69	DD	5.49	W	4.72	W	0.28	DD	0.29	D	1.50	WW	23.86	D
7	1925	1.06	W	1.22	W	0.74	D	1.70	D	0.33	DD	3.55	D	1.75	D	2.41	D	7.87	WW	1.75	N	0.74	D	1.45	WW	24.57	D
8	1926	1.10	W	0.39	D	0.72	D	0.64	DD	3.51	N	3.53	D	6.45	WW	2.56	D	9.69	WW	0.59	D	1.44	N	2.03	WW	32.65	W
9	1927	0.16	D	0.98	N	1.70	N	6.60	WW	5.02	W	1.84	DD	0.47	DD	2.09	D	5.62	W	0.59	D	0.64	D	1.52	WW	27.23	N
10	1928	0.17	D	1.20	W	1.55	N	2.12	N	3.91	N	5.45	W	1.48	D	6.04	WW	1.66	D	1.74	N	1.23	N	0.60	D	27.15	N
11	1929	1.60	WW	1.32	W	1.09	D	3.20	W	2.05	D	2.19	DD	2.30	D	2.03	D	3.80	N	2.30	W	1.41	N	0.42	D	23.71	D
12	1930	0.92	W	0.35	D	0.29	DD	2.91	N	4.31	W	2.48	D	0.32	DD	2.77	D	3.35	N	1.28	D	2.50	WW	0.13	DD	21.61	DD
13	1931	0.17	D	0.05	DD	0.97	D	1.56	D	2.47	D	3.38	D	2.00	D	4.38	W	5.83	WW	3.35	WW	3.69	WW	2.38	WW	30.23	W
14	1932	2.40	WW	0.94	N	1.48	N	1.24	D	4.24	W	2.53	D	2.43	D	4.30	N	2.34	D	1.28	D	1.33	N	0.53	D	25.04	D
15	1933	0.83	N	0.50	D	3.77	WW	0.79	DD	1.53	DD	0.59	DD	5.04	W	4.06	N	3.26	N	0.98	D	0.68	D	1.30	W	23.33	D
16	1934	0.74	N	0.13	DD	0.86	D	1.97	D	0.24	DD	7.80	WW	5.47	W	2.83	D	3.04	N	1.57	N	2.43	WW	0.58	D	27.66	N
17	1935	0.60	N	1.02	N	1.34	N	3.13	W	2.63	D	6.28	W	3.88	N	3.12	N	1.94	D	2.25	W	0.67	D	1.61	WW	28.47	N
18	1936	1.38	WW	2.22	WW	1.16	D	0.55	DD	3.48	N	3.21	D	0.60	DD	4.41	W	2.90	N	1.45	N	0.64	D	1.26	W	23.26	D
19	1937	1.75	WW	0.38	D	2.09	W	3.32	W	6.41	WW	5.16	W	1.05	DD	7.28	WW	2.20	D	2.71	W	0.29	D	1.11	W	33.75	WW
20	1938	0.49	D	1.08	N	1.51	N	2.89	N	6.08	WW	5.39	W	4.84	W	1.31	DD	12.00	WW	0.65	D	1.28	N	0.73	N	38.25	WW
21	1939	0.88	W	1.52	W	0.57	D	1.20	D	2.79	D	4.52	N	2.74	N	6.94	WW	0.49	DD	1.17	D	0.03	DD	0.41	D	23.26	D
22	1940	0.40	D	1.14	N	1.49	N	3.58	W	1.27	DD	7.53	WW	1.55	D	3.36	N	0.09	DD	2.99	WW	2.02	W	1.07	W	26.49	N
23	1941	1.04	W	0.50	D	1.24	N	3.52	W	2.02	D	7.49	WW	2.75	N	1.71	D	6.43	WW	3.19	WW	3.18	WW	1.14	W	34.21	WW
24	1942	0.40	D	0.83	N	2.07	W	0.47	DD	7.14	WW	5.78	W	4.13	W	4.04	N	3.33	N	0.76	D	0.87	D	1.10	W	30.92	W
25	1943	0.94	W	0.62	D	1.56	N	0.91	DD	4.67	W	8.92	WW	5.31	W	4.08	N	1.18	D	1.68	N	1.66	N	0.07	DD	31.60	W
26	1944	1.03	W	0.85	N	1.50	N	1.56	D	4.78	W	5.97	W	5.69	WW	8.71	WW	2.02	D	0.47	DD	1.00	N	0.13	DD	33.71	WW
27	1945	0.45	D	1.21	W	1.58	N	2.86	N	4.95	W	6.29	W	3.61	N	1.66	D	1.59	D	0.07	DD	0.32	D	1.76	WW	26.35	N
28	1946	0.16	D	0.74	N	3.12	WW	1.42	D	4.56	W	3.56	D	1.05	DD	2.40	D	3.56	N	3.03	WW	2.91	WW	0.47	D	26.98	N
29	1947	0.82	N	0.16	DD	0.22	DD	4.70	WW	2.87	D	5.12	W	1.83	D	0.45	DD	4.87	W	3.28	WW	3.17	WW	0.65	N	28.14	N
30	1948	0.05	DD	1.31	W	0.37	DD	3.39	W	3.16	N	5.61	W	3.35	N	3.03	N	0.76	DD	1.57	N	1.74	W	0.62	D	24.96	D
31	1949	1.73	WW	0.38	D	1.58	N	1.41	D	4.43	W	4.43	N	2.97	N	2.35	D	4.89	W	1.23	D	0.01	DD	0.40	D	25.81	N
32	1950	0.68	N	0.47	D	0.94	D	1.18	D	3.21	N	3.02	D	6.42	WW	0.69	DD	3.18	N	0.97	D	0.24	D	0.35	D	21.35	DD
33	1951	0.51	N	2.63	WW	4.29	WW	5.07	WW	5.17	W	6.82	WW	6.77	WW	6.52	WW	3.59	N	1.74	N	0.33	D	0.71	N	44.15	WW
34	1952	1.66	WW	0.43	D	1.55	N	1.19	D	2.73	D	4.24	N	3.90	N	4.44	W	0.95	D	0.00	DD	0.52	D	0.36	D	21.97	D
35	1953	0.77	N	1.36	W	2.94	WW	3.33	W	1.91	D	7.75	WW	2.27	D	3.39	N	0.98	D	0.46	DD	1.46	N	1.03	W	27.65	N
36	1954	0.20	D	1.81	WW	1.67	N	3.18	W	3.20	N	7.85	WW	3.16	N	6.65	WW	2.62	N	3.99	WW	0.19	DD	0.26	DD	34.78	WW
37	1955	0.27	D	1.19	W	0.34	DD	2.63	N	1.83	D	3.26	D	4.68	W	0.60	DD	1.80	D	1.31	D	0.27	D	0.80	N	18.98	DD
38	1956	0.59	N	0.35	D	0.85	D	1.81	D	2.63	D	2.67	D	4.22	W	5.62	W	0.38	DD	1.29	D	2.74	WW	0.33	D	23.48	D
39	1957	0.16	D	0.23	D	1.29	N	0.79	DD	5.84	WW	4.47	N	2.18	D	3.45	N	2.72	N	2.72	W	2.61	WW	0.46	D	26.92	N
40	1958	0.34	D	0.27	D	0.46	DD	3.22	W	1.27	DD	3.77	N	2.17	D	1.13	DD	0.78	DD	0.17	DD	0.63	D	0.20	DD	14.41	DD
41	1959	0.29	D	1.59	W	2.14	W	0.73	DD	11.40	WW	3.24	D	0.17	DD	3.65	N	3.47	N	1.92	N	1.77	W	1.75	WW	32.12	W
42	1960	0.73	N	0.49	D	1.40	N	2.47	N	6.99	WW	2.22	DD	3.80	N	3.43	N	4.02	N	0.59	D	1.03	N	0.90	N	28.07	N
43	1961	0.20	D	2.27	WW	3.67	WW	1.65	D	3.41	N	1.51	DD	6.26	WW	1.95	D	4.04	N	1.47	N	0.77	D	1.10	W	28.30	N
44	1962	0.32	D	3.11	WW	1.68	N	1.13	D	2.85	D	6.10	W	6.87	WW	5.59	W	1.71	D	1.02	D	0.39	D	0.25	DD	31.02	W
45	1963	0.56	N	0.77	N	1.31	N	1.05	D	2.20	D	2.92	D	4.93	W	2.31	D	2.15	D	2.28	W	0.04	DD	0.45	D	20.97	DD
46	1964	0.36	D	0.06	DD	1.05	D	4.45	WW	3.94	N	3.73	N	6.00	WW	4.62	W	8.77	WW	0.69	D	0.27	D	1.24	W	35.18	WW
47	1965	0.56	N	1.74	WW	2.70	WW	3.59	W	5.15	W	2.10	DD	1.54	D	4.15	N	7.96	WW	0.61	D	0.68	D	0.47	D	31.25	W

Table 2a. Continued

RAINFALL DATA FOR SPENCER NORTHWEST IOWA 11:25 THURSDAY, FEBRUARY 14, 1980 4

OBS	YEAR	M1	JANUARY	M2	FEBRUARY	M3	MARCH	M4	APRIL	M5	MAY	M6	JUNE	M7	JULY	M8	AUGUST	M9	SEPT	M10	OCTOBER	M11	NOVEMBER	M12	DECEMBER	M13	ANNUAL
48	1966	0.60	N	0.59	D	0.80	D	1.54	D	3.04	N	2.39	D	2.00	D	2.71	D	0.78	DD	1.65	N	0.10	DD	0.79	N	16.99	DD
49	1967	0.95	W	0.32	D	0.41	DD	2.93	N	3.35	N	7.92	WW	0.45	DD	0.89	DD	0.44	DD	1.24	D	0.20	D	0.76	N	19.86	DD
50	1968	0.54	N	0.13	DD	0.22	DD	2.41	N	2.45	D	3.06	D	5.90	WW	2.35	D	6.83	WW	4.67	WW	0.54	D	1.29	W	30.39	W
51	1969	1.44	WW	1.77	WW	1.47	N	1.34	D	5.05	W	7.73	WW	7.54	WW	6.03	WW	1.41	D	2.48	W	0.24	D	1.53	WW	38.03	WW
52	1970	0.15	DD	0.23	D	1.89	N	1.73	D	5.57	WW	2.67	D	1.48	D	1.30	DD	3.87	N	6.06	WW	2.04	W	0.94	N	27.93	N
53	1971	0.16	D	2.35	WW	1.18	D	1.00	DD	2.27	D	5.46	W	6.31	WW	1.06	DD	1.50	D	4.39	WW	2.11	W	0.47	D	28.26	N
54	1972	0.35	D	0.58	D	1.09	D	3.30	W	3.43	N	2.49	D	6.18	WW	2.39	D	3.04	N	2.62	W	1.30	N	1.54	WW	28.31	N
55	1973	1.17	W	0.54	D	2.62	WW	4.70	WW	4.47	W	2.01	DD	3.11	N	4.03	N	6.21	WW	2.03	N	3.37	WW	1.06	W	35.32	WW
56	1974	0.13	DD	0.10	DD	1.20	D	1.56	D	2.38	D	2.64	D	0.84	DD	4.07	N	1.51	D	1.31	D	0.67	D	0.32	D	16.73	DD
57	1975	1.61	WW	0.40	D	2.15	W	6.87	WW	4.31	W	6.54	WW	0.22	DD	12.13	WW	0.79	DD	0.37	DD	2.75	WW	0.22	DD	38.36	WW
58	1976	0.14	DD	0.68	N	3.71	WW	1.05	D	2.15	D	2.72	D	1.22	D	0.56	DD	2.61	N	1.15	D	0.13	DD	0.58	D	16.70	DD
59	1977	0.29	D	0.75	N	4.60	WW	3.95	W	2.44	D	2.21	DD	2.61	D	5.18	W	4.20	W	3.50	WW	3.11	WW	0.59	D	33.43	W
60	1978	0.19	D	0.27	D	0.57	D	3.95	W	2.60	D	3.98	N	8.91	WW	2.29	D	1.52	D	0.37	DD	1.08	N	0.30	D	26.03	N

Table 2b. Computed monthly transitional matrix, J-F

```
JANUARY          FEBRUARY

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      1 |      1 |      1 |      1 |      0 |      4
         |   1.67 |   1.67 |   1.67 |   1.67 |   0.00 |   6.67
         |  25.00 |  25.00 |  25.00 |  25.00 |   0.00 |
         |  16.67 |   4.55 |   7.69 |  10.00 |   0.00 |
---------+--------+--------+--------+--------+--------+
DRY      |      2 |      5 |      7 |      5 |      5 |     24
         |   3.33 |   8.33 |  11.67 |   8.33 |   8.33 |  40.00
         |   8.33 |  20.83 |  29.17 |  20.83 |  20.83 |
         |  33.33 |  22.73 |  53.85 |  50.00 |  55.56 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      3 |      5 |      3 |      1 |      2 |     14
         |   5.00 |   8.33 |   5.00 |   1.67 |   3.33 |  23.33
         |  21.43 |  35.71 |  21.43 |   7.14 |  14.29 |
         |  50.00 |  22.73 |  23.08 |  10.00 |  22.22 |
---------+--------+--------+--------+--------+--------+
WET      |      0 |      7 |      1 |      2 |      0 |     10
         |   0.00 |  11.67 |   1.67 |   3.33 |   0.00 |  16.67
         |   0.00 |  70.00 |  10.00 |  20.00 |   0.00 |
         |   0.00 |  31.82 |   7.69 |  20.00 |   0.00 |
---------+--------+--------+--------+--------+--------+
WWET     |      0 |      4 |      1 |      1 |      2 |      8
         |   0.00 |   6.67 |   1.67 |   1.67 |   3.33 |  13.33
         |   0.00 |  50.00 |  12.50 |  12.50 |  25.00 |
         |   0.00 |  18.18 |   7.69 |  10.00 |  22.22 |
---------+--------+--------+--------+--------+--------+
TOTAL           6       22       13       10        9       60
            10.00    36.67    21.67    16.67    15.00   100.00
```

Table 2c. Computed monthly transitional matrix, F-M

```
FEBRUARY     MARCH

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      2 |      4 |      0 |      0 |      0 |      6
         |   3.33 |   6.67 |   0.00 |   0.00 |   0.00 |  10.00
         |  33.33 |  66.67 |   0.00 |   0.00 |   0.00 |
         |  28.57 |  22.22 |   0.00 |   0.00 |   0.00 |
---------+--------+--------+--------+--------+--------+
DRY      |      3 |      7 |      7 |      2 |      3 |     22
         |   5.00 |  11.67 |  11.67 |   3.33 |   5.00 |  36.67
         |  13.64 |  31.82 |  31.82 |   9.09 |  13.64 |
         |  42.86 |  38.89 |  35.00 |  40.00 |  30.00 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      0 |      0 |      8 |      2 |      3 |     13
         |   0.00 |   0.00 |  13.33 |   3.33 |   5.00 |  21.67
         |   0.00 |   0.00 |  61.54 |  15.38 |  23.08 |
         |   0.00 |   0.00 |  40.00 |  40.00 |  30.00 |
---------+--------+--------+--------+--------+--------+
WET      |      2 |      4 |      2 |      1 |      1 |     10
         |   3.33 |   6.67 |   3.33 |   1.67 |   1.67 |  16.67
         |  20.00 |  40.00 |  20.00 |  10.00 |  10.00 |
         |  28.57 |  22.22 |  10.00 |  20.00 |  10.00 |
---------+--------+--------+--------+--------+--------+
WWET     |      0 |      3 |      3 |      0 |      3 |      9
         |   0.00 |   5.00 |   5.00 |   0.00 |   5.00 |  15.00
         |   0.00 |  33.33 |  33.33 |   0.00 |  33.33 |
         |   0.00 |  16.67 |  15.00 |   0.00 |  30.00 |
---------+--------+--------+--------+--------+--------+
TOTAL           7       18       20        5       10       60
            11.67    30.00    33.33     8.33    16.67   100.00
```

Table 2d. Computed monthly transitional matrix, M-A

```
MARCH          APRIL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       0 |       0 |       4 |       2 |       1 |      7
         |    0.00 |    0.00 |    6.67 |    3.33 |    1.67 |  11.67
         |    0.00 |    0.00 |   57.14 |   28.57 |   14.29 |
         |    0.00 |    0.00 |   44.44 |   14.29 |   11.11 |
---------+---------+---------+---------+---------+---------+
DRY      |       3 |       8 |       1 |       3 |       3 |     18
         |    5.00 |   13.33 |    1.67 |    5.00 |    5.00 |  30.00
         |   16.67 |   44.44 |    5.56 |   16.67 |   16.67 |
         |   33.33 |   42.11 |   11.11 |   21.43 |   33.33 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       2 |       8 |       4 |       5 |       1 |     20
         |    3.33 |   13.33 |    6.67 |    8.33 |    1.67 |  33.33
         |   10.00 |   40.00 |   20.00 |   25.00 |    5.00 |
         |   22.22 |   42.11 |   44.44 |   35.71 |   11.11 |
---------+---------+---------+---------+---------+---------+
WET      |       3 |       0 |       0 |       1 |       1 |      5
         |    5.00 |    0.00 |    0.00 |    1.67 |    1.67 |   8.33
         |   60.00 |    0.00 |    0.00 |   20.00 |   20.00 |
         |   33.33 |    0.00 |    0.00 |    7.14 |   11.11 |
---------+---------+---------+---------+---------+---------+
WWET     |       1 |       3 |       0 |       3 |       3 |     10
         |    1.67 |    5.00 |    0.00 |    5.00 |    5.00 |  16.67
         |   10.00 |   30.00 |    0.00 |   30.00 |   30.00 |
         |   11.11 |   15.79 |    0.00 |   21.43 |   33.33 |
---------+---------+---------+---------+---------+---------+
TOTAL            9        19         9        14         9       60
             15.00     31.67     15.00     23.33     15.00   100.00
```

Table 2e. Computed monthly transitional matrix, A-M

```
APRIL        MAY

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      2 |      1 |      2 |      1 |      3 |      9
         |   3.33 |   1.67 |   3.33 |   1.67 |   5.00 |  15.00
         |  22.22 |  11.11 |  22.22 |  11.11 |  33.33 |
         |  28.57 |   5.26 |  15.38 |   7.14 |  42.86 |
---------+--------+--------+--------+--------+--------+
DRY      |      2 |      8 |      3 |      5 |      1 |     19
         |   3.33 |  13.33 |   5.00 |   8.33 |   1.67 |  31.67
         |  10.53 |  42.11 |  15.79 |  26.32 |   5.26 |
         |  28.57 |  42.11 |  23.08 |  35.71 |  14.29 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      0 |      2 |      2 |      3 |      2 |      9
         |   0.00 |   3.33 |   3.33 |   5.00 |   3.33 |  15.00
         |   0.00 |  22.22 |  22.22 |  33.33 |  22.22 |
         |   0.00 |  10.53 |  15.38 |  21.43 |  28.57 |
---------+--------+--------+--------+--------+--------+
WET      |      2 |      7 |      3 |      1 |      1 |     14
         |   3.33 |  11.67 |   5.00 |   1.67 |   1.67 |  23.33
         |  14.29 |  50.00 |  21.43 |   7.14 |   7.14 |
         |  28.57 |  36.84 |  23.08 |   7.14 |  14.29 |
---------+--------+--------+--------+--------+--------+
WWET     |      1 |      1 |      3 |      4 |      0 |      9
         |   1.67 |   1.67 |   5.00 |   6.67 |   0.00 |  15.00
         |  11.11 |  11.11 |  33.33 |  44.44 |   0.00 |
         |  14.29 |   5.26 |  23.08 |  28.57 |   0.00 |
---------+--------+--------+--------+--------+--------+
TOTAL           7       19       13       14        7       60
            11.67    31.67    21.67    23.33    11.67   100.00
```

Table 2f. Computed monthly transitional matrix, M-J

```
MAY            JUNE

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY      |DRY       |NORMAL    |WET       |WWET      |   TOTAL
---------+----------+----------+----------+----------+----------+
DDRY     |       2  |       1  |       2  |       0  |       2  |       7
         |    3.33  |    1.67  |    3.33  |    0.00  |    3.33  |   11.67
         |   28.57  |   14.29  |   28.57  |    0.00  |   28.57  |
         |   18.18  |    5.56  |   22.22  |    0.00  |   18.18  |
---------+----------+----------+----------+----------+----------+
DRY      |       2  |       7  |       4  |       4  |       2  |      19
         |    3.33  |   11.67  |    6.67  |    6.67  |    3.33  |   31.67
         |   10.53  |   36.84  |   21.05  |   21.05  |   10.53  |
         |   18.18  |   38.89  |   44.44  |   36.36  |   18.18  |
---------+----------+----------+----------+----------+----------+
NORMAL   |       2  |       5  |       1  |       2  |       3  |      13
         |    3.33  |    8.33  |    1.67  |    3.33  |    5.00  |   21.67
         |   15.38  |   38.46  |    7.69  |   15.38  |   23.08  |
         |   18.18  |   27.78  |   11.11  |   18.18  |   27.27  |
---------+----------+----------+----------+----------+----------+
WET      |       4  |       3  |       1  |       2  |       4  |      14
         |    6.67  |    5.00  |    1.67  |    3.33  |    6.67  |   23.33
         |   28.57  |   21.43  |    7.14  |   14.29  |   28.57  |
         |   36.36  |   16.67  |   11.11  |   18.18  |   36.36  |
---------+----------+----------+----------+----------+----------+
WWET     |       1  |       2  |       1  |       3  |       0  |       7
         |    1.67  |    3.33  |    1.67  |    5.00  |    0.00  |   11.67
         |   14.29  |   28.57  |   14.29  |   42.86  |    0.00  |
         |    9.09  |   11.11  |   11.11  |   27.27  |    0.00  |
---------+----------+----------+----------+----------+----------+
TOTAL          11         18          9         11         11         60
            18.33      30.00      15.00      18.33      18.33     100.00
```

Table 2g. Computed monthly transitional matrix, J-J

```
JUNE           JULY

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       2 |       3 |       2 |       3 |       1 |     11
         |    3.33 |    5.00 |    3.33 |    5.00 |    1.67 |  18.33
         |   18.18 |   27.27 |   18.18 |   27.27 |    9.09 |
         |   16.67 |   20.00 |   20.00 |   27.27 |    8.33 |
---------+---------+---------+---------+---------+---------+
DRY      |       5 |       6 |       0 |       3 |       4 |     18
         |    8.33 |   10.00 |    0.00 |    5.00 |    6.67 |  30.00
         |   27.78 |   33.33 |    0.00 |   16.67 |   22.22 |
         |   41.67 |   40.00 |    0.00 |   27.27 |   33.33 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       2 |       2 |       3 |       0 |       2 |      9
         |    3.33 |    3.33 |    5.00 |    0.00 |    3.33 |  15.00
         |   22.22 |   22.22 |   33.33 |    0.00 |   22.22 |
         |   16.67 |   13.33 |   30.00 |    0.00 |   16.67 |
---------+---------+---------+---------+---------+---------+
WET      |       1 |       2 |       3 |       2 |       3 |     11
         |    1.67 |    3.33 |    5.00 |    3.33 |    5.00 |  18.33
         |    9.09 |   18.18 |   27.27 |   18.18 |   27.27 |
         |    8.33 |   13.33 |   30.00 |   18.18 |   25.00 |
---------+---------+---------+---------+---------+---------+
WWET     |       2 |       2 |       2 |       3 |       2 |     11
         |    3.33 |    3.33 |    3.33 |    5.00 |    3.33 |  18.33
         |   18.18 |   18.18 |   18.18 |   27.27 |   18.18 |
         |   16.67 |   13.33 |   20.00 |   27.27 |   16.67 |
---------+---------+---------+---------+---------+---------+
TOTAL          12        15        10        11        12        60
            20.00     25.00     16.67     18.33     20.00    100.00
```

Table 2h. Computed monthly transitional matrix, J-A

```
JULY            AUGUST

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |      1  |      3  |      3  |      3  |      2  |     12
         |   1.67  |   5.00  |   5.00  |   5.00  |   3.33  |  20.00
         |   8.33  |  25.00  |  25.00  |  25.00  |  16.67  |
         |  11.11  |  17.65  |  20.00  |  27.27  |  25.00  |
---------+---------+---------+---------+---------+---------+
DRY      |      4  |      3  |      5  |      2  |      1  |     15
         |   6.67  |   5.00  |   8.33  |   3.33  |   1.67  |  25.00
         |  26.67  |  20.00  |  33.33  |  13.33  |   6.67  |
         |  44.44  |  17.65  |  33.33  |  18.18  |  12.50  |
---------+---------+---------+---------+---------+---------+
NORMAL   |      0  |      3  |      4  |      1  |      2  |     10
         |   0.00  |   5.00  |   6.67  |   1.67  |   3.33  |  16.67
         |   0.00  |  30.00  |  40.00  |  10.00  |  20.00  |
         |   0.00  |  17.65  |  26.67  |   9.09  |  25.00  |
---------+---------+---------+---------+---------+---------+
WET      |      2  |      3  |      3  |      3  |      0  |     11
         |   3.33  |   5.00  |   5.00  |   5.00  |   0.00  |  18.33
         |  18.18  |  27.27  |  27.27  |  27.27  |   0.00  |
         |  22.22  |  17.65  |  20.00  |  27.27  |   0.00  |
---------+---------+---------+---------+---------+---------+
WWET     |      2  |      5  |      0  |      2  |      3  |     12
         |   3.33  |   8.33  |   0.00  |   3.33  |   5.00  |  20.00
         |  16.67  |  41.67  |   0.00  |  16.67  |  25.00  |
         |  22.22  |  29.41  |   0.00  |  18.18  |  37.50  |
---------+---------+---------+---------+---------+---------+
TOTAL           9        17        15        11         8        60
            15.00     28.33     25.00     18.33     13.33    100.00
```

Table 2i. Computed monthly transitional matrix, A-S

```
AUGUST        SEPT

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      2 |      2 |      3 |      1 |      1 |      9
         |   3.33 |   3.33 |   5.00 |   1.67 |   1.67 |  15.00
         |  22.22 |  22.22 |  33.33 |  11.11 |  11.11 |
         |  25.00 |  11.76 |  15.00 |  16.67 |  11.11 |
---------+--------+--------+--------+--------+--------+
DRY      |      1 |      3 |      7 |      2 |      4 |     17
         |   1.67 |   5.00 |  11.67 |   3.33 |   6.67 |  28.33
         |   5.88 |  17.65 |  41.18 |  11.76 |  23.53 |
         |  12.50 |  17.65 |  35.00 |  33.33 |  44.44 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      2 |      5 |      5 |      1 |      2 |     15
         |   3.33 |   8.33 |   8.33 |   1.67 |   3.33 |  25.00
         |  13.33 |  33.33 |  33.33 |   6.67 |  13.33 |
         |  25.00 |  29.41 |  25.00 |  16.67 |  22.22 |
---------+--------+--------+--------+--------+--------+
WET      |      1 |      3 |      3 |      2 |      2 |     11
         |   1.67 |   5.00 |   5.00 |   3.33 |   3.33 |  18.33
         |   9.09 |  27.27 |  27.27 |  18.18 |  18.18 |
         |  12.50 |  17.65 |  15.00 |  33.33 |  22.22 |
---------+--------+--------+--------+--------+--------+
WWET     |      2 |      4 |      2 |      0 |      0 |      8
         |   3.33 |   6.67 |   3.33 |   0.00 |   0.00 |  13.33
         |  25.00 |  50.00 |  25.00 |   0.00 |   0.00 |
         |  25.00 |  23.53 |  10.00 |   0.00 |   0.00 |
---------+--------+--------+--------+--------+--------+
TOTAL           8       17       20        6        9       60
            13.33    28.33    33.33    10.00    15.00   100.00
```

Table 2j. Computed monthly transitional matrix, S-0

```
SEPT            OCTOBER

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      2 |      3 |      2 |      0 |      1 |      8
         |   3.33 |   5.00 |   3.33 |   0.00 |   1.67 |  13.33
         |  25.00 |  37.50 |  25.00 |   0.00 |  12.50 |
         |  25.00 |  14.29 |  15.38 |   0.00 |  10.00 |
---------+--------+--------+--------+--------+--------+
DRY      |      5 |      4 |      2 |      5 |      1 |     17
         |   8.33 |   6.67 |   3.33 |   8.33 |   1.67 |  28.33
         |  29.41 |  23.53 |  11.76 |  29.41 |   5.88 |
         |  62.50 |  19.05 |  15.38 |  62.50 |  10.00 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      0 |      7 |      7 |      3 |      3 |     20
         |   0.00 |  11.67 |  11.67 |   5.00 |   5.00 |  33.33
         |   0.00 |  35.00 |  35.00 |  15.00 |  15.00 |
         |   0.00 |  33.33 |  53.85 |  37.50 |  30.00 |
---------+--------+--------+--------+--------+--------+
WET      |      1 |      3 |      0 |      0 |      2 |      6
         |   1.67 |   5.00 |   0.00 |   0.00 |   3.33 |  10.00
         |  16.67 |  50.00 |   0.00 |   0.00 |  33.33 |
         |  12.50 |  14.29 |   0.00 |   0.00 |  20.00 |
---------+--------+--------+--------+--------+--------+
WWET     |      0 |      4 |      2 |      0 |      3 |      9
         |   0.00 |   6.67 |   3.33 |   0.00 |   5.00 |  15.00
         |   0.00 |  44.44 |  22.22 |   0.00 |  33.33 |
         |   0.00 |  19.05 |  15.38 |   0.00 |  30.00 |
---------+--------+--------+--------+--------+--------+
TOTAL           8       21       13        8       10       60
            13.33    35.00    21.67    13.33    16.67   100.00
```

Table 2k. Computed monthly transitional matrix, O-N

```
OCTOBER         NOVEMBER

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       0 |       4 |       3 |       0 |       1 |      8
         |    0.00 |    6.67 |    5.00 |    0.00 |    1.67 |  13.33
         |    0.00 |   50.00 |   37.50 |    0.00 |   12.50 |
         |    0.00 |   17.39 |   27.27 |    0.00 |    7.69 |
---------+---------+---------+---------+---------+---------+
DRY      |       3 |      11 |       4 |       0 |       3 |     21
         |    5.00 |   18.33 |    6.67 |    0.00 |    5.00 |  35.00
         |   14.29 |   52.38 |   19.05 |    0.00 |   14.29 |
         |   42.86 |   47.83 |   36.36 |    0.00 |   23.08 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       2 |       4 |       2 |       3 |       2 |     13
         |    3.33 |    6.67 |    3.33 |    5.00 |    3.33 |  21.67
         |   15.38 |   30.77 |   15.38 |   23.08 |   15.38 |
         |   28.57 |   17.39 |   18.18 |   50.00 |   15.38 |
---------+---------+---------+---------+---------+---------+
WET      |       1 |       3 |       2 |       0 |       2 |      8
         |    1.67 |    5.00 |    3.33 |    0.00 |    3.33 |  13.33
         |   12.50 |   37.50 |   25.00 |    0.00 |   25.00 |
         |   14.29 |   13.04 |   18.18 |    0.00 |   15.38 |
---------+---------+---------+---------+---------+---------+
WWET     |       1 |       1 |       0 |       3 |       5 |     10
         |    1.67 |    1.67 |    0.00 |    5.00 |    8.33 |  16.67
         |   10.00 |   10.00 |    0.00 |   30.00 |   50.00 |
         |   14.29 |    4.35 |    0.00 |   50.00 |   38.46 |
---------+---------+---------+---------+---------+---------+
TOTAL            7        23        11         6        13       60
             11.67     38.33     18.33     10.00     21.67   100.00
```

Table 21. Computed monthly transitional matrix, N-D

```
NOVEMBER      DECEMBER

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       1 |       4 |       2 |       0 |       0 |      7
         |    1.67 |    6.67 |    3.33 |    0.00 |    0.00 |  11.67
         |   14.29 |   57.14 |   28.57 |    0.00 |    0.00 |
         |   12.50 |   19.05 |   20.00 |    0.00 |    0.00 |
---------+---------+---------+---------+---------+---------+
DRY      |       2 |       5 |       3 |       7 |       6 |     23
         |    3.33 |    8.33 |    5.00 |   11.67 |   10.00 |  38.33
         |    8.70 |   21.74 |   13.04 |   30.43 |   26.09 |
         |   25.00 |   23.81 |   30.00 |   63.64 |   60.00 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       2 |       4 |       2 |       1 |       2 |     11
         |    3.33 |    6.67 |    3.33 |    1.67 |    3.33 |  18.33
         |   18.18 |   36.36 |   18.18 |    9.09 |   18.18 |
         |   25.00 |   19.05 |   20.00 |    9.09 |   20.00 |
---------+---------+---------+---------+---------+---------+
WET      |       0 |       2 |       2 |       1 |       1 |      6
         |    0.00 |    3.33 |    3.33 |    1.67 |    1.67 |  10.00
         |    0.00 |   33.33 |   33.33 |   16.67 |   16.67 |
         |    0.00 |    9.52 |   20.00 |    9.09 |   10.00 |
---------+---------+---------+---------+---------+---------+
WWET     |       3 |       6 |       1 |       2 |       1 |     13
         |    5.00 |   10.00 |    1.67 |    3.33 |    1.67 |  21.67
         |   23.08 |   46.15 |    7.69 |   15.38 |    7.69 |
         |   37.50 |   28.57 |   10.00 |   18.18 |   10.00 |
---------+---------+---------+---------+---------+---------+
TOTAL            8        21        10        11        10       60
             13.33     35.00     16.67     18.33     16.67   100.00
```

Table 2m. Annual transitional matrix

```
LAGANNUA      ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      1 |      1 |      0 |      4 |      3 |      9
         |   1.69 |   1.69 |   0.00 |   6.78 |   5.08 |  15.25
         |  11.11 |  11.11 |   0.00 |  44.44 |  33.33 |
         |  11.11 |   8.33 |   0.00 |  40.00 |  30.00 |
---------+--------+--------+--------+--------+--------+
DRY      |      1 |      3 |      6 |      1 |      1 |     12
         |   1.69 |   5.08 |  10.17 |   1.69 |   1.69 |  20.34
         |   8.33 |  25.00 |  50.00 |   8.33 |   8.33 |
         |  11.11 |  25.00 |  33.33 |  10.00 |  10.00 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      2 |      4 |      7 |      1 |      3 |     17
         |   3.39 |   6.78 |  11.86 |   1.69 |   5.08 |  28.81
         |  11.76 |  23.53 |  41.18 |   5.88 |  17.65 |
         |  22.22 |  33.33 |  38.89 |  10.00 |  30.00 |
---------+--------+--------+--------+--------+--------+
WET      |      2 |      2 |      3 |      2 |      2 |     11
         |   3.39 |   3.39 |   5.08 |   3.39 |   3.39 |  18.64
         |  18.18 |  18.18 |  27.27 |  18.18 |  18.18 |
         |  22.22 |  16.67 |  16.67 |  20.00 |  20.00 |
---------+--------+--------+--------+--------+--------+
WWET     |      3 |      2 |      2 |      2 |      1 |     10
         |   5.08 |   3.39 |   3.39 |   3.39 |   1.69 |  16.95
         |  30.00 |  20.00 |  20.00 |  20.00 |  10.00 |
         |  33.33 |  16.67 |  11.11 |  20.00 |  10.00 |
---------+--------+--------+--------+--------+--------+
TOTAL           9       12       18       10       10       59
            15.25    20.34    30.51    16.95    16.95   100.00
```

additional tables for the other seven stations under study, it was decided to list only the annual transitional matrices in the Appendix. Therefore, Appendix B represents the computer algorithm for these computations and the annual transitional matrices for these remaining stations (Tables B-1 through B-7). To obtain an overall transitional matrix for the region under study, the weighted means (weighted by length of record) of the transitional probabilities were calculated on the basis of annual transitional probabilities. Table 3 gives this mean annual transitional matrix for the region under study. A stochastic Markov chain process was applied to this matrix in order to achieve the probabilities of dryness and wetness. In terms of stochastic processes, the steady-state probabilities of the transitional matrix represent the dryness and wetness cycle. (See Review of Literature.) The summary of the calculations is as follows:

$$T^T = \begin{bmatrix} 0.057 & 0.101 & 0.139 & 0.211 & 0.180 \\ 0.168 & 0.278 & 0.197 & 0.209 & 0.311 \\ 0.308 & 0.289 & 0.241 & 0.234 & 0.198 \\ 0.323 & 0.182 & 0.262 & 0.221 & 0.188 \\ 0.144 & 0.150 & 0.161 & 0.126 & 0.109 \end{bmatrix} \qquad (47)$$

and for the steady-state condition:

$$\begin{bmatrix} \\ \\ T^T \\ \\ \\ \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \end{bmatrix} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \end{bmatrix}$$

Table 3. Mean annual transitional matrix for the region under study[a]

	DD	D	N	W	WW
DD	0.0573	0.1681	0.3082	0.3226	0.1438
D	0.1010	0.2782	0.2891	0.1817	0.1500
N	0.1388	0.1969	0.2406	0.2624	0.1614
W	0.2107	0.2090	0.2338	0.2208	0.1257
WW	0.1803	0.3111	0.1979	0.1881	0.1085

[a] 1) Weighted mean transitional matrix for area under study consists of eight stations as follows:

Station	No. of records
1) Rock Rapids	75
2) Sheldon	54
3) Spencer	60
4) LeMars	83
5) Sioux City	79
6) Storm Lake	79
7) Alton	74
8) Onawa	80
	584

2) The overall rainfall mean and standard deviation for the region under study are 27.12 in. and 6.1 in., respectively.

or

$$\begin{aligned}
q_1 &= 0.057q_1 + 0.101q_2 + 0.139q_3 + 0.211q_4 + 0.18q_5 \\
q_2 &= 0.168q_1 + 0.278q_2 + 0.197q_3 + 0.209q_4 + 0.311q_5 \\
q_3 &= 0.308q_1 + 0.289q_2 + 0.241q_3 + 0.234q_4 + 0.198q_5 \\
q_4 &= 0.323q_1 + 0.182q_2 + 0.262q_3 + 0.221q_4 + 0.188q_5 \\
q_5 &= 0.144q_1 + 0.150q_2 + 0.161q_3 + 0.126q_4 + 0.109q_5
\end{aligned} \tag{48}$$

To this set of equations, another equation must be added to complete the probabilistic conditions. The additional equation is in the form of:

$$q_1 + q_2 + q_3 + q_4 + q_5 = 1 \tag{49}$$

so there are six equations with five unknowns. Therefore, one equation is redundant and can be dropped from the system. According to the Markov chain procedure, the redundant equation can be any of the first five equations, but the last equation added must be considered essential. The solution of these simultaneous equations provides the needed steady-state probabilities as follows:

q_1 = the probability of "dry-dry" occurrence = 0.141
q_2 = " " " "dry" " = 0.231
q_3 = " " " "normal" " = 0.254
q_4 = " " " "wet" " = 0.232
q_5 = " " " "wet-wet" " = <u>0.142</u>
Sum 1.000

Using the relationship between the steady-state probabilities and the recurrence time (see Review of Literature), the recurrence times are obtained as follows:

μ_1 = the probability for "dry-dry" occurrence = 7.092 years
μ_2 = " " " "dry" " = 4.336 "
μ_3 = " " " "normal" " = 3.941 " (50)
μ_4 = " " " "wet" " = 4.309 "
μ_5 = " " " "wet-wet" " = 7.016 "

These durations show the average long-term recurrence on a probability basis, but do not indicate the exact sequence with which they will occur in the future. If the current once in 20- to 22-year severe drought cycle in Iowa is considered relevant, then the above data can be expanded to illustrate one uniform cyclical pattern. Conversion into this pattern is shown in Figure 3.

The calculation and the achieved results show that the stochastic Markov process worked successfully for determining cyclical precipitation events in this region and the higher probability events have the greatest likelihood of occurring in the future. In the meantime, one should realize that the cycle presented is based on the assumptions made. Therefore, the sequence of events during a drought period may remain random. To guide future investigations, it is recommended that the boundary limits for such a period be explored in more detail. For example, one needs to redefine the limits for extreme dryness or wetnesses, with regard to

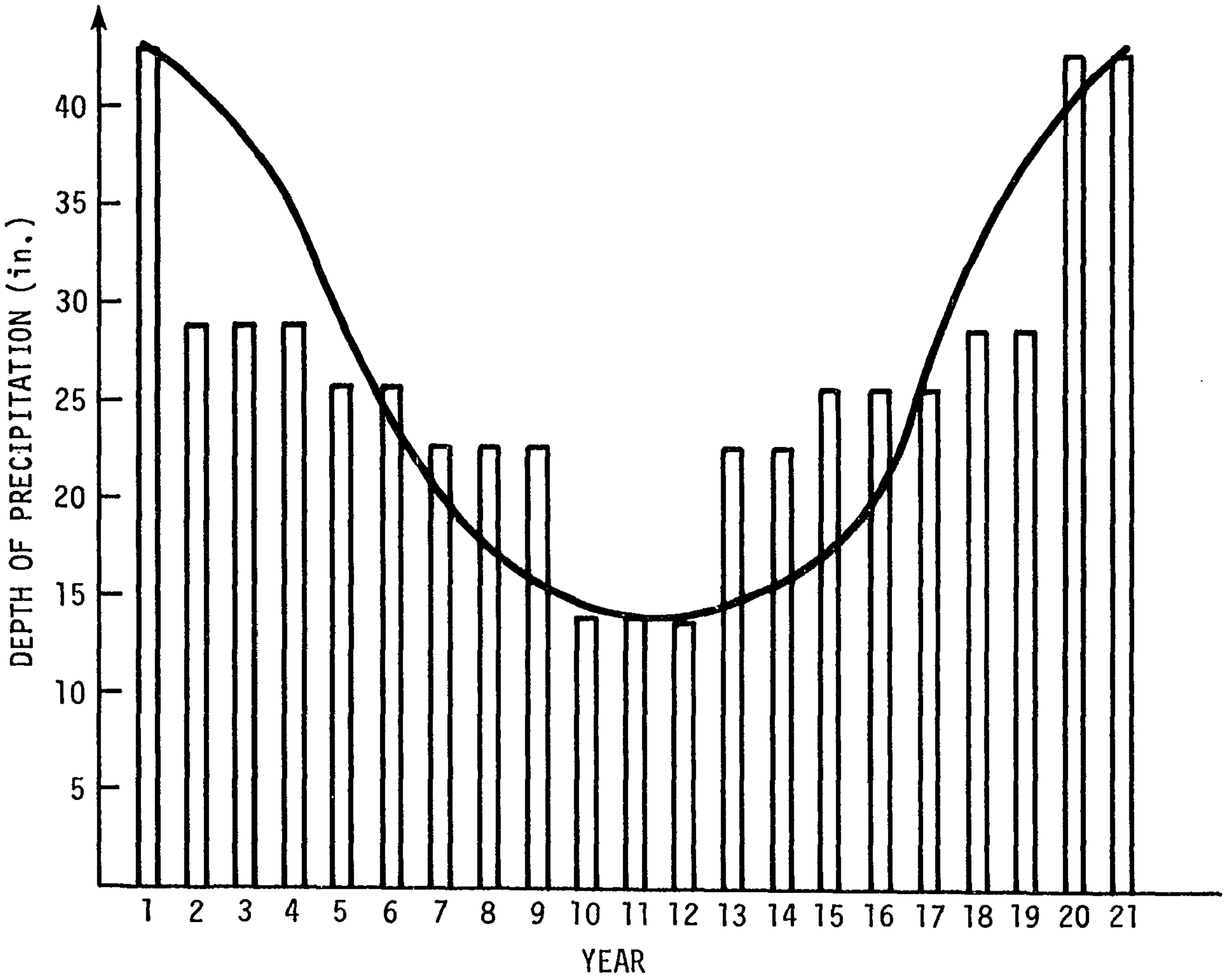


Figure 3. Dryness and wetness cycle for the region under study

the available data, i.e., one should investigate what depth of precipitation represents the extreme dryness or wetness. For "dry-dry" years, in this study a range of variations below the $\bar{X}$ - 2S might work for extreme dryness, and similarly, the values above the $\bar{X}$ + 1.5S or $\bar{X}$ + 2S might represent the extreme wetnesses. Whatever arrangement is applied, the resultant cycle would differ from that obtained for those assumptions used in this study. The general procedure shows that the period of recurrence interval becomes larger when more limits are considered. For Iowa, a cycle having these extreme values might have a recurrence interval of between 20 to 22 years compared to the 4 to 7 year average obtained for this general wetness or dryness study.

The cycle obtained and the related probabilities will be used for evaluating groundwater probabilistic fluctuations later in this study. It should be added that these analyses took place on the basis of calendar year data (Jan. through Dec.). Since there is a shift of three months between calendar and water years, the results are not strictly applicable for a water year cycle. However, the shift of months should not materially change the cycle results in long period studies.

Rainfall-Runoff Relationship

There are many ways and methods to relate rainfall and runoff. Despite the availability of relatively good methods such as the unit hydrograph method, coaxial diagrams, curve number approach, and others, there is still no simple method devised to define this relationship exactly. So far, mathematical models that consider more dominant factors, and are more costly, offer a better way for such a study. The term "mathematical model" used here is referred to as a more complex model than a simple rainfall-runoff relationship. As the next chapter describes, a mathematical model of the hydrologic cycle, called a hydromodel, is developed to describe the rainfall-runoff cause and effect relationship as well as other hydrological responses in the region under study. This model is used to evaluate the groundwater occurrences. However, an evaluation of the rainfall-runoff relationship for the study region is needed as one of the several processes included in the model development. To provide a necessary process for a mass water balance in the area, an approximate rainfall-runoff relationship is needed. Two well-known and reputable approaches were examined to define this relationship in the area under study:

1. the curve number approach developed by the Soil Conservation Service of the U.S. Dept. of Agriculture (112a, 112c), and
2. a multiple regression approach for rainfall-runoff relationship.

The following sections discuss these approaches.

Curve number approach

As described in groundwater movement previously, the infiltration process is a very complex phenomenon. Since the ground surface divides the receiving rainfall into two parts (infiltration or direct surface runoff), it would be easy to estimate the runoff if the infiltration process could be easily modeled. As a matter of fact, this process (although well understood) is too complex with many variables. Consequently, there always exist problems to estimate or predict the exact amount of runoff occurring after a rainfall. There are some sophisticated methods to evaluate the components of the rainfall-runoff relationship in hydrology science, namely the ϕ index method or infiltration indices method. Another well-known method introduced by the U.S. Soil Conservation Service (U.S. SCS) gives an estimation of rainfall excess by considering the composite soil cover complex (113). The CN (curve number) approach originated from the fact that a plot of natural precipitation and its resultant rainfall excess for a large storm and over a small area shows some type of linear relationship. This plot is shown in Figure 4. A lag of rainfall necessary to start the runoff is introduced and represents the volume of rainfall needed for the initial abstractions (interception and depression storage). Based on this concept, the U.S. SCS has empirically

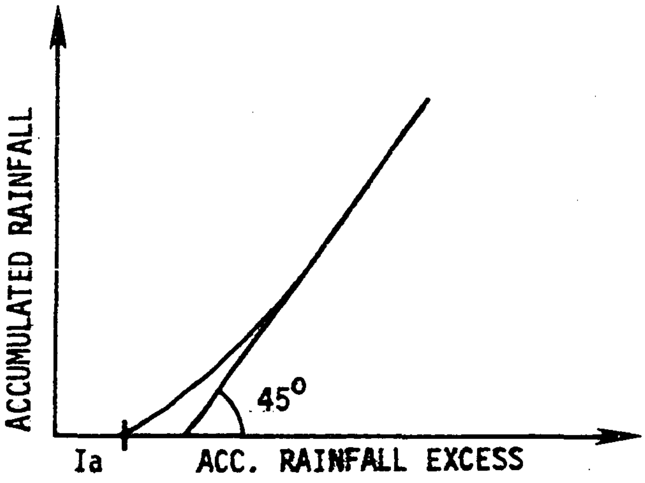


Figure 4. Accumulated rainfall vs accumulated runoff

developed a method by which the estimation of runoff (rainfall excess) from an occurred rainfall is possible. The method, which is called the CN approach, has many applications in hydrological engineering works. A brief description of the method follows; however, for more detailed information, one can refer to appropriate documents, some of which are given in the list of references in this paper (24, 112a, 115, etc.). According to SCS, the general equation for the precipitation-rainfall excess relationship is as follows:

$$Q = (P - Ia)^2/[(P - Ia) + (S' + Ia)] \tag{51}$$

where: Q = excess rainfall or runoff in inches,

P = precipitation in inches,

Ia = initial abstractions in inches, and

S' = potential maximum retention which is greater than or equal to actual retention (F) in inches.

The initial abstraction includes all losses occurring before the runoff reaches the stream. These losses are mainly interception, infiltration and surface storage. On the basis of experimental watershed evaluations, the SCS also found the following relationships.

$$\begin{aligned} &F \leq S \\ &S = S' + Ia \\ &Q \leq (P - Ia) \\ &Ia = 0.2S \end{aligned} \tag{52}$$

Finally, the SCS developed the following equation which describes the precipitation-rainfall excess relationship, and it is used for estimating the direct runoff from a storm rainfall.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{53}$$

The parameter "S" is still unknown and should be evaluated on the basis of the soil-cover complex. The SCS also attempted to relate the "S" parameter to the soil type and its cover. The following equation met this purpose

$$CN = \frac{1000}{10 + S} \tag{54}$$

Therefore, instead of using "S," SCS advises the use of the parameter CN (curve number) which must be found from soil grouping information. The SCS has classified the soils with regard to the soil practices and hydrological conditions. A CN is associated with each combination of land use, soil practice, hydrological condition and hydrological soil group. This classification gives a large number of alternatives. Having determined the appropriate CN for the area under consideration, one might use a set of curves to estimate direct runoff from a particular rainfall storm. Figure 5 shows this set of curves established by SCS. Appendix C represents the necessary tables for soil classification worked out by the SCS.

Research conducted based on SCS idea

According to SCS, the CN used to estimate direct runoff from storm rainfall depends on the soil moisture conditions. The general classification for antecedent soil moisture (AMC) is referred to as the antecedent

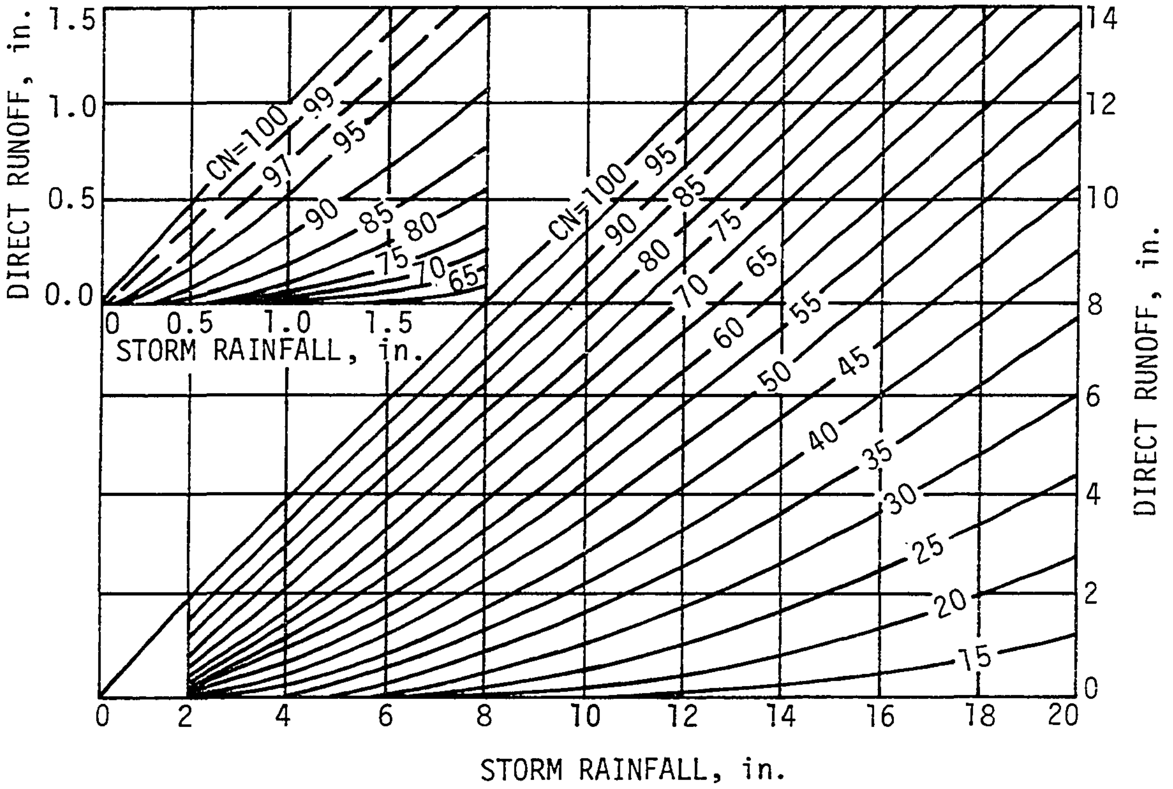


Figure 5. Chart for estimating direct runoff [from U.S. Soil Conservation Service (112a)]

soil moisture condition and is defined for day j as follows:

$$0 \leq \sum_{i=1}^{5} P_i \leq 1.5'' \qquad \text{Condition I} \qquad (55)$$

where i is the number of prior days. In this condition the soil is dry but not to the wilting point so that cultivation is possible.

$$1.5'' \leq \sum_{i=1}^{5} P_{j-i} \leq 3'' \qquad \text{Condition II} \qquad (56)$$

This condition represents the case for annual floods. It is also an average of conditions which precedes the occurrence of maximum annual flood on numerous watersheds.

$$\sum_{i=1}^{5} P_i > 3'' \qquad \text{Condition III} \qquad (57)$$

This condition includes the occurrence of heavy rainfall or continuous light rainfall accompanied by low temperatures during the five days preceding this storm. The soil can be considered almost saturated.

In the case of monthly analysis, which is the object of this study, a modification of these conditions is made.

An examination of monthly rainfall records revealed that the rainfall of certain months may not meet these limits established for daily rainfall. Also, the rainfall of some months exceeds these limits, whereas in some other months the depth of rainfall falls below these limits. Since the study considers the monthly variation of soil moisture as an average, it does not consider the rainfall distribution throughout the month. It may not be correct to assign Conditions II or III for low rainfall months or Condition III always for high rainfall months. That is, it may happen that in a low rainfall month the

time distribution of rainfall may meet the criterion of Condition II or III, or conversely for high rainfall months, the criterion for Condition II might be met. Although the examination of daily rainfall data shows this, the philosophy of this study is based upon monthly data and upon seeking an empirical method for this analysis. Therefore, the following assumptions are made to start the investigation.
The following list, based on SCS soil condition limits, shows the new defined limits for the month of January.

Monthly Condition I: below 0.45" received rainfall
Monthly Condition II: between 0.45" and 0.89" received rainfall
Monthly Condition III: over 0.89" received rainfall
$\overline{X} = 0.67"$ for this month.

Similar calculations were performed for other months. Table 4 represents calculated limits and adjusted monthly soil conditions for months January through December for the Spencer station. A possible maximum monthly rainfall was also assumed for each month (based on available data but visually estimated) to truncate the established curves properly. The last column of Table 4 represents these maximum values. The Spencer station was chosen to represent an average location for the region under study. To offer a wide range of possibilities, a set of curves, describing the relation between CN's and P_{t-1} (prior month's precipitation), was established as a practical and useful procedure. This set of curves includes CN values of Condition II (based on SCS classification) from 100 to 50 which appears to be covering enough of the range of variations for the area. The equations

Table 4. Calculated limits and monthly soil conditions for Spencer station

Variable/ month	Monthly average rainfall	Monthly AMC values			Probable max. rain
		I Min. rainfall (in.)	II Mid rainfall (in.)	III Max. rainfall (in.)	
Jan.	0.67	0.45	0.89	> 0.89	3"
Feb.	0.91	0.61	1.21	> 1.21	4"
Mar.	1.58	1.05	2.11	> 2.11	4.5"
Apr.	2.52	1.68	3.36	> 3.36	7.5"
May	3.67	2.45	4.89	> 4.89	12"
June	4.29	2.86	5.72	> 5.72	12"
July	3.36	2.24	4.48	> 4.48	12"
Aug.	3.64	2.43	4.85	> 4.85	12"
Sept.	3.34	2.23	4.45	> 4.45	12"
Oct.	1.72	1.15	2.29	> 2.29	6"
Nov.	1.30	0.87	1.73	> 1.73	4.5"
Dec.	0.81	0.53	1.08	> 1.08	3"
Annual	27.70	18.47	36.93	> 36.93	

and their relevant curves represent the relation between equivalent CN's for three conditions (Condition I, II and III) from one side and the AMC from the other side. The derived equations were numbered from 1 to 11 (covering CN's of 100 to 50 for Condition II, and its equivalent for Conditions I and III). Table 5 shows the relation between the numbered curves and their equivalent CN's for three conditions.

Table 5. Relation between numbered derived curves and the soil conditions (113)

No. of numbered curves	Condition I	Condition II	Condition III
1	100	100	100
2	87	95	98
3	78	90	96
4	70	85	94
5	63	80	91
6	57	75	88
7	51	70	85
8	45	65	82
9	40	60	78
10	35	55	74
11	31	50	70

When the new monthly soil conditions were defined (Table 4), a linear relationship of $CN = a_0 P_{t-1} + a_1$ assumed to establish a set of curves for each month. These curves are supposed to describe the relation between the monthly antecedent soil moisture (prior month's precipitation) and its related CN's. With the given values of CN and P_{t-1}, the above-mentioned linear relationship was solved for a range of CN's and the related P_{t-1}'s to find the coefficients of a_0 and a_1. Therefore, to derive each equation of the set (the set starts at No. 1 and ends at No. 11 as Table 5 shows) for each month, the CN values given in Table 5 along with their relevant P_{t-1} (Table 4) for that particular month have been used. Having established each equation, one may find the specified monthly CN with regard to the observed P_{t-1}. Consequently, the SCS rainfall-runoff curves of Figure 5 can be used for monthly runoff predictions. That is, when the CN and the rainfall for the current month are given, the excess rainfall is obtainable. In summary, the developed procedure is supposed to be used for appropriate monthly CN determination.

Table 6 shows the derived equations for the month of January and Figure 6 shows the related graphs. The same procedure was used to derive equations and graphs for the other remaining 11 months for this station. Since they are similar to those of the month January, they were not included in this report, but those belonging to the month of June are given in Figure 7 to represent an extreme month.

Using all tables or graphs is neither convenient nor practical for further studies. Therefore, a summarizing procedure attempted to select the best combination of the equations or the graphs. According to U.S.G.S. records, the sum of 12 months of SRO is less than 2.5 in. in the region under study. Not all equations in the set are responsive to produce this much of the annual SRO. For example, if numbered curves of 4 are used for all 12 months of the year, the total annual depth of SRO sums to 11.05 in. (see Table 7), which is too high. The reason evidently is that the selected CN's are high. By the same token, numbered curves of 11 will produce probably a very low annual depth of SRO which does not comply with field data. After examining the responses of the graphs and analyzing the outcomes of these

Table 6. CN equations for the month of January for the Spencer station[a]

No.	a_1	a_0	Equations
1	100	0.00	$CN_1 = 100$
2	88.13	5.5	$CN_2 = 5.5P_{t-1} + 83.13$
3	79.30	9.19	$CN_3 = 9.19P_{t-1} + 71.30$
4	71.24	12.43	$CN_4 = 12.43P_{t-1} + 71.24$
5	64.19	14.59	$CN_5 = 14.59P_{t-1} + 64.19$
6	57.91	16.29	$CN_6 = 16.29P_{t-1} + 57.91$
7	51.63	18.00	$CN_7 = 18P_{t-1} + 51.63$
8	45.35	19.70	$CN_8 = 19.70P_{t-1} + 45.35$
9	40.09	20.33	$CN_9 = 20.33P_{t-1} + 40.09$
10	34.83	20.95	$CN_{10} = 20.95P_{t-1} + 34.83$
11	30.33	21.13	$CN_{11} = 21.13P_{t-1} + 30.33$

[a] The calculated values and assumed maximum rainfall are as follows:

P_{t-1}	0.225"	0.670"	1.945"
Soil condition	I	II	III

Maximum rainfall assumed = 3"/mo. January.

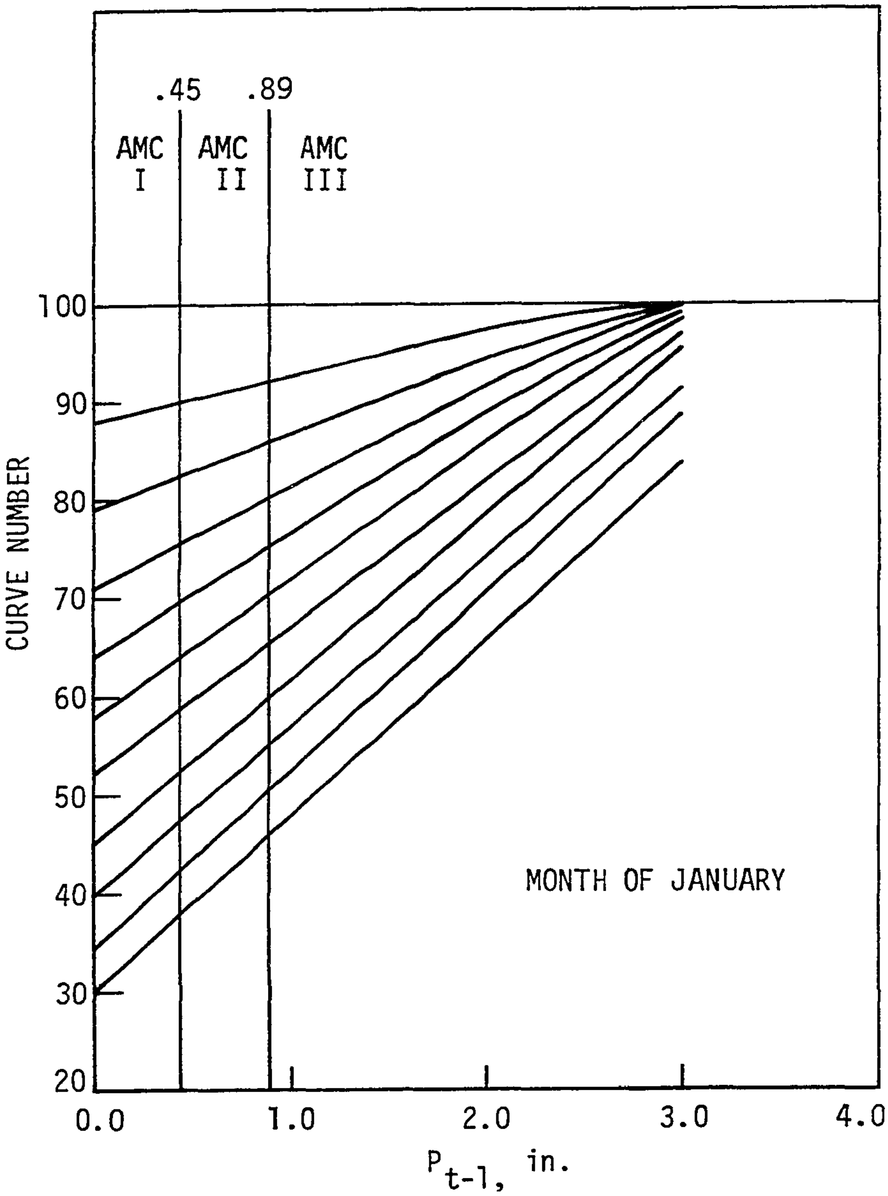


Figure 6. Numbered curves 1-11 showing relation between SCS CN's and monthly antecedent soil moisture, top to bottom

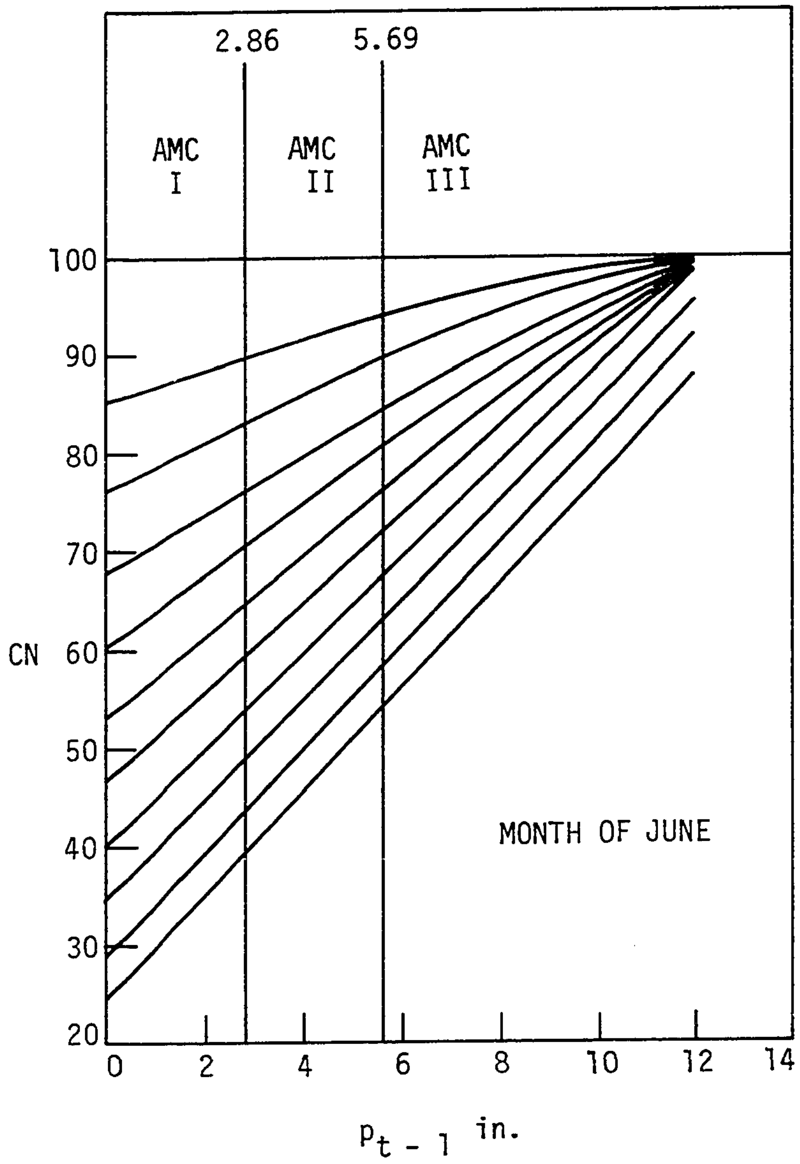


Figure 7. Numbered curves 1-11 showing relation between SCS CN's and monthly antecedent soil moisture, top to bottom

combinations, a single set of graphs was established so that the overall estimate would be coincident with that occurring in the area. Table 7 shows the selected combinations and Figure 8 represents the related set of graphs. This set of graphs or equivalent equations were used in the hydromodel to describe the surface runoff in the area. The CN approach was used to fulfill the surface runoff requirements in the hydromodel as a practical tool. Several other combinations of the monthly equations were considered for increasing or decreasing the S's and SRO's (see Table 7), but the hydromodel was too sensitive to utilize this approach. Therefore, the CN approach was dropped. The next section gives the reasons for this decision. A regression analysis approach was then initiated to obtain an equation needed for SRO determination in the hydromodel. The following sections describe this approach.

Regression analysis approach

Multiple regression analysis is a widely used statistical method for hydrologic studies. For this particular study, five regression models are evaluated. The models are as described below.

Model 1 — Relationship between the direct monthly runoff (Q) and the monthly rainfall in the form of:

$$Q = aP_t^b \tag{58}$$

Model 2 — Relationship between the direct monthly runoff, the monthly rainfall and the immediate previous monthly rainfall in the form of:

$$Q = aP_t^b P_{t-1}^c \tag{59}$$

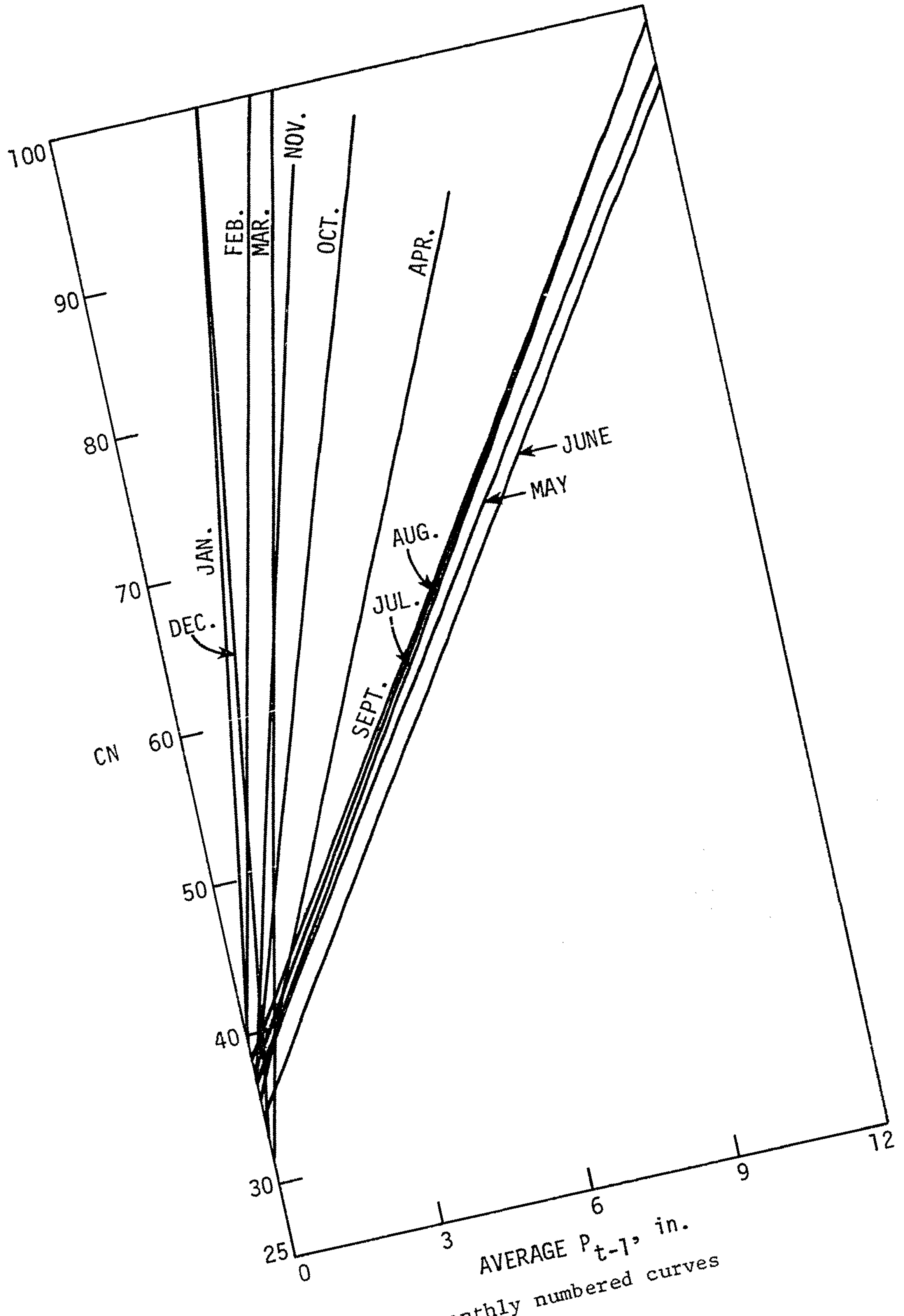


Figure 8. Summarized monthly numbered curves

Table 7. Calculated 'S' and 'SRO' using the developed 'CN' curves

Month	Ave. P_t in.	Ave. P_{t-1} in.	Numbered curve 4			Numbered curve 6			Numbered curve 8			Numbered curve 9		
			CN	$S_{in.}$	SRO_{in}	CN	$S_{in.}$	$SRO_{in.}$	CN	$S_{in.}$	$SRO_{in.}$	CN	$S_{in.}$	$SRO_{in.}$
Dec.	0.81													
Jan.	0.67	0.81	81.3	2.30	0	71.1	4.06	0	61.3	6.31	0	56.6	7.68	0
Feb.	0.91	0.67	77.6	2.88	0.05	66.4	5.05	0	55	8.15	0	50	9.95	0
Mar.	1.58	0.91	75.4	3.26	0.20	63.5	5.75	0.01	52.2	9.15	0	47.2	11.18	0
Apr.	2.52	1.58	76.3	3.11	0.7	64.6	5.49	0.30	53.5	8.71	0.05	48.5	10.65	0
May	3.57	2.52	77	3.00	1.6	65.5	5.27	0.80	54.5	8.34	0.35	49.6	10.17	0.2
June	4.29	3.57	79	2.66	2.1	68.1	4.86	1.50	57.7	7.33	0.85	52.9	8.90	0.6
July	3.36	4.29	83.1	2.03	1.7	73.5	3.60	1.15	64.3	5.56	0.60	59.6	6.78	0.4
Aug.	3.64	3.36	79.7	2.55	1.7	67	4.5	1.00	58.8	7.01	0.55	54	8.54	0.35
Sept.	3.34	3.64	81.2	2.32	1.6	71	4.10	0.90	61.1	6.37	0.50	56.3	7.75	0.35
Oct.	1.72	3.34	90.4	1.06	0.95	83	2.04	0.50	75.7	3.21	0.30	71.4	4.00	0.20
Nov.	1.30	1.72	83.8	1.93	0.30	74.4	3.44	0.10	63.3	5.31	0	66	5.15	0
Dec.	0.81	1.30	86.3	1.59	0.15	77.5	2.90	0.05	69.1	4.47	0	59.3	6.86	0
					11.05			6.31			3.20			2.10

Model 3 — Relation between the direct monthly runoff, the monthly rainfall, immediate previous monthly rainfall and the maximum daily rainfall as a 24-hour average intensity (I_t) which occurred during the current month under consideration in the form of:

$$Q = aP_t^b P_{t-1}^c I_t^d \tag{60}$$

Model 4 — Relation between direct monthly runoff, monthly rainfall, immediate previous monthly rainfall, maximum daily intensity and the average temperature of the current month under consideration (T_t) in the form of:

$$Q = aP_t^b P_{t-1}^c I_t^d T_t^e \tag{61}$$

Model 5 — Relationship between monthly direct runoff, the monthly rainfall and the sum of the 12-month antecedent precipitation in the form of:

$$Q = aP_t^b \left(\sum_{i=1}^{12} P_{t-1}\right)^c \tag{62}$$

To find the regression coefficients for the above equations, the SAS algorithm was used with a minor subroutine to convert the computations into the logarithmic form. Tables 8 and 9 show the equations obtained and the coefficient of determination, R^2, computed for each of the five models above. Model 5 was selected for incorporation into the hydromodel.

Since another procedure was used for snow months (December through March), as the next chapter dealing with the hydromodel describes, the fifth model was developed only for the eight months of April through November. As Table 9 shows, the results are satisfactory and the computed R^2 are relatively high for Model 5. It should be explained also that total streamflow, including surface water and groundwater contributions, was used in this regression analysis. Because of the low average annual precipitation in this area of Iowa, and the high evapotranspiration rates, there is little groundwater contribution. Therefore, as a first estimate, the regression equations are acceptable. Refinements can be introduced in the verification phase.

Table 8. Regression equations and 'R^2' for a month and a combination of months in the area under study

Model 1

Month	$Q = aP_t^b$	R^2
Dec.	$Q = 0.017P_t^{0.294}$	0.015
Jan.	$Q = 0.011P_t^{0.497}$	0.051
Feb.	$Q = 0.021P_t^{1.004}$	0.167
Mar.	$Q = 0.157P_t^{1.13}$	0.203
Apr.	$Q = 0.133P_t^{0.477}$	0.021
Total 5 mo.	$Q = 0.133P_t^{0.477}$	0.306
May	$Q = 0.099P_t^{0.27}$	0.011
June	$Q = 0.066P_t^{2.52}$	0.337
July	$Q = 0.062P_t^{0.185}$	0.021
Aug.	$Q = 0.006P_t^{1.64}$	0.514
Sept.	$Q = 0.012P_t^{0.78}$	0.165
Oct.	$Q = 0.024P_t^{0.76}$	0.189
Nov.	$Q = 0.033P_t^{0.475}$	0.150
Total 7 mo.	$Q = 0.032P_t^{0.69}$	0.169

Model 2

Month	$Q = aP_t^b P_{t-1}^c$	R^2
Dec.	$Q = 0.030P_t^{0.49}P_{t-1}^{0.96}$	0.363
Jan.	$Q = 0.012P_t^{0.44}P_{t-1}^{0.26}$	0.062
Feb.	$Q = 0.017P_t^{1.00}P_{t-1}^{-0.19}$	0.171

Table 8. Continued

	Model 2	
Month	$Q = aP_t^bP_{t-1}^c$	R^2
Mar.	$Q = 0.226P_t^{0.83}P_{t-1}^{0.49}$	0.273
Apr.	$Q = 0.091P_t^{0.52}P_{t-1}^{1.21}$	0.283
Total 5 mo.	$Q = 0.058P_t^{1.22}P_{t-1}^{0.56}$	0.356
May	$Q = 0.069P_t^{0.31}P_{t-1}^{1.12}$	0.425
June	$Q = 0.004P_t^{2.6}P_{t-1}^{0.25}$	0.340
July	$Q = 0.012P_t^{0.42}P_{t-1}^{1.18}$	0.124
Aug.	$Q = 0.006P_t^{1.63}P_{t-1}^{-0.07}$	0.515
Sept.	$Q = 0.003P_t^{0.91}P_{t-1}^{1.2}$	0.489
Oct.	$Q = 0.01P_t^{0.6}P_{t-1}^{1.06}$	0.423
Nov.	$Q = 0.028_t^{0.45}P_{t-1}^{0.59}$	0.313
Total 7 mo.	$Q = 0.024P_t^{0.64}P_{t-1}^{0.37}$	0.202

	Model 3	
Month	$Q = aP_t^bP_{t-1}^cI_t^d$	R^2
Dec.	$Q = 0.036P_t^{0.17}P_{t-1}^{0.9}I_t^{0.395}$	0.369
Jan.	$Q = 0.017P_t^{0.201}P_{t-1}^{0.32}I_t^{0.29}$	0.065
Feb.	$Q = 0.026P_t^{0.48}P_{t-1}^{-0.19}I_t^{0.57}$	0.181
Mar.	$Q = 0.13P_t^{1.25}P_{t-1}^{0.57}I_t^{-0.84}$	0.317
Apr.	$Q = 0.24P_t^{-0.26}P_{t-1}^{1.39}I_t^{1.1}$	0.311
Total 5 mo.	$Q = 0.84P_t^{0.89}P_{t-1}^{0.57}I_t^{0.42}$	0.361

Table 8. Continued

Model 3

Month	$Q = aP_t^b P_{t-1}^c I_t^d$	R^2
May	$Q = 0.069P_t^{0.31}P_{t-1}^{0.98}I_t^{0.90}$	0.511
June	$Q = 0.010P_t^{1.77}P_{t-1}^{0.25}I_t^{0.93}$	0.399
July	$Q = 0.015P_t^{0.26}P_{t-1}^{1.13}I_t^{0.18}$	0.179
Aug.	$Q = 0.012P_t^{1.04}P_{t-1}^{-0.13}I_t^{0.63}$	0.551
Sept.	$Q = 0.0019P_t^{1.31}P_{t-1}^{1.18}I_t^{-0.6}$	0.511
Oct.	$Q = 0.0054P_t^{1.17}P_{t-1}^{1.21}I_t^{-0.65}$	0.442
Nov.	$Q = 0.058P_t^{-0.38}P_{t-1}^{0.68}I_t^{0.95}$	0.368
Total 7 mo.	$Q = 0.0414P_t^{0.077}P_{t-1}^{0.38}I_t^{0.702}$	0.244

Model 4

Month	$Q = aP_t^b P_{t-1}^c I_t^d T_t^e$	R^2
Dec.	$Q = 0.0005P_t^{0.41}P_{t-1}^{0.84}I_t^{0.26}T_t^{1.42}$	0.400
Jan.	$Q = 0.0004P_t^{0.16}P_{t-1}^{0.51}I_t^{0.29}T_t^{1.54}$	0.160
Feb.	$Q = 0.0139P_t^{0.49}P_{t-1}^{-0.19}I_t^{0.56}T_t^{0.22}$	0.182
Mar.	$Q = 28.87P_t^{1.1}P_{t-1}^{0.53}I_t^{-0.87}T_t^{-1.57}$	0.356
Apr.	$Q = 2.39 * 10^{11}P_t^{0.192}P_{t-1}^{1.31}I_t^{0.22}T_t^{-7.36}$	0.392
Total 5 mo.	$Q = 0.0008P_t^{0.67}P_{t-1}^{0.478}I_t^{0.274}T_t^{1.386}$	0.426
May	$Q = 0.0014P_t^{0.28}P_{t-1}^{0.94}I_t^{0.94}T_t^{0.97}$	0.512
June	$Q = 0.3205P_t^{1.76}P_{t-1}^{0.24}I_t^{0.92}T_t^{-0.83}$	0.400
July	$Q = 0.0012P_t^{0.26}P_{t-1}^{1.13}I_t^{0.18}T_t^{0.58}$	0.179
Aug.	$Q = 3.73 * 10^{-15}P_t^{1.17}P_{t-1}^{-0.05}I_t^{0.57}T_t^{6.72}$	0.564

Table 8. Continued

Month	Model 4 $Q = aP_t^b P_{t-1}^c I_t^d T_t^e$	R^2
Sept.	$Q = 1.21 * 10^{13} P_t^{1.18} P_{t-1}^{0.99} I_t^{-0.53} T_t^{-8.8}$	0.559
Oct.	$Q = 2.08 P_t^{1.1} P_{t-1}^{1.21} I_t^{-0.63} T_t^{-1.52}$	0.446
Nov.	$Q = 3.3 * 10^{-9} P_t^{23} P_{t-1}^{0.81} I_t^{0.296} T_t^{4.63}$	0.477
Total 7 mo.	$Q = 0.2473 P_t^{0.135} P_{t-1}^{0.412} I_t^{0.70} T_t^{-0.48}$	0.247

Table 9. Regression analysis for monthly rainfall and its 12-month antecedent precipitation (Model 5)

Month (nonsnow months)	Coefficients			
	a	b	c	R^2
April	$(e)^{-21.3}$	5.99	0.452	0.647
May	$(e)^{-13.13}$	2.96	1.24	0.495
June	$(e)^{-17.13}$	3.54	2.94	0.444
July	$(e)^{-14.07}$	3.47	0.335	0.384
Aug.	$(e)^{-16.46}$	3.57	1.45	0.655
Sept.	$(e)^{-19.18}$	4.51	1.06	0.583
Oct.	$(e)^{-24.64}$	6.44	0.587	0.631
Nov.	$(e)^{-19.76}$	5.012	0.159	0.568

CHAPTER IV. MATHEMATICAL MODEL USED FOR THIS STUDY

General View

The following two sections give a scope of scientific hydrology and indicate the proliferation of mathematical models. The brief description about hydrologic and mathematical models which follows this discussion is just a reminder for readers to focus later on the procedures pursued in this study. It is believed that this information is too brief to give all the essential tools for recognizing what is going on in hydrologic and mathematical models today, and what ways and means are available for evaluating and verifying the models. To get a more comprehensive idea of this subject, it is recommended that the reader study the literature review, together with this brief discussion concerning the purpose and results of this study.

Brief definition of hydrology

Hydrology is a science that measures the circulation of water through atmosphere, surface and underground of the earth. Hydrology consists of two words, "hydro" and "logy." The first means water and the second is similar to the study of a phenomenon. This word (hydrology) is analogous to sociology, pathology, geology, etc. The science of hydrology describes and measures the movement of water from the earth and to the earth. For example, water evaporates or transpires from the surface of the earth (from sea, river, vegetative cover and bare surfaces), rises to the sky, makes rain, snow and other precipitation (hail, drizzle, sleet, dew) and falls to the surface of the earth again. This precipitation runs on the surface or infiltrates into the ground and flows back into the sea, from where it evaporates again. The science of hydrology deals with this type of movement of the water and the measurement of these phenomena.

So, there are several methods to delineate the path of movement and to quantify the water balance through this path. One of the most powerful methods for studying the water cycle is model simulation. The following section describes the types of modeling in general and illustrates the concept of mathematical modeling in hydrological studies.

Reasons for using mathematical models

Generally, a model is an imitation of the prototype (actual system), and is similar to the prototype in every respect except that the size usually is smaller. This definition applies to the physical models. To calculate results, mostly the costs and benefits of a project, experts operate the model rather than the prototype itself. The project is said to be justified, if the model test yields the desired results. The most recent idea is to construct a model on the basis of mathematical formulation. That is, instead of constructing a physical model similar to that of the prototype (sometimes as large as the prototype itself), experts develop a mathematical model so that it can answer the desired questions. This is called a mathematical or simulation model and has many applications in engineering works.

The main advantages of a simulation model are: 1) cost preferences; 2) ease of maintenance, 3) time-savings, and 4) adaptability. In summary, George Fleming (39) gives the following reasons stated by Kisiel to defend mathematical models versus using a physical model:

1. Dissatisfaction with older and perhaps empirically based and geographically-oriented models.
2. Development of computers.
3. Development of new mathematical tools for data analysis and model building.
4. Availability of research funds to evaluate old methods and develop new methods.
5. Gaps in data on and understanding of different kinds of hydrologic systems.
6. Philosophical basis for the model, e.g., deterministic, stochastic or nonmathematical.
7. Complexity of system to be modeled, e.g., too many parameters.
8. Errors in forecasting or prediction.
9. Cost of implementing the model.

These reasons justify the use of mathematical models. The following discussion describes the elements and purposes of a mathematical model.

What is a mathematical model in hydrology supposed to do? As discussed already (Chapters I and III), by no means should we expect a mathematical model to simulate precisely the real events of the nature in complex interactions like those occurring in hydrology. Rather, we may expect from this to trace the most likelihood events coincident to those that happened or may happen again. Therefore, this prediction is highly dependent on the input data fed to the model which are themselves dependent upon the accuracy of the measurements and the techniques applied to input these data in the right place. The more accurate the data and the better the modeling, the better response from the model. The following chart (Figure 9) given by George Fleming (39) gives the mathematical modeling concept.

Although the concept for mathematical models is unique, the approaches for applying this unit concept are immense. In general, two types of modeling are considered in hydrology to follow this concept, and each type has its own advantages and disadvantages. They are: 1) lumped models which consider the overall average of the dominant hydrological factors in a particular point of interest in the basin, and 2) the distributed models which divide the whole basin in appropriate parts, compute the hydrological responses of each part and route them to a particular point of interest. The distributed models are more accurate (if enough information were available) but more time-consuming and specific. The lumped models are more empirical and general. The better precision from a lumped model can be expected by choosing a smaller hydrologic area and extending the time intervals to shorter periods. Indeed, some of the lumped models, like that chosen for this study (hydromodel), have the ability of performing the same actions that a distributed model does. This is the reason for adoption of the hydromodel for this research study. The plan is to develop a unit model to represent the hydrological interactions in a smaller basin, and in later studies include the necessary means for applying the unit model for predicting in a larger basin.

The following sections describe the properties of this model which is believed to be an acceptable one for this type of study.

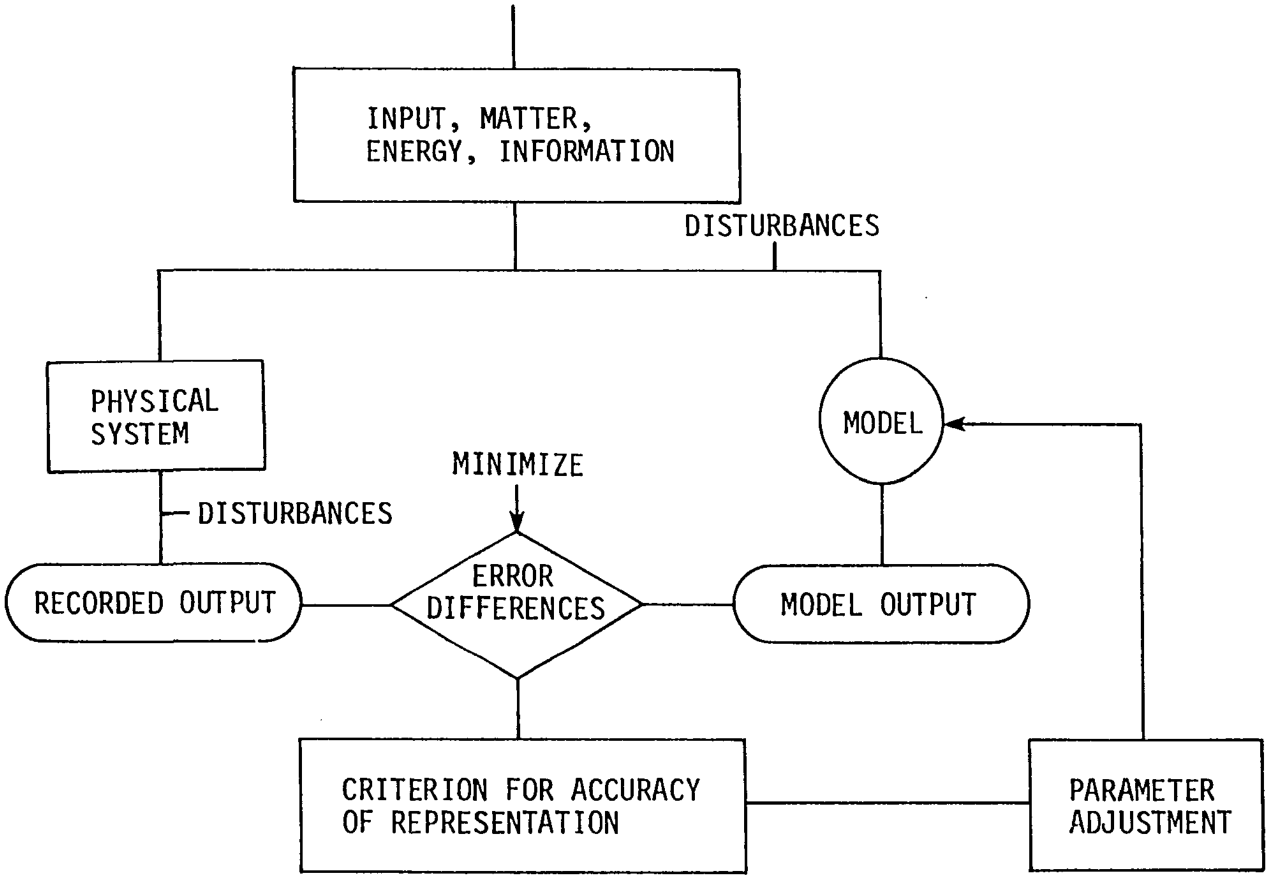


Figure 9. The mathematical model concept (after G. Fleming)

Hydromodel

Generally speaking, every model established to evaluate the cause and effect relationship of the hydrological cycle in a basin, or dealing with hydrodynamic balances in a system, may be called a hydromodel. But in this study, the name "hydromodel" was adopted from a mathematical model developed by A. Leon Huber as a basic computer model. According to Austin (3), it computes a hydrologic mass balance for the water resource. The literature of mathematical models in hydrology shows that a well-accepted model has met the verification criteria for modeling. Possibly one or more persons initiate the thought processes and begin to develop the model concepts. But the challenge for improving it continues until a well-behaved model is obtained, or other new ideas are introduced. A mathematical model in hydrology is subject to change along with progress in hydrological techniques and newer computer advances. This explains the modification of Austin's hydromodel (3) using local hydrological techniques and applied to a new location in Northwest Iowa, to the upper Floyd River basin.

The hydromodel discussed in this report has the following main segments:

A. Computer language translator alphabets and statements including dimensions, read and write commands to provide means for receiving data, compiling them and performing computations. This segment which is distributed throughout the whole program in appropriate places consists of computer algorithms and follows normal computer logic (FORTRAN language) in order to output the monthly and annual interactions.

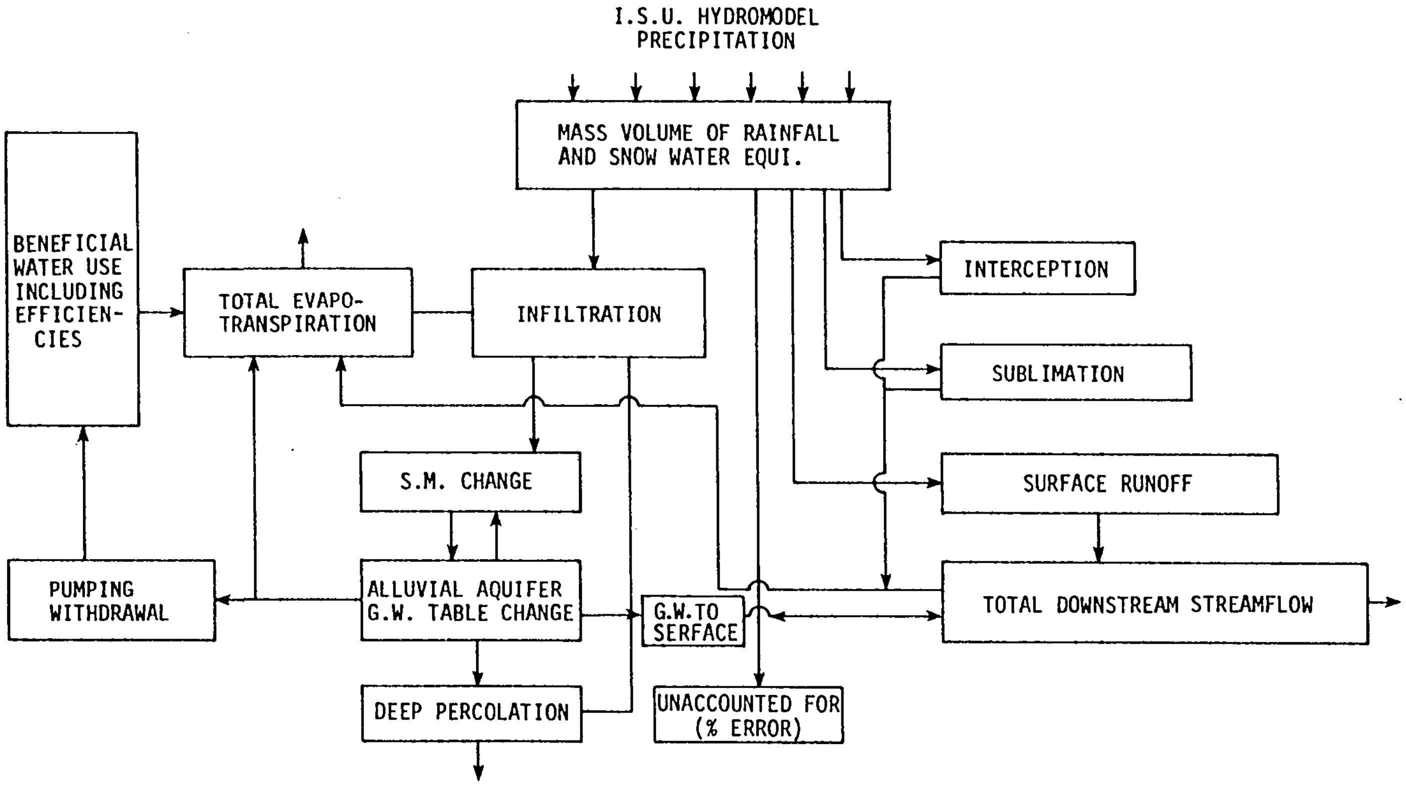
B. Hydrological segments which follow the conceptual and logical commands to perform hydrological manipulation in order to find the cause and effect behavior of the catchment. These segments which follow both hydrological and computer logic consist of the following subsegments:

1. Runoff evaluation — The model computes the fractions of the receiving rainfall and snow which go to surface runoff, surface detention, infiltration, or evapotranspiration or sublimation phenomena.
2. Soil moisture and root zone supply — The model computes soil moisture conditions, based on the incoming and outgoing water mass balance including rainfall, snowmelt and evapotranspiration phenomena for both upland and floodplain and water demands from the floodplain areas of the basin.
3. Groundwater transition and addition — The model computes the contribution of the surplus soil moisture to the groundwater and subsequent changes in water table elevation.

C. Mass balance segment performs necessary arithmetic computations in order to provide commanded outputs including monthly and interannual hydrobalance in the river basin. This segment follows normal computer language logic for its function using the computed values. It follows the hydrological pattern as instructed to give the conceptually acceptable outputs. For this reason, all interacted sources of mass water such as reservoir storage, canal diversions, surface and groundwater coming to or going from the basin, etc., will be accounted for if it had been considered as a dominant factor in the model. Some of these factors are set to zero for this particular model. However, the algorithm for this program permits the introduction of these factors in the model for more detailed studies. Figure 10 shows the flow chart of the model. A discussion of the hydrological concepts of the model follows. Appendix D presents a copy of the computer algorithm for this model.

Hydrological Concepts Used in the Model

Three main concepts for handling the hydrological cause and effect behavior of the basin are: 1) concept of surface runoff modeling, 2) concept of snowmelt modeling, and 3) concept of groundwater modeling. To accomplish modeling of the hydrological cycle in the basin, some other hydrological principles such as soil moisture exchange, evapotranspiration phenomenon, beneficial water use from the basin are considered also. A brief discussion of these routines will follow the description of the main concepts.



TYPE OF DISTRIBUTION OF MASS TRANSFER

ISU UNIT HYDROMODEL FOR FLOYED RIVER BASIN AT ALTON BASED ON 23 YRS. AVE.

BENEFICIAL WATER USE INCLUDES:
MUNICIPAL, INDUSTRIAL, RURAL DEMANDS, IRRIGATION, LIVESTOCKS, ETC.

RURAL DEMAND INCLUDES:
FARMSTEAD, HOMESTEAD, ETC.

Figure 10. Flow chart of hydromodel covering different hydrological processes

Concept of surface runoff modeling

In the last chapter, a description was given of the rainfall-runoff relationships. However, the curve number (CN) approach failed to adequately model the Floyd River Basin for the following reasons:

1. The concept of monthly antecedent soil moisture and the assumptions made were not realistic, at least for the area under study. The time period is too great.
2. Although the estimated annual stream discharge (SRO) values by this method were close to those measured values in the basin (see Table 7, page 87), the monthly distribution of the estimated SRO's could not match the similar values and resulted in discrepancies (+ and -) throughout the year.
3. In contrast to the flexibility of the CN approach for estimating SRO of short time intervals (daily intervals, for example), in the case of monthly periods, this method is not flexible enough. However, with regard to the overall advantages of this method, it is recommended that more research be conducted to increase its flexibility for the case of monthly evaluations. Therefore, this method is not completely rejected, although it failed to satisfy the needs of this particular model.
4. The equations and graphs for this method (CN approach) were developed on the basis of assumptions which were originally developed based on daily soil moistures. The daily assumptions for antecedent soil moisture were not essentially true in the case of monthly evaluations, and averaging the daily

antecedent soil moisture throughout the month was not practical.

5. Since the soil cover complex is subject to variation in different parts of the basin and the location of storm centers can affect the amount of runoff, it was expected that a set of curves (equations) as an average condition may not represent the actual field situation. Again, more investigation and development of local curves instead of an average condition might be helpful.

6. The failure of this approach was the reason for developing another approach. Consequently, regression equations involving dominant factors, including a different antecedent precipitation index for predicting surface runoff, were used. This approach gave improved responses in the model, compared to those of the CN approach. Still, the result was not entirely satisfactory, for the following reasons:
   a. In most cases, a monthly method is considered to be a poor approach for determining rainfall-runoff relationships. The research did show that a better parameter for antecedent soil moisture should be introduced. Basing the condition of soil moisture on one month antecedent rainfall is not enough, because the monthly rainfall values change quite a bit through the year.
   b. Some of the computed coefficients and exponents for derived equations are quite small or quite large, compared to those of the general expressions for such a

gression. So the derived equations describe the statistical relationship in some degree of confidence, but the standard error or correlation coefficient may not be acceptable.

c. The equations obtained were not well-behaved. That is, the range of variation for computed coefficients and exponents from month to month was high in both the positive and negative directions. Some attempt was made to smooth these coefficients and exponents in order to obtain a well-behaved range for them. But the response of the hydromodel for Models 1-4 was not satisfactory. These corrected coefficients affected the "best fit" relationships obtained statistically and introduced additional error in the predictions. Therefore, it was found that this approach (regression for dominant factors including one-month antecedent precipitation) is not a good one either for this particular modeling effort.

Finally, it was understood that the soil moisture condition due to rainfall of several previous months influences the runoff from the basin. Examining the early output of the model and utilizing the experience of the supervising professors, consideration was given of the sum of the 12-month antecedent rainfall. This improved the predictions. Therefore, the third approach was tried and led to the relatively good results. The equation applied for runoff estimation (model 5), as described in the previous chapter, is of the form:

$$Q = aP_t^b\left(\sum_{i=1}^{12} P_{t-1}\right)^c \qquad (63)$$

where: Q is the average monthly depth of runoff on the whole basin in inches,

P_t is monthly rainfall for current month,

$\sum_{i=1}^{12} P_{t-1}$ is the sum of the 12-month antecedent rainfall prior to the current month, and

a, b, and c are empirical coefficients for this area.

This type of equation was developed for the months of April, May, June, July, August, September, October, and November only. The remaining months are considered to be snow accumulation months, and a specific procedure was applied to them as the next section describes.

Concept of snowmelt modeling

No successful general analytical procedure is available to evaluate snowmelt and its contribution to surface runoff and soil moisture in a relatively large area such as the basin considered for this study. In the case of northwest Iowa, some research has been conducted by Dougal, et al. (32b) to evaluate this phenomenon. Most of the methods are based on practical observations to represent an empirical approach for evaluation. Snowmelt evaluation has been important in this research to accomplish the water balance in the basin. It has not been a prime concern that would necessitate conducting an exclusive study, but is of secondary importance in this modeling effort. Because of its influence on the water balance, much time was spent to work out a practical trial and error method to obtain results. The general problem was how to allocate the appropriate percentage of snowfall and snow accumulation in each month to the phenomena of sublimation, surface detention to infiltration (F), snowmelt to surface runoff (SRO), and carryover snowpack storage. Based on consultation and hydrological facts, the author tried various estimates, and after six trials the estimated surface runoff was close to that measured in the field. Although the estimated percentages resulted in the close estimation of runoff to those of gaged values, these percentages did not precisely follow the pattern of actual percentages found in nature. These percentages were first developed based on the 22-year average monthly snowfall and gaged streamflow, and would not necessarily forecast actual monthly variations. To compensate for this defect, a change in the sublimation and surface detention to infiltration relationships was made to make them dependent on the monthly snowpack storage measured in terms of inches of water equivalent. Figures 11 and 12 show these hypothetical curvilinear relationships for sublimation and surface detention to infiltration, respectively. Since the month of April is a transitional type of month (completion of snowmelt) that has both snow and rainfall, it was treated in two ways for contribution to surface runoff.

Concept of groundwater modeling

The concept behind the segment of groundwater in the hydromodel is both analytical and empirical. The relationships worked out for groundwater movement in the basin are based upon the idea that the model should be general and responsive for the area under study. To reflect

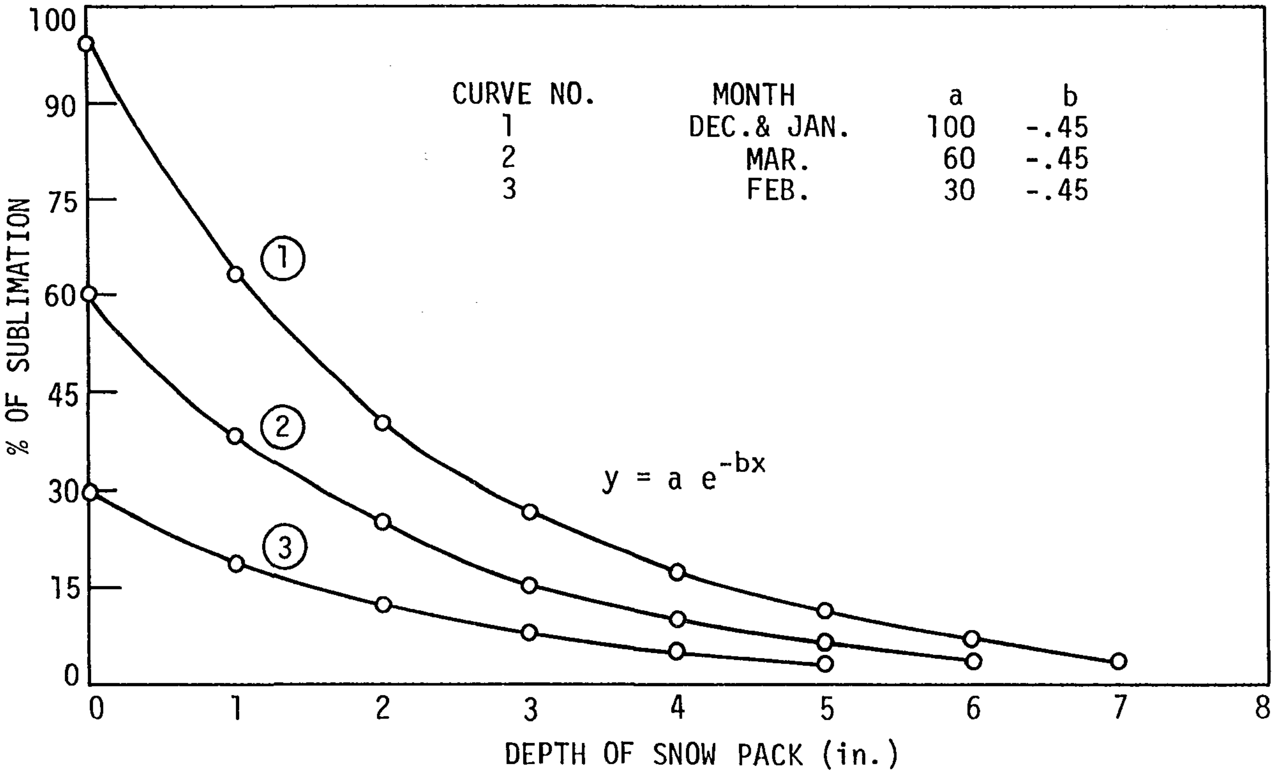


Figure 11. Curvilinear relationship for percent of sublimation versus the depth of snowpack

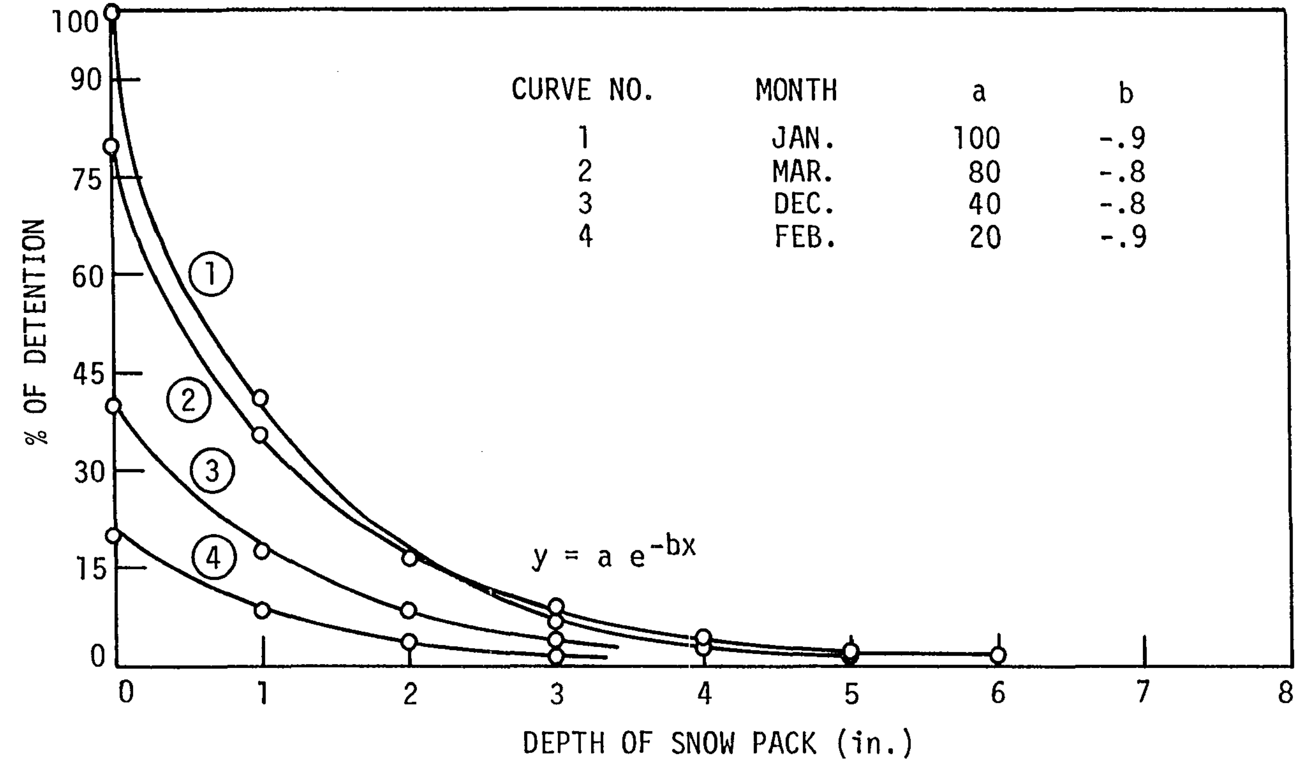


Figure 12. Curvilinear relationship for percent of detention versus the depth of snowpack

this, the concept uses the analytical principles for groundwater mining in surficial aquifers, and is made flexible to permit using more precise input data whenever such data become available. Figure 13 shows the sketch of an average cross section of the floodplain. For surficial groundwater mining, it is needed to distinguish between upland and floodplain characteristics. The upland groundwater system was assumed <u>not</u> to be in direct connection with the stream/alluvial aquifer. The floodplain is assumed to be underlain with a shallow alluvial aquifer.

Definitions in general

Δh = change in groundwater level, monthly change as dependent variable, in ft

L_v = length of valley, ft

W_v = width of alluvial valley, ft

Z_v = depth of alluvial materials in valley-permeable stratum, ft

h = height of groundwater table above valley bottom, ft

Z_b = height of channel bottom above valley bottom, ft

W_s = width of stream, ft

Z_s = depth of water in stream, ft

h_n = net head for groundwater movement, $(h_{t-1} + \Delta h_t) - (Z_b + Z_s)$, ft

P = precipitation, in.

SRO = direct surface runoff, ac-ft/mo

F = infiltration, in.

ET = evapotranspiration, in.

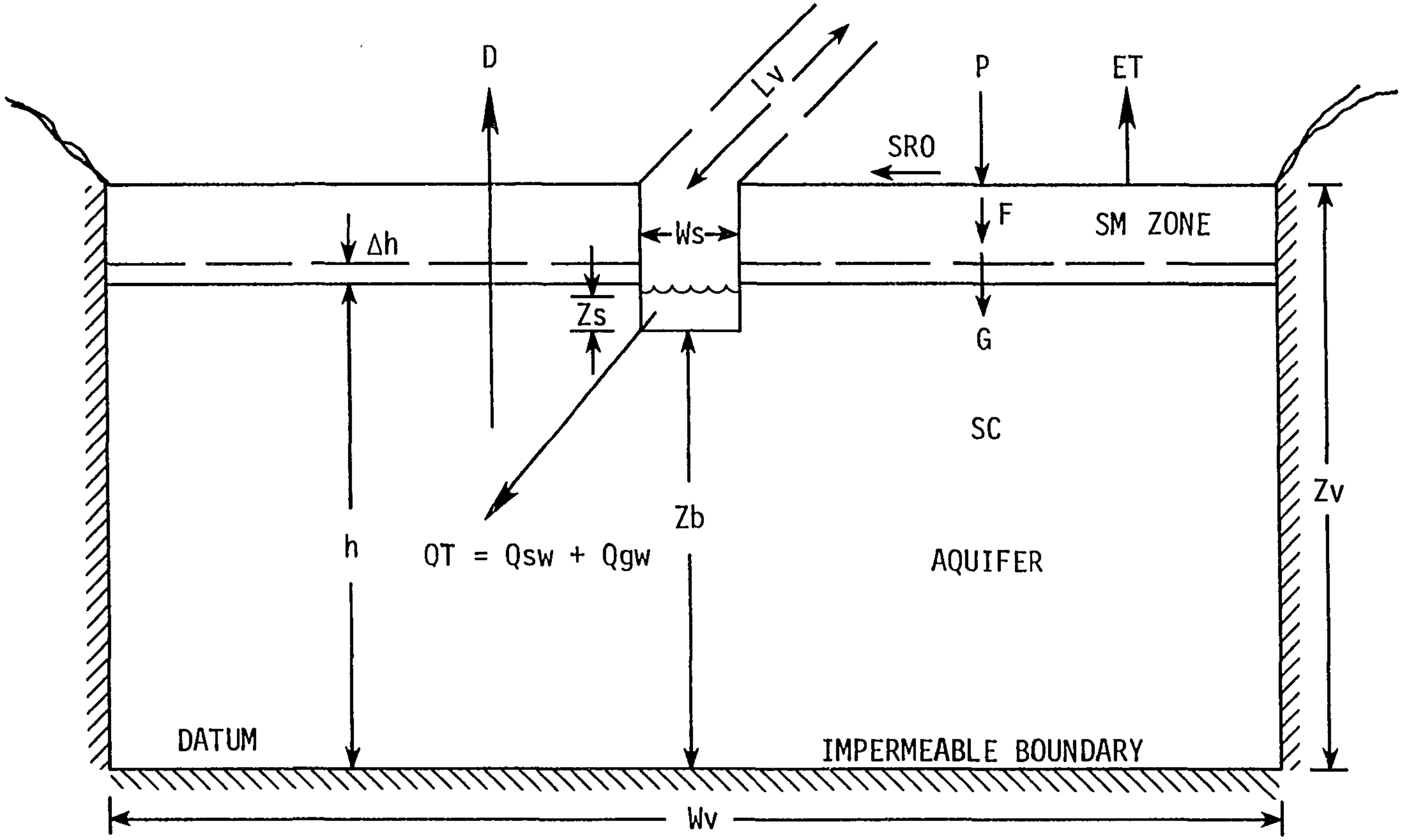


Figure 13. Hypothetical floodplain cross section

I_a = initial abstraction from rainfall by vegetation, surfaces, etc., in.

S_M = soil moisture zone, in.

G = monthly groundwater contribution (amount or portion of F passing through S_M zone), ac-ft/mo

D = demand, from groundwater for specific beneficial use, ac-ft/mo.

These definitions are used for groundwater modeling. Some additional definitions and symbols were used later in the computer modeling. All of these symbols, translated into characters for FORTRAN programming, are found at the end of Appendix D, along with the computer program.

To compute monthly groundwater variations, a combination of steady-state and transient conditions for groundwater movement was used to lead to an overall satisfactory response of the hydromodel. That is, for this particular model, it is assumed that the transient condition of the groundwater can be averaged for each month, and the averaged values used for steady-state conditions at the end of the month. Therefore, the groundwater discharged from or recharged into the stream obeys the one-dimensional Darcy's equation as follows:

$$Q_{GW} = AK \frac{dh}{dL} \tag{64}$$

where Q_{GW} is the groundwater contribution to the stream (positive or negative), A is the cross-sectional area perpendicular to the flow, K is the hydraulic conductivity of the aquifer, and dh/dL is the slope of the water table. To evaluate the state of groundwater replenishment, the division of upland and floodplain in the basin must be determined. Basin data showed that about 10% of the basin was floodplain and the remaining 90% was upland. The characteristics of the shallow alluvial groundwater aquifer were adopted on the basis of experience and research conducted by Meyer (82) for the lower Floyd River basin. Each part of the basin (upland and floodplain) was treated separately for groundwater. The model computes the monthly soil moisture balance based on incoming and outgoing water masses (rainfall, evapotranspiration, irrigation, etc.). The water reaching the soil replenishes the soil moisture content, and may excess water above field capacity of the soil goes to a deeper layer as groundwater (G). The groundwater contribution from the uplands was added to the deep groundwater aquifers and was not available for discharge to the streams. Groundwater contribution from the floodplain was used to calculate the groundwater addition to the surface water. The groundwater segment in the model handles this excess water, and allocates the monthly distribution of the groundwater contributions.

In the model, two subprograms do this task for upland and floodplain. These two are: 1) groundwater replenishment from the upland and 2) the groundwater budget in the floodplain. The hydromodel results show the addition to groundwater from upland is small, and can be treated as deep percolation which is not available for use in the vicinity of the floodplain. The model maintains the groundwater table in the uplands in an almost steady state. In contrast, the floodplain alluvial aquifer responds readily to groundwater elevation changes. According to Meyer (82), the floodplain in the lower Floyd River has a width of about one-half to one mile. Based on this information, the necessary assumptions were made for groundwater modeling in the floodplain. Figure 14 shows the adopted values (half of the floodplain). The following descriptions give a brief summary about evapotranspiration and water demand from the basin. Chapter V gives more descriptions about the development of the model, but for an itemized step-by-step procedure of the model for hydrological evaluation of the processes, it helps to follow Figure 10 (flow chart of the model).

Evapotranspiration procedure in hydromodel

Undoubtedly, evapotranspiration is one of the most sensitive and important phases in every water budget model. It affects the balance of water in every basin and controls the energy budget substantially. It is also a very complicated phenomenon, subject to change in time and space. So, it has drawn the attention of many scientists who work in this area of research. Due to its complicated nature, many methods of evaluation are available. Some of them are very responsive to this phenomenon. Some detailed methods consider frequent measurements in small plots and in determining the amount of evapotranspiration. More general procedures frequently are also needed. Fortunately, there are many approaches available. There are some methods, such as the Penman, Thornwaite, Christiansen, Blaney-Criddle, etc., that are universally accepted for general application. Also, there is general agreement that the Penman method is the best for obvious reasons. It is the best because it considers more factors contributing to evapotranspiration. The only disadvantage of this method is that not

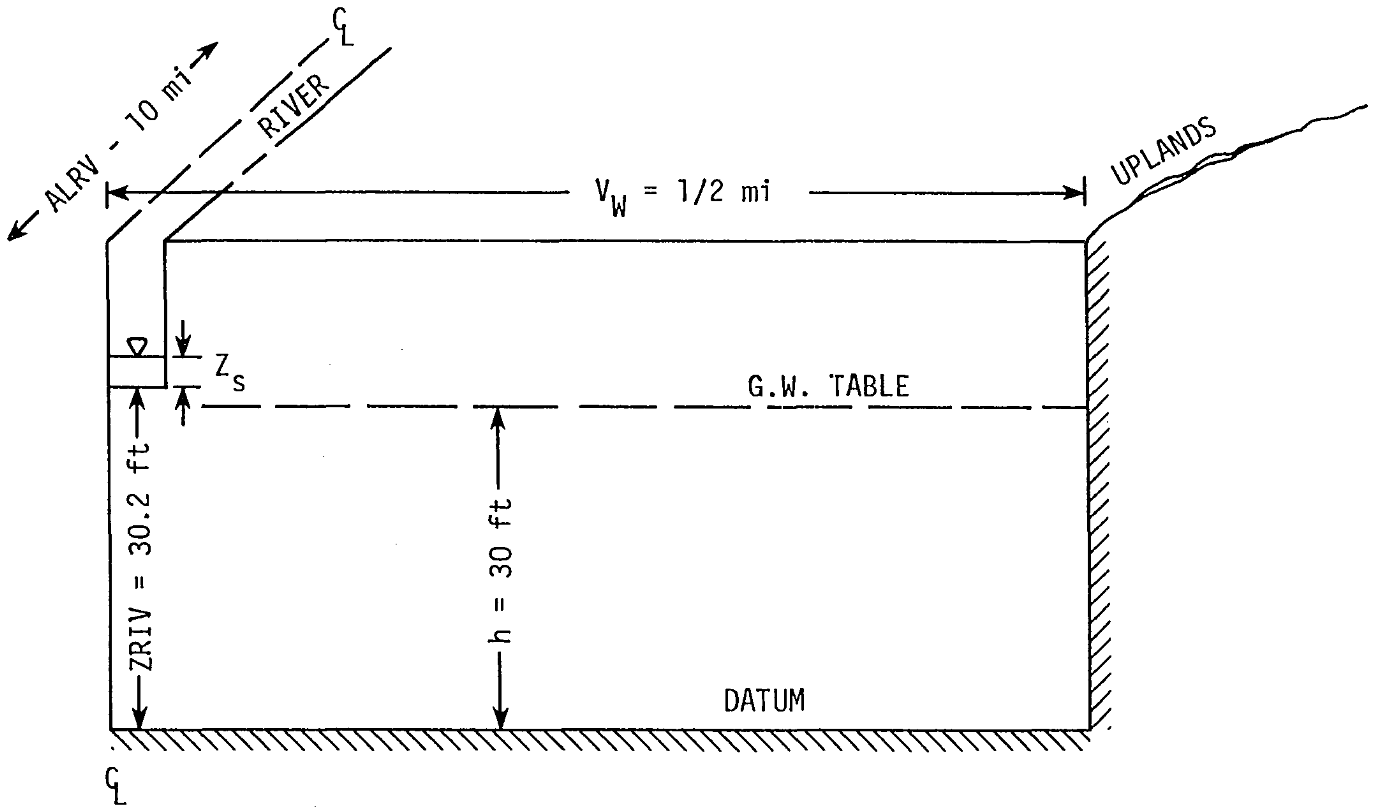


Figure 14. The half cross section of the floodplain with initial assumptions used for modeling

all data required for the equations are available for every location. The relation between the evaporation pan and the Penman methods, to achieve a better estimation of evapotranspiration in a project, has been a matter of consideration among the researchers for a relatively long time. A compromise should be made between the accuracy of the methods available, the availability of data and the amount of effort needed for evaluation of this phenomenon.

For this particular model, for the stated objectives, it is believed that the Blaney-Criddle method is adequate. However, it may not be the best for Northwest Iowa. According to Shaw (101b), the Penman method is the best for this area. But again, this idea originates from the view of a detailed model where a precise relationship between soil moisture, rainfall and crop vegetation, preferably in small plots, is the main concern. The generality of the hydromodel, particularly for monthly periods, does not necessitate the detail or the accuracy of the Penman method. The copy of the program and sample output (in the next chapter) lists the assumed input coefficients and other elements of the Blaney-Criddle method. The sample output also lists the computed monthly evapotranspiration as well. The computed values seem to be reasonable for this area.

The Blaney-Criddle method for evaluation of evapotranspiration is as follows (99):

$$u = \frac{ktp}{100} = kf \tag{65}$$

for monthly calculations and

$$U = KF \tag{66}$$

for the entire growing season calculations, where:

u = monthly consumptive use (evapotranspiration), in.,

k = monthly consumptive use coefficient, obtained from experimental data,

t = mean monthly temperature, ^{o}F,

p = monthly percent of daytime hours,

$f = \frac{tp}{100}$ = monthly consumptive use factor,

U and K = correspond to u and k of Equation (65), and

F = sum of monthly consumptive use factors for the season.

The consumptive use coefficient "k" is a product of two coefficients, k_c and k_t, which are called "crop growth stage coefficient" and "climatic coefficient," respectively. Based on experimental data, Blaney and Criddle (15) present graphs of k_c versus the times of growing for several crops. A mathematical function:

$$k_t = 0.0173t - 0.314 \qquad (67)$$

where t is average temperature in ^{o}F, is used for k_t evaluations. The hydromodel uses Equation (67) and the k_c values given as inputs for consumptive use calculations.

Beneficial Water Use in Floyd River Basin at Alton

The ultimate objective of every water resource project is seeking the ways that the available resources can be used beneficially. The type of beneficial use of water depends much on the goal which is pursued. Among the goals of water resources projects, which may be tangible or intangible, one goal is certain. That is, even before a question of economics is approached, the basic water need of living creatures should be provided. Thereafter, the problems of economical development and other goals will be of concern. Of course, some type of economical or political planning within the range of water supply for living creatures in the area will lead to a better and more beneficial use of water.

The following typical population numbers and water consumption in gallons per capita per day (gpcd) were obtained from tables and information available in a report by Rossmiller (94). This information, combined with physiographic characteristics of the basin, provide the necessary means for determining water consumption in the area under study.

The total area of the basin (Floyd River basin at Alton) is 265 square miles and covers three Iowa northwestern counties partially as follows:

23% of O'Brien County

12% of Sioux County

3% of Osceola County.

The population of the major towns located in the basin as well as total rural population of the counties for three decades are as found in Table 10.

The total acreage of crops and hay in the counties under consideration and for three typical years are as shown in Table 12.

Table 10. Name of the communities, counties and their population[a]

Name of town or community	Name of county	Population in years of 1950	1960	1970
Sanborn	O'Brien	1,337	1,323	1,465
Sheldon	O'Brien	4,001	4,251	4,532
Archer	O'Brien	167	209	134
Alton	Sioux	1,038	1,048	1,018
Hospers	Sioux	604	600	646
Total rural of county	O'Brien	8,239	7,675	6,307
	Sioux	13,454	12,342	10,713
	Osceola	5,960	5,313	4,258

[a] After Rossmiller (94).

Table 11. Number of marketed livestock for three counties under consideration and for three typical years[a]

Name of county	Type of livestock	No. of livestock for years 1952	1960	1970
O'Brien	Cattle	28,947	51,057	97,598
	Hogs[b]	220,782	229,850	236,156
Sioux	Cattle	56,581	98,114	217,467
	Hogs[b]	361,462	368,420	447,510
Osceola	Cattle	12,653	28,740	50,176
	Hogs[b]	109,198	113,744	104,630

[a] After Rossmiller (94).

[b] Data belongs to years 1967, 1970 and 1976 rather than 1952, 1960 and 1970, respectively.

Table 12. Crop acreage and the counties[a]

Name of county	Year	Corn	Soybeans	Hay
O'Brien	1952	128,510	35,090	29,554
	1960	152,932	53,457	25,708
	1970	132,320	95,187	15,211
Sioux	1952	185,085	24,757	33,234
	1960	230,864	27,075	38,968
	1970	178,149	56,754	37,051
Osceola	1952	91,214	20,658	17,623
	1960	109,354	35,007	19,333
	1970	86,458	60,820	13,368

[a] After Rossmiller (94).

A summary of rate of demand showing typical values are presented in Tables 13, 14, 15 and 16.

Table 13. Projected water use rates in the Iowa portion of the Missouri River basin (gpcd)[a]

Range of population	Water use rate (gpcd)
2500-7000	125
Less than 2500	80
Rural homes:	
With pressurized system	50
Without pressurized system	10

[a] After Rossmiller, et al. (95).

Table 14. Water demand by community size in the SICOG region for year 1970[a]

User category	Demand (gpcd)
Individual rural households and unincorporated communities	40
Incorporated communities:	
Population below 500	58
Population below 500- 750	64
Population below 750- 1,000	69
Population below 1,000- 1,500	76
Population below 1,500- 2,000	82
Population below 2,000- 3,000	91
Population below 3,000- 5,000	103
Population below 5,000-10,000	123

[a] After Austin and Patton (4).

Table 15. Municipal and industrial typical water use (gpcd)

Year	Central supplies	Industrial	Total
1960	78	32	110
1980	93	35	128

Table 16. Typical values for livestock water consumption cited by Schulz and Austin (100b) and presented by Rossmiller (94)

Livestock	In terms of gallons per day	
	Average	Peak
Cattle	6.6	9.0
Hogs	1.5	2.1

Thus far, these tables give the information necessary for defining some average values of water consumption in the area under study. Although the water resources in the basin should meet the demand in the basin, the main reason for this part of the study is to estimate the water needed to be pumped from the shallow surficial aquifer. Based on experience and information presented, some typical values are adopted to represent that part of total demand which should come from the groundwater of the basin, extracted by the hydromodel, etc. Therefore, some appropriate rates were selected to represent average values for the area under study. These estimated values fulfill the model requirements. However, for a more detailed study, more recent values are needed. Table 17 represents the adopted values.

Table 17. Adopted average demands for different user categories

User category	Demand as average
Communities (population consumption)	60 gpcd
Municipal & industrial	100 gpcd
Rural consumption	30 gpcd
Livestock:	
Cattle	8 gpd/head
Hogs	2 gpd/head

To find the total demand in the Floyd River basin at Alton, the following assumptions were made:

1. The total rural population living in the basin is proportional to the percentage of the total area of the county contributing

to the total area of the basin;

2. The total number of livestock existing in the basin is proportional to the percentage of the total area of the county contributing to the total area of the basin;
3. the total acreage of vegetation existing in the basin is proportional to the percentage of the total area of the county contributing to the total area of the basin; and
4. The rural population, number of livestock, and other data are uniformly distributed over the area of the county.

Considering the percentages of the area of each county contributing to the total area of the basin, the following values are obtained. The year 1960 is considered to represent average data for the duration under study (1956-1970).

Table 18. Estimated rural population living in the Floyd River basin above Alton

Name of county	% of contribution to the basin	Population
O'Brien	23	1,765
Sioux	12	1,481
Osceola	3	159
Total		3,405

Table 19. Estimated population of the towns existing in the Floyd River basin above Alton (year 1960 as a typical year)[a]

Name of town	Population
Sanborn	1,323
Sheldon	4,251
Archer	209
Alton	1,048
Hospers	600
Total	7,431

[a] After Rossmiller (94).

Table 20. Estimated water demands for municipalities and rural residents

Type	Population	Rate (gpcd)	Total demand (MGD)
Towns	7,431	60	0.44
Rural	3,405	30	0.10
Municipal & industrial (only in towns)	7,431	100	0.74
Total			1.28

Tables 21 and 22 show the estimated number of livestock in the basin and the estimated water demand. The values adopted assume these numbers of livestock are present 12 months of the year, to average the relative on-farm time-of-use between short-term market animals and carry-over breeding stock.

Table 21. Number of livestock in the Floyd River basin

Name of county	% of contribution to the basin	Head of livestock in the basin	
		Cattle	Hogs
O'Brien	23	11,743	52,865
Sioux	12	11,773	44,210
Osceola	3	862	3,412
Total		24,378	100,487

Table 22. Livestock water demand in the Floyd River basin above Alton

Type of livestock	No. of head	Rate of demand gpd/head	Total demand MGD
Cattle	24,378	8	0.20
Hogs	100,487	2	0.20
Total			0.40

Finally, the total water demand in the basin for domestic, municipal, industrial and livestock is 1.68 MGD or 155 ac-ft/month.

Irrigation water use in Floyd River Basin above Alton

Irrigation water is indeed a part of beneficial water use. It had to be separated from other uses in this study. Since the computer program of the hydromodel considers this beneficial water use implicitly along with its execution of other procedures, not much explanation of the calculation of irrigation water is needed in this section. However, Chapter VII provides more information about this complementary process.

The computer program of the hydromodel can introduce the varying amounts of irrigation water as a component of the water balance in the basin. The amount of water needed for irrigation is the amount required to compensate for evapotranspiration deficiencies, to maintain the steady growth of the crops (irrigation water). According to the model, this water together with other beneficial water uses should come from surficial aquifers in the basin. Therefore, it affects the groundwater table fluctuations.

The amount of consumptive use in the basin is calculated by the Blaney-Criddle method as described earlier in this chapter. The computer algorithm considers only the floodplain as a suitable area for irrigation development. After computing the amount of evapotranspiration (using the Blaney-Criddle method and appropriate input data), the model determines the soil moisture balance. If inadequate soil moisture is available, the model determines the amount of irrigation water to be applied in order to bring the soil moisture back to field capacity. The irrigation water is lumped together with the other beneficial water uses and is withdrawn from the surficial aquifer. As it will be seen later, the withdrawal of the beneficial water use from the surficial aquifer is intended to cause the groundwater table to fluctuate, and initiate a surface water and groundwater interaction. The following section describes the procedures used in the hydromodel, and the location in the hydromodel of the program for beneficial water use extraction from the surficial aquifer.

Step-by-Step Procedures of the Hydromodel

Figure 10 shows the flow chart of the model. The model takes the following steps, as instructed through the computer algorithm.

1. It determines the net amount of precipitation falling to the ground through the implementation of interception and sublimation processes.
2. It calculates the amount of surface runoff based on the precipitation that reached the ground surface.
3. It considers the precipitation reaching the ground, minus the calculated surface runoff, as available water for infiltration.
4. The infiltrable water enters the soil to provide the source of water for plant growth and the subsequent evapotranspiration.
5. The model does a mass balance on the soil moisture to determine increases in soil moisture and additions to the surficial or deep groundwater systems.
6. If a demand of beneficial water use is imposed, it extracts the required water from the surficial aquifer and determines the change in the groundwater table elevation.
7. The model calculates the amount of water moving either into or from the stream into the groundwater system using the one-dimensional Darcy equation.
8. The water table elevation is adjusted to account for the surface water/groundwater interactions.

9. The model accumulates totals for the various processes.

The following chapters provide more information about the development and application of the model.

CHAPTER V. DEVELOPMENT, CALIBRATION AND TESTING OF THE MODEL

Development and Calibration

In previous chapters, some definitions, theories and concepts were introduced to direct the reader towards the development of a simulation model, with specific attention given to a hydro-model. Almost all contributing elements for such a model have been described previously, including the hydrologic relations between the various elements.

To understand the program, the reader should be familiar with these previous sections. In summary, the objective was to model a complex hydrologic system which could respond adequately to actual hydrologic events, and predict the cause and effect of these events on the system. The model was constructed on the basis of mathematical functions describing all necessary hydrologic relationships and was written in a programming language which can be used on a digital computer.

To develop the simulation model for the system (Floyd River basin at Alton, Iowa), like any other simulation model, three basic steps are necessary: 1) the simulation model should consider the continuity of inputs and outputs and treat the hydrological cycle as a closed system; 2) the simulation model should consider the linkages between the processes, based on the concepts valid for natural, complex phenomena; and 3) the simulation model accuracy should be examined through a set of criteria. These three steps were addressed in developing the model to assure completeness.

For the first step (continuity of inputs and outputs), the inputs for the hydromodel include monthly hydrometeorologic data on precipitation, temperature and stream flow. In addition to these, other data such as physical and process parameters of the basin are introduced. The sample printout of input data (Figure 15) shows all of the input data. To find the name of each variable, if it is not stated directly, the reader should refer to the appropriate statement in the text of the program. Tables 23, 24 and 25 show the dominant hydrometeorological input data of total monthly rainfall, average monthly temperature and total monthly streamflow, respectively, for a period of 23 years (1956-1978) which were later used for various verification runs. It is important to mention that the computer program considers the rainfall and streamflow in terms of ac-ft per month and makes the necessary conversions of input data. The output of the model consists of many mass balance calculations, as Figure 16 shows. Figure 17 shows the output for evapotranspiration. The listed input and output printouts, as shown in Figures 15, 16 and 17, are for just one year of assigned record. The model operates on a monthly time period with calculations accumulated to determine the annual values. Therefore, a set of printouts is obtained for each year in the length of record introduced to the model.

For the second step (the linkage between processes), the different algorithms for different processes are linked together within the computer program and the program is clearly segmented. The reader can follow the linkage easily. The mathematical equations consider all necessary parameters which influence the physical and logical relationships to actual processes such as estimation of surface runoff (SRO),

Table 23. Average precipitation for the whole basin[a]

	O	N	D	J	F	M	A	M	J	J	A	S
1956	1.64	0.59	0.76	0.64	0.38	0.56	1.84	2.64	2.96	4.27	3.88	0.56
57	0.76	2.21	0.40	0.26	0.45	1.34	1.15	3.52	6.25	3.18	3.80	2.80
58	3.04	2.09	0.17	0.12	0.78	0.53	2.86	1.25	3.42	3.03	0.90	1.28
59	0.07	0.81	0.29	0.18	1.34	1.56	0.77	8.82	3.71	0.31	4.95	2.70
1960	2.74	2.02	1.41	0.39	0.31	1.57	3.52	6.97	2.38	1.72	7.45	5.06
61	0.67	1.07	0.88	0.24	1.49	2.19	1.59	3.81	3.06	2.73	3.40	3.46
62	1.33	0.64	1.17	0.30	3.07	2.05	1.63	3.38	3 71	5.38	5.11	1.69
63	0.92	0.27	0.32	0.64	0.55	1.10	0.99	1.44	2.78	4.91	2.26	3.42
64	1.02	0.13	0.43	0.22	0.10	1.54	3.19	3.07	3.26	5.34	3.64	7.18
65	0.76	0.29	1.05	0.44	1.65	2.75	3.41	6.79	3.58	1.95	2.29	5.30
66	0.90	0.57	0.60	1.01	1.04	1.49	1.33	2.11	3.57	2.05	3.34	1.66
67	2.16	0.27	1.04	0.72	0.38	0.3	1.73	2.32	6.99	0.62	3.25	1.04
68	1.04	0.12	0.59	0.36	0.05	0.35	2.48	3.06	2.45	4.15	1.88	6.50
69	5.45	0.57	1.91	1.40	1.84	1.86	0.87	3.47	3.19	5.83	4.06	0.50

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[a] From U.S.W.B. (110).

Table 23. Continued

	O	N	D	J	F	M	A	M	J	J	A	S
1970	2.08	0.21	1.32	0.27	0.31	2.03	1.77	4.53	1.86	1.85	0.73	6.11
71	3.91	1.25	0.79	0.07	1.78	0.96	1.22	2.50	8.39	2.72	1.08	1.35
72	3.01	2.03	1.13	0.17	0.24	0.98	3.26	5.27	2.11	6.31	2.78	1.87
73	2.12	1.64	1.64	0.86	0.71	2.34	1.30	2.72	2.95	4.80	6.03	4.39
74	1.25	2.0	0.82	0.16	0.09	1.14	1.64	3.10	3.28	1.07	8.19	0.94
75	1.40	0.71	41	1.99	0.32	1.94	4.08	2.25	7.45	0.45	6.69	2.01
76	0.29	3.14	0.10	0.17	0.66	3.03	1.91	2.21	2.68	2.17	0.83	2.38
77	0.94	0.06	0.55	0.22	0.62	3.61	2.32	3.28	2.79	5.68	4.18	3.75
78	3.04	2.26	1.35	0.25	0.61	0.35	3.64	2.25	2.15	6.96	3.72	1.73
Ave.	1.76	1.09	0.83	0.48	0.84	1.55	2.11	3.51	3.69	3.37	3.67	2.94

Table 24. Runoff in inches for Floyd River at Alton station[a]

	O	N	D	J	F	M	A	M	J	J	A	S
1956	0.009	0.006	0.002	0.001	0.001	0.045	0.049	0.037	0.018	0.019	0.064	0.004
57	0.001	0.006	0.003	0.002	0.001	0.100	0.050	0.046	0.134	0.173	0.013	0.014
58	0.029	0.047	0.025	0.009	0.014	0.029	0.102	0.041	0.120	0.014	0.002	0.001
59	0.001	0.001	0.001	0.001	0.001	0.003	0.015	0.298	0.302	0.032	0.076	0.006
1960	0.012	0.011	0.033	0.022	0.013	0.877	0.511	0.137	0.002	0.049	0.324	0.246
61	0.11	0.07	0.04	0.02	0.09	1.60	0.27	0.20	0.16	0.06	0.06	0.04
62	0.03	0.03	0.01	0.008	0.09	2.59	1.12	0.22	0.67	0.15	0.08	0.10
63	0.05	0.03	0.02	0.01	0.009	0.12	0.05	0.03	0.02	0.02	0.02	0.007
64	0.003	0.006	0.005	0.001	0.001	0.02	0.03	0.06	0.02	0.11	0.01	0.13
65	0.03	0.02	0.008	0.003	0.01	0.75	2.67	0.48	0.30	0.08	0.02	0.06
66	0.29	0.10	0.08	0.03	0.64	0.15	0.23	0.13	0.22	0.02	0.01	0.004
67	0.01	0.01	0.009	0.003	0.008	0.33	0.04	0.02	0.64	0.06	0.02	0.005
68	0.004	0.008	0.008	0.002	0	0.01	0.02	0.01	0.009	0.02	0.001	0.04
69	0.23	0.09	0.04	0.007	0.009	0.43	3.81	0.22	0.21	0.41	0.13	0.05

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[a] From U.S.G.S. (111).

Table 24. Continued

	O	N	D	J	F	M	A	M	J	J	A	S
1970	0.02	0.03	0.02	0.01	0.05	0.73	0.44	0.28	0.15	0.03	0.009	0.04
71	0.04	0.05	0.02	0.004	0.99	0.30	0.16	0.07	1.87	0.18	0.03	0.009
72	0.03	0.04	0.02	0.007	0.004	0.88	0.12	0.65	0.41	0.38	0.19	0.04
73	0.05	0.16	0.21	0.47	0.17	1.57	0.41	0.27	0.32	0.49	0.38	0.11
74	0.35	0.28	0.17	0.09	0.16	0.22	0.32	0.23	0.44	0.10	0.22	0.08
75	0.07	0.08	0.06	0.02	0.006	0.77	1.57	0.68	1.75	0.29	0.31	0.13
76	0.06	0.09	0.10	0.03	0.12	0.48	0.29	0.20	0.14	0.05	0.01	0.006
77	0.01	0.01	0.0001	0.0001	0.0001	0.08	0.04	0.04	0.02	0.07	0.04	0.02
78	0.06	0.24	0.14	0.02	0.01	0.87	0.45	0.27	0.19	0.53	0.13	0.05
Ave.	0.065	0.062	0.045	0.033	0.104	0.563	0.555	0.201	0.353	0.145	0.093	0.052

Table 25. Mean monthly temperature for Sheldon, Iowa station[a]

	O	N	D	J	F	M	A	M	J	J	A	S
1956	51.3	26	13.6	12.9	15.5	29.3	42.2	59.9	74.6	70.3	70.6	61.6
57	57.0	33.1	25.4	10.3	24.5	31.8	46.4	56.7	66.5	76.8	70.6	58.9
58	48.0	33.4	29.1	23.8	16.6	32.8	47.3	62.2	65.6	69.3	73.3	64.1
59	53.5	36.1	17.2	12.1	14.6	33.4	47.6	60.1	71.1	71.9	74.7	61.3
1960	45.5	24.6	30.1	16.1	17.1	18.2	47.3	58.2	65.3	71.7	71.9	62.6
61	51.1	37.2	20.7	14.8	23.0	34.4	41.9	55.5	67.9	70.8	71.2	59.5
62	51.8	33.3	16.0	11.5	17.8	24.1	45.4	63.5	66.6	70.1	69.9	58.8
63	53.0	39.5	22.9	7.5	19.5	38.3	50.5	59.2	72.9	74.3	70.4	64.8
64	59.7	39.8	12.8	23.3	26.1	27.7	48.0	63.0	68.9	75.9	67.4	60.6
65	49.9	35.4	16.4	13.7	15.5	21.2	45.5	62.4	68.1	71.9	69.4	54.0
66	53.0	34.3	29.5	8.9	19.0	38.1	42.5	56.3	68.7	76.5	67.9	60.8
67	49.4	32.0	20.4	17.9	16.8	37.5	47.7	54.2	66.8	70.9	68.3	61.4
68	48.4	33.2	23.6	17.0	19.4	40.6	49.0	54.3	69.8	71.7	71.6	60.6
69	50.8	33.5	17.1	9.7	20.9	21.7	48.6	60.5	62.5	73.7	71.3	62.5

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[a] From U.S.W.B. (110).

Table 25. Continued

	O	N	D	J	F	M	A	M	J	J	A	S
1970	45.2	34.9	20.4	6.8	12.1	27.2	46.8	61.5	71.1	73.8	71.9	62.3
71	47.5	33.6	18.6	10.1	20.6	31.6	49.0	56.9	72.6	69.1	69.5	61.6
72	53.1	34.9	20.2	10.2	13.5	32.3	45.3	60.1	67.9	69.2	69.0	60.1
73	46.4	32.9	14.5	18.5	22.9	39.9	46.4	57.4	70.0	72.0	72.4	60.1
74	54.5	35.4[b]	18.2[b]	14.2[b]	24.5[b]	34.7	49.3[b]	57.4[b]	67.7[b]	76.7[b]	67.1	58.0
75	52.2	34.8	23.6	16.3	16.7	25.2	41.3	62.2	67.3	75.1	72.4	57.9
76	53.1	35.8	23.1	17.5	30.7	34.3	52.0	58.4	70.0	74.8	72.7	63.1
77	44.8	28.5	17.3	6.4	26.8	38.2	54.6	66.8	70.5	74.6	67.5	62.9
78	48.6	32.7	17.8	4.8	10.8	31.6	45.9	59.8	69.0	72.1	70.7	66.8

[b] Estimated by means of neighboring stations.

```
INPUT DATA FOR**** FLOYD RIVER BASIN ABOVE ALTON -  SIMULATION PERIOD 1956 TO 1978 ****
FRB1   23 12  3  4  0  1  0  0  0  0  0  0  0  0  1  1  0  1 0.00 0.00 0.000 0.000 1.000 0.100 0.060  30.0  26.0
FRB2      152640.    16960.          0.  39836.  4.50  2.00  0.00          0.       300.   0.010      3000.   114460.          0.          0.
FRB3           0.     5274.    11000.
HYDRAULIC VARIABLES        20.0000  0.1400  0.0010  0.0350  0.0010 10.0000  0.1500 30.2000   5290.   31.47
ITEM--YEAR1970             OCT     NOV     DEC     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     YEAR
CROP GW-RETURN FLO COEF     0.100   0.200   0.800   1.000   1.000   0.800   0.300   0.100   0.000   0.000   0.000   0.000
SURFACE SUPPLY TO WL COEF   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PROPORTION DAYLIGHT HOURS  0.0773  0.0663  0.0639  0.0660  0.0666  0.0838  0.0897  0.1010  0.1021  0.1037  0.0964  0.0842
COA1                     -23.8000-20.0000  0.0000  0.0000  0.0000-21.3000-30.6600-12.2000-16.2000-14.9500-17.0000-18.6000
COA2                     -23.8000-20.0000  0.0000  0.0000  0.0000-21.3000-30.6600-12.2000-16.2000-14.9500-17.0000-18.6000
POB1                       6.4400  5.0100  0.0000  0.0000  0.0000  5.9900  5.9000  2.9600  3.5400  3.5500  3.5700  4.5100
POB2                       6.4400  5.0100  0.0000  0.0000  0.0000  5.9900  5.9000  2.9600  3.5400  3.5500  3.5700  4.5100
POC1                       0.5870  2.1600  0.0000  0.0000  0.0000  1.4250  1.4250  1.2400  2.9400  1.7000  2.4500  1.0600
POC2                       0.5870  2.1600  0.0000  0.0000  0.0000  1.4250  1.4250  1.2400  2.9400  1.7000  2.4500  1.0600
PSM1                       0.0000  0.0000  0.0690  0.0010  0.0350  0.3300  0.1000  0.0000  0.0000  0.0000  0.0000  0.0000
PSM2                       0.0000  0.0000  0.0690  0.0010  0.0850  0.3300  0.1000  0.0000  0.0000  0.0000  0.0000  0.0000
CFA1                       0.0000  0.0000100.0000100.0000 30.0000 60.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CFB1                       0.0000  0.0000 -0.4500 -0.4500 -0.4500 -0.4500 -0.4500  0.0000  0.0000  0.0000  0.0000  0.0000
CFA2                       0.0000  0.0000 40.0000100.0000 20.0000 30.0000 40.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CFB2                       0.0000  0.0000 -0.8000 -0.9000 -0.9000 -0.8000 -0.8000  0.0000  0.0000  0.0000  0.0000  0.0000
CRA1                       0.9000  0.9500  1.0000  1.0000  1.0000  1.0000  1.0000  0.9000  0.8800  0.8500  0.8500  0.9000
CRA2                       1.0000  1.0000  1.0000  1.0000  1.0000  1.4100  1.9400  3.8100  1.0000  1.0000  1.0000  1.0000
CRB1                       0.9800  0.7270  1.0000  1.0000  1.0000  1.0000  0.7210  0.6500  0.6220 -0.0770  0.3250  0.2220
CRB2                       0.9800  0.7270  1.0000  1.0000  1.0000  1.0000  0.7210  0.6500  0.6220 -0.0770  0.3250  0.2220
GWCOE                      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CROP AREAS  22896.   65635.   64109. 152640.
  1 GRSS    K COEF           0.63    0.54    0.00    0.00    0.00    0.00    0.68    0.72    0.74    0.74    0.73    0.70
  2 CORN    K COEF           0.25    0.15    0.00    0.00    0.00    0.00    0.29    0.39    0.58    0.64    0.58    0.42
  3 SBNS    K COEF           0.26    0.15    0.00    0.00    0.00    0.00    0.27    0.37    0.51    0.57    0.51    0.38
WLPH AREAS    339.     2544.    7293.   6784.  16960.
  1 WTR     K COEF           0.54    0.38    0.00    0.00    0.00    0.00    0.73    0.88    0.94    1.00    0.94    0.75
  2 GRSS    K COEF           0.59    0.50    0.00    0.00    0.00    0.00    0.64    0.68    0.69    0.69    0.68    0.65
  3 CORN    K COEF           0.23    0.14    0.00    0.00    0.00    0.00    0.27    0.37    0.54    0.60    0.54    0.39
  4 SBNS    K COEF           0.25    0.14    0.00    0.00    0.00    0.00    0.26    0.35    0.48    0.53    0.48    0.35
                         INPUT PRECIPITATION
1970                         2.08    0.21    1.32    0.27    0.31    2.03    1.77    4.53    1.86    1.85    0.73    6.11   23.07
                         AVERAGE TEMPERATURE
1970                        45.20   34.90   20.40    6.80   12.10   27.20   46.80   61.50   71.10   73.80   71.90   62.30  534.00
                           GAGED OUTFLOW
1970                       335.00  376.00  248.00  207.00  769.0010300.00 6210.00 3970.00 2070.00  393.00  139.00  381.0025598.00
                           GW OUTFLOW
1970                         0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    I          ZGW             ZS           ZRIV        DELH              DGW             GW           GIRR
    1        31.91           1.15          31.35    0.21943E-03          36.17           0.00           0.00
    2        31.88           0.05          30.25    0.63382E-03          94.13           0.00           0.00
    3        31.85           0.46          30.66    0.46337E-03          71.63           0.00           0.00
    4        31.81           0.01          30.21    0.62367E-03          92.26           0.00           0.00
    5        31.78           0.33          30.53    0.48679E-03          74.35           0.00           0.00
    6        31.80           2.31          32.51   -0.27741E-03         -50.49           0.00           0.00
    7        31.85           3.11          33.31   -0.57518E-03        -111.51           0.00           0.00
    8        31.85           1.76          31.96   -0.44784E-04          -7.79           0.00           0.00
    9        31.82           0.43          30.63    0.46206E-03          71.27           0.00           0.00
   10        31.80           0.56          30.76    0.40407E-03          63.07           0.00           0.00
   11        31.76           0.04          30.24    0.59247E-03          87.92           0.00           0.00
   12        31.73           0.29          30.49    0.48395E-03          73.61           0.00           0.00
                                                                                                  0.00 INCHES
```

Figure 15. Input data and G.W. table calculations (Run '0')

```
                               **** FLOYD RIVER BASIN ABOVE ALTON -  SIMULATION PERIOD 1956 TO 1978 ****
ITEM--YEAR1970                  OCT     NOV     DEC     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP    YEAR
  MEASURED INFLOW            0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  UNMEASURED INFLOW          0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
PUMPED WATER                 0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
TOTAL MANAGEABLE WATER       0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
GROUNDWATER INFLOW           0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  CROPLAND DIVERSIONS        0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  AMOUNT TO ROOT ZONE        0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  CROPLAND RETURN FLOW       0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
RUNOFF FROM UPLANDS       1315.      9.    390.      0.    227.   5815.   9558.   3703.    357.    543.      6.    181.  22604.
  SURFACE RETURN FLOW        0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  GW RETURN FLOW             0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
CROPLAND PRECIPITATION   23812.   2533.  16790.   3434.   3943.  25822.  22514.  51859.  20820.  20002.   7893.  69947. 269375.
SNOW STORAGE ADDED           0.      0.   5256.  -4911.   2102.   9358. -11806.      0.      0.      0.      0.      0.      0.
  ACCUM SNOW STORAGE         0.      0.      0.   5256.    345.   2447.  11806.      0.      0.      0.      0.      0.      0.
DETENTION ON CROPS           0.      0.   1874.   1955.    508.   4409.   2247.      0.      0.      0.      0.      0.  10994.
SUBLIMATION FROM CROPS       0.      0.   9270.   6390.   1105.   6239.      0.      0.      0.      0.      0.      0.  23005.
  SNOW MELT                  0.      0.    390.      0.    227.   5815.   9558.      0.      0.      0.      0.      0.  15990.
  ROOT ZONE SUPPLY       21997.   2529.   1874.   1955.    508.   4409.  24762.  48156.  20463.  19459.   7887.  69766. 223766.
  CROPLAND P.C.U.        13831.   6137.      0.      0.      0.      0.  18161.  34061.  53058.  60900.  50527.  29706. 266380.
  RZ SUPPLY-P.C.U.        8166.  -3607.   1874.   1955.    508.   4409.   6601.  14095. -32594. -41441. -42640.  40061. -42613.
ACCUM SOIL MOISTURE    I- 39886.  48052.  44445.  46319.  48274.  46782.  53192.  59793.  73888.  41294.      0.      0.  40061.
  CONS. USE DEFICIT          0.      0.      0.      0.      0.      0.      0.      0.      0.   -148. -42640.      0. -42788.
ACTUAL CROPLAND C.U.     13831.   6137.      0.      0.      0.      0.  18161.  34061.  53058.  60752.   7887.  29706. 223592.
  INTERFLOW ADDED            0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
ACCUM INTERFLOW        I-    0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
DETENTION ON WETLAND         0.      0.    208.    217.     56.    490.    250.      0.      0.      0.      0.      0.   1222.
SUBLIMATION FROM WETLAND     0.      0.   1030.    710.    123.    693.      0.      0.      0.      0.      0.      0.   2556.
  GROUNDWATER ADDITION       0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  GROUNDWATER TO SURFACE    36.     94.     72.     92.     74.    -50.   -112.     -8.     71.     63.     88.     74.    495.
DOMESTIC USE                 0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IRRIGATION FOR WTLCROPS      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
EXPORTS                      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  SURFACE SUPPLY TO WL       0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
WETLAND PRECIPITATION     2646.    282.   1866.    392.    438.   2869.   2502.   5762.   2313.   2222.    877.   7772.  29931.
RUNOFF FROM FLOODPLAINS    202.      1.     43.      0.     25.    646.   1062.    411.     40.     60.      1.     29.   2512.
SNOW STORAGE ADDED           0.      0.    584.   -546.    234.   1040.  -1312.      0.      0.      0.      0.      0.      0.
  ACCUM SNOW STORAGE         0.      0.      0.    584.     38.    272.   1312.      0.      0.      0.      0.      0.      0.
SNOW MELT                    0.      0.     43.      0.     25.    646.   1062.      0.      0.      0.      0.      0.   1777.
  TOTAL SUPPLY TO WL      2444.    281.    208.    217.     56.    490.   2751.   5351.   2274.   2162.    876.   7752.  24863.
  POTENTIAL WETLAND CU    1473.    650.      0.      0.      0.      0.   1964.   3676.   5607.   6419.   5339.   3115.  28243.
  TSWL-WL P.C.U.           972.   -369.    208.    217.     56.    490.    787.   1675.  -3333.  -4257.  -4463.   4637.  -3381.
ACCUM WL SOIL MOIST    I- 5274.   6246.   5877.   6085.   6302.   6359.   6649.   7636.   9310.   5977.   1720.      0.   4637.
  WETLAND DEFICIT            0.      0.      0.      0.      0.      0.      0.      0.      0.      0.  -2743.      0.  -2743.
ACTUAL WETLAND C.U.       1473.    650.      0.      0.      0.      0.   1964.   3676.   5607.   6419.   2596.   3115.  25501.
  WL ADD TO SRFC AND GW      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  SURFACE WTR IN CHANNEL  2053.    103.    504.     93.    327.   6410.  10509.   4107.    468.    667.     95.    275.  25610.
TOTAL OUTFLOW             2053.    103.    504.     93.    327.   6410.  10509.   4107.    468.    667.     95.    275.  25610.
  GW OUTFLOW                 0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
SURFACE OUTFLOW           2053.    103.    504.     93.    327.   6410.  10509.   4107.    468.    667.     95.    275.  25610.
  GAGED OUTFLOW            335.    376.    248.    207.    769.  10300.   6210.   3970.   2070.    393.    139.    581.  25598.
  DIFFERENCE XCOMP-GAGED  1718.   -273.    256.   -114.   -442.  -3890.   4299.    137.  -1602.    274.    -44.   -306.     12.
```

Figure 16. Mass balance calculations for different processes (Run '0')

```
                                                         CONSUMPTIVE USE CALCULATIONS
      YEAR1970                     OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      YEAR
AVERAGE TEMPERATURE               45.20    34.90    20.40     6.90    12.10    27.20    46.60    61.50    71.10    73.80    71.90    62.30     44.50
BLANEY-CRIDDLE @F@                 3.47     2.31     1.30     0.45     0.81     2.28     4.20     6.21     7.26     7.65     6.93     5.25     48.14
AGRICULTURAL CROPS
 1 GRSS    UNIT USE (IN.)          2.20     1.25     0.00     0.00     0.00     0.00     2.85     4.47     5.37     5.66     5.06     3.67     30.54
 1 GRSS    USE (ACRE-FT)          4200.    2384.       0.       0.       0.       0.    5447.    8533.   10250.   10806.    9654.    7005.    56279.
 2 CORN    UNIT USE (IN.)          0.87     0.35     0.00     0.00     0.00     0.00     1.22     2.42     4.21     4.90     4.02     2.20     20.19
 2 CORN    USE (ACRE-FT)          4779.    1898.       0.       0.       0.       0.    6659.   13250.   23029.   26790.   21988.   12050.   110442.
 3 SBNS    UNIT USE (IN.)          0.91     0.35     0.00     0.00     0.00     0.00     1.13     2.30     3.70     4.36     3.53     1.99     18.28
 3 SBNS    USE (ACRE-FT)          4353.    1854.       0.       0.       0.       0.    6055.   12278.   19779.   23305.   18885.   10649.    97659.
  CROPLAND P.C.U.                13331.    6137.       0.       0.       0.       0.   18161.   34061.   53058.   60900.   50527.   29706.   266380.
ACTUAL CROPLAND C.U.             13831.    6137.       0.       0.       0.       0.   18161.   34061.   53058.   60752.    7887.   29706.   223592.
WET LAND PHREATOPHYTES
 1 WTR     UNIT USE (IN.)          1.89     0.88     0.00     0.00     0.00     0.00     3.15     5.47     6.82     7.65     6.52     3.93     36.31
 1 WTR     USE (ACRE-FT)            53.      25.       0.       0.       0.       0.      89.     155.     193.     216.     184.     111.     1026.
 2 GRSS    UNIT USE (IN.)          2.06     1.16     0.00     0.00     0.00     0.00     2.69     4.22     5.01     5.28     4.71     3.41     28.54
 2 GRSS    USE (ACRE-FT)           437.     245.       0.       0.       0.       0.     570.     895.    1062.    1119.     999.     723.     6051.
 3 CORN    UNIT USE (IN.)          0.80     0.32     0.00     0.00     0.00     0.00     1.13     2.30     3.92     4.59     3.74     2.05     18.86
 3 CORN    USE (ACRE-FT)           488.     197.       0.       0.       0.       0.     689.    1397.    2382.    2791.    2275.    1243.    11462.
 4 SBNS    UNIT USE (IN.)          0.37     0.32     0.00     0.00     0.00     0.00     1.09     2.17     3.48     4.06     3.33     1.84     17.17
 4 SBNS    USE (ACRE-FT)           494.     183.       0.       0.       0.       0.     617.    1229.    1970.    2293.    1881.    1038.     9705.
  POTENTIAL WETLAND CU            1473.     650.       0.       0.       0.       0.    1964.    3676.    5607.    6419.    5339.    3115.    28243.
ACTUAL WETLAND C.U.               1473.     650.       0.       0.       0.       0.    1964.    3676.    5607.    6419.    2596.    3115.    25501.
```

Figure 17. Output printout for evapotranspiration

infiltration, soil moisture capacity and percolation to groundwater. The physical characteristics, together with necessary input data, control the response of the physical system at each increment of time, which in this model is one month.

For the third step (criteria for accuracy of the model), the standards of evaluation are more difficult to describe and are subject to change in accordance with the purpose of the study. Although a physical criterion such as computed versus measured streamflow has been used for initial comparison, the overall criteria for acceptance were based somewhat on the experience of the research faculty in determining which variables or parameters should be estimated most accurately. Since the fluctuation of the groundwater is of greatest concern to water users in the valley, it has been the major objective of the research for the basic study period (15 years for calibration from 1956 to 1970, 8 years for testing from 1971 to 1978 and 23 years for final overall application and review from 1956 to 1978). The main variable on which the model focused was the volume of water transferred through the sequential hydrologic processes using precipitation as the starting point. With regard to the generality of the model, effort was first expended in developing and calibrating a model for the first 15 years of data, assuming it would then be responsive to any other period of record in the area. To achieve the required accuracy and responsiveness, trial computer runs were made with different combinations of process parameters. A set of comparisons made between the consecutive, the current and the previous runs and the gain or loss in improvement was recorded.

Since a relatively large number of parameters was considered, theoretically the number of trial runs might have been in the thousands or more for a precise calibration. This was neither practical nor economical for a model using monthly data. For this reason, in every simulation model, a number of assumptions are made. Depending on the purpose of the study, the dominant assumptions must be physically meaningful. Because of time and monetary limitations for developing this model, a combination of trial and error along with experimental adjustments, based on intermediate computations or regressions, was utilized. The development required six months of effort and over 200 trial runs. An adequate set of parameters was obtained, and final adjustments permitted the research study to be completed.

The total volume of streamflow during the period of record is of primary interest in the model. Due to the many complex relationships and data limitations, it was not expected that monthly balances would be as accurate. However, a reasonable monthly balance was reached. Hydrologically speaking, the resultant errors for estimation of any hydrologic event, should lie in the range of ± 20% limits as a general rule. With some minor exceptions, this condition was met for the calibration and testing periods, particularly for <u>annual and period of record</u> results (Table 26). It should be kept in mind that one criterion adopted for comparison, and the one used for computing the error range, was the measured outflow from the basin (total streamflow) during the periods of calibration and testing. Since the actual streamflow observations and measurements have been carried out as in normal practice (USGS program), with no special treatment being imposed for

Table 26. Gaged and estimated monthly and annual average volume of water for calibration, testing and total durations including the percents of errors for estimated versus gaged values

Duration		15 years		8 years		23 years	
Month	Type	Average volume (ac-ft)	% err.	Average volume (ac-ft)	% err.	Average volume (ac-ft)	% err.
Oct.	Gag.	787	- 28	1,196	- 21	929	- 4
	Est.	564		940		891	
Nov.	Gag.	409	- 44	1,686	- 17	854	- 16
	Est.	231		1,392		715	
Dec.	Gag.	291	- 39	1,296	- 73	640	- 53
	Est.	177		350		299	
Jan.	Gag.	130	- 63	1,130	- 88	478	- 80
	Est.	48		139		97	
Feb.	Gag.	895	- 26	3,571	- 67	1,478	- 35
	Est.	662		853		959	
Mar.	Gag.	7,339	- 12	9,139	9	7,965	25
	Est.	6,494		9,942		9,952	
Apr.	Gag.	9,266	- 26	5,914	20	8,100	15
	Est.	6,890		7,068		9,348	
May	Gag.	2,436	- 34	4,246	- 131	3,066	- 27
	Est.	1,615		1,835		2,253	
June	Gag.	2,903	- 31	9,076	- 20	5,050	- 10
	Est.	2,007		7,230		4,521	
July	Gag.	1,167	31	3,703	- 12	2,049	29
	Est.	1,523		3,250		2,653	
Aug.	Gag.	793	60	2,316	- 12	1,323	16
	Est.	1,266		2,038		1,534	
Sept.	Gag.	694	- 33	790	- 12	727	- 3
	Est.	465		688		704	

Table 26. Continued

Duration		15 years		8 years		23 years	
Month	Type	Average volume (ac-ft)	% err.	Average volume (ac-ft)	% err.	Average volume (ac-ft)	% err.
Annual	Gag. Est.	27,160 32,970	21	40,616 35,724	- 12	31,841 33,927	7

more precise measurements, some type of observation errors are expected. Therefore, for better model testing, more accurate field data might be needed. For this reason, and based on the experience available, it is concluded that verification through calibration has been achieved satisfactorily and the response of the model to the many variables is sufficiently accurate to meet the objectives of the study. Table 26 shows the percents of error for: 1) the 15-year period of calibration (1956-1970), 2) the 8-year period of testing (1971-1978), and 3) the total 23-year period (1956-1978).

Testing of the Model

As mentioned in previous sections, the model was calibrated for a period of 15 years. Theoretically, the model should then work with any other period of record and produce the same results within the specified percent of error. In the case of a very complex hydrologic system, this may be impossible unless all the contributing factors have been taken into account recursively. For example, the range of input values used for the various parameters should not be exceeded. Minor differences occurred in the model between calibration and testing runs. This is not such a problem for this model which is a lumped one but could be a problem for any other more detailed model. For a complex hydrological system, the reason can be attributed to undefined relationships not fully described or values which cannot be bound. Some of the models' mathematical relationships may not be described perfectly at the present stage of hydrology. However, some type of response can be expected from the model when it is applied to different periods or different basins. If different parts of the model work in the same proportion for different periods, it can be said that the model is responsive. A reasonable stage of responsiveness has been reached for the model.

For the time being, for the input data used, the model works satisfactorily. The criterion of accuracy of simulation has been met, in estimating streamflow and groundwater levels.

The average percent of error during the study period, 1956-1972, is reasonably acceptable. As Table 26 shows, the percent of error is not the same for calibration, testing and for the total period analysis. For each individual period, it is possible to adjust the model in some fashion (changing the coefficients) to reduce the average percent of error. But this attempt violates the principle of the modeling effort. That is, the analyst is restricted to using the calibration period only. In this study another set of trial and error attempts took place to improve the outcome of the model for both calibration and testing periods. The testing period, for example, was a period of much greater rainfall, etc. Although the range of errors became wider (more than ± 20%) for monthly results, annual period results remained within the range. In a wider sense, due to the theory of "central limit theorem," in a long series of durations, theoretically in an infinite series, the average percent of error tend to be zero. This fact can be visualized from Table 26 which indicates that the algebraic sum of the errors for three durations has the tendency towards zero. Consequently, the conclusion is reached that the percent of error results are compensative rather than additive. So, in another sense, the percent of error will decrease if the number of years in the period increases. This fact also is apparent in Table 26 which shows the percent of error values for the total period of study (months and years) are generally lower than those of the other two periods.

These illustrate that the model behaves correctly and proportionally. But it is important to note that it somewhat overestimates streamflow in the dry years, underestimates the wet years and simulates best in years of average precipitation. This is a very important point when the model is applied to a relatively short period of hydrologic record. However, this will tend to give conservative results for drought year groundwater levels, since less groundwater contribution is forecast.

Results of Testing of the Model

Surface and groundwater interaction is one of the main objectives of the study. Groundwater table fluctuation in the alluvial aquifer of the basin can be used to best describe this interaction. To increase the validity of the model and cover several possible combinations of the variables, different conditions were introduced into the model. For each condition, the criteria of accuracy were carefully considered and those tests which were acceptable were chosen for presentation later in this chapter.

In the case of groundwater table fluctuations in the shallow aquifer of the basin, the most important factor is the amount of water withdrawn from the shallow aquifer for beneficial water use. Chapter IV included the method for estimating beneficial water use in the basin. The estimate of beneficial water use (except irrigation) was estimated to be 155 ac-ft per month to be applied to the total period of testing (1956-1978). Using the same source of information (94), it is projected that the total water consumption in the year 1980 and the year 2020 are 175 and 235 ac-ft per month, respectively. This beneficial water use includes industrial, municipal, rural, livestock, farmsteads and homestead uses. Another important water use withdrawn from the shallow aquifer is water for irrigation. The computer program responds to irrigation demands in the floodplain when it is needed. Table 27 shows the summary of conditions imposed in the first set of testing. Run numbers hereafter will be used to distinguish the curves which are presented later. In this first set it is assumed that the floodplain covers 10% of the whole basin. Figures 15, 16 and 17 belonged to Run '0' and provided all necessary information about the inputs and outputs of the model as samples of input and output printouts. Charts of Figures 18, 19 and 20 also belong to Run

Table 27. Condition imposed for the first set of testing[a]

Run No.	Amount of withdrawal from aquifer ac-ft/month	% of irrigation in floodplain	Average 23-year period total irrigation season use (total depth in in.)
0	0	0	0
1	15.5	0	0
2	155	0	0
4	155	100	4.21
6	235	100	4.21

[a] Runs '0' through '4' are for the current situation, and Run '6' is for future conditions, for the years 1980 and 2020, respectively.

'0' and present the mass balance of the model in terms of total ac-ft accumulated during the 23-year period, average annual depth in inches over the basin and percentage of total rainfall, respectively. These values represent the annual average amounts during 23 years of data used in testing. Figures 21, 22 and 23 give the annual soil moisture variations during 23 years data of testing for those months of crop cultivation and maximum growth (June-July-August). Figures 24 and 25 show the same variable for the months of May and September, respectively. These soil moisture values compare favorably with the relative frequencies of various soil moisture deficits as calculated by Rossmiller (94).

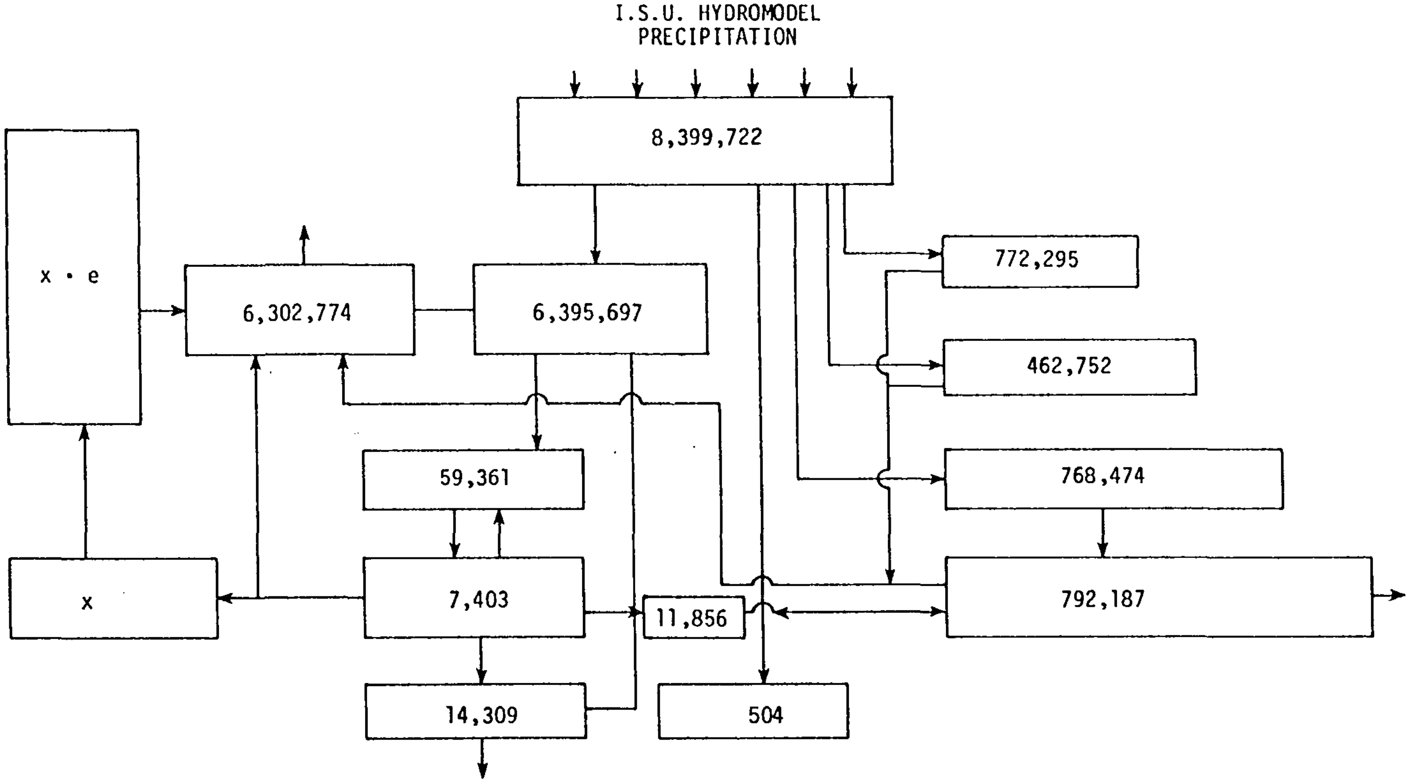

Figure 18. Water mass distribution for different processes (ac-ft). ISU unit hydromodel for Floyd River Basin at Alton based on 23-year average. X = pumped water; e = efficiency

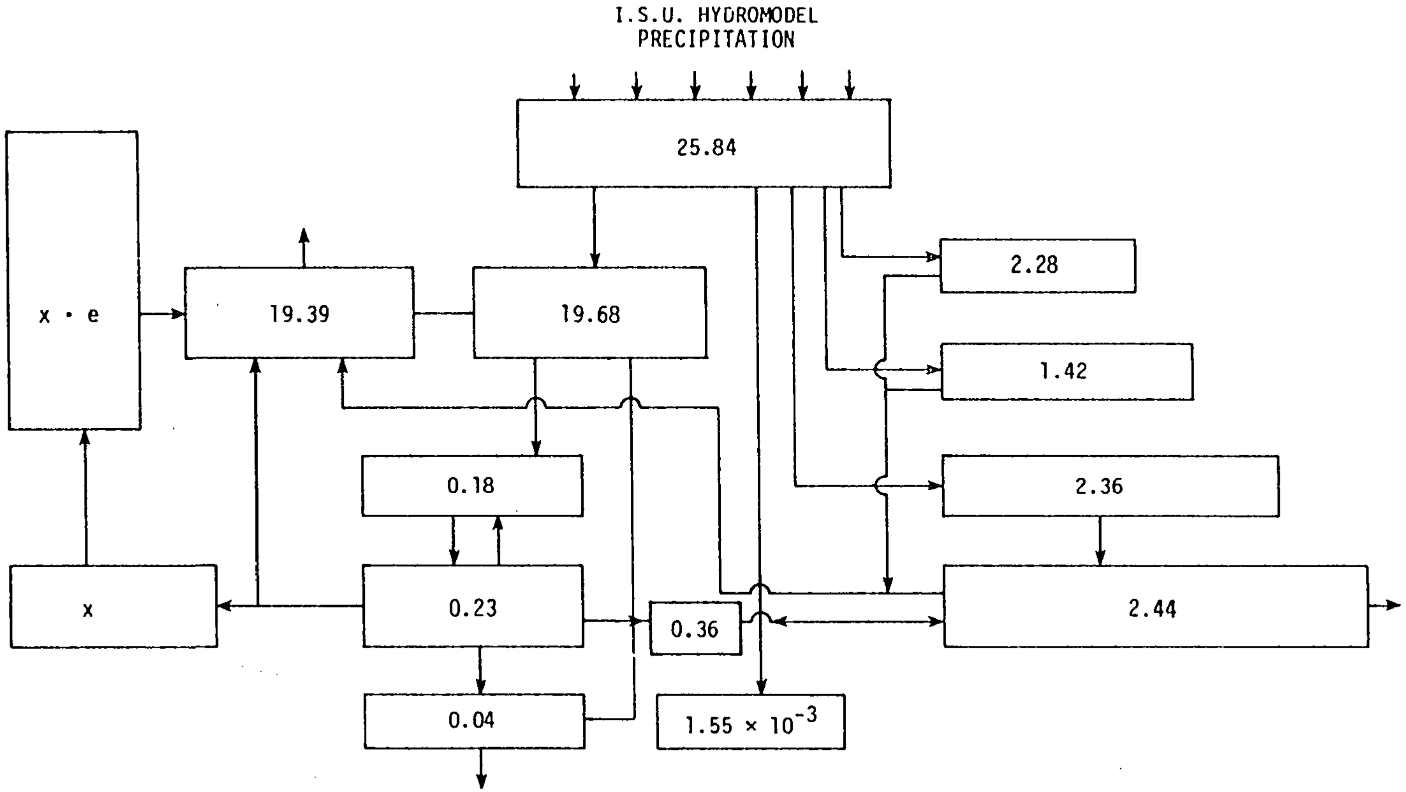

Figure 19. Rainfall depth distribution for different processes (in.). ISU unit hydromodel for Floyd River Basin at Alton based on 23-year average

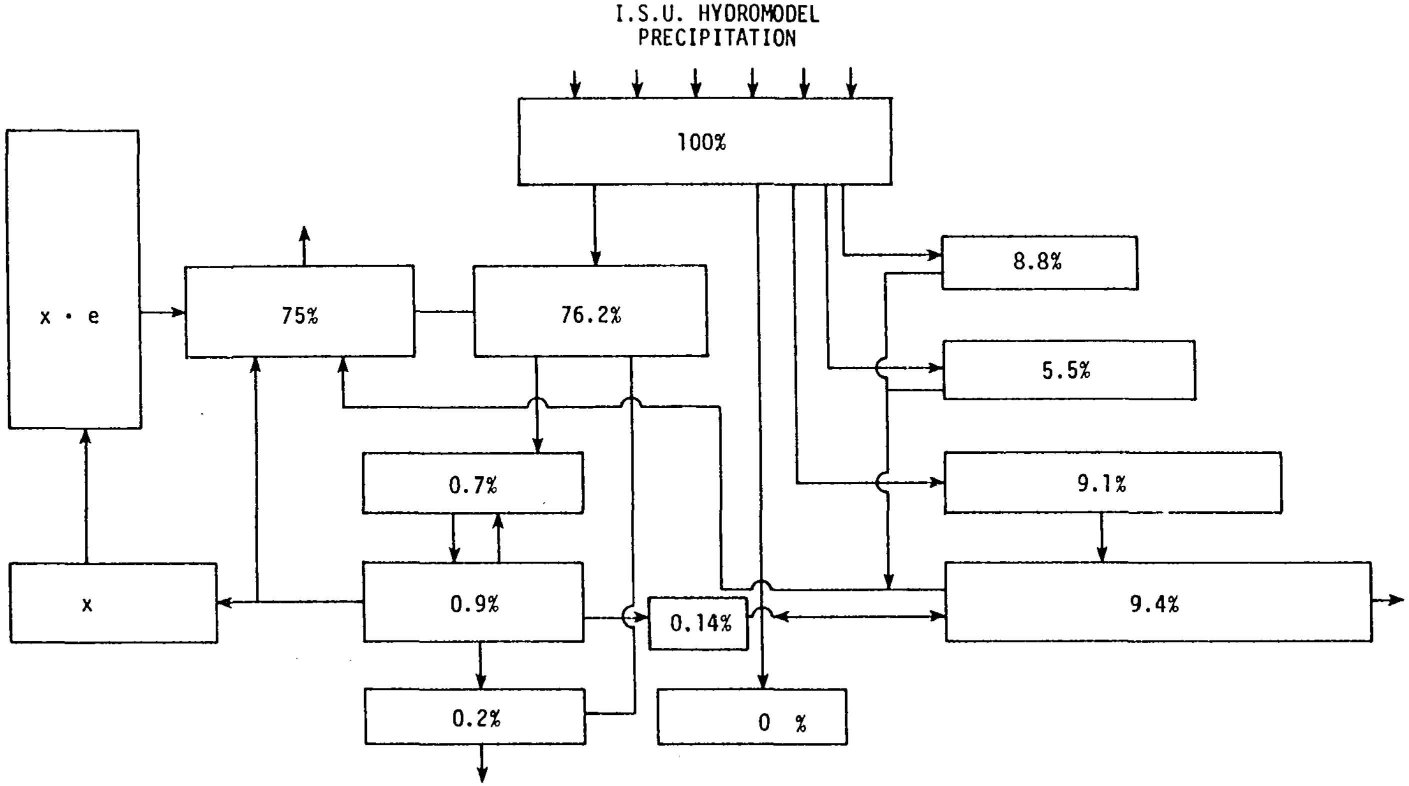

Figure 20. Percentages of distribution compared to that of total rainfall. ISU unit hydromodel for Floyd River Basin at Alton based on 23-year average

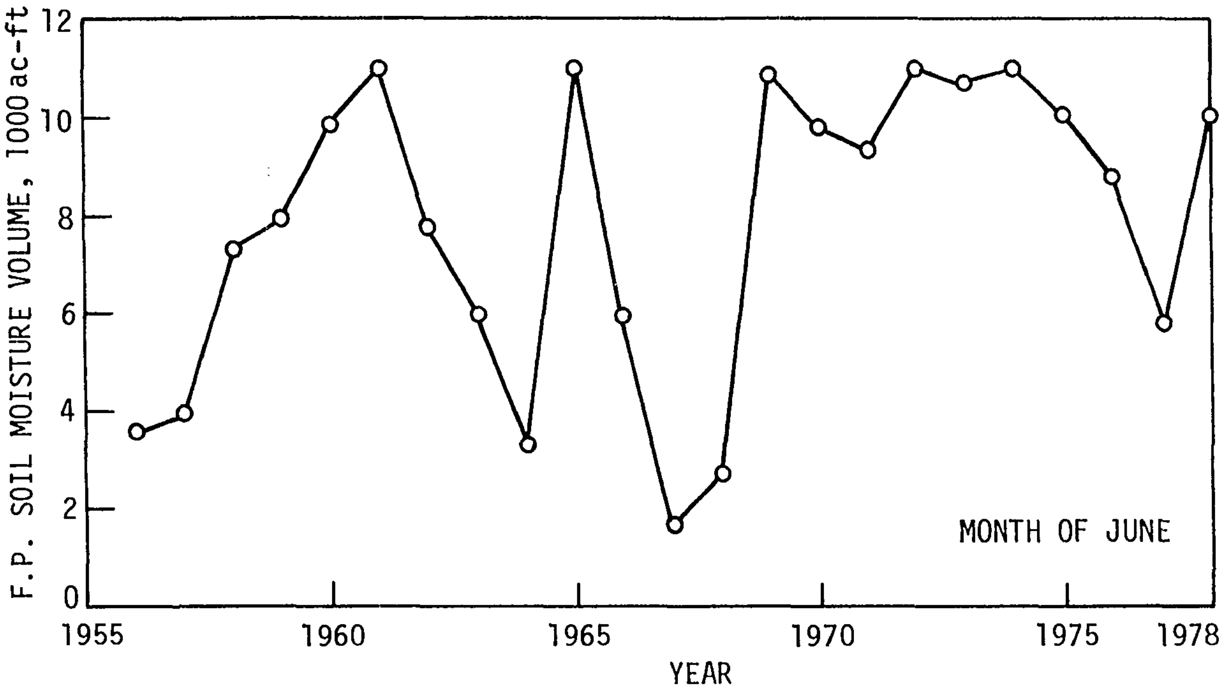

Figure 21. Annual soil moisture values during the period of study for June

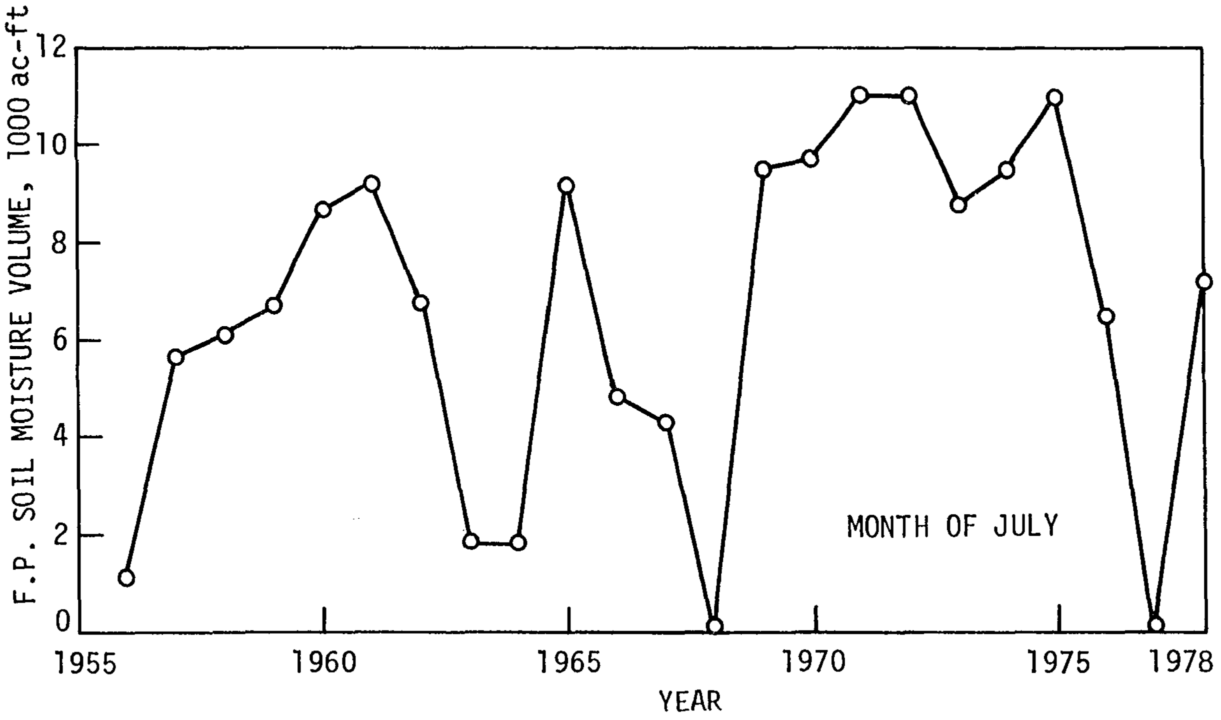

Figure 22. Annual soil moisture values during the period of study for July

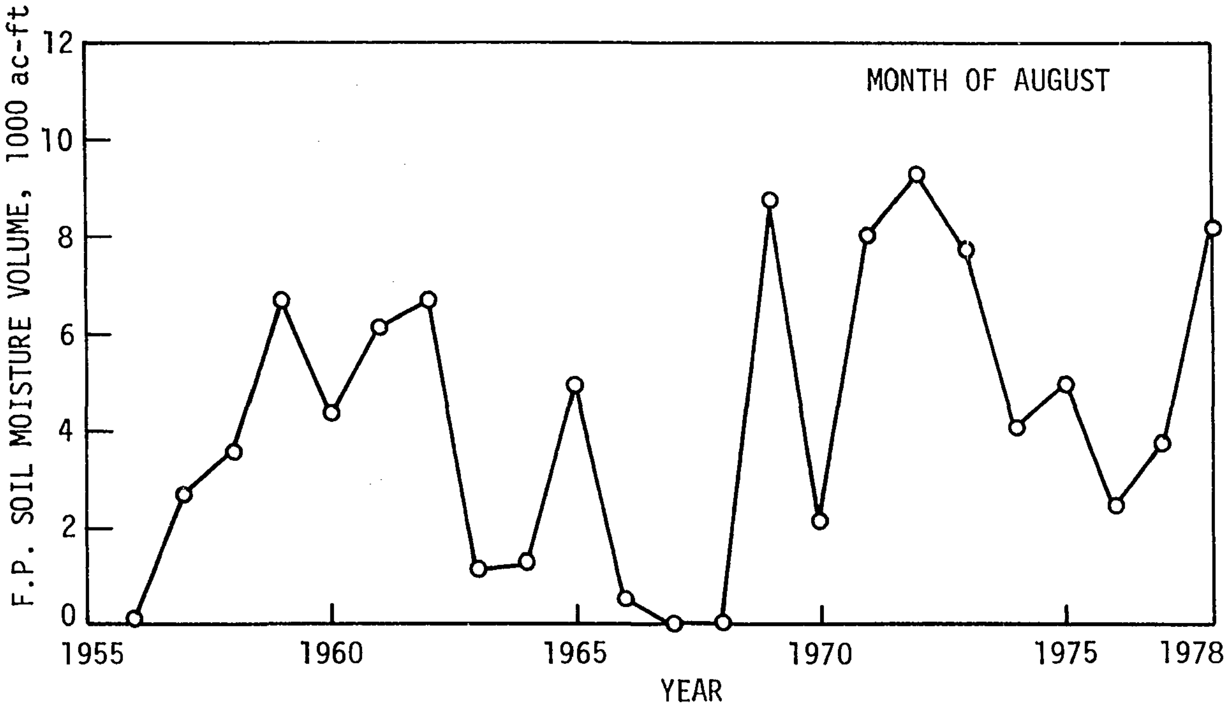

Figure 23. Annual soil moisture values during the period of study for August

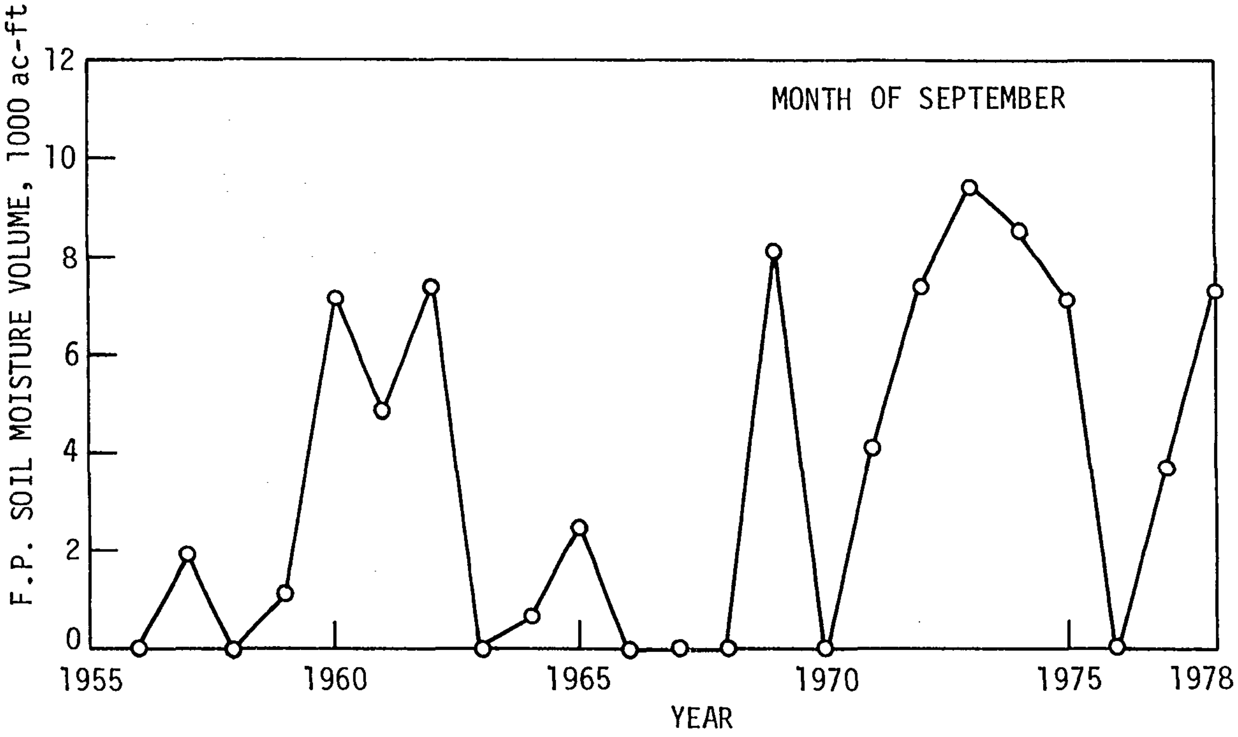

Figure 24. Annual soil moisture values during the period of study for May

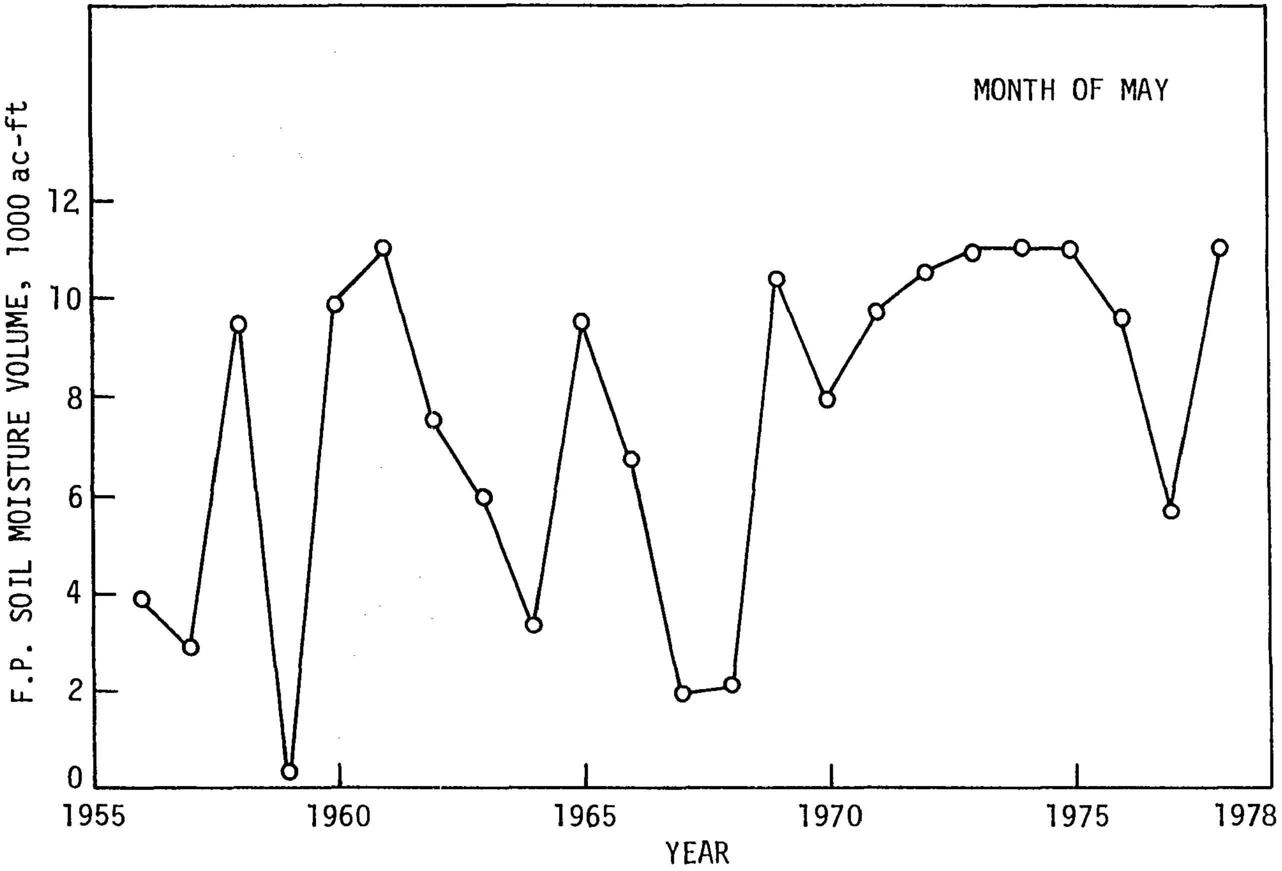

Figure 25. Annual soil moisture values during the period of study for September

In Run '1' and the later runs (2, 4, and 6), different water withdrawals have been applied in order to evaluate the groundwater table fluctuation in the shallow aquifer of the basin. In Run '1,' 15.5 ac-ft/month withdrawal is considered. It is estimated that this withdrawal is required to meet the floodplain farmstead needs only (10% of the total basin). Again, it is emphasized that the withdrawals given in the second column of Table 27 are total amounts of beneficial water use and exclude the withdrawal for irrigation purposes. The model computes the amount of water needed for irrigation if a soil moisture deficiency exists. The computer program adds the amount of water which is required to be pumped from the shallow aquifer. The sample printouts from the mathematical model presented on pages 137, 138 and 139, including the soil moisture graphs, belong to Run '0,' where no withdrawal and irrigation water was considered.

To show the effect of withdrawal and irrigation on the water balance, two additional printouts are attached. Figures 26 and 27 belong to Run '6' where 235 ac-ft/month withdrawal and a 100% irrigation are considered.

The following figures (28, 29 and 30) present the groundwater table fluctuation in the shallow aquifer of the basin. The numbers allocated to the curves are the same as those of previous runs. In all of these curves, the main assumptions are as follows:

1. Floodplain covers 10% of the area of the basin.
2. The remaining 90% of the area of the basin is upland.

```
INPUT DATA FOR**** FLOYD RIVER BASIN ABOVE ALTON -  SIMULATION PERIOD 1956 TO 1978 ****
FRB1   23 12  3  4  0  1  0  0  1  0  0  0  0  0  1  1  0  0 0.00 0.00 0.000 0.000 1.000 0.100 0.060  30.0  26.0
FRB2     152640.    16960.         0.  39886.  4.50  2.00  0.00          0.       300.   0.010      3000.   114480.         0.          0.
FRB3          0.      7838.     11000.
HYDRAULIC VARIABLES      20.0000  0.1400  0.0010  0.0350  0.0010 10.0000  0.1500 30.2000   5280.   19.51
ITEM--YEAR1970              OCT     NOV     DEC     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     YEAR
CROP GW-RETURN FLO COEF     0.100   0.200   0.800   1.000   1.000   0.800   0.300   0.100   0.000   0.000   0.000   0.000
SURFACE SUPPLY TO WL COEF   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PROPORTION DAYLIGHT HOURS  0.0773  0.0663  0.0639  0.0660  0.0666  0.0838  0.0897  0.1010  0.1021  0.1037  0.0964  0.0842
COA1                     -23.8000-20.0000  0.0000  0.0000  0.0000-21.3000-30.6600-12.2000-16.2000-14.9500-17.0000-18.6000
COA2                     -23.8000-20.0000  0.0000  0.0000  0.0000-21.3000-30.6600-12.2000-16.2000-14.9500-17.0000-18.6000
POB1                       6.4400  5.0100  0.0000  0.0000  0.0000  5.9900  5.9000  2.9600  3.5400  3.5500  3.5700  4.5100
POB2                       6.4400  5.0100  0.0000  0.0000  0.0000  5.9900  5.9000  2.9600  3.5400  3.5500  3.5700  4.5100
POC1                       0.5870  2.1600  0.0000  0.0000  0.0000  1.4250  1.4250  1.2400  2.9400  1.7000  2.4500  1.0600
POC2                       0.5870  2.1600  0.0000  0.0000  0.0000  1.4250  1.4250  1.2400  2.9400  1.7000  2.4500  1.0600
PSM1                       0.0000  0.0000  0.0690  0.0010  0.0850  0.3300  0.1000  0.0000  0.0000  0.0000  0.0000  0.0000
PSM2                       0.0000  0.0000  0.0690  0.0010  0.0850  0.3300  0.1000  0.0000  0.0000  0.0000  0.0000  0.0000
CFA1                       0.0000  0.0000100.0000100.0000 30.0000 60.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CFB1                       0.0000  0.0000 -0.4500 -0.4500 -0.4500 -0.4500 -0.4500  0.0000  0.0000  0.0000  0.0000  0.0000
CFA2                       0.0000  0.0000 40.0000100.0000 20.0000 80.0000 40.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CFB2                       0.0000  0.0000 -0.8000 -0.9000 -0.9000 -0.8000 -0.8000  0.0000  0.0000  0.0000  0.0000  0.0000
CRA1                       0.9000  0.9500  1.0000  1.0000  1.0000  1.0000  1.0000  0.9000  0.8800  0.8500  0.8500  0.9000
CRA2                       1.0000  1.0000  1.0000  1.0000  1.0000  1.4100  1.9400  3.8100  1.0000  1.0000  1.0000  1.0000
CRB1                       0.9800  0.7270  1.0000  1.0000  1.0000  1.0000  0.7210  0.6500  0.6220 -0.0770  0.3250  0.2220
CRB2                       0.9800  0.7270  1.0000  1.0000  1.0000  1.0000  0.7210  0.6500  0.6220 -0.0770  0.3250  0.2220
GWCOE                      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CROP AREAS  22896.  65635.  64109. 152640.
  1 GRSS    K COEF           0.63    0.54    0.00    0.00    0.00    0.00    0.68    0.72    0.74    0.74    0.73    0.70
  2 CORN    K COEF           0.25    0.15    0.00    0.00    0.00    0.00    0.29    0.39    0.58    0.64    0.58    0.42
  3 SBNS    K COEF           0.26    0.15    0.00    0.00    0.00    0.00    0.27    0.37    0.51    0.57    0.51    0.38
WLPH AREAS     339.    2544.   7293.   6784.  16960.
  1 WTR     K COEF           0.54    0.38    0.00    0.00    0.00    0.00    0.75    0.88    0.94    1.00    0.94    0.75
  2 GRSS    K COEF           0.59    0.50    0.00    0.00    0.00    0.00    0.64    0.68    0.69    0.69    0.68    0.65
  3 CORN    K COEF           0.23    0.14    0.00    0.00    0.00    0.00    0.27    0.37    0.54    0.60    0.54    0.39
  4 SBNS    K COEF           0.25    0.14    0.00    0.00    0.00    0.00    0.26    0.35    0.48    0.53    0.48    0.35
                         PUMPED WATER
1970                      235.00  235.00  235.00  235.00  235.00  235.00  235.00  235.00  235.00  235.00  235.00  235.00 2820.00
                         INPUT PRECIPITATION
1970                        2.08    0.21    1.32    0.27    0.31    2.03    1.77    4.53    1.86    1.85    0.73    6.11   23.07
                         AVERAGE TEMPERATURE
1970                       45.20   34.90   20.40    6.80   12.10   27.20   46.80   61.50   71.10   73.80   71.90   62.30  534.00
                           GAGED OUTFLOW
1970                      335.00  376.00  248.00  207.00  769.0010300.00 6210.00 3970.00 2070.00  393.00  139.00  581.0025598.00
                           GW OUTFLOW
1970                        0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    I          ZGW             ZS            ZRIV       DELH                QGW                GW            QIRR
    1         22.19           1.15           31.35  -0.35713E-02         -588.67              0.00            0.00
    2         22.09           0.05           30.25  -0.30987E-02            9.18              0.00            0.00
    3         21.83           0.46           30.66  -0.32916E-02          432.84              0.00            0.00
    4         21.74           0.01           30.21  -0.32204E-02            0.38              0.00            0.00
    5         21.55           0.33           30.53  -0.33786E-02          252.61              0.00            0.00
    6         21.75           2.31           32.51  -0.42046E-02         -765.27              0.00            0.00
    7         22.00           3.11           33.31  -0.44307E-02         -859.01              0.00            0.00
    8         22.50           1.76           31.96  -0.36930E-02         -642.22              0.00          900.52
    9         22.25           0.43           30.63  -0.31264E-02          396.32              0.00            0.00
   10         20.92           0.56           30.76  -0.38286E-02         -597.57              0.00         3749.94
   11         19.13           0.04           30.24  -0.42224E-02            6.62              0.00         4320.83
   12         19.22           0.29           30.49  -0.42561E-02          200.91              0.00            0.00
                                                                                                     6.35 INCHES
```

Figure 26. Input data and G.W. table calculations (Run '6')

```
                              **** FLOYD RIVER BASIN ABOVE ALTON -  SIMULATION PERIOD 1956 TO 1978 ****
ITEM--YEAR1970                      OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      YEAR
  MEASURED INFLOW                    0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  UNMEASURED INFLOW                  0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
PUMPED WATER                       235.     235.     235.     235.     235.     235.     235.     235.     235.     235.     235.     235.     2820.
TOTAL MANAGEABLE WATER             235.     235.     235.     235.     235.     235.     235.     235.     235.     235.     235.     235.        0.
GROUNDWATER INFLOW                   0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  CROPLAND DIVERSIONS                0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  AMOUNT TO ROOT ZONE                0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  CROPLAND RETURN FLOW               0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
RUNOFF FROM UPLANDS               1815.       8.     390.       0.     227.    5815.    9558.    3703.     357.     543.       6.     181.    22604.
  SURFACE RETURN FLOW                0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  GW RETURN FLOW                     0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
CROPLAND PRECIPITATION           23812.    2538.   16790.    3434.    3943.   25822.   22514.   51859.   20820.   20002.    7893.   69947.   269375.
SNOW STORAGE ADDED                   0.       0.    5256.   -4911.    2102.    9358.  -11806.       0.       0.       0.       0.       0.        0.
  ACCUM SNOW STORAGE                 0.       0.       0.    5256.     345.    2447.   11806.       0.       0.       0.       0.       0.        0.
DETENTION ON CROPS                   0.       0.    1874.    1955.     508.    4409.    2247.       0.       0.       0.       0.       0.    10994.
SUBLIMATION FROM CROPS               0.       0.    9270.    6390.    1105.    6239.       0.       0.       0.       0.       0.       0.    23005.
  SNOW MELT                          0.       0.     390.       0.     227.    5815.    9558.       0.       0.       0.       0.       0.    15990.
  ROOT ZONE SUPPLY               21997.    2529.    1874.    1955.     508.    4409.   24762.   48156.   20463.   19459.    7887.   69766.   223766.
  CROPLAND P.C.U.                13831.    6137.       0.       0.       0.       0.   18161.   34061.   53058.   60900.   50527.   29706.   266380.
  RZ SUPPLY-P.C.U.                8166.   -3607.    1874.    1955.     508.    4409.    6601.   14095.  -32594.  -41441.  -42640.   40061.   -42613.
ACCUM SOIL MOISTURE    I-        39886.   48052.   44445.   46319.   48274.   48782.   53192.   59793.   73888.   41294.       0.       0.    40061.
  CONS. USE DEFICIT                  0.       0.       0.       0.       0.       0.       0.       0.       0.    -148.  -42640.       0.   -42788.
ACTUAL CROPLAND C.U.             13831.    6137.       0.       0.       0.       0.   18161.   34061.   53058.   60752.    7887.   29706.   223592.
  INTERFLOW ADDED                    0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
ACCUM INTERFLOW        I-            0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
DETENTION ON WETLAND                 0.       0.     208.     217.      56.     490.     250.       0.       0.       0.       0.       0.     1222.
SUBLIMATION FROM WETLAND             0.       0.    1030.     710.     123.     693.       0.       0.       0.       0.       0.       0.     2556.
  GROUNDWATER ADDITION               0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  GROUNDWATER TO SURFACE          -589.       9.     433.       0.     253.    -765.    -859.    -642.     396.    -598.       7.     201.    -2154.
DOMESTIC USE                         0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
IRRIGATION FOR WTLCROPS              0.       0.       0.       0.       0.       0.       0.     901.       0.    3750.    4321.       0.     8971.
EXPORTS                              0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
  SURFACE SUPPLY TO WL               0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
WETLAND PRECIPITATION             2646.     282.    1866.     382.     438.    2869.    2502.    5762.    2313.    2222.     877.    7772.    29931.
RUNOFF FROM FLOODPLAINS            202.       1.      43.       0.      25.     646.    1062.     411.      40.      60.       1.      20.     2512.
SNOW STORAGE ADDED                   0.       0.     584.    -546.     234.    1040.   -1312.       0.       0.       0.       0.       0.        0.
  ACCUM SNOW STORAGE                 0.       0.       0.     584.      38.     272.    1312.       0.       0.       0.       0.       0.        0.
SNOW MELT                            0.       0.      43.       0.      25.     646.    1062.       0.       0.       0.       0.       0.     1777.
  TOTAL SUPPLY TO WL              2444.     281.     208.     217.      56.     490.    2751.    6251.    2274.    5912.    5197.    7752.    33834.
  POTENTIAL WETLAND CU            1473.     650.       0.       0.       0.       0.    1964.    3676.    5607.    6419.    5339.    3115.    28243.
  TSWL-WL P.C.U.                   972.    -369.     208.     217.      56.     490.     787.    2575.   -3333.    -507.    -142.    4637.     5591.
ACCUM WL SOIL MOIST    I-         7838.    8810.    8441.    8649.    8866.    8923.    9413.   10200.   11000.    7667.    7159.    7018.    11000.
  WETLAND DEFICIT                    0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
ACTUAL WETLAND C.U.               1473.     650.       0.       0.       0.       0.    1964.    3676.    5607.    6419.    5339.    3115.    28243.
  WL ADD TO SRFC AND GW              0.       0.       0.       0.       0.       0.       0.    1775.       0.       0.       0.     654.     2429.
  SURFACE WTR IN CHANNEL          1663.     253.    1101.     236.     740.    5931.    9996.    3707.    1028.     241.     248.     637.    25781.
TOTAL OUTFLOW                     1428.      18.     866.       1.     505.    5696.    9761.    5247.     793.       6.      13.    1056.    25390.
  GW OUTFLOW                         0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.        0.
SURFACE OUTFLOW                   1428.      18.     866.       1.     505.    5696.    9761.    3472.     793.       6.      13.     402.    22961.
  GAGED OUTFLOW                    335.     376.     248.     207.     769.   10300.    6210.    3970.    2070.     393.     139.     581.    25598.
  DIFFERENCE XCOMP-GAGED          1093.    -358.     618.    -206.    -264.   -4604.    3551.    -498.   -1277.    -387.    -126.    -179.    -2637.
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Figure 27. Mass balance calculations for different processes (Run '6')

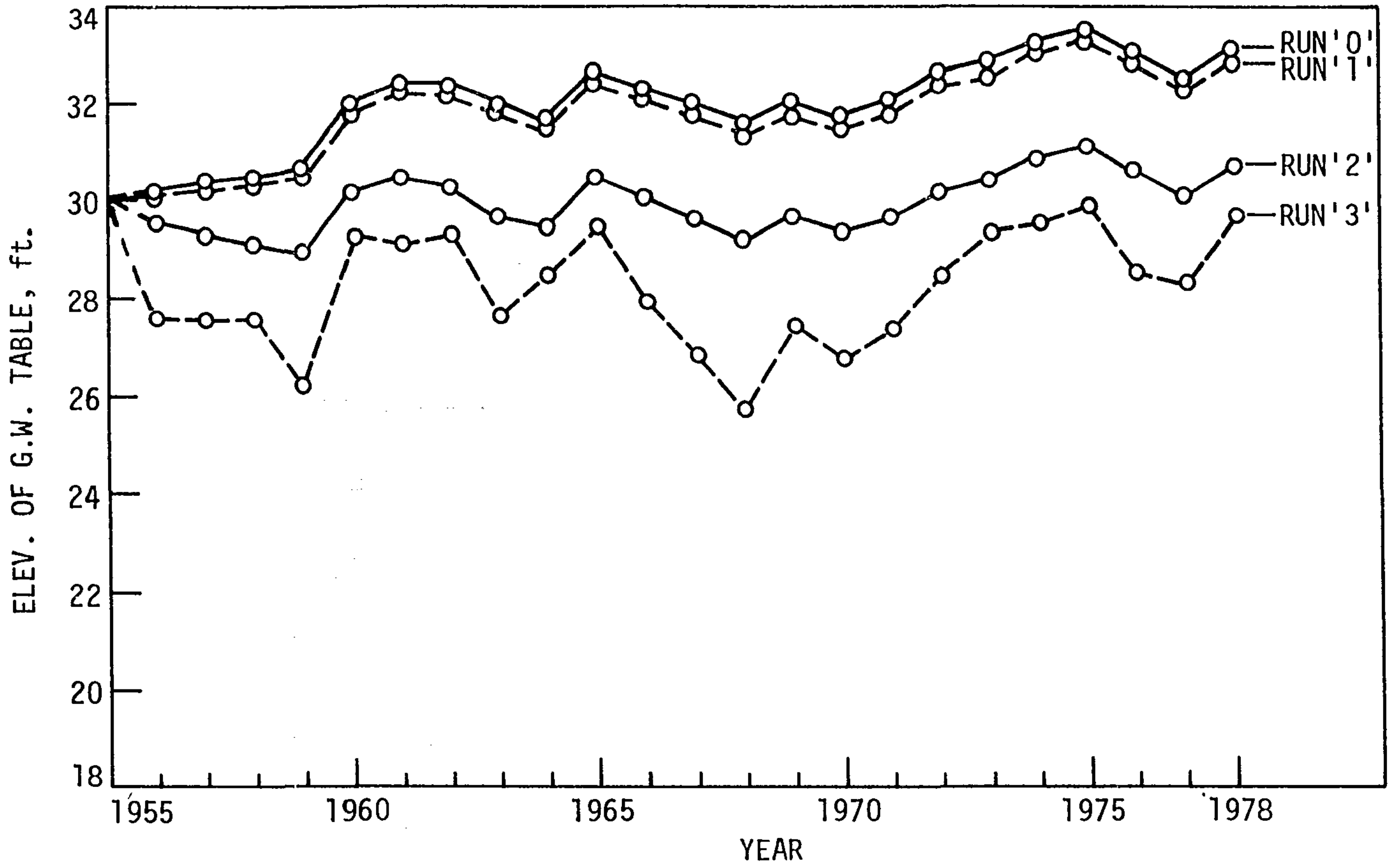

Figure 28. **Sh**allow aquifer groundwater table fluctuations for Runs 0-3

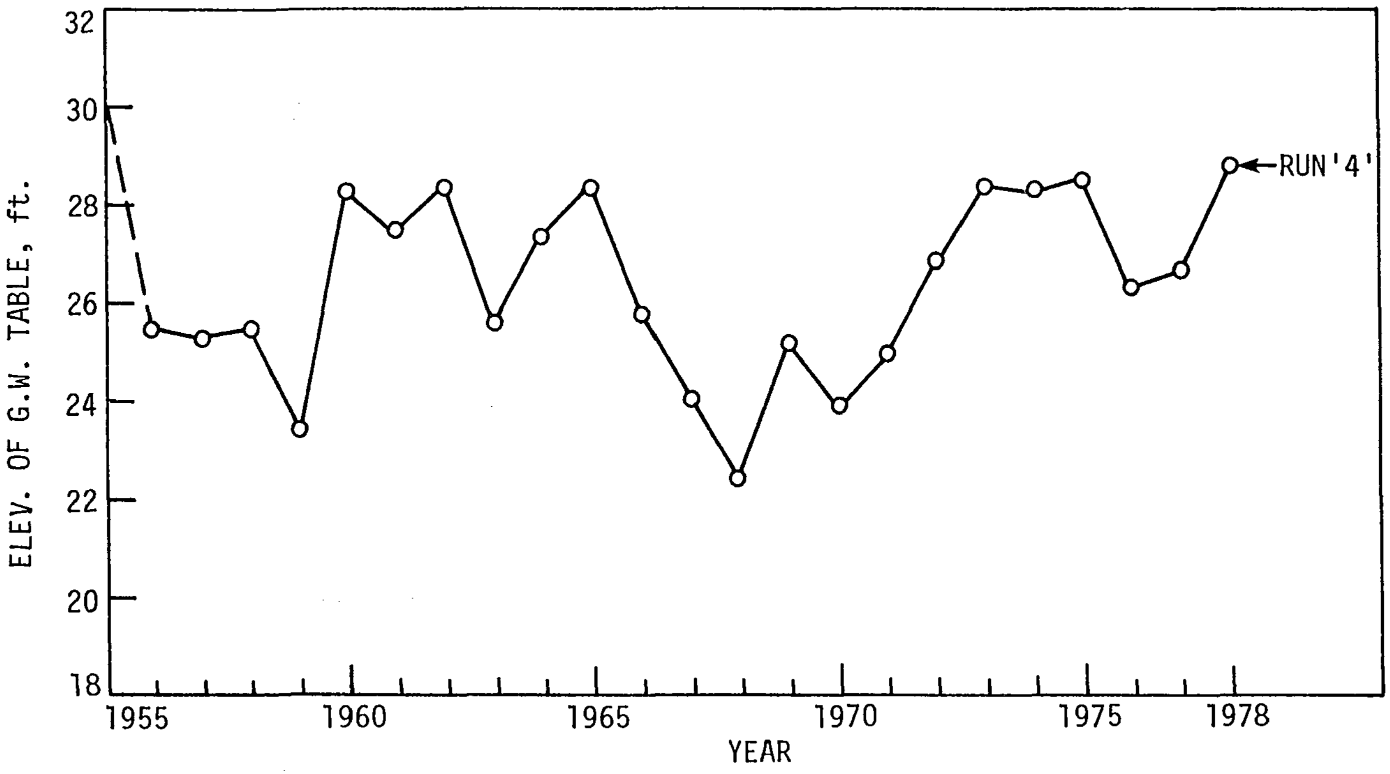

Figure 29. Shallow aquifer groundwater table fluctuations for Run 4

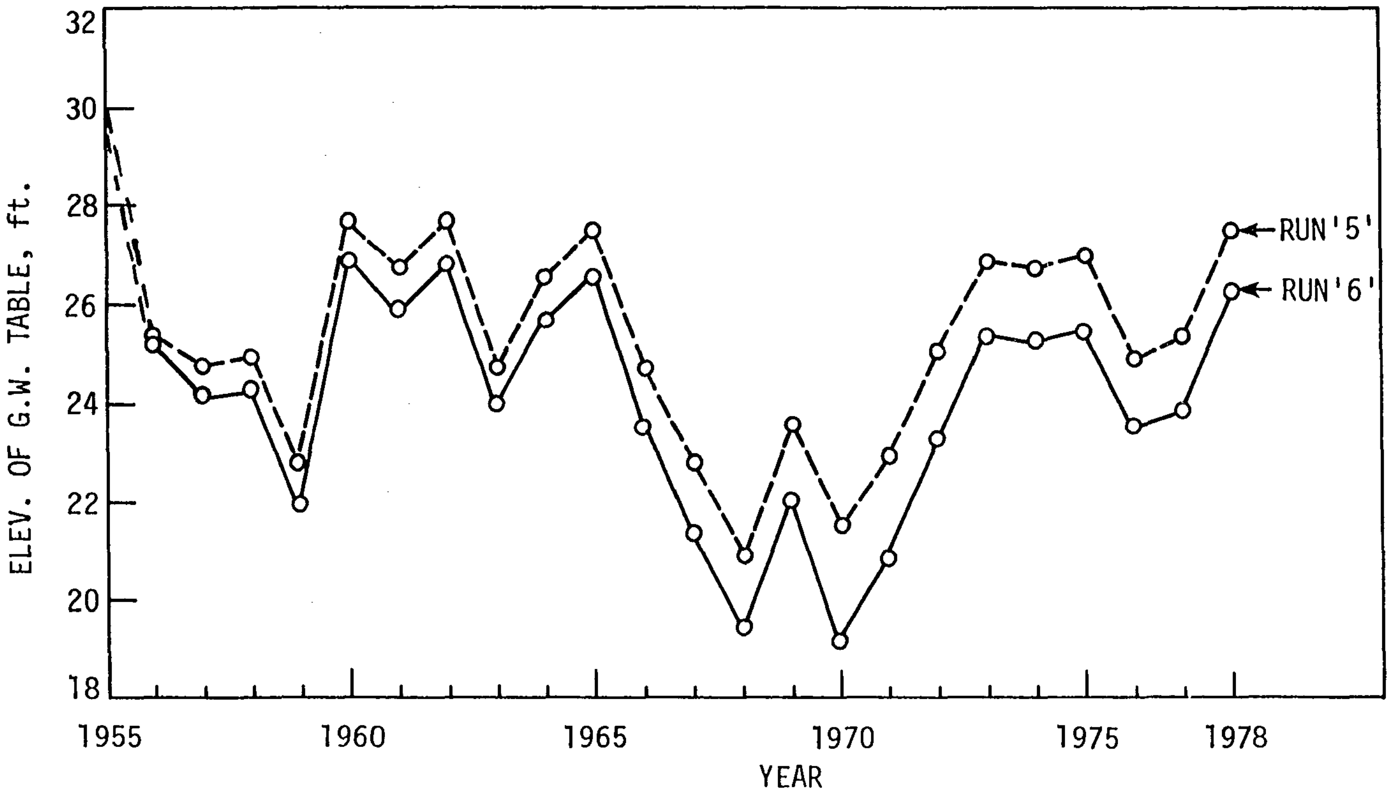

Figure 30. Shallow aquifer groundwater table fluctuations for 100% irrigation, and estimated (interpolated) values for 50% irrigation

3. The initial groundwater table elevation (ZINT) is assumed to be 30 ft above the datum.
4. The adopted variables and coefficients are the same as shown in the printouts of Figures 15 and 16. (The printouts show the first two assumptions, too.)
5. The basic values and assumptions for the model are shown in Table 28.

Improving Several Important Variables

Table 28 gives an appropriate list of dominant variables in the model. Not every possible test of changing variables is expected from this study. However, an awareness about (1) the important variables and (2) several appropriate tests with regard to the effect of dominant variables is advisable.

This section discusses these types of tests and the responses of the model with regard to the changes of some variables.

The first set of testing was based on the assumptions which were considered in the model calibration. As in any other mathematical models, the prime concern was the goodness of fit and less attention was paid to physical justification. However, this latter purpose must be kept in mind.

Although the results presented are quite justified physically, as far as the mathematical modeling is concerned, another set of testing was carried out to diminish the range of uncertainties and strengthen the physical aspects of several assumptions. The comparison between

Table 28. Basic actual values and assumptions for the hydromodel of the Floyd River Basin at Alton, northwest Iowa[a]

Item	Amount
Total area of the basin	169,600 acres
Area of upland (90% of total)	152,640 acres
Area of floodplain (10% of total)	16,960 acres
Number of years in record	23 years
Number of periods in each year	12 months
Number of crops in upland (15% grass, 43% corn, 42% soybeans)	3
Number of crops in floodplain (including water area) (15% grass, 43% corn, 40% soybeans, 2% water area)	4
Root zone depth	4.5 ft
Porosity of alluvium	15%
Hydraulic conductivity of alluvial aquifer	1500 gpd/ft^2
Average width of river	50 ft
Depth of river channel	10 ft
Effective length of the river	10 miles
Average width of floodplain	1 mile
Average slope of the river	5 ft/mile
Mannings "n" for stream channel	0.035
Elevation of stream bottom from datum	30.2 ft
Initial elevation of G.W. table from datum	30 ft
G.W. movement	One-dimensional

[a] In the case of irrigation the floodplain crops are irrigated totally, in the hydromodel program.

Table 29. Conditions imposed for second set of testing. Run '0' is also listed for comparison[a]

Run No.	% of F.P.	Effective length of river in the basin (mile) (ALRV)	Effective width of F.P. (mile) (Vw)	Initial G.W. table elevation feet (ZINT)
0	10	10	1.0	30
7	10	20	1.3	30
8	5	10	1.3	30
9	5	20	0.65	30
10	10	20	1.3	28
11	10	20	1.3	31

[a] Runs '7' through '11' do not consider any water withdrawal and irrigation requirements. Therefore, the related columns as appeared in Table 27 have been eliminated in this table.

the results of this set and those of the first set reveals the calibration assumptions have not been too far from physical meaningful assumptions, and the results (output) of the model remain almost the same. The second set of tests offers a broader range of options for model application in the future when a better field measurement of the variables may be available. Table 29 shows the major changes in dominant variables. Since the model is responsive to the imposed conditions, these changes made some differences in the mass balance, and in the range of model accuracy, it shifts the groundwater table elevations up and down proportionally. Table 30 gives the resultant effect of these changes on groundwater table fluctuations.

Table 30. G.W. table elevations in feet for second set of testing compared to those of Run '0' of the first set of testing[a]

Run Year	"0"	"7"	"8"	"9"	"10"	"11"
1956	30.21	30.31	30.31	30.75	28.69	30.96
57	30.43	30.61	30.61	31.14	29.43	31.03
58	30.54	30.70	30.70	30.89	29.89	30.97
59	30.70	30.89	30.89	31.15	30.32	31.06
1960	32.08	32.02	31.20	31.80	31.67	32.12
61	32.48	32.30	31.44	31.79	32.08	32.36
63	32.03	31.79	31.45	31.06	31.70	31.81
64	31.77	31.51	31.30	31.11	31.46	31.53
65	32.76	32.40	31.72	32.26	32.37	32.41
66	32.39	32.01	31.57	31.37	31.99	32.01
67	32.02	31.62	31.33	30.99	31.60	31.62
68	31.64	31.22	31.04	30.59	31.22	31.23
69	32.04	31.87	31.58	32.23	31.87	31.87
1970	31.80	31.61	31.42	31.25	31.61	31.61
71	32.06	31.90	31.54	31.74	31.89	31.90
72	32.62	32.30	31.43	31.34	32.30	32.30
73	32.85	32.48	31.53	31.65	32.48	32.48
74	33.31	32.74	31.39	31.26	32.74	32.74
75	33.57	33.00	31.62	32.04	33.00	33.00

---

[a] No withdrawals and irrigation water requirements are considered in the runs appearing in this table.

Table 30. Continued

Run Year	"0"	"7"	"8"	"9"	"10"	"11"
76	33.05	32.48	31.61	(No	32.48	32.48
77	32.52	31.93	31.39	print	31.93	31.93
78	33.11	32.52	31.33	out)	32.51	32.52

Much more explanation and interpretation are needed, rather than just presenting the figures and tables for this chapter, to describe the responses of the model with regard to groundwater fluctuations. Since the research study covers different aspects of the hydrological system in the basin, including the deterministic and stochastic events and hydrogeological conditions, a specific chapter (Chapter VII) will be used to present a discussion where all necessary information are provided at the beginning. However, some additional information is needed to document the results of this chapter. With reference to Table 28, the following temporary conclusions resulted from the tests conducted in this chapter.

The shallow groundwater table fluctuations, under the imposition of the given conditions (Tables 27 and 29) as shown in Figures 21, 22 and 23 and presented in Table 30, respectively, illustrate a depletion of the groundwater table, but the water table is restored quickly to a new stable level. As a result, the shallow aquifer groundwater levels are recovered under the assigned withdrawals (Table 27) and with some gain in level in the case of no withdrawals (Table 30). Therefore, the withdrawal of the beneficial water use projected in Chapter IV, including 100% irrigation of the floodplain, will not result in excessive or permanent depletion of the groundwater in the shallow aquifer of the basin. However, a conservative schedule for greater withdrawals may be needed.

The next chapter provides more information and results for extreme cases of drought occurrence and resultant shallow aquifer groundwater table fluctuations.

CHAPTER VI. STOCHASTIC STUDIES

So far, all explanations about the nature, development, calibration and testing of the hydromodel were based on the deterministic assumptions. Since a model is expected to be used for prediction purposes, one may argue that we should also be able to use a specified model for stochastic predictions. Using a deterministic model for prediction does not necessarily mean the prediction is a stochastic one. However, it is possible to design the model with enough parametric flexibility to permit it to be used also for stochastic predictions. In addition to flexibility of the model, some studies about the probabilistic (stochastic) laws of the events are required. The additional studies needed to accomplish this purpose have been considered in this research study and the probabilistic laws for the dominant hydrological event (precipitation) were conducted.

Based on the definitions selected for dryness and wetness throughout a drought cycle in this study, a characteristic drought period was sought. It is emphasized that the drought period (dry, normal, and wet years within the drought cycle) depends on arbitrary precipitation limits that must be evaluated with regard to the type of the use to be made of the data. In this study, emphasis was placed on the effect of the drought cycle on the groundwater fluctuations, rather than the drop in yield, for example. Although a 5- to 7-year drought period seems reasonable for this purpose, from restricted meteorological observations, it is believed that the overall drought cycle in this area has a return period of 20 to 22 years. Table 3, presented in Chapter III, gives the relative probabilities for moving through the sequential events of the precipitation. This table may be used in many different ways for stochastic uses, particularly for simulation study. It enables the analysts to simulate hydrological records (rainfall records) for the area for as many time periods as needed. According to experience, some particular paths might be useful in conducting the stochastical studies in the area. Figure 31 shows the sample paths. Of these, two were chosen and extended to accomplish the objectives of the study. Table 31 represents the relative joint probabilities for each path of Figure 31. Based on Figure 31 and Table 31, two 8-year paths were adopted and extended. The single-lined path on Figure 32 depicts the "worst" sequential events, whereas the double-lined path shows the "most probable" sequence of events. The "worst" sequential events were established on the basis of both experience and high probability of the outcome of the event. To simulate appropriate numerical values for the events described by these paths for the basin under study (Floyd River Basin at Alton), the statistical parameters of the annual precipitation (the mean and the standard deviation) of the total 23-year period of record for the basin were used. Table 32 represents the simulated numerical depth of precipitation for establishing an 8-year drought period. Since the temperature does not have the tremendous effect compared to that of precipitation, the numerical values of temperature were considered to be the same as those of the 8-year period of 1971-1978. The numerical values of gaged flow in this study are used only for comparison, and do not enter into the total water balance comparisons. Therefore, they

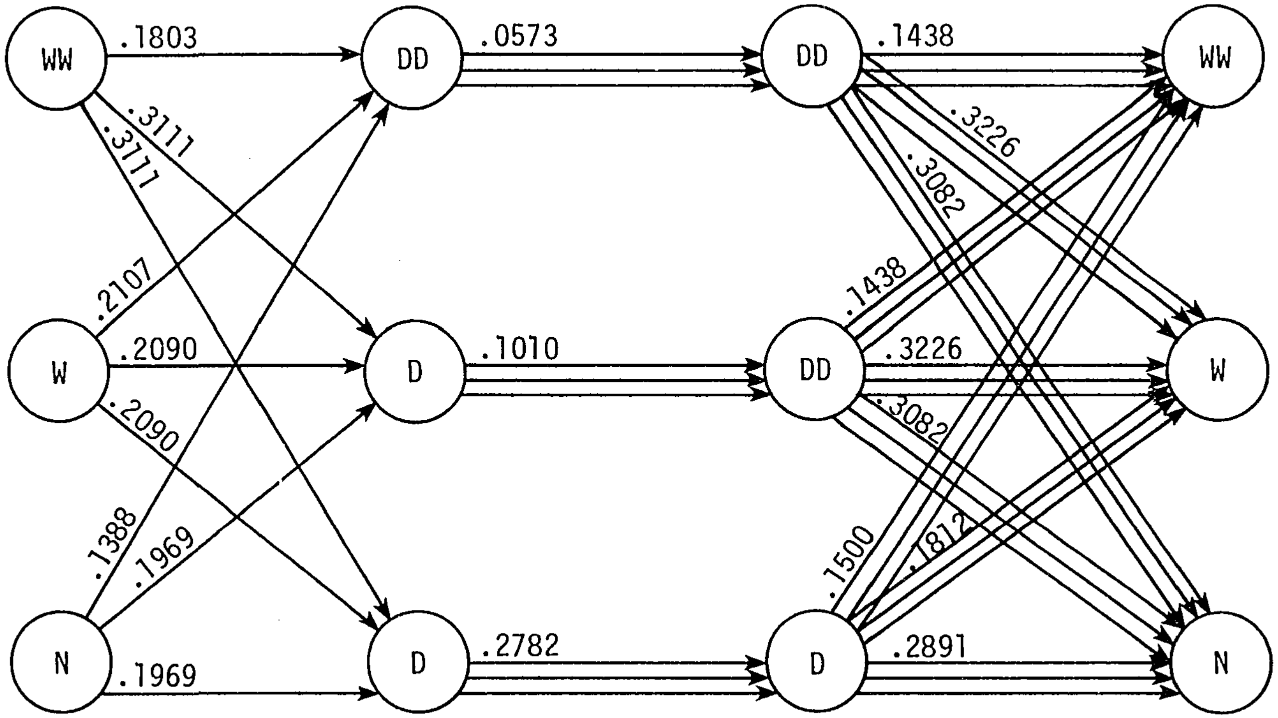

Figure 31. Sequential precipitation pathways selected for application of stochastic probabilities

Table 31. Appropriate paths for sequential events and their joint probabilities

Sequential events				Joint probability
W	DD	DD	W	0.001486
W^w	DD	DD	W^w	0.003333
W^w_w	DD	DD	N	0.003184
W	D	DD	W	0.004518
W^w	D	DD	W	0.010136
W^w_w	D	DD	N	0.009684
W	D	D	W	0.012982
W^w	D	D	W	0.015726
W^w_w	D	D	N	0.025021
W	DD	DD	W	0.001736
W	DD	DD	W^w	0.003895
W	DD	DD	N	0.003721
W	D	DD	W	0.003035
W	D	DD	W^w	0.006810
W	D	DD	N	0.006506
W	D	D	W	0.008722
W	D	D	W^w	0.010565
W	D	D	N	0.01609
N	DD	DD	W	0.001127
N	DD	DD	W^w	0.002529
N	DD	DD	N	0.002416
N	D	DD	W	0.002860
N	D	DD	W^w	0.006416
N	D	DD	N	0.006129
N	D	D	W	0.008217
N	D	D	W^w	0.009953
N	D	D	N	0.015836

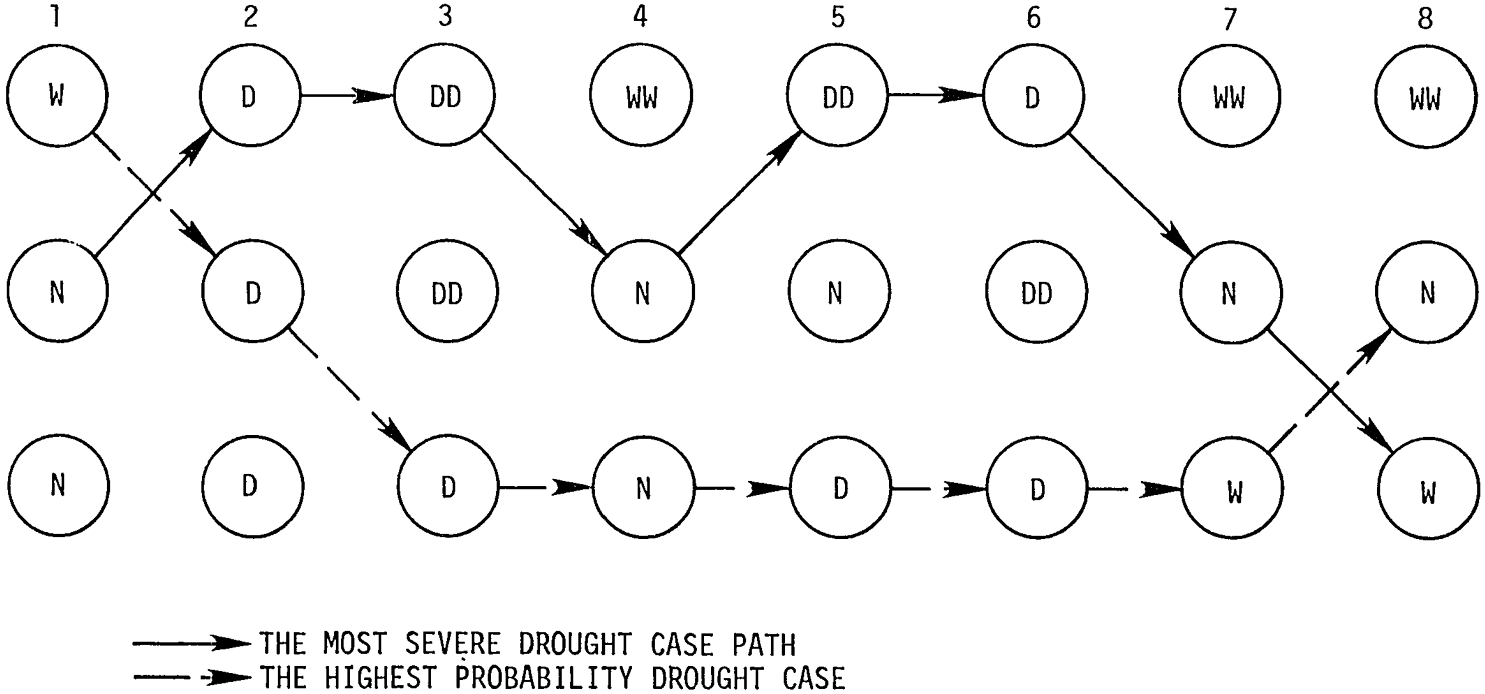

Figure 32. Designed sequential pathways considered for stochastical shallow aquifer G.W. table fluctuations

Table 32. Simulated numerical values of precipitation depth for stochastic events (in.)

Type of events	Depth, inches, for designated category				
Month	WW	W	N	D	DD
Oct.	2.93	1.99	1.76	1.58	0.93
Nov.	1.79	1.21	1.08	0.96	0.57
Dec.	1.39	0.93	0.83	0.73	0.44
Jan.	0.81	0.54	0.48	0.42	0.25
Feb.	1.40	0.94	0.84	0.74	0.44
Mar.	2.58	1.74	1.55	1.37	0.83
Apr.	3.51	2.36	2.11	1.87	1.11
May	5.84	3.93	3.51	3.11	1.85
June	6.14	4.13	3.69	3.27	1.94
July	5.60	3.77	3.37	2.98	1.78
Aug.	6.10	4.11	3.67	3.25	1.93
Sept.	4.89	3.29	2.94	2.60	1.55
Total annual	42.98	28.94	25.85	22.88	13.62

Note: The averaged lowest and averaged highest observed values during the 23-year period were chosen for the calculation of DD and WW events, respectively. $\overline{X} = 25.85$; $S = 4.60$.

could be set equal to zero for this test. But as a set of random numerical values, those streamflows from the period of 1971-1978 have also been used. Other parameters were kept the same as those used for calibration and testing of the hydromodel. The amount of water withdrawals projected for the years 1980 and 2020 (175 ac-ft/month and 235 ac-ft/month, respectively) were also entered into the input data, in their proper place and sense to evaluate the effect of the sequential events for the current (155 ac-ft/month withdrawal) or prospective future withdrawals (175 and 235 ac-ft/month). Along with the many withdrawal implications, the additional withdrawal for irrigation purposes was considered. Table 33 represents the condition imposed for stochastic evaluations. Figures 33 and 34 depict the effect of the most probable and worst sequential events on groundwater table fluctuations of the shallow aquifer, respectively. Table 34 represents the amount of groundwater decline under the imposed effect of the selected stochastic events.

Chapter VII includes a general discussion of the effects of stochastic events on the responses of the model. The specific conclusions from this chapter can be viewed in Figures 33 and 34 and Table 34. Due to the nature of the mathematical models, some responses are expected for every condition imposed. The results must be interpreted in light of model limitations. For example, declines in water table of the shallow aquifer may exceed the depth of the aquifer. This is not physically meaningful since the total depth of the shallow aquifer might be

Table 33. Conditions imposed for stochastical program runs

Run No.	Type of sequential events	Amount of withdrawal excluding the irrigation ac-ft/month	% of irrigation including the appropriate withdrawal that computer program calculates	Prospect time
12	Highest probability drought case	0	0	Current
13	Highest probability drought case	175	100	Prospect of year 1980
14	Highest probability drought case	235	100	Prospect of year 2020
15	Most severe drought case	0	0	Current
16	Most severe drought case	235	100	Prospect of year 2020

assumed to be less. These runs point out that during very severe droughts, temporary depletion of the shallow groundwater system is possible. However, the results show that the depletion is not severe, and recovery takes place as precipitation returns to normal or to "wet" conditions.

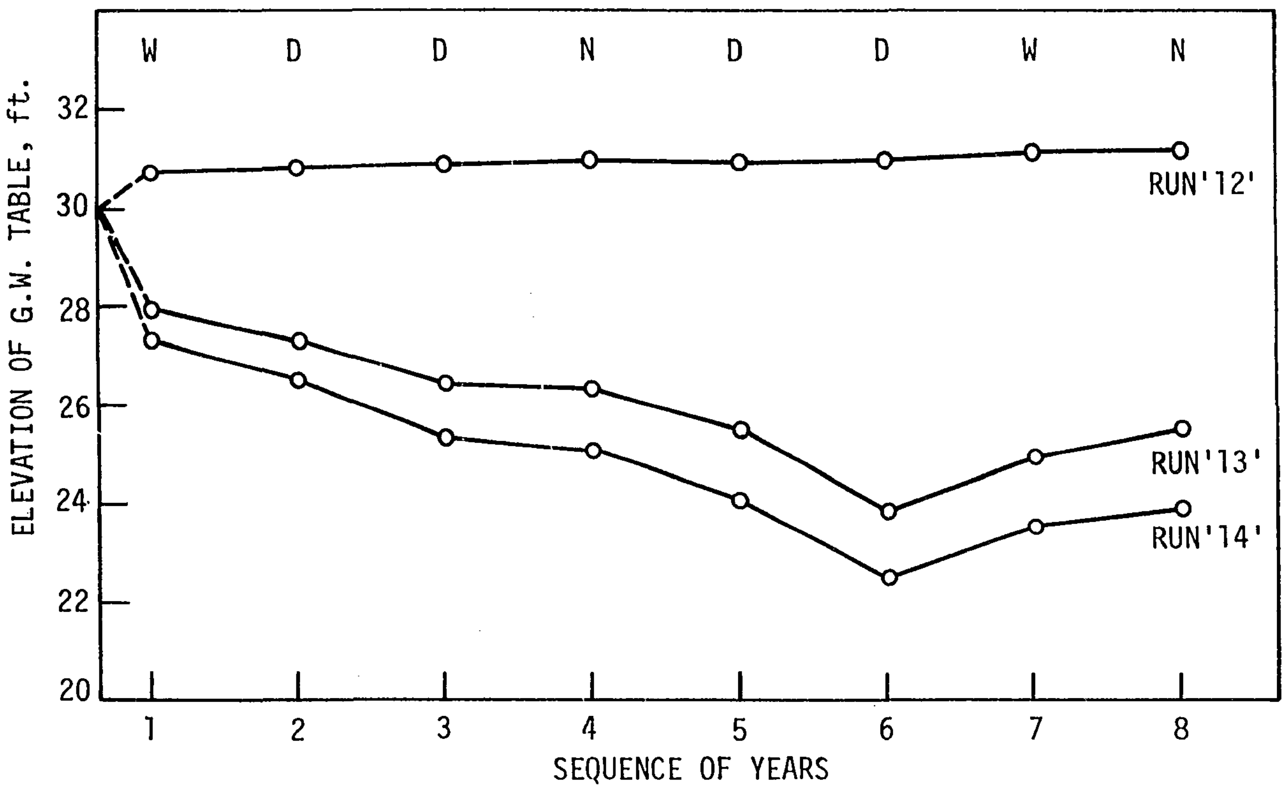

Figure 33. Stochastical fluctuation of the shallow aquifer groundwater table for the most probable sequential pathway

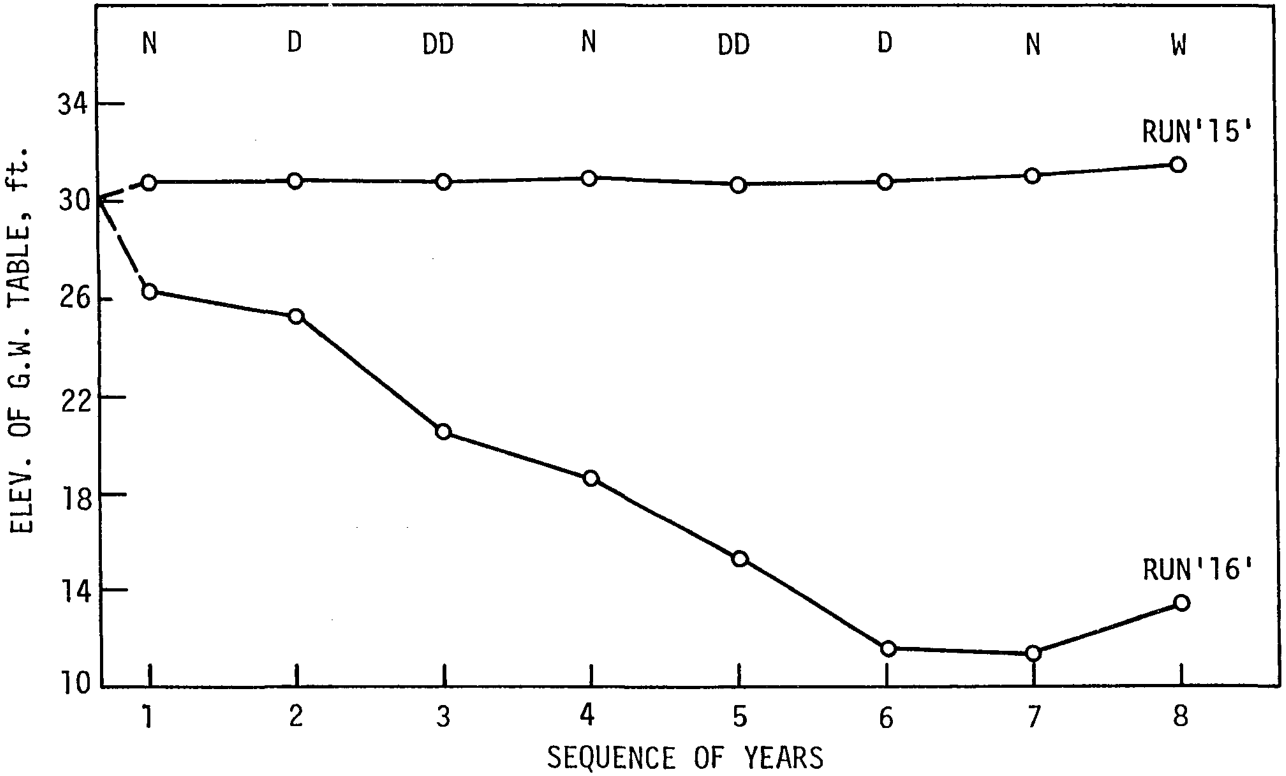

Figure 34. Stochastical fluctuation of the shallow aquifer groundwater table for the worst sequence of events

Table 34. Amount of decline in shallow aquifer G.W. table during eight years of stochastic test (ft)

Year	Run No. 13 175 ac-ft/mo withdrawal and 100% irrigation	Run No. 14 235 ac-ft/mo withdrawal and 100% irrigation	Run No. 16 235 ac-ft/mo withdrawal and 100% irrigation
1	2.10	2.66	3.90
2	2.79	3.56	4.84
3	3.60	4.69	9.55
4	3.68	4.99	10.49
5	4.59	5.91	14.79
6	6.15	7.54	18.38
7	5.03	6.44	18.62
8	4.49	6.07	16.61

CHAPTER VII. DICUSSION, CONCLUSIONS AND RECOMMENDATIONS

Discussion

Many fundamental concepts, delineation of the physical processes, development of the model and its calibration, testing and verification were discussed in previous chapters. However, it is advisable to summarize the results of the previous chapters to aid the reader. Some substantial questions may arise from the sections of this report which describe the modeling concepts. In particular, the mathematical functions and their linkages must be fully understood if the computer program is to be used correctly. The elements and functions of the model and their interactions have been checked carefully and the trade-off between the processes is logical and correct, even though intermediate calculations or results do not appear in printouts but are kept in the computer memory. To assist those individuals who cannot spend more time to study the computer algorithms of this hydromodel, Table 28 in Chapter V provides the basic assumptions made or developed by trial and error and used for final verification of the model. It is neither simple nor practical to present all information of this type in a single table to represent the entire computer program. But Table 28 was presented to add details from the computer program and introduced the scope of the model. The values given in this table belong to Run '0' which has served as the basis for testing, verification and comparisons. As described in Chapters V and VI, some of these values were changed in later phases to widen the validity of the model and increase its effectiveness to predict.

Due to the acute responsiveness of the model, a change in hydrometeorological input data or relevant coefficients will affect the output of the model. This is to be expected in a natural system. Any other changes in the values of parameters included in Table 28 will lead to a distinct change in the mass water balance results. All possible consequences from changing the parametric variables were not expected to be researched in this study. However, 16 different and important changes have been recorded, in addition to the basic assumptions (Run '0'), which were represented in Chapters V and VI in the form of graphs and tables. These graphs and tables provide results for one of the main objectives of the study, i.e., the type of groundwater table fluctuations in the shallow alluvial aquifer.

There is not enough verified physiographic, hydraulic and hydrologic information available for the area to compare the assumed values with them, and verify precisely their validity. However, the assumed values (based on available studies in the area) led to reasonable results for the model which comply with the streamflow experience. Therefore, the assumptions made are believed to be satisfactory, and hydrologically acceptable to represent the actual conditions of the basin.

In the following pages, in the Conclusions and Recommendations, the results and implications of the Floyd River Basin hydromodel are summarized in terms of accomplishments and potential future applications.

Conclusions

As discussed earlier in this chapter, the hydromodel is controlled by the assumptions and the input data. The conceptualized hydrologic processes such as sublimation and detention are expressed in terms of exponential relationships, and the surface runoff (SRO) model in terms of nonlinear expressions appears to operate properly. Other models used for evapotranspiration, soil moisture computation and groundwater transition perform adequately as fitted into the structure of the hydromodel. It is a reality that in a complex hydrologic system, such as the one used in this study, a monthly model cannot be expected to be as adequate in prediction as those using shorter periods of time, say weekly or daily, or even hourly. Also, the relationship between observed rainfall and surface runoff values does not always predict accurately. But for a hydromodel developed on the basis of monthly water balances, as in this model, the primary response for the desired variables is acceptable.

The degree of responsiveness of the model can well be viewed from figures and tables of Chapters V and VI. These figures and tables reveal that the model is responsive and has a degree of sensitivity with regard to the indicated parametric changes. One of the most important factors affecting the model in a predictive mode is irrigation water need. This is, of course, a future concern of the farmers in the area. The computer algorithm of the hydromodel calculates the amount of water required for irrigation and then is withdrawn from the shallow aquifer. Since the total amount of water withdrawn includes the irrigation water implicitly through the mathematical computations, all water withdrawn is lumped in one input value. Figures and tables presented in Chapters V and VI do not show the actual amount of water used for irrigation. So, it is necessary to present the required irrigation water separately.

Those values introduced as input data for beneficial water use (155, 175, and 235 ac-ft/mo) exclude the irrigation water, but the final withdrawals considered by the computer include the beneficial and irrigation water uses as a total. Table 35 contains a sample of irrigation water demands as calculated by the computer program of the model.

The results in this table belong to Run '6,' where the maximum projected withdrawal is 235 ac-ft/mo (prospect of year 2020), excluding irrigation water. The required irrigation water demand will be added to this amount by the model to calculate the total withdrawal. This particular run was selected in order to illustrate a conservative situation. Of course, for less withdrawal and less acreage under irrigation (50%, for example), less decrease in the groundwater table is expected.

The computer program computes the irrigation requirement in terms of soil moisture content, i.e., in the crop season whenever the soil moisture falls below 90% of the saturation value, the necessary amount of irrigation water will be withdrawn and applied to the land surface. The effect of this water addition to the soil on the following months is also considered. The computer algorithm also considers appropriate overall irrigation efficiency (80%). Figure 35 shows the effect of total

Table 35. Monthly and seasonal irrigation water needed for 100% of floodplain irrigation of different crops. Results of Run '6,' where 235 ac-ft/mo regional rural withdrawal in addition to irrigation water is considered

Years	Months May (ac-ft/mo)	 June (ac-ft/mo)	 July (ac-ft/mo)	 Aug. (ac-ft/mo)	Total irrigation season use (total depth in in.)	Groundwater table elev. (ft)
1956	7932	–	2633	956	8.19	25.15
57	1049	–	–	3392	3.14	24.15
58	–	2541	1016	2703	4.43	24.29
59	7795	–	1323	6454	11.02	21.97
1960	–	–	2634	4475	5.03	26.94
61	–	–	2013	3228	3.71	25.95
62	–	–	1087	45	0.80	26.88
63	1591	1816	2428	526	4.50	23.99
64	–	27	1701	347	1.47	25.68
65	–	–	2084	4457	4.63	26.57
66	–	994	1154	4628	4.79	23.59
67	–	419	–	6108	4.62	21.42
68	1023	–	2804	1108	3.49	19.51

Table 35. Continued

Years	Months				Total irrigation season use (total depth in in.)	Groundwater table elev. (ft)
	May (ac-ft/mo)	June (ac-ft/mo)	July (ac-ft/mo)	Aug. (ac-ft/mo)		
69	696	–	1572	536	1.98	22.05
1970	901	–	3750	4321	6.35	19.22
71	89	470	–	3337	2.67	20.88
72	–	–	3184	–	2.25	23.32
73	124	340	2227	776	2.45	25.36
74	–	–	1728	5886	5.39	25.27
75	–	1228	–	6755	5.65	25.48
76	–	1040	2505	4150	5.44	23.57
77	–	–	2410	–	1.71	23.93
78	–	1179	3082	–	3.62	26.39

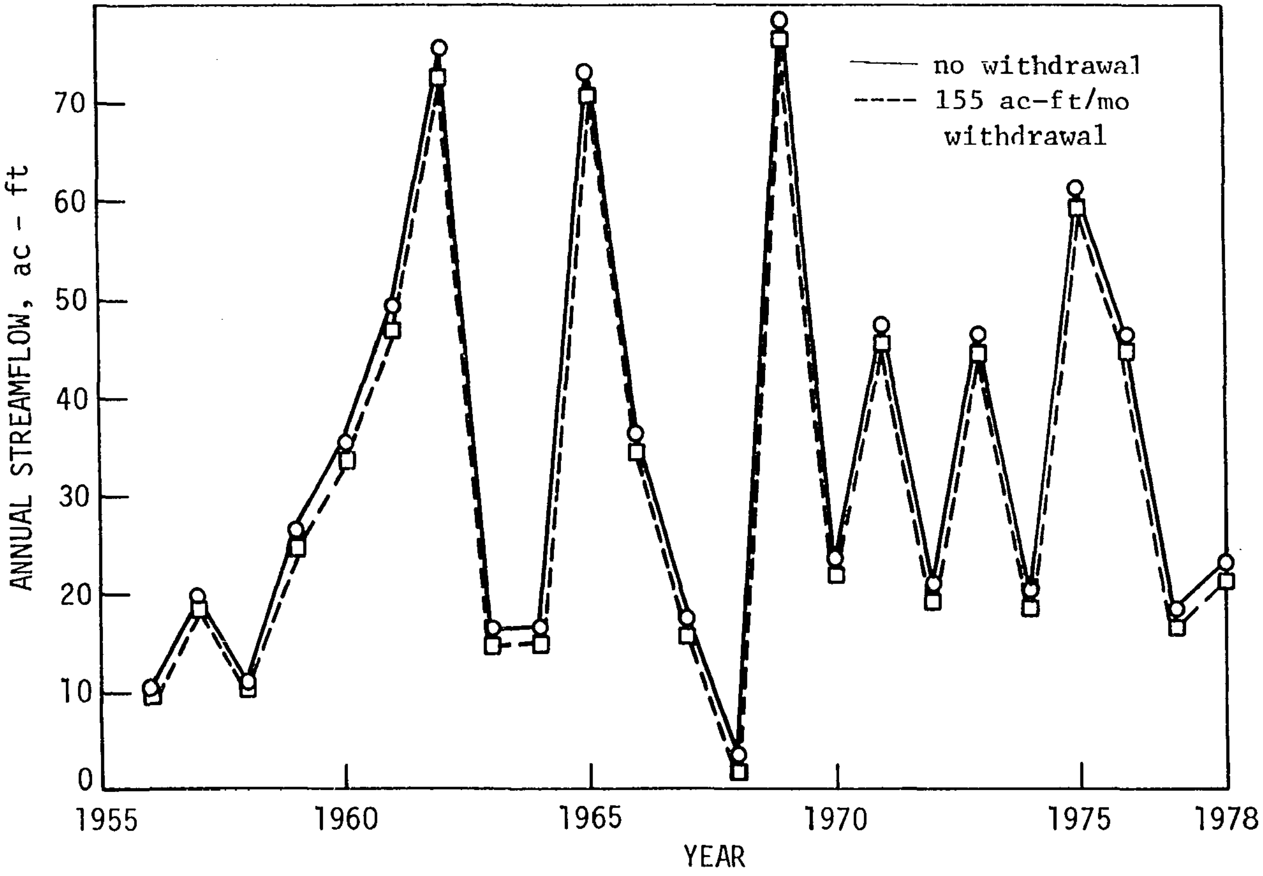

Figure 35. Annual fluctuation of the surface water (Run '6')

withdrawal on the streamflow for a normal condition (155 ac-ft/mo withdrawal and 100% irrigation). To show the high effect of drought on the irrigation water requirements, Table 36 includes the amount of water required for the cases that stochastic sequential events may demand. These sequential events are the same as those discussed in the stochastic analyses section. The monthly effect of the maximum withdrawal (235 ac-ft/mo and 100% irrigation) on the groundwater table of the shallow aquifer is shown in Figure 36. This figure shows the monthly variation of the groundwater table during the year of maximum drawdown (year 1970 depicted on Figure 30 of Chapter V which belongs to Run '6').

The overall average of soil moisture deficiency without water withdrawal and irrigation through the 23-year period (potential consumptive use-actual consumptive use) was found to be 1.14 in. per year. That is, the average 23-year potential consumptive use (neglecting interception and sublimation) calculated by the model was 20.53 in. per year which is 1.14 in. more than the available average 23-year value for this process.

The study revealed that the total normal requirement for beneficial water use (including irrigation water) can be safely withdrawn from the shallow aquifer without unduly stressing the groundwater aquifer. Although an initial drop of about 2 ft results from the total withdrawal in a normal season, the sharp drops of groundwater table in the shallow aquifer (about a 10-ft drop) during drought periods will be replenished in the following wet periods. But as Figures 33 and 34 and Table 34 of Chapter VI indicate, in the case of

Table 36. The effect of stochastic events on irrigation water requirements

	Most probable events[a] Run '13'		Worst sequential events[a] Run '16'	
Year	Total irri. season use[b], in in.	Drop of groundwater table in ft	Total irri. season use[b], in in.	Drop of groundwater table in ft
1	2.19	2.10	2.72	3.90
2	3.10	2.79	3.05	4.84
3	3.32	3.60	6.55	9.55
4	2.91	3.68	3.00	10.49
5	3.44	4.59	6.61	14.79
6	3.52	6.15	4.25	18.38
7	2.36	5.03	2.92	18.62
8	2.80	4.49	2.20	16.61

[a] For definitions of "most probable events" and "worst sequential events," see Chapter VI and Figures 34 and 35.

[b] 175 ac-ft/mo withdrawal and 50% irrigation are associating with the most probable events. 235 ac-ft/mo withdrawal and 100% irrigation are associating with the worst sequential events.

continued repeating of drought periods, a greater drop in the groundwater table might be expected. A survey of the depth of the alluvial depositions in the basin is needed to find how much drop is actually permissible. In this study the depth of alluvium in the basin is assumed to be 30 ft (82). Therefore, if this assumption is true, in the case of events like those of stochastic sequences, some temporary depletion of the shallow aquifer water may be expected in the most severe drought periods, however small the probability might be.

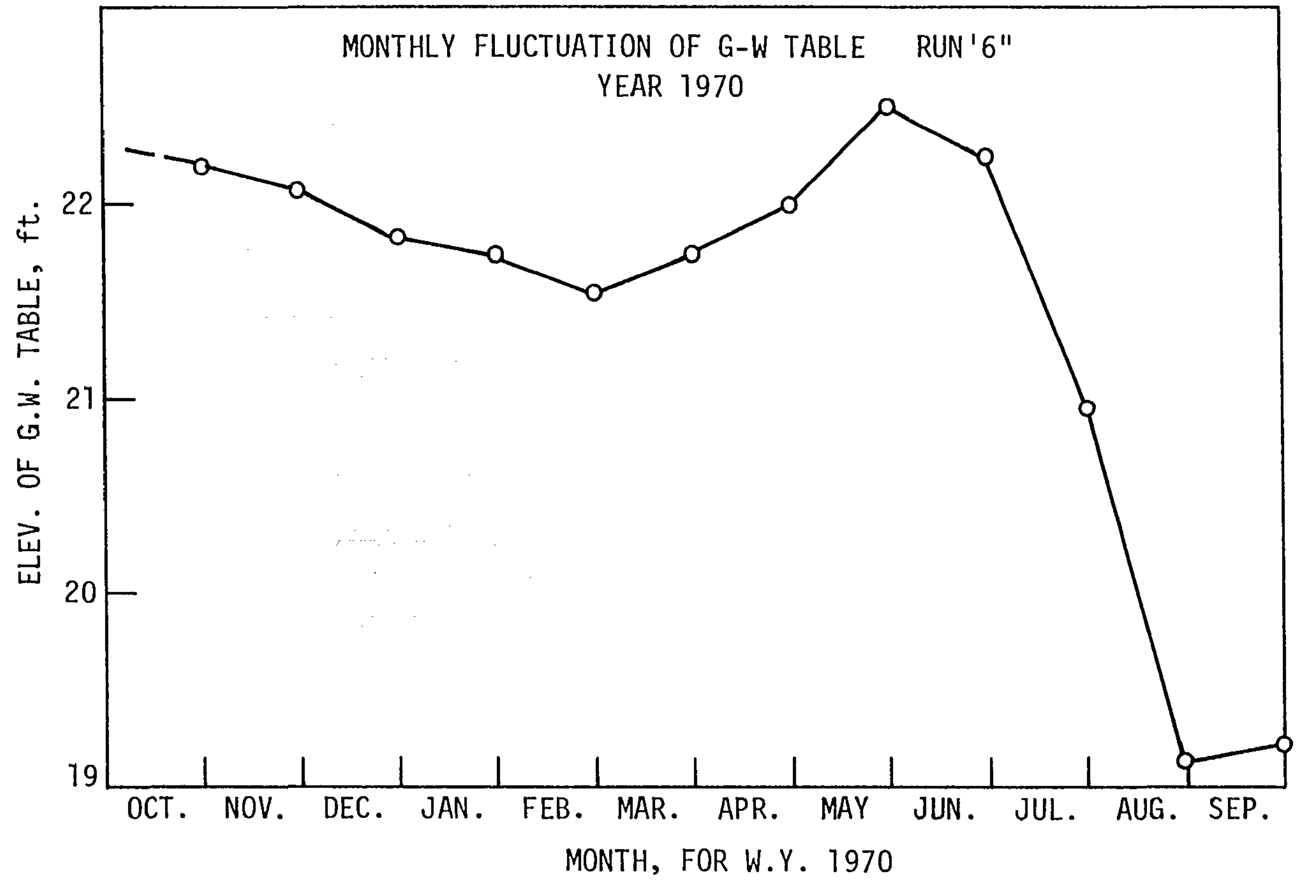

Figure 36. Monthly fluctuation of the groundwater table (Run '6')

The following list of recommendations will lead to a better understanding and utilization of the shallow aquifer groundwaters of the basin in Northwest Iowa.

Recommendations

1. A more detailed study of hydrogeological characteristics would provide a better and more actual description of the surficial groundwater resources in these basins having shallow aquifers.

2. The area of floodplain surrounding the water courses, assumed to have a level relief in this study, may undulate. Therefore, a topographical survey would help to locate the actual floodplain, and the shallow aquifer groundwater orientation would be better defined.

3. As Figure 35 shows, under normal conditions (155 ac-ft/mo withdrawal and 100% irrigation, outcome of Run '3'), groundwater extraction from the shallow aquifer does not seriously affect the surface runoff based on the estimated floodplain area. It means that the replenishment of the groundwater by streamflow, if the well is located a few hundred feet from the water course, has not been accounted for. Therefore, more water transfer from river to the shallow aquifer can be expected if wells are located near the rivers. So, the location of the wells should be viewed carefully. The Iowa Natural Resources Council, to prevent undue impact on low streamflow, requires wells to be located away from the stream banks at least 1/8 to 1/4 mile.

4. Due to the nature of alluvial aquifers (unconfined aquifers), the spacing of the wells and the amount of withdrawals should be carefully considered in order to avoid undue stress and rapid or complete exhaustion of the groundwater resource.

5. Since the floodplain is used for transportation, water pollution control plants, and has a higher rate of farming activities in terms of crop acreage, shallow aquifers are more exposed to pollution, and the point and nonpoint sources of pollution should be considered in locating wells. For drinking water purposes, wells should be sealed effectively.

6. The economics of groundwater extraction should be compared with that of direct streamflow diversion or river withdrawal, as far as the surface water resource can be utilized. So, it is recommended that the groundwater reserve in the shallow aquifer be used for the most productive purposes.

7. Finally, a trade-off between technical needs, economic water use, and sociological and institutional factors will permit full development of the area to maximize the profits attributed to the beneficial water use of the basin.

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APPENDIX A.

A LIST OF DEFINITIONS FOR SOME IMPORTANT MATHEMATICAL PROGRAMMINGS

MATHEMATICAL PROGRAMMING: A mathematical technique by which a numerical function of one or more variables constraining in some way is optimized.

LINEAR PROGRAMMING: A mathematical technique by which a linear function of one or more variables is optimized while the solution must satisfy one or more constraints placed on the variables.

DYNAMIC PROGRAMMING: A mathematical technique by which a multi-stage process is optimized within the principle of optimality.

INTEGER PROGRAMMING: A mathematical technique by which a linear programming problem is solved with additional restriction of the decision variables which must have integer values through the procedure of solution.

Note: Integer programming may be used for nonlinear cases also, but in this case it becomes a particular type of dynamic programming.

NONLINEAR PROGRAMMING: A mathematical technique by which a nonlinear function of one or more variables is optimized subject to satisfaction of one or more nonlinear constraints bounding the variables. Indeed, the nonlinear programming is the same technique as that of linear programming, with the difference that the technique should consider the concept of "local" and "global" optima and continue the procedure to the point that the global optima is reached.

Note: Sometimes is is possible to convert a nonlinear programming problem into a linear programming problem, but it often is necessary to deal directly with the nonlinear cases.

QUADRATIC PROGRAMMING: A mathematical technique by which a quadratic objective function is optimized subject to the linear inequality constraints and the nonnegative variables of the problem.

RECURSIVE PROGRAMMING: A mathematical technique by which a dynamic programming whose parameters are changing over time is solved. Therefore, the time itself is a discrete variable. It may deal with linear or nonlinear cases.

GOAL PROGRAMMING: A mathematical technique by which a system of complex objectives (rather than one objective) along with single or multiple goals with multiple subgoals have nonhomogeneous units is simultaneously solved. It is a modified and extended type of linear programming.

STOCHASTIC PROGRAMMING: A mathematical technique by which an optimization problem with random variables (rather than the constant ones) is solved. Depending on known or unknown probability distribution of the random variables, the problem may involve risk or uncertainty, respectively.

APPENDIX B.

SAS COMPUTER PROGRAM AND ANNUAL TRANSITION MATRICES OUTPUTS FOR AREA UNDER STUDY

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THE JOB C215AB HAS BEEN RUN UNDER RELEASE 76.6D OF SAS AT IOWA STATE UNIVERSITY.


      TITLE RAINFALL DATA FOR SPENCER NORTHWEST IOWA ;
      DATA RAIN;
      INPUT YEAR 1-4 M1 6-10 M2 11-15 M3 16-20 M4 21-25  M5 26-30 M6 31-35
      M7 36-40 M8 41-45 M9 46-50 M10 51-55 M11 56-60 M12 61-65 ;
      M13=SUM(OF M1-M12);
      CARDS;

DATA SET WORK.RAIN HAS 60 OBSERVATIONS AND 14 VARIABLES. 112 OBS/TRK.
THE DATA STATEMENT USED 0.20 SECONDS AND 104K.

      PROC MEANS N MEAN STD SUM USS;
      VAR M1-M13 ;
      OUTPUT OUT=STAT1 MEAN= MM1-MM13 STD= STDM1-STDM13;

DATA SET WORK.STAT1 HAS 1 OBSERVATIONS AND 26 VARIABLES. 61 OBS/TRK.
THE PROCEDURE MEANS USED 0.22 SECONDS AND 128K AND PRINTED PAGE 1.

      PROC MATRIX; FETCH X DATA=STAT1;
      *  IN THE MATRIX OPERATION Y=J(N,1,1), N IS THE NO. OF OBSERVATIONS IN THE DATA;
      Y=J(60,1,1);
      P=Y*X ; OUTPUT P OUT=STAT2;

DATA SET WORK.STAT2 HAS 60 OBSERVATIONS AND 27 VARIABLES. 59 OBS/TRK.
THE PROCEDURE MATRIX USED 0.21 SECONDS AND 142K AND PRINTED PAGE 2.

      DATA STAT3;
      MERGE RAIN STAT2;

DATA SET WORK.STAT3 HAS 60 OBSERVATIONS AND 41 VARIABLES. 39 OBS/TRK.
THE DATA STATEMENT USED 0.13 SECONDS AND 112K.
```

```
DATA STAT4;
SET STAT3;
MACRO CHECKIT
 IF ((MEAN-STD/3) LE RAIN AND RAIN LE (MEAN+STD/3)) THEN  MONTH=' N';
 IF ((MEAN-STD) LE RAIN AND RAIN LT (MEAN-STD/3)) THEN MONTH=' D';
 IF (RAIN LT (MEAN-STD)) THEN MONTH='DD';
 IF ((MEAN+STD/3) LT RAIN AND RAIN LE (MEAN+STD)) THEN MONTH=' W';
 IF ((MEAN+STD) LT RAIN) THEN MONTH='WW'; %
RAIN=M1 ; MEAN=COL1 ; STD=COL14; CHECKIT
                                         ;
JANUARY=MONTH;
RAIN=M2 ; MEAN=COL2 ; STD=COL15; CHECKIT
                                         ;
FEBRUARY=MONTH;
RAIN=M3 ; MEAN=COL3 ; STD=COL16; CHECKIT
                                         ;
MARCH=MONTH;
RAIN=M4 ; MEAN=COL4 ; STD=COL17; CHECKIT
                                         ;
APRIL=MONTH;
RAIN=M5 ; MEAN=COL5 ; STD=COL18; CHECKIT
                                         ;
MAY=MONTH;
RAIN=M6 ; MEAN=COL6 ; STD=COL19; CHECKIT
                                         ;
JUNE=MONTH;
RAIN=M7 ; MEAN=COL7 ; STD=COL20; CHECKIT
                                         ;
JULY=MONTH;
RAIN=M8 ; MEAN=COL8 ; STD=COL21; CHECKIT
                                         ;
AUGUST=MONTH;
RAIN=M9 ; MEAN=COL9 ; STD=COL22; CHECKIT
                                         ;
```

```
    SEPT=MONTH;
    RAIN=M10; MEAN=COL10; STD=COL23; CHECKIT
                                              ;
    OCTOBER=MONTH;
    RAIN=M11; MEAN=COL11; STD=COL24; CHECKIT
                                              ;
    NOVEMBER=MONTH;
    RAIN=M12; MEAN=COL12; STD=COL25; CHECKIT
                                              ;
    DECEMBER=MONTH;
    RAIN=M13; MEAN=COL13; STD=COL26; CHECKIT
                                              ;
    ANNUAL=MONTH;

DATA SET WORK.STAT4 HAS 60 OBSERVATIONS AND 58 VARIABLES. 33 OBS/TRK.
THE DATA STATEMENT USED 0.54 SECONDS AND 112K.

    PROC PRINT;
    VAR YEAR M1 JANUARY M2 FEBRUARY M3 MARCH M4 APRIL M5 MAY
    M6 JUNE M7 JULY M8 AUGUST M9 SEPT  M10 OCTOBER
    M11 NOVEMBER M12 DECEMBER M13 ANNUAL;

THE PROCEDURE PRINT USED 0.44 SECONDS AND 116K AND PRINTED PAGES 3 TO 4.

    PROC FORMAT;
    VALUE $ATT  'DD'=DDRY  ' D'=DRY ' N'=NORMAL ' W'=WET 'WW'=WWET;

THE PROCEDURE FORMAT USED 0.05 SECONDS AND 112K.

    PROC FREQ ;
    FORMAT JANUARY $ATT. FEBRUARY $ATT. MARCH $ATT. APRIL $ATT. MAY $ATT.
     JUNE $ATT. JULY $ATT. AUGUST $ATT. SEPT $ATT. OCTOBER $ATT.
     NOVEMBER $ATT. DECEMBER $ATT. ;
```

```
    TABLES JANUARY*FEBRUARY FEBRUARY*MARCH MARCH*APRIL
    APRIL*MAY MAY*JUNE JUNE*JULY JULY*AUGUST AUGUST*SEPT
     SEPT*OCTOBER OCTOBER*NOVEMBER NOVEMBER*DECEMBER;

THE PROCEDURE FREQ USED 0.68 SECONDS AND 142K AND PRINTED PAGES 5 TO 15.

    DATA STAT5 ;
    SET STAT4;
    RETAIN LAGANNUA;
    OUTPUT;
    LAGANNUA=ANNUAL;
    KEEP ANNUAL LAGANNUA;

DATA SET WORK.STAT5 HAS 60 OBSERVATIONS AND 2 VARIABLES. 1628 OBS/TRK.
THE DATA STATEMENT USED 0.15 SECONDS AND 112K.

    DATA STAT6 (KEEP=ANNUAL LAGANNUA);
    SET STAT5;
    IF _N_ EQ 1 THEN DELETE;

DATA SET WORK.STAT6 HAS 59 OBSERVATIONS AND 2 VARIABLES. 1628 OBS/TRK.
THE DATA STATEMENT USED 0.09 SECONDS AND 104K.

    PROC FREQ DATA=STAT6;
    FORMAT LAGANNUA $ATT. ANNUAL $ATT. ;
    TABLE LAGANNUA*ANNUAL;

THE PROCEDURE FREQ USED 0.25 SECONDS AND 140K AND PRINTED PAGE 16.

SAS USED 142K MEMORY.
```

BARR, GOODNIGHT, SALL AND HELWIG
SAS INSTITUTE INC.
P.O. BOX 10066
RALEIGH, N.C. 27605

```
                    RAINFALL DATA FOR SPENCER NORTHWEST IOWA          11:25 THURSDAY, FE



VARIABLE       N          MEAN          STANDARD            SUM      UNCORRECTED
                                        DEVIATION                         SS

M1            60      0.67183333      0.51277739     40.31000000      42.5951000
M2            60      0.91366667      0.71635132     54.82000000      80.3636000
M3            60      1.57600000      1.02201562     94.56000000     210.6530000
M4            60      2.51600000      1.48804980    150.96000000     510.4586000
M5            60      3.56850000      1.86421868    214.11000000     969.0949000
M6            60      4.28683333      2.05233599    257.21000000    1351.1293000
M7            60      3.36416667      2.21529758    201.85000000     968.6021000
M8            60      3.63550000      2.17439290    218.13000000    1071.9627000
M9            60      3.33600000      2.45835290    200.16000000    1024.3002000
M10           60      1.72083333      1.22150961    103.25000000     265.7091000
M11           60      1.29716667      1.09948076     77.83000000     172.2811000
M12           60      0.80983333      0.52694029     48.59000000      55.7321000
M13           60     27.69633333      5.93780076   1661.78000000   48105.4040000
```

Table B-1. Annual transition matrix for Rock Rapids station, Northwest Iowa

```
LAGANNUA        ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       0 |       2 |       2 |       3 |       2 |      9
         |    0.00 |    2.70 |    2.70 |    4.05 |    2.70 |  12.16
         |    0.00 |   22.22 |   22.22 |   33.33 |   22.22 |
         |    0.00 |   11.11 |   10.53 |   16.67 |   18.18 |
---------+---------+---------+---------+---------+---------+
DRY      |       1 |       6 |       4 |       4 |       3 |     18
         |    1.35 |    8.11 |    5.41 |    5.41 |    4.05 |  24.32
         |    5.56 |   33.33 |   22.22 |   22.22 |   16.67 |
         |   12.50 |   33.33 |   21.05 |   22.22 |   27.27 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       4 |       3 |       5 |       3 |       3 |     18
         |    5.41 |    4.05 |    6.76 |    4.05 |    4.05 |  24.32
         |   22.22 |   16.67 |   27.78 |   16.67 |   16.67 |
         |   50.00 |   16.67 |   26.32 |   16.67 |   27.27 |
---------+---------+---------+---------+---------+---------+
WET      |       2 |       4 |       4 |       5 |       3 |     18
         |    2.70 |    5.41 |    5.41 |    6.76 |    4.05 |  24.32
         |   11.11 |   22.22 |   22.22 |   27.78 |   16.67 |
         |   25.00 |   22.22 |   21.05 |   27.78 |   27.27 |
---------+---------+---------+---------+---------+---------+
WWET     |       1 |       3 |       4 |       3 |       0 |     11
         |    1.35 |    4.05 |    5.41 |    4.05 |    0.00 |  14.86
         |    9.09 |   27.27 |   36.36 |   27.27 |    0.00 |
         |   12.50 |   16.67 |   21.05 |   16.67 |    0.00 |
---------+---------+---------+---------+---------+---------+
TOTAL           8        18        19        18        11        74
            10.81     24.32     25.68     24.32     14.86    100.00
```

Table B-2. Annual transition matrix for Sheldon station, Northwest Iowa

```
LAGANNUA      ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       0 |       1 |       3 |       2 |       1 |      7
         |    0.00 |    1.89 |    5.66 |    3.77 |    1.89 |  13.21
         |    0.00 |   14.29 |   42.86 |   28.57 |   14.29 |
         |    0.00 |    7.69 |   20.00 |   16.67 |   14.29 |
---------+---------+---------+---------+---------+---------+
DRY      |       1 |       3 |       2 |       4 |       2 |     12
         |    1.89 |    5.66 |    3.77 |    7.55 |    3.77 |  22.64
         |    8.33 |   25.00 |   16.67 |   33.33 |   16.67 |
         |   16.67 |   23.08 |   13.33 |   33.33 |   28.57 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       2 |       3 |       6 |       3 |       1 |     15
         |    3.77 |    5.66 |   11.32 |    5.66 |    1.89 |  28.30
         |   13.33 |   20.00 |   40.00 |   20.00 |    6.67 |
         |   33.33 |   23.08 |   40.00 |   25.00 |   14.29 |
---------+---------+---------+---------+---------+---------+
WET      |       3 |       2 |       2 |       2 |       3 |     12
         |    5.66 |    3.77 |    3.77 |    3.77 |    5.66 |  22.64
         |   25.00 |   16.67 |   16.67 |   16.67 |   25.00 |
         |   50.00 |   15.38 |   13.33 |   16.67 |   42.86 |
---------+---------+---------+---------+---------+---------+
WWET     |       0 |       4 |       2 |       1 |       0 |      7
         |    0.00 |    7.55 |    3.77 |    1.89 |    0.00 |  13.21
         |    0.00 |   57.14 |   28.57 |   14.29 |    0.00 |
         |    0.00 |   30.77 |   13.33 |    8.33 |    0.00 |
---------+---------+---------+---------+---------+---------+
TOTAL            6        13        15        12         7       53
             11.32     24.53     28.30     22.64     13.21   100.00
```

Table B-3. Annual transition matrix for LeMars station, Northwest Iowa

```
LAGANNUA        ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       1 |       2 |       4 |       5 |       0 |     12
         |    1.22 |    2.44 |    4.88 |    6.10 |    0.00 |  14.63
         |    8.33 |   16.67 |   33.33 |   41.67 |    0.00 |
         |    8.33 |   10.00 |   20.00 |   25.00 |    0.00 |
---------+---------+---------+---------+---------+---------+
DRY      |       1 |       5 |       7 |       5 |       2 |     20
         |    1.22 |    6.10 |    8.54 |    6.10 |    2.44 |  24.39
         |    5.00 |   25.00 |   35.00 |   25.00 |   10.00 |
         |    8.33 |   25.00 |   35.00 |   25.00 |   20.00 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       5 |       3 |       3 |       5 |       4 |     20
         |    6.10 |    3.66 |    3.66 |    6.10 |    4.88 |  24.39
         |   25.00 |   15.00 |   15.00 |   25.00 |   20.00 |
         |   41.67 |   15.00 |   15.00 |   25.00 |   40.00 |
---------+---------+---------+---------+---------+---------+
WET      |       3 |       6 |       4 |       3 |       3 |     19
         |    3.66 |    7.32 |    4.88 |    3.66 |    3.66 |  23.17
         |   15.79 |   31.58 |   21.05 |   15.79 |   15.79 |
         |   25.00 |   30.00 |   20.00 |   15.00 |   30.00 |
---------+---------+---------+---------+---------+---------+
WWET     |       2 |       4 |       2 |       2 |       1 |     11
         |    2.44 |    4.88 |    2.44 |    2.44 |    1.22 |  13.41
         |   18.18 |   36.36 |   18.18 |   18.18 |    9.09 |
         |   16.67 |   20.00 |   10.00 |   10.00 |   10.00 |
---------+---------+---------+---------+---------+---------+
TOTAL          12        20        20        20        10        82
            14.63     24.39     24.39     24.39     12.20    100.00
```

Table B-4. Annual transition matrix for Sioux City station, Northwest Iowa

```
LAGANNUA     ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      1 |      1 |      4 |      2 |      4 |     12
         |   1.28 |   1.28 |   5.13 |   2.56 |   5.13 |  15.38
         |   8.33 |   8.33 |  33.33 |  16.67 |  33.33 |
         |   8.33 |   5.26 |  21.05 |  15.38 |  26.67 |
---------+--------+--------+--------+--------+--------+
DRY      |      2 |      4 |      9 |      0 |      3 |     18
         |   2.56 |   5.13 |  11.54 |   0.00 |   3.85 |  23.08
         |  11.11 |  22.22 |  50.00 |   0.00 |  16.67 |
         |  16.67 |  21.05 |  47.37 |   0.00 |  20.00 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      2 |      4 |      2 |      7 |      4 |     19
         |   2.56 |   5.13 |   2.56 |   8.97 |   5.13 |  24.36
         |  10.53 |  21.05 |  10.53 |  36.84 |  21.05 |
         |  16.67 |  21.05 |  10.53 |  53.85 |  26.67 |
---------+--------+--------+--------+--------+--------+
WET      |      4 |      3 |      2 |      2 |      2 |     13
         |   5.13 |   3.85 |   2.56 |   2.56 |   2.56 |  16.67
         |  30.77 |  23.08 |  15.38 |  15.38 |  15.38 |
         |  33.33 |  15.79 |  10.53 |  15.38 |  13.33 |
---------+--------+--------+--------+--------+--------+
WWET     |      3 |      7 |      2 |      2 |      2 |     16
         |   3.85 |   8.97 |   2.56 |   2.56 |   2.56 |  20.51
         |  18.75 |  43.75 |  12.50 |  12.50 |  12.50 |
         |  25.00 |  36.84 |  10.53 |  15.38 |  13.33 |
---------+--------+--------+--------+--------+--------+
TOTAL          12       19       19       13       15       78
            15.38    24.36    24.36    16.67    19.23   100.00
```

Table B-5. Annual transition matrix for Storm Lake station, Northwest Iowa

```
LAGANNUA      ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY    |DRY     |NORMAL  |WET     |WWET    |  TOTAL
---------+--------+--------+--------+--------+--------+
DDRY     |      1 |      1 |      7 |      2 |      1 |     12
         |   1.28 |   1.28 |   8.97 |   2.56 |   1.28 |  15.38
         |   8.33 |   8.33 |  58.33 |  16.67 |   8.33 |
         |   8.33 |   7.14 |  30.43 |  10.00 |  11.11 |
---------+--------+--------+--------+--------+--------+
DRY      |      2 |      2 |      5 |      2 |      3 |     14
         |   2.56 |   2.56 |   6.41 |   2.56 |   3.85 |  17.95
         |  14.29 |  14.29 |  35.71 |  14.29 |  21.43 |
         |  16.67 |  14.29 |  21.74 |  10.00 |  33.33 |
---------+--------+--------+--------+--------+--------+
NORMAL   |      1 |      4 |      7 |      9 |      2 |     23
         |   1.28 |   5.13 |   8.97 |  11.54 |   2.56 |  29.49
         |   4.35 |  17.39 |  30.43 |  39.13 |   8.70 |
         |   8.33 |  28.57 |  30.43 |  45.00 |  22.22 |
---------+--------+--------+--------+--------+--------+
WET      |      6 |      3 |      4 |      6 |      1 |     20
         |   7.69 |   3.85 |   5.13 |   7.69 |   1.28 |  25.64
         |  30.00 |  15.00 |  20.00 |  30.00 |   5.00 |
         |  50.00 |  21.43 |  17.39 |  30.00 |  11.11 |
---------+--------+--------+--------+--------+--------+
WWET     |      2 |      4 |      0 |      1 |      2 |      9
         |   2.56 |   5.13 |   0.00 |   1.28 |   2.56 |  11.54
         |  22.22 |  44.44 |   0.00 |  11.11 |  22.22 |
         |  16.67 |  28.57 |   0.00 |   5.00 |  22.22 |
---------+--------+--------+--------+--------+--------+
TOTAL          12       14       23       20        9       78
            15.38    17.95    29.49    25.64    11.54   100.00
```

Table B-6. Annual transition matrix for Alton station, Northwest Iowa

```
LAGANNUA      ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |       1 |       2 |       2 |       6 |       0 |     11
         |    1.37 |    2.74 |    2.74 |    8.22 |    0.00 |  15.07
         |    9.09 |   18.18 |   18.18 |   54.55 |    0.00 |
         |    9.09 |   10.53 |   16.67 |   25.00 |    0.00 |
---------+---------+---------+---------+---------+---------+
DRY      |       3 |       8 |       3 |       4 |       1 |     19
         |    4.11 |   10.96 |    4.11 |    5.48 |    1.37 |  26.03
         |   15.79 |   42.11 |   15.79 |   21.05 |    5.26 |
         |   27.27 |   42.11 |   25.00 |   16.67 |   14.29 |
---------+---------+---------+---------+---------+---------+
NORMAL   |       1 |       3 |       1 |       3 |       3 |     11
         |    1.37 |    4.11 |    1.37 |    4.11 |    4.11 |  15.07
         |    9.09 |   27.27 |    9.09 |   27.27 |   27.27 |
         |    9.09 |   15.79 |    8.33 |   12.50 |   42.86 |
---------+---------+---------+---------+---------+---------+
WET      |       4 |       4 |       5 |      10 |       1 |     24
         |    5.48 |    5.48 |    6.85 |   13.70 |    1.37 |  32.88
         |   16.67 |   16.67 |   20.83 |   41.67 |    4.17 |
         |   36.36 |   21.05 |   41.57 |   41.67 |   14.29 |
---------+---------+---------+---------+---------+---------+
WWET     |       2 |       2 |       1 |       1 |       2 |      8
         |    2.74 |    2.74 |    1.37 |    1.37 |    2.74 |  10.96
         |   25.00 |   25.00 |   12.50 |   12.50 |   25.00 |
         |   18.18 |   10.53 |    8.33 |    4.17 |   28.57 |
---------+---------+---------+---------+---------+---------+
TOTAL          11        19        12        24         7       73
            15.07     26.03     16.44     32.88      9.59   100.00
```

Table B-7. Annual transition matrix for Onawa station, Northwest Iowa

```
LAGANNUA        ANNUAL

FREQUENCY|
 PERCENT |
 ROW PCT |
 COL PCT |DDRY     |DRY      |NORMAL   |WET      |WWET     |  TOTAL
---------+---------+---------+---------+---------+---------+
DDRY     |      0  |      4  |      4  |      3  |      1  |     12
         |   0.00  |   5.06  |   5.06  |   3.80  |   1.27  |  15.19
         |   0.00  |  33.33  |  33.33  |  25.00  |   8.33  |
         |   0.00  |  22.22  |  18.18  |  15.79  |  11.11  |
---------+---------+---------+---------+---------+---------+
DRY      |      2  |      6  |      1  |      4  |      4  |     17
         |   2.53  |   7.59  |   1.27  |   5.06  |   5.06  |  21.52
         |  11.76  |  35.29  |   5.88  |  23.53  |  23.53  |
         |  18.18  |  33.33  |   4.55  |  21.05  |  44.44  |
---------+---------+---------+---------+---------+---------+
NORMAL   |      3  |      4  |      6  |      7  |      2  |     22
         |   3.80  |   5.06  |   7.59  |   8.86  |   2.53  |  27.85
         |  13.64  |  18.18  |  27.27  |  31.82  |   9.09  |
         |  27.27  |  22.22  |  27.27  |  36.84  |  22.22  |
---------+---------+---------+---------+---------+---------+
WET      |      4  |      4  |      8  |      2  |      1  |     19
         |   5.06  |   5.06  |  10.13  |   2.53  |   1.27  |  24.05
         |  21.05  |  21.05  |  42.11  |  10.53  |   5.26  |
         |  36.36  |  22.22  |  36.36  |  10.53  |  11.11  |
---------+---------+---------+---------+---------+---------+
WWET     |      2  |      0  |      3  |      3  |      1  |      9
         |   2.53  |   0.00  |   3.80  |   3.80  |   1.27  |  11.39
         |  22.22  |   0.00  |  33.33  |  33.33  |  11.11  |
         |  18.18  |   0.00  |  13.64  |  15.79  |  11.11  |
---------+---------+---------+---------+---------+---------+
TOTAL          11        18        22        19         9       79
            13.92     22.78     27.85     24.05     11.39   100.00
```

APPENDIX C.

SCS SOIL CLASSIFICATION FOR RAINFALL-RUNOFF RELATIONSHIP

Table C-1. Runoff curve numbers for hydrologic soil-cover complexes[a] (for watershed conditions II and $I_s = 0.2S$)

(1) Land use or cover	(2) Treatment or practice	(3) Hydrologic condition	(4) Hydrologic soil group A	 B	 C	 D
Fallow	Straight row	Poor	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	72	79	82
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close-seeded legumes[b] or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88

---

[a] From U.S. Soil Conservation Service (112a).

[b] Close-drilled or broadcast.

Table C-1. Continued

(1)	(2)	(3)	(4)			
	Treatment or practice	Hydrologic condition	Hydrologic soil group			
Land use or cover			A	B	C	D
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woodlands (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads, dirt[c]			72	82	87	89
Roads, hard-surface[c]			74	84	90	92

[c] Including right-of-way.

Table C-2. Runoff curve number (CN), conversions and constants[a]

CN for condition II (1)	CN for AMC		S values[b], in. (4)	Curve[b] starts where P = (in.) (5)
	I (2)	III (3)		
100	100	100	0.000	0.00
98	94	99	0.204	0.04
96	89	99	0.417	0.08
94	85	98	0.638	0.13
92	81	97	0.870	0.17
90	78	96	1.11	0.22
88	75	95	1.36	0.27
86	72	94	1.63	0.33
84	68	93	1.90	0.38
82	66	92	2.20	0.44
80	63	91	2.50	0.50
78	60	90	2.82	0.56
76	58	89	3.16	0.63
74	55	88	3.51	0.70
72	53	86	3.89	0.78
70	51	85	4.28	0.86
68	48	84	4.70	0.94
66	46	82	5.15	1.03
64	44	81	5.62	1.12
62	42	79	6.13	1.23
60	40	78	6.67	1.33
58	38	76	7.24	1.45
56	36	75	7.86	1.57
54	34	73	8.52	1.70
52	32	71	9.23	1.85
50	31	70	10.0	2.00
48	29	68	10.8	2.16
46	27	66	11.7	2.34
44	25	64	12.7	2.54
42	24	62	13.8	2.76
40	22	60	15.0	3.00

---

[a] From U.S. Conservation Service (112a).

[b] For CN in column 1.

Table C-2. Continued

CN for condition II (1)	CN for AMC I (2)	CN for AMC III (3)	S values[b], in. (4)	Curve[b] starts where P = (in.) (5)
38	21	58	16.3	3.26
36	19	56	17.8	3.56
34	18	54	19.4	3.88
32	16	52	21.2	4.24
30	15	50	23.3	4.66
25	12	43	30.0	6.00
20	9	37	40.0	8.00
15	6	30	56.7	11.34
10	4	22	90.0	18.00
5	2	13	190.0	38.00
0	0	0	Infinitely	Infinitely

APPENDIX D.

ISU UNIT HYDROMODEL COMPUTER PROGRAM AND THE RELATED DICTIONARY OF VARIABLES

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$JOB            ARFA,TIME=5,PAGES=75
C                   I.S.U. UNIT HYDROMODEL
C     UNIT HYDROMODEL(HYDROLOGIC MASS BALANCE MODEL PROGRAM)
C     ,A MODIFIED HYDROMODEL WORKED OUT FOR FLOYD RIVER
C     BASIN AT ALTON,NORTHWEST IOWA.
C     DEPARTMENT OF CIVIL ENGINEERING,IOWA STATE UNIVERSITY,
C     AMES,IOWA,U.S.A.
      COMMON LYR
      INTEGER NAME(20)
      DIMENSION PDH(12),AC1(13),RIF(13),F(13),CD(13),PW(13),
     1PCL(13),DWRZ(13),GWOF(13),TSRZ(13),TEMP(13),
     2PCUU(13,13),PCU(13,13),PGSC(12,13),AC2(13),
     3WLCUU(13,13),SPCU(13),SWLCU(13),SMS(13),ASMS(13),DEF(1
     4AGW(13),EMI(13),TIF(13),SWL(13),SOF(13),SGW(13),DGW(13
     5RES(13),EXPO(13),TOF(13),GWRT(13),SRTF(13),STW(12)
      DIMENSION PREC(13),TAVE(13),PWL(13),ACU(13),RTFLO(13),
     1SKW(13),AGSC(13,13),WLCU(13,13)
      DIMENSION WLDEF(13),TSWL(13),SWLK(12),SSIC(13),
     1 CROP(13),DRES(13),USW(13),GFLO(13),DCG(13),SSC(13),
     2SMA(13),SMW(13),DSC(13),DSW(13),RTK(12),GWIN(13),
     3AWLCU(13),PRES(13),EVAP(13),WGSC(12),WLSM(13),
     4SSW(13),GWTS(13),WLAGW(13),PW1(6),PHR(13),AWLSM(13)
      DIMENSIONRIF1(6),TIF1(6),RES1(6),DRES1(6),USW1(6),
     1DWRZ1(6),GWOF1(6),PCL1(6),TSRZ1(6),SMS1(6),ASMS1(6),
     2DEF1(6),ACU1(6),AGW1(6),RTFLO1(6),EMI1(6),SWL1(6),
     3SWLCU1(6),EXPO1(6),TEMP1(6),BCF(6),WSE1(6),DGW1(6),
     4PREC1(6),GFLO1(6),DCG1(6),SMA1(6),DSC1(6),SGW1(6),
     5SPCU1(6),PWL1(6),SSC1(6),SOF1(6),CD1(6),TOF1(6)
      DIMENSION WLAGW1(6),TSWL1(6),SSIC1(6),WLDEF1(6),
     1GWRT1(6),SRTF1(6),SMW1(6),DSW1(6),VAR1(13),GWIN1(6),
     2AWLCU1(6),PRES1(6),EVAP1(6),WLSM1(6),AWLSM1(6),
     3DET1(13),COA1(12)
      DIMENSION SUB1(13),SUB2(13),SUB11(6),SUB21(6),
     1DET11(6),DET21(6),Q1(13),Q2(13),Q11(6),Q21(6),
     2POB1(12),POB2(12),POC1(12),POC2(12),PSM1(12),PSM2(12),
     3CFB1(13),CFA2(13),CFB2(13),CRA1(12),CRA2(12),CRB1(12),
     4PSU1(13),PSU2(13),SUMP(13),AP(13),PDE1(13),PDE2(13),
     5GWTS1(6),DET2(13),COA2(12),CFA1(13),CRB2(12),FSUB1(13)
      DIMENSION QINC(13),DELZ(13),ZGW(13),ZS(13),DELH(13),
     1GWCOE(7),ZRIV(13),GW(19),QGW(13),GWTEL(13),FDET1(13),
     2FSUB2(13),FDET2(13),QIRR1(6),QIRR(13)
C
C     READ LABELS FOR BUDGET OUTPUT
C
      DUM=0.0
      READ(5,500) RIF1,TIF1,RES1
      READ(5,500) DRES1,USW1,CD1
      READ(5,500) DWRZ1,PW1,GWIN1
      READ(5,500)PCL1,TSRZ1,SMS1
```

```
      READ(5,500) ASMS1,SPCU1,DEF1
      READ(5,500) ACU1,PREC1,RTFLO1
      READ(5,500) EMI1,SWL1,PWL1
      READ(5,500) SWLCU1,EXPO1,SOF1
      READ(5,500) TEMP1,BCF,WSE1
      READ(5,500) SSC1,SMA1,DSC1
      READ(5,500) AGW1,SGW1,DGW1
      READ(5,500) TOF1,GFLO1,DCG1
      READ(5,500) GWOF1,GWRT1,SRTF1
      READ(5,500) DSW1,SMW1,GWTS1
      READ(5,500) PRES1,EVAP1,WLSM1
      READ(5,500) AWLCU1,AWLSM1,WLDEF1
      READ(5,500) WLAGW1,TSWL1,SSIC1
      READ(5,500) Q11,Q21,SUB11
      READ(5,500) SUB21,DET11,DET21
      READ(5,500) QIRR1
      READ(5,501) VAR1
 1    READ(5,101,END=999) NAME
 500  FORMAT(3(6A4,1X))
 501  FORMAT(13(2X,A4))
  101 FORMAT(20A4)
C
C     READ INITIALIZATION PARAMETERS
C
      READ(5,102)STA,NYR,IM,NC1,NC2,MBC,NPR,NRIF,NCD,NPW,
     1NMI,NTIF,NGWIN,NRES,NEXPO,NGFLO,NGWOF,IG,NCU,EFOF,
     2EFCV,CC,CW,CT,EKGW,EKS,TP,TSM
      READ(5,103)STA1,TAC,TAWL,RESF,ASMS(1),RZD,SMC1,SSO,
     1SGW(1),GWC,TKGW,GWCAP
      READ(5,109) B,COCO,SO,COMN,S,ALRV,P,ZB,VW
      READ(5,107) STA2,TARES,AWLSM(1), WLSMC,PINT,ZINT
      READ(5,440) (AP(I),I=1,IM)
      AP(13)=0.0
      DO 480 I=1,12
480   AP(13)=AP(13)+AP(I)
      READ(5,667) (COA1(I),I=1,IM)
      READ(5,667) (COA2(I),I=1,IM)
      READ(5,666) (POB1(I),I=1,IM)
      READ(5,666) (POB2(I),I=1,IM)
      READ(5,666) (POC1(I),I=1,IM)
      READ(5,666) (POC2(I),I=1,IM)
      READ(5,666) (PSM1(I),I=1,IM)
      READ(5,666) (PSM2(I),I=1,IM)
      READ(5,667) (CFA1(I),I=1,IM)
      READ(5,667) (CFB1(I),I=1,IM)
      READ(5,667) (CFA2(I),I=1,IM)
      READ(5,667) (CFB2(I),I=1,IM)
      READ(5,666) (CRA1(I),I=1,IM)
      READ(5,666) (CRA2(I),I=1,IM)
```

```
      READ(5,666) (CRB1(I),I=1,IM)
      READ(5,666) (CRB2(I),I=1,IM)
      READ(5,666) (GWCOE(I),I=1,7)
440   FORMAT(6X,12F5.3)
667   FORMAT(6X,12F6.2)
666   FORMAT(6X,12F5.4)
      PANT=PINT
      ASMS(13)=ASMS(1)
      AWLSM(13)=AWLSM(1)
      SGW(13)=SGW(1)
C
C     READ INITIALIZATION COEFFICIENTS FOR TRANSITIONAL GW
C     STORAGE
C
      IF(IG.EQ.0) GO TO 2
      READ(5,104)(STW(I),I=1,IG)
 102  FORMAT(2X,A4,17I2,I1,2F3.2,5F5.3,2F4.1)
 103  FORMAT(2X,A4,3F8.0,F6.0,3F5.2,2F8.0,F5.3,F8.0)
109   FORMAT(6X,8F6.4,F6.0)
 107  FORMAT(2X,A4,5F10.0)
 104  FORMAT(14X,12F5.3)
    2 ZIM=IM
      IMT=IM+1
C
C     READ CROPLAND GROUNDWATER RETURN FLOW COEFFICIENTS
C
      READ(5,104)(RTK(I),I=1,IM)
C
C     READ SURFACE SUPPLY TO WETLAND COEFFICIENTS
C
      READ(5,104)(SWLK(I),I=1,IM)
C
C     READ PROPORTION OF DAYLIGHT HOURS
C
      READ(5,130)(PDH(I),I=1,IM)
 130  FORMAT(14X,12F5.4)
C
C     READ PROPORTION CROP AREAS AND GROWTH STAGE COEFFS.
C
      IF(NCI)10,10,5
    5 READ(5,106)(AC1(J),J=1,NC1)
  106 FORMAT(10X,13F5.3)
      DO 6 J=1,NC1
      READ(5,105) CROP(J),(AGSC(I,J),I=1,IM)
 105  FORMAT(8X,A4,2X,12F5.2)
      AC1(J)=TAC*AC1(J)
    6 CONTINUE
C
C     READ PROPORTION PHREATOPHYTE AREAS AND GROWTH STAGE
```

```
C     COEFFICIENTS
C
   10 IF(NC2)15,15,11
   11 READ(5,106)(AC2(J),J=1,NC2)
      DO 12 J=1,NC2
      READ(5,105)PHR(J),(PGSC(I,J),I=1,IM)
      AC2(J)=TAWL*AC2(J)
   12 CONTINUE
C
C     READ RESERVOIR WATER SURFACE GROWTH STAGE COEFFICIENTS
C
   15 IF(NRES.NE.0) READ(5,105) WTR,(WGSC(I), I=1,IM)
C
C     READ INPUT DATA
      DO 700 I=1,19
700   GW(I)=0.
C
      IJYR=0
      IF(IG.EQ.0) GO TO 1100
      TRI=1.
      DO 7 I=1,IG
    7 TRI=TRI-STW(I)
      WRITE(6,511)(STW(I),I=1,IG),TRI
 511  FORMAT(1X,20HTRANSITIONAL GW COEF,5X,13F8.3)
      DO 8 I=1,IG
    8 STW(I)=STW(I)*SGW(1)
      TRI=SGW(1)*TRI
      WRITE(6,512)(STW(I),I=1,IG),TRI
 1100 READ(5,1000,END=999) LYR
      IJYR=IJYR+1
      ASMS(1)=ASMS(13)
      AWLSM(1)=AWLSM(13)
      SGW(1)=SGW(13)
      DO 702 I=1,7
702   GW(I)=GW(12+I)
 1000 FORMAT(20A4)
      DO 703 I=8,19
703   GW(I)=0.
C
C     CALCULATE CROPLAND SOIL MOISTURE CAPACITY AND INITIAL
C     SNOW STORAGE ON THE UPLAND AND FLOODPLAIN
C     THE CROPLAND AND WETLAND
C
      SMC=RZD*SMC1*TAC/12.
      SSC(1)=SSO*TAC/12.
      SSW(1)=SSO*TAWL/12.
C
C     PRINT ORIGINAL INPUT DATA IF NPR NE 0
C
```

```
      IF(NPR.EQ.0) GO TO 13
      WRITE(6,507) NAME
  507 FORMAT(15H1INPUT DATA FOR,20A4)
      WRITE(6,508)STA,NYR,IM,NC1,NC2,MBC,NPR,NRIF,NCD,NPW,
     1NMI,NTIF,NGWIN,NRES,NEXPO,NGFLO,NGWOF,IG,NCU,EFOF,
     2EFCV,CC,CW,CT,EKGW,EKS,TP,TSM
      WRITE(6,509)STA1,TAC,TAWL,RESF,ASMS(1),RZD,SMC1,SSO,
     1SGW(1),GWC,TKGW,GWCAP,SMC,SSC(1),SSW(1)
 508  FORMAT(1X,A4,2X,18I3,2F5.2,3F6.3,2F6. 3,2F6. 1)
 509  FORMAT(1X,A4,2X,3F10.0,F8.0,3F6.2,2F10.0,F8.3,4F10.0)
      WRITE(6,509) STA2,TARES,AWLSM(1),WLSMC
      WRITE(6,110) B,COCO,SO,COMN,S,ALRV,P,ZB,VW,ZINT
110   FORMAT(1X,19HHYDRAULIC VARIABLES,5X,8F8.4,F8.0,F8.2)
  13  CONTINUE
   14 IF(NPR.EQ.0) GO TO 200
  512 FORMAT(1X,23HINITIAL TRANSITIONAL GW ,2X,12F8.0)
      WRITE(6,560) LYR,VAR1
      WRITE(6,510)(RTK(I),I=1,IM)
  510 FORMAT(1X,25HCROP GW-RETURN FLO COEF   ,12F8.3)
      WRITE(6,513)(SWLK(I),I=1,IM)
  513 FORMAT(1X,25HSURFACE SUPPLY TO WL COEF,12F8.3)
      WRITE(6,502)(PDH(I),I=1,IM)
  502 FORMAT(1X,25HPROPORTION DAYLIGHT HOURS,12F8.4)
      WRITE(6,402)(COA1(I),I=1,IM)
402   FORMAT(1X,4HCOA1,21X,12F8.4)
      WRITE(6,403)(COA2(I),I=1,IM)
403   FORMAT(1X,4HCOA2,21X,12F8.4)
      WRITE(6,404)(POB1(I),I=1,IM)
404   FORMAT(1X,4HPOB1,21X,12F8.4)
      WRITE(6,405)(POB2(I),I=1,IM)
405   FORMAT(1X,4HPOB2,21X,12F8.4)
      WRITE(6,406)(POC1(I),I=1,IM)
406   FORMAT(1X,4HPOC1,21X,12F8.4)
      WRITE(6,407)(POC2(I),I=1,IM)
407   FORMAT(1X,4HPOC2,21X,12F8.4)
      WRITE(6,408)(PSM1(I),I=1,IM)
408   FORMAT(1X,4HPSM1,21X,12F8.4)
      WRITE(6,409)(PSM2(I),I=1,IM)
409   FORMAT(1X,4HPSM2,21X,12F8.4)
      WRITE(6,410)(CFA1(I),I=1,IM)
410   FORMAT(1X,4HCFA1,21X,12F8.4)
      WRITE(6,411)(CFB1(I),I=1,IM)
411   FORMAT(1X,4HCFB1,21X,12F8.4)
      WRITE(6,412)(CFA2(I),I=1,IM)
412   FORMAT(1X,4HCFA2,21X,12F8.4)
      WRITE(6,413)(CFB2(I),I=1,IM)
413   FORMAT(1X,4HCFB2,21X,12F8.4)
      WRITE(6,437) (CRA1(I),I=1,IM)
437   FORMAT(1X,4HCRA1,21X,12F8.4)
```

```
      WRITE(6,438) (CRA2(I),I=1,IM)
438   FORMAT(1X,4HCRA2,21X,12F8.4)
      WRITE(6,439) (CRB1(I),I=1,IM)
439   FORMAT(1X,4HCRB1,21X,12F8.4)
      WRITE(6,460) (CRB2(I),I=1,IM)
460   FORMAT(1X,4HCRB2,21X,12F8.4)
      WRITE(6,463) (GWCOE(I),I=1,7)
463   FORMAT(1X,5HGWCOE,20X,7F8.4)
      IF(NC1.EQ.0) GO TO 91
      WRITE(6,520)(AC1(J),J=1,NC1),TAC
  520 FORMAT(11H CROP AREAS,14F8.0)
      WRITE(6,504)(J,CROP(J),(AGSC(I,J),I=1,IM),J=1,NC1)
 504  FORMAT(1X,I3,1X,A4,2X,7H K COEF ,8X,12F8.2)
   91 IF(NC2.EQ.0) GO TO 93
      WRITE(6,521)(AC2(J),J=1,NC2),TAWL
  521 FORMAT(11H WLPH AREAS,14F8.0)
      WRITE(6,504)(J,PHR(J),(PGSC(I,J),I=1,IM),J=1,NC2)
   93 IF(NRES.NE.0) WRITE(6,522) WTR,(WGSC(I),I=1,IM)
 522  FORMAT(1H0,A4,2X,7H K COEF ,11X,12F8.2)
      IF(NRIF.NE.0.AND.NPR.NE.0)WRITE(6,506)RIF1
 506  FORMAT(25X,6A4)
  200 CALL INPUT(NRIF,1,IM,RIF,NPR)
      IF(NCD.NE.0.AND.NPR.NE.0)WRITE(6,506)CD1
      CALL INPUT(NCD,1,IM,CD,NPR)
      IF(NPW.NE.0.AND.NPR.NE.0)WRITE(6,506)PW1
      CALL INPUT(NPW,1,IM,PW,NPR)
      IF(IJYR.GT.1) ZINT=ZGW(12)
      IF(IJYR.GT.1) PANT=PREC(12)
      IF(IJYR.LE.1) GO TO 462
      AP(13)=AP(13)-AP(12)+PANT
      DO 461 I=1,IM
461   AP(I)=PREC(I)
462   CONTINUE
      IF(NPR.NE.0)WRITE(6,506)PREC1
      CALL INPUT(1,1,IM,PREC,NPR)
      IF(NPR.NE.0)WRITE(6,506)TEMP1
      CALL INPUT(1,1,IM,TEMP,NPR)
      IF(NMI.NE.0.AND.NPR.NE.0)WRITE(6,506)EMI1
      CALL INPUT(NMI,1,IM,EMI,NPR)
      IF(NTIF.NE.0.AND.NPR.NE.0)WRITE(6,506)TIF1
      CALL INPUT(NTIF,1,IM,TIF,NPR)
      IF(NGWIN.NE.0.AND.NPR.NE.0)WRITE(6,506)GWIN1
      CALL INPUT(NGWIN,1,IM,GWIN,NPR)
      IF(NRES.NE.0.AND.NPR.NE.0)WRITE(6,506)RES1
      CALL INPUT(NRES,1,IM,RES,NPR)
      IF(NEXPO.NE.0.AND.NPR.NE.0)WRITE(6,506)EXPO1
      CALL INPUT(NEXPO,1,IM,EXPO,NPR)
      IF(NGFLO.NE.0.AND.NPR.NE.0)WRITE(6,506)GFLO1
      CALL INPUT(NGFLO,1,IM,GFLO,NPR)
```

```
      IF(NPR.NE.0)WRITE(6,506)GWOF1
      CALL INPUT(NGWOF,1.IM,GWOF,NPR)
      WRITE(6,467)
467   FORMAT(5X,'I',11X,'ZGW',13X,'ZS',11X,'ZRIV',8X,'DELH',
     114X,'QGW',14X,'GW',11X,'QIRR')
C
C     INITIALIZATION OF ANNUAL COLUMN AND TOTALS
C
   18 SSC(IMT)=0.
      SSW(IMT)=0.
      SMA(IMT)=0.
      DSC(IMT)=0.
      SMW(IMT)=0.
      DSW(IMT)=0.
      SGW(IMT)=0.
      DGW(IMT)=0.
      DCG(IMT)=0.
      DRES(IMT)=0.
      USW(IMT)=0.
      DWRZ(IMT)=0.
      PCL(IMT)=0.
      Q1(IMT)=0.
      Q2(IMT)=0.
      DET1(IMT)=0.
      DET2(IMT)=0.
      SUB1(IMT)=0.
      SUB2(IMT)=0.
      TSRZ(IMT)=0.
      SPCU(IMT)=0.
      SPCU(IMT)=0.
      SMS(IMT)=0.
      DEF(IMT)=0.
      ACU(IMT)=0.
      AGW(IMT)=0.
      RTFLO(IMT)=0.
      SWL(IMT)=0.
      PWL(IMT)=0.
      AWLCU(IMT)=0.
      SWLCU(IMT)=0.
      TAVE(IMT)=0.
      QIRR(IMT)=0.
      F(IMT)=0.
      SOF(IMT)=0.
      TOF(IMT)=0.
      GWRT(IMT)=0.
      SRTF(IMT)=0.
      GWTS(IMT)=0.
      PRES(IMT)=0.
      EVAP(IMT)=0.
```

```
      WLSM(IMT)=0.
      WLAGW(IMT)=0.
      SSIC(IMT)=0.
      TSWL(IMT)=0.
      WLDEF(IMT)=0.
      IF(NC1)21,21,19
   19 DO 20 K=1,NC1
      PCUU(IMT,K)=0.
   20 PCU(IMT,K)=0.
   21 IF(NC2)24,24,22
   22 DO 23 K=1,NC2
      WLCUU(IMT,K)=0.
   23 WLCU(IMT,K)=0.
   24 CONTINUE
C
C     CALCULATE CHANCE IN RESERVOIR STORAGE.  RES(I) IS
C     STORAGE AT THE END OF PERIOD I.
C
      DRES(1)=RES(1)-RESF
      DO 16 I=2,IM
   16 DRES(I)=RES(I)-RES(I-1)
      RES(IMT)=RES(IM)
      DRES(IMT)=RES(IM)-RESF
      RESF=RES(IM)
C
C     BUDGET CALCULATIONS BEGIN HERE
C
      SSC(1)=0.
      SSW(1)=0.
      EKT=1.
      DO 60 I=1,IM
C
C     CALCULATE POTENTIAL CONSUMPTIVE USE
C
      TAVE(I)=CT*TEMP(I)
      F(I)=TAVE(I)*PDH(I)
      IF(MBC.NE.0)EKT=.0173*TAVE(I)-.314
      IF(EKT.LT.0.)EKT=0.
      SPCU(I)=0.
      IF(NC1)29,29,27
   27 DO 28 K=1,NC1
      PCUU(I,K)=F(I)*EKT*AGSC(I,K)
      PCU(I,K)=PCUU(I,K)*(AC1(K)/12.)
   28 SPCU(I)=SPCU(I)+PCU(I,K)
   29 SWLCU(I)=0.
      IF(NC2)32,32,30
   30 DO 31 K=1,NC2
      WLCUU(I,K)=F(I)*EKT*PGSC(I,K)
      WLCU(I,K)=WLCUU(I,K)*(AC2(K)/12.)
```

```
   31 SWLCU(I)=SWLCU(I)+WLCU(I,K)
C
C     CALCULATE PRECIPITATION AND EVAPORATION FROM RESERVOIR
C
   32 EVAP(I)=0.
      PRES(I)=0.
      IF(NRES.EQ.0) GO TO 205
      EVAP(I)=F(I)*EKT*WGSC(I)*TARES/12.
      PRES(I)=PREC(I)*TARES/12.
C
C     CALCULATE SNOW STORAGE AND SNOW MELT
205   SMA(I)=0.
      SUB1(I)=0.
      SUB2(I)=0.
      SMW(I)=0.
      PSU1(I)=0.
      PSU2(I)=0.
      PDE1(I)=0.
      PDE2(I)=0.
      DET1(I)=0.
      DET2(I)=0.
      DSC(I)=0.
      DSW(I)=0.
      Q1(I)=0.
      Q2(I)=0.
      GWTS(I)=0.
      PREC(I)=PREC(I)*CRA1(I)
      SUMP(I)=0.0
      IF(I.EQ.1) GO TO 470
      AP(13)=AP(13)-AP(I-1)+PREC(I-1)
470   SUMP(I)=AP(13)
      IF(I.GT.2.AND.I.LT.8) GO TO 307
      Q1(I)=(EXP(COA1(I)))*(SUMP(I)**POB1(I))*(PREC(I)**
     1POC1(I))
      Q2(I)=(EXP(COA2(I)))*(SUMP(I)**POB2(I))*(PREC(I)**
     1POC2(I))
      SSC(I+1)=0.
      SSW(I+1)=0.
      GO TO 414
307   SSC(I+1)=SSC(I)+PREC(I)*TAC/12.
      IF(I.EQ.6.AND.TAVE(I).GT.37.) GO TO 308
      GO TO 309
308   Q1(I)=(EXP(COA1(I)))*(SUMP(I)**POB1(I))*(PREC(I)**
     1POC1(I))
      Q2(I)=(EXP(COA2(I)))*(SUMP(I)**POB2(I))*(PREC(I)**
     1POC2(I))
      Q1(I)=Q1(I)+SSC(I)*12./TAC
      Q2(I)=Q2(I)+SSW(I)*12./TAWL
      SMA(I)=SSC(I)
```

```
      SMW(I)=SSW(I)
      SUB1(I)=0.
      SUB2(I)=0.
      DET1(I)=0.
      DET2(I)=0.
      DSC(I)=-SSC(I)
      SSC(I+1)=0.
      SSW(I+1)=0.
      DSW(I)=-SSW(I)
      GO TO 414
309   IF(I.EQ.7) SSC(I+1)=SSC(I)
      DSC(I)=0.
      PSU1(I)=(CFA1(I)*(EXP(CFB1(I)*SSC(I+1)*12./TAC)))/100.
      SUB1(I)=PSU1(I)*SSC(I+1)
      SSC(I+1)=SSC(I+1)-SUB1(I)
      PDE1(I)=(CFA2(I)*(EXP(CFB2(I)*SSC(I+1)*12./TAC)))/100.
      DET1(I)=PDE1(I)*SSC(I+1)
      SSC(I+1)=SSC(I+1)-DET1(I)
      SMA(I)=PSM1(I)*SSC(I+1)
      SSC(I+1)=SSC(I+1)-SMA(I)
      IF(SSC(I+1)) 320,330,330
320   DUM2=SUB1(I)+DET1(I)+SMA(I)
      CORR=1.0+(SSC(I+1)/DUM2)
      SUB1(I)=SUB1(I)*CORR
      DET1(I)=DET1(I)*CORR
      SMA(I)=SMA(I)*CORR
      SSC(I+1)=0.
330   DSC(I)=PREC(I)*TAC/12.-SUB1(I)-DET1(I)-SMA(I)
      IF(I.EQ.7) DSC(I)=-SUB1(I)-DET1(I)-SMA(I)
      SSW(I+1)=SSW(I)+PREC(I)*TAWL/12.
      IF(I.EQ.7)SSW(I+1)=SSW(I)
      DSW(I)=0.
      PSU2(I)=(CFA1(I)*(EXP(CFB1(I)*SSW(I+1)*12./TAWL)))/
     1100.
      SUB2(I)=PSU2(I)*SSW(I+1)
      SSW(I+1)=SSW(I+1)-SUB2(I)
      PDE2(I)=(CFA2(I)*(EXP(CFB2(I)*SSW(I+1)*12./TAWL)))/
     1100.
      DET2(I)=PDE2(I)*SSW(I+1)
      SSW(I+1)=SSW(I+1)-DET2(I)
      SMW(I)=PSM2(I)*SSW(I+1)
      SSW(I+1)=SSW(I+1)-SMW(I)
      IF(SSW(I+1)) 340,350,350
340   DUM2=SUB2(I)+DET2(I)+SMW(I)
      CORR=1.0+(SSW(I+1)/DUM2)
      SUB2(I)=SUB2(I)*CORR
      DET2(I)=DET2(I)*CORR
      SMW(I)=SMW(I)*CORR
      SSW(I+1)=0.
```

```
 350  DSW(I)=PREC(I)*TAWL/12.-SUB2(I)-DET2(I)-SMW(I)
      IF(I.EQ.7) DSW(I)=-SUB2(I)-DET2(I)-SMW(I)
      IF(I.NE.7) GO TO 414
       IF(SSC(I+1).GT.0.) SMA(I)=SMA(I)+SSC(I+1)
      IF(SSW(I+1).GT.0.) SMW(I)=SMW(I)+SSW(I+1)
      SSC(I+1)=0.
      SSW(I+1)=0.
      Q1(I)=(EXP(COA1(I)))*(SUMP(I)**POB1(I))*(PREC(I)**
     1POC1(I))
      Q2(I)=(EXP(COA2(I)))*(SUMP(I)**POB2(I))*(PREC(I)**
     1POC2(I))
 414  Q1(I)=Q1(I)*TAC/12.+SMA(I)
      Q2(I)=Q2(I)*TAWL/12.+SMW(I)
      PCL(I)=PREC(I)*TAC/12.
      PWL(I)=PREC(I)*TAWL/12.
C
C     CALCULATE ROOT ZONE SUPPLY
C
      DWRZ(I)=CD(I)*EFCV*EFOF
      TSRZ(I)=DWRZ(I)+PCL(I)-Q1(I)
      IF(I.EQ.7) TSRZ(I)=PCL(I)+DET1(I)
      IF(I.EQ.7) DSC(I)=-SSC(I)
      IF(I.GT.2.AND.I.LT.7) TSRZ(I)=DWRZ(I)+DET1(I)
      IF(I.EQ.6.AND.TAVE(I).GT.37.) TSRZ(I)=PCL(I)-Q1(I)+
     1SMA(I)
      SMS(I)=TSRZ(I)-SPCU(I)
      RTFLO(I)=CD(I)-DWRZ(I)
      GWRT(I)=RTK(I)*RTFLO(I)
      SRTF(I)=RTFLO(I)-GWRT(I)
      IF(SMS(I))33,33,35
   33 IF(SMS(I)+ASMS(I))34,34,35
   34 ASMS(I+1)=0.
      AGW(I)=0.
      DEF(I)=SMS(I)+ASMS(I)
      ACU(I)=SPCU(I)+DEF(I)
      GO TO 45
   35 ASMS(I+1)=ASMS(I)+SMS(I)
      IF(ASMS(I+1)-SMC)38,38,40
   38 AGW(I)=0.
      GO TO 43
   40 AGW(I)=ASMS(I+1)-SMC
      ASMS(I+1)=SMC
   43 ACU(I)=SPCU(I)
      DEF(I)=0.
C
C     CALCULATE GW TRANSITION AND ADDITION
C
   45 SGW(I+1)=SGW(I)+AGW(I)+GWRT(I)+GWIN(I)
      IF(SGW(I+1).LT.GWCAP)GO TO 46
```

```
      SGW(I+1)=GWCAP
   46 IF(IG.EQ.0) GO TO 65
      TRI=TRI+STW(IG)
      IF(IG.EQ.1) GO TO 63
      DO 62 IK=2,IG
      K=IG+2-IK
   62 STW(K)=STW(K-1)
   63 STW(1)=AGW(I)+GWRT(I)+GWIN(I)-GWTS(I)
      DGW(I)=EKGW*TRI
      IF(DGW(I).LT.GWC)DGW(I)=GWC
      IF(TRI.LT.GWC)DGW(I)=TRI
      TRI=TRI-DGW(I)
      GO TO 68
   65 DGW(I)=EKGW*SGW(I+1)
      IF(DGW(I).LT.GWC)DGW(I)=GWC
      IF(SGW(I+1).LT.GWC)DGW(I)=SGW(I+1)
   68 SGW(I+1)=SGW(I+1)-DGW(I)
C
C     CALCULATE RECHARGE TO OR DISCHARGE FROM THE RIVER
C
      DO 701 K=1,7
      LL=I+K-1
      GW(LL)=GW(LL)+GWCOE(K)*AGW(I)
701   CONTINUE
C
C     CALCULATE MANAGEABLE SUPPLY AND SURFACE WATER IN
C     CHANNEL
C
      USW(I)=RIF(I)+TIF(I)+PRES(I)+PW(I)-EVAP(I)+RES(I)-
     1DRES(I)
      SSIC(I)=USW(I)-RES(I)-CD(I)-EXPO(I)-EMI(I)+SRTF(I)+
     1GWTS(I)
      SSIC(I)=SSIC(I)+Q2(I)+Q1(I)
   69 WLAGW(I)=0.
      IF(NC2.EQ.0) GO TO 250
C
C     CALCULATE WETLAND ROOT ZONE STORAGE, CONSUMPTIVE USE,
C     AND ADDITION TO GROUNDWATER
C
      SWL(I)=SWLK(I)*SSIC(I)
      SSIC(I)=SSIC(I)-SWL(I)
      QIRR(I)=0.
      IF(I.GT.7.AND.I.LT.12) QIRR(I)=(DUM*0.9)*(WLSMC-
     1AWLSM(I))/0.8
      TSWL(I)=SWL(I)+PWL(I)-Q2(I)+QIRR(I)
      IF(I.EQ.7) TSWL(I)=PWL(I)+DET2(I)
      IF(I.EQ.7) DSW(I)=-SSW(I)
      IF(I.GT.2.AND.I.LT.7) TSWL(I)=SWL(I)+DET2(I)
      IF(I.EQ.6.AND.TAVE(I).GT.37.) TSWL(I)=PWL(I)-Q2(I)+
```

```
     1SMW(I)
      WLSM(I)= TSWL(I)-SWLCU(I)
      IF(WLSM(I)) 215,215,220
  215 IF(WLSM(I)+AWLSM(I))216,216,220
 216  AWLSM(I+1)=0.
      WLAGW(I)=0.
      WLDEF(I)=WLSM(I)+AWLSM(I)
      AWLCU(I)= SWLCU(I)+WLDEF(I)
      GO TO 250
  220 AWLSM(I+1)= AWLSM(I)+WLSM(I)
      IF(AWLSM(I+1)-WLSMC) 225,225,230
  225 WLAGW(I)=0.
      GO TO 235
  230 WLAGW(I)= AWLSM(I+1)-WLSMC
      AWLSM(I+1)= WLSMC
  235 AWLCU(I)= SWLCU(I)
      WLDEF(I)=0.
250   QINC(I)=(Q1(I)+Q2(I))/(1.98*30.)
      DELZ(I)=(WLAGW(I)-(PW(I)+QIRR(I)))/(TAWL*P)
      IF(I.GT.1) GO TO 710
      ZGW(I)=ZINT+DELZ(I)
      GO TO 711
710   ZGW(I)=ZGW(I-1)+DELZ(I)
711   ZS(I)=((QINC(I)*COMN)/(B*1.49*SO**.5))**0.6
      ZRIV(I)=ZB+ZS(I)
      DELH(I)=(ZGW(I)-ZRIV(I))/(VW*.5-B/2.)
      QGW(I)=COCO*(B+2*ZS(I))*ALRV*5280.*DELH(I)
      DQ=Q1(I)+Q2(I)+QGW(I)
      IF(DQ.LT.0.) QGW(I)=Q1(I)+Q2(I)
      DELZ(I)=QGW(I)/(TAWL*P)
      ZGW(I)=ZGW(I)-DELZ(I)
      SSIC(I)=SSIC(I)+QGW(I)+GW(I)
      GWTS(I)=GWRT(I)+QGW(I)+GW(I)
      WRITE(6,770) I,ZGW(I),ZS(I),ZRIV(I),DELH(I),QGW(I),
     1GW(I),QIRR(I)
770   FORMAT(1X,I5,3F15.2,E15.5,3F15.2)
C
C     CALCULATE TOTAL OUTFLOW AND CHANGE IN GW STORAGE
C
      TOF(I)=DGW(I)+WLAGW(I)-PW(I)+SSIC(I)
C
C     CALCULATE ANNUAL VALUES FOR YEAR
C
      IF(NRES.EQ.0) GO TO 260
      PRES(IMT)=PRES(IMT)+PRES(I)
      EVAP(IMT)= EVAP(IMT)+EVAP(I)
  260 PCL(IMT)=PCL(IMT)+PCL(I)
      Q1(IMT)=Q1(IMT)+Q1(I)
      Q2(IMT)=Q2(IMT)+Q2(I)
```

```
      SMS(IMT)=SMS(IMT)+SMS(I)
      TAVE(IMT)=TAVE(IMT)+TAVE(I)/ZIM
      F(IMT)=F(IMT)+F(I)
      DWRZ(IMT)=DWRZ(IMT)+DWRZ(I)
      GWRT(IMT)=GWRT(IMT)+GWRT(I)
      SRTF(IMT)=SRTF(IMT)+SRTF(I)
      TSRZ(IMT)=TSRZ(IMT)+TSRZ(I)
      RTFLO(IMT)=RTFLO(IMT)+RTFLO(I)
      DEF(IMT)=DEF(IMT)+DEF(I)
      SPCU(IMT)=SPCU(IMT)+SPCU(I)
      ACU(IMT)=ACU(IMT)+ACU(I)
      AGW(IMT)=AGW(IMT)+AGW(I)
      SWLCU(IMT)=SWLCU(IMT)+SWLCU(I)
      PWL(IMT)=PWL(IMT)+PWL(I)
      TOF(IMT)=TOF(IMT)+TOF(I)
      DSC(IMT)=DSC(IMT)+DSC(I)
      DET1(IMT)=DET1(IMT)+DET1(I)
      DET2(IMT)=DET2(IMT)+DET2(I)
      SUB1(IMT)=SUB1(IMT)+SUB1(I)
      SUB2(IMT)=SUB2(IMT)+SUB2(I)
      DSW(IMT)=DSW(IMT)+DSW(I)
      SMA(IMT)=SMA(IMT)+SMA(I)
      SMW(IMT)=SMW(IMT)+SMW(I)
      DGW(IMT)=DGW(IMT)+DGW(I)
      SWL(IMT)=SWL(IMT)+SWL(I)
      TSWL(IMT)=TSWL(IMT)+TSWL(I)
      GWTS(IMT)=GWTS(IMT)+GWTS(I)
      SSIC(IMT)=SSIC(IMT)+SSIC(I)
      QIRR(IMT)=QIRR(IMT)+QIRR(I)
      IF(NC1.EQ.0) GO TO 48
      DO 47 K=1,NC1
      PCUU(IMT,K)=PCUU(IMT,K)+PCUU(I,K)
   47 PCU(IMT,K)=PCU(IMT,K)+PCU(I,K)
   48 IF(NC2.EQ.0) GO TO 60
      DO 49 L=1,NC2
      WLCUU(IMT,L)=WLCUU(IMT,L)+WLCUU(I,L)
   49 WLCU(IMT,L)=WLCU(IMT,L)+WLCU(I,L)
      AWLCU(IMT)= AWLCU(IMT)+AWLCU(I)
      WLSM(IMT)=WLSM(IMT)+WLSM(I)
      WLAGW(IMT)=WLAGW(IMT)+WLAGW(I)
      WLDEF(IMT)=WLDEF(IMT)+WLDEF(I)
   60 CONTINUE
C
C     CALCULATE GW OUTFLOW, SURFACE OUTFLOW AND DIFF BTWN
C     COMPUTED AND GAGED SURFACE OUTFLOW FOR EACH MONTH
C
      PKGW=0.
      IF(NGWOF.NE.0) GO TO 72
      GWOF(IMT)=TKGW*TOF(IMT)
```

```
      DGX=DGW(IMT)
      IF(DGX.LE.0.) DGX=1.
      PKGW=GWOF(IMT)/DGX
   72 DO 61 I=1,IM
      IF(NGWOF.NE.0) GO TO 74
      GWOF(I)=DGW(I)*PKGW
 74   SOF(I)=TOF(I)-GWOF(I)-WLAGW(I)-DGW(I)
      IF(SOF(I).LT.0.) SOF(I)=0.
   61 DCG(I)=SOF(I)-GFLO(I)
C
C     CALCULATE ANNUAL VALUES AND ACCUMULATE SUM FOR USW,
C     SOF, AND DCG
C
      USW(IMT)=RIF(IMT)+RES(IMT)+TIF(IMT)-DRES(IMT)
      SOF(IMT)=TOF(IMT)-GWOF(IMT)-WLAGW(IMT)-DGW(IMT)
      DCG(IMT)=SOF(IMT)-GFLO(IMT)
C
C     OUTPUT OF MASS BALANCE WATER BUDGET
C
      QDUM=QIRR(IMT)
      WRITE(6,468) QDUM
468   FORMAT(91X,F15.2,' INCHES')
      WRITE(6,1001)NAME
 1001 FORMAT(1H1,25X,20A4)
      WRITE(6,560)LYR,VAR1
 560  FORMAT(11H ITEM--YEAR  ,A4,11X,13(2X,A4,2X))
  550 FORMAT(1H ,6A4,1X ,12F8.0,F9.0)
      WRITE(6,550)RIF1,(RIF(I),I=1,IMT)
      WRITE(6,550)TIF1,(TIF(I),I=1,IMT)
      WRITE(6,550)PW1,(PW(I),I=1,IMT)
      IF(NRES.EQ.0) GO TO 125
      WRITE(6,550) RES1,(RES(I),I=1,IMT)
      WRITE(6,550) PRES1,(PRES(I),I=1,IMT)
      WRITE(6,550) EVAP1,(EVAP(I),I=1,IMT)
      WRITE(6,550)DRES1,(DRES(I),I=1,IMT)
  125 WRITE(6,550)USW1,(USW(I),I=1,IMT)
      WRITE(6,550)GWIN1,(GWIN(I),I=1,IMT)
      IF(NC1.EQ.0) GO TO 127
      WRITE(6,550)CD1,(CD(I),I=1,IMT)
      WRITE(6,550)DWRZ1,(DWRZ(I),I=1,IMT)
      WRITE(6,550)RTFLO1,(RTFLO(I),I=1,IMT)
      WRITE(6,550) Q11,(Q1(I),I=1,IMT)
      WRITE(6,550)SRTF1,(SRTF(I),I=1,IMT)
      WRITE(6,550)GWRT1,(GWRT(I),I=1,IMT)
      WRITE(6,550)PCL1,(PCL(I),I=1,IMT)
      WRITE(6,550)DSC1,(DSC(I),I=1,IMT)
      WRITE(6,550)SSCI,(SSC(I),I=1,IMT)
      WRITE(6,550) DET11,(DET1(I),I=1,IMT)
      WRITE(6,550) SUB11,(SUB1(I),I=1,IMT)
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```
      WRITE(6,550)SMA1,(SMA(I),I=1,IMT)
      WRITE(6,550)TSRZ1,(TSRZ(I),I=1,IMT)
      WRITE(6,550)SPCU1,(SPCU(I),I=1,IMT)
      WRITE(6,550)SMS1,(SMS(I),I=1,IMT)
      WRITE(6,550)ASMS1,(ASMS(I),I=1,IMT)
      WRITE(6,550)DEF1,(DEF(I),I=1,IMT)
      WRITE(6,550)ACU1,(ACU(I),I=1,IMT)
      WRITE(6,550)AGW1,(AGW(I),I=1,IMT)
  127 WRITE(6,550)SGW1,(SGW(I),I=1,IMT)
      WRITE(6,550) DET21,(DET2(I),I=1,IMT)
      WRITE(6,550) SUB21,(SUB2(I),I=1,IMT)
      WRITE(6,550)DGW1,(DGW(I),I=1,IMT)
      WRITE(6,550)GWTS1,(GWTS(I),I=1,IMT)
      WRITE(6,550)EMI1,(EMI(I),I=1,IMT)
      WRITE(6,550) QIRR1,(QIRR(I),I=1,IMT)
      WRITE(6,550)EXPO1,(EXPO(I),I=1,IMT)
      IF(NC2.EQ.0) GO TO 126
      WRITE(6,550) SWL1,(SWL(I),I=1,IMT)
      WRITE(6,550)PWL1,(PWL(I),I=1,IMT)
      WRITE(6,550) Q21,(Q2(I),I=1,IMT)
      WRITE(6,550)DSW1,(DSW(I),I=1,IMT)
      WRITE(6,550)SSC1,(SSW(I),I=1,IMT)
      WRITE(6,550)SMW1,(SMW(I),I=1,IMT)
      WRITE(6,550)TSWL1,(TSWL(I),I=1,IMT)
      WRITE(6,550) SWLCU1 ,(SWLCU(I),I=1,IMT)
      WRITE(6,550) WLSM1,(WLSM(I),I=1,IMT)
      WRITE(6,550) AWLSM1,(AWLSM(I),I=1,IMT)
      WRITE(6,550) WLDEF1 ,(WLDEF(I),I=1,IMT)
      WRITE(6,550) AWLCU1,(AWLCU(I),I=1,IMT)
      WRITE(6,550) WLAGW1 ,(WLAGW(I),I=1,IMT)
  126 WRITE(6,550)SSIC1,(SSIC(I),I=1,IMT)
      WRITE(6,550) TOF1,(TOF(I),I=1,IMT)
      WRITE(6,550)GWOF1,(GWOF(I),I=1,IMT)
      WRITE(6,550)SOF1,(SOF(I),I=1,IMT)
      WRITE(6,550)GFLO1,(GFLO(I),I=1,IMT)
      WRITE(6,550)DCG1,(DCG(I),I=1,IMT)
      IF(IG.EQ.0) GO TO 80
      IF(SGW(IMT)) 9999,9999,9998
 9999 DO 9997 I=1,IG
 9997 SKW(I)=0.
      SKW(IG+1)=0.
      GO TO 9996
 9998 CONTINUE
      DO 79 I=1,IG
   79 SKW(I)=STW(I)/SGW(IMT)
      SKW(IG+1)=TRI/SGW(IMT)
 9996 CONTINUE
      WRITE(6,515)(SKW(I),I=1,IG),SKW(IG+1)
  515 FORMAT(1H0,20HFINAL TRANS GW COEF ,5X,13F7.3)
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```
      WRITE(6,516)(STW(I),I=1,IG),TRI,SGW(IMT)
  516 FORMAT(1X,21HFINAL TRANS GW SUBDIV ,4X,14F7.0)
   80 IF(NCU.EQ.0) GO TO 1100
C
C     OUTPUT OF CONSUMPTIVE USE DATA IF NCU NE 0
C
      WRITE(6,1005)
 1005 FORMAT(1H1,50X,28HCONSUMPTIVE USE CALCULATIONS)
      WRITE(6,1006)LYR,VAR1
 1006 FORMAT(7X,4HYEAR,A4,12X,   13(2X,A4,2X))
 1010 FORMAT(1X,6A4,1X,12F8.2,F9.2)
 1011 FORMAT(1X,I2,1X,A4,2X,15H UNIT USE (IN.),1X,12F8.2,
     1F9.2)
 1012 FORMAT(1X,I2,1X,A4,2X,14H USE (ACRE-FT),2X,12F8.0,
     1F9.0)
 1013 FORMAT(1X,18HAGRICULTURAL CROPS)
 1014 FORMAT(1X,22HWET LAND PHREATOPHYTES)
      WRITE(6,1010)TEMP1,(TAVE(I),I=1,IMT)
      WRITE(6,1010)BCF,(F(I),I=1,IMT)
      IF(NC1.EQ.0) GO TO 160
      WRITE(6,1013)
      DO 150 K=1,NC1
      WRITE(6,1011)K,CROP(K),(PCUU(I,K),I=1,IMT)
  150 WRITE(6,1012)K,CROP(K),(PCU(I,K),I=1,IMT)
      WRITE(6,550)SPCU1,(SPCU(I),I=1,IMT)
      WRITE(6,550)ACU1,(ACU(I),I=1,IMT)
  160 IF(NC2.EQ.0) GO TO 1100
      WRITE(6,1014)
      DO 170 K=1,NC2
      WRITE(6,1011)K,PHR(K),(WLCUU(I,K),I=1,IMT)
  170 WRITE(6,1012)K,PHR(K),(WLCU(I,K),I=1,IMT)
      WRITE(6,550)SWLCU1,(SWLCU(I),I=1,IMT)
      WRITE(6,550)AWLCU1,(AWLCU(I),I=1,IMT)
      GO TO 1100
  999 CONTINUE
      STOP
      END
      SUBROUTINE INPUT(N,NYR,IM,Q,NPR)
      COMMON LYR
      DIMENSION Q(13),F(13),FMT(14)
      IF(N.NE.0)READ(5,100)FMT
  100 FORMAT(20A4)
      IMT=IM+1
      K=1
      IF(N-1)5,10,15
    5 DO 7 I=1,IMT
    7 Q(I)=0.
      GO TO 30
   10 L=1
```

```
C               DICTIONARY OF VARIABLES FOR
C                 I.S.U. UNIT HYDROMODEL
C         NOTE:
C           1-THIS DICTIONARY INCLUDES THE VARIABLES USED
C       BASICALLY FOR ORIGINAL HYDROMODEL.
C           2-IT INCLUDES VARIABLES LATER ADDED TO DEVELOP
C       I.S.U. UNIT HYDROMODEL FOR FLOYD RIVER BASIN AT ALTON
C       IN NORTHWEST IOWA.
C           3-IT DOES NOT INCLUDE THE DEFINED COEFFICIENTS,
C       MODIFIERS AND UNITS USED.
C           4-THE WORDS WETLANDS AND FLOODPLAINS USED INTER-
C       CHANGEABLY HAVE THE SAME MEANING.
C           5-THE WORDS CROPLANDS AND UPLANDS USED INTER-
C       CHANGEABLY HAVE THE SAME MEANING.
C
C       AC1    =AREA(ACRES) OF EACH CROP IN UPLANDS
C       AC2    =AREA (ACRES) OF VARIOUS CROPS IN FLOOD PLAIN
C       ACU=ACTUAL CONSUMPTIVE USE (PCU-DEF)
C       AGSC=CROP POTENTIAL C.U. FACTOR FOR BLANNEY CRIDDLE
C            EQU. FOR UPLANDS
C       AGW=ADDITION TO GROUNWATER
C       ALRV=EFFECTIVE LENGTH OF THE RIVER
C       ASMS=ACCUMULATED SOIL MOISTURE STORAGE
C       AWLCU=ACTUAL WETLANDS CONSUMPTIVE USE
C       AWLSM=ACCUMULATED WET LANDS SOIL MOISTURE
C       B=WIDTH OF RIVER BOTTOM
C       CD=CANAL DIVERSION
C       COCO=HYDROLIC CONDUCTIVITY
C       COMN=MANNING'S COEFFICIENT
C       CROP=LABELS FOR VARIOUS CROPS USED
C       DCG=PREDICTED OUTFLOW
C       DEF=DEFICIT CONSUMPTIVE USE FROM CROPLAND
C       DELZ=ELEVATION CHANGES IN G.W. TABLE
C       DET=DETENTION
C       DGW=DEEP GROUVDWATER
C       DRES=CHANGE IN RESERVOIR STORAGE
C       DSC=ADDITION TO SNOW PACK ON CROP LANDS
C       DSW=ADDITION TO SNOW PACK ON FLOOD PLAINS
C       DWRZ=CANAL DIVERSION TO THE ROOT ZONE:(CD)(EFOV)(EFOF)
C       EMI=MUNICIPAL AND INDUSTRIAL WATER
C       EXPO=EXPORTED WATER OUT OF BASIN
C       F=AVE. TEMP. *% DAYLIGHT HRS. (BLANNEY-CRIDDLE EQU.)
C       GFLO=GAGED OUTFLOW
C       GW=GROUNWATER REPLENISHED FROM UPLANDS
C       GWIN=GROUNWATER INFLOW FROM UPSTREAM SUBBASIN
C       GWOF=GROUNWATER OUTFLOW
C       GWRT=GROUNDWATER RETURN FLOW
C       GWTS=GROUNDWATER DISCHARGED TO SURFACE
C       NC1=NUMBER OF CROPS ON UPLANDS
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C      NPR=INPUT PRINT STATEMENT (0.DO NOT PRINT,1.PRINT)
C      P=POROSITY
C      PCL=PRECIPITATION ON CROPLAND
C      PCU=POTENTIAL CONSUMPTIVE USE PER CROP
C      PCUU=POTENTIAL CONSUMPTIVE USE UNIT(PER ACRE) PER CROP
C      PDH=PERCENT OF DAYLIGHT HOURS
C      PGSC=CROP POTENTIAL CONSUMPTIVE USE FACTOR FOR FLOOD-
C           PLAIN
C      PINT=INITIAL PRECIPITATION
C      PHR=PHREATOPHYTE NAME LABEL
C      PRES=PRECIPITATION ON THE RESERVOIR
C      PW=PUMPED WATER
C      PWL=PRECIPITATION ON WET LANDS
C      QGW=VOLUME OF G.W. CONTRIBUTION(POSITIVE OR NEGATIVE)
C      QINC=TOTAL SURFACE WATER IN CHANNEL
C      QIRR=IRRIGATION WATER
C      RES=RESERVOIR STORAGE
C      RIF=MEASURED INFLOW FROM UPSTREAM SUBAREAS
C      RTFLO=RETURNE FLOW FROM IRRIGATION
C      RTK=MONTHLY RETURNE FLOW COEFFICIENT
C      S=DELH=DRIVING FORCE
C      SGW=ACCUMULATED INTERFLOW STORAGE (AMOUNT OF WATER IN
C          THE INTERFLOW BOX
C      SMA=SNOW MELT VOLUME FROM CROP LANDS: =K(TAVE.-TSM)*
C          (SNOW STORAGE)
C      SMS=TOTAL SUPPLY TO ROOT ZONE MINUSE TOTAL PCU FOR
C          UPLANDS(AMOUNT ADDED OR SUBTRACTED FROM ASMS)
C      SMW=SNOW MELT VOLUME FROM FLOOD PLAINS
C      SO=SLOP OF THE RIVER
C      SOF=SURFACE OUTFLOW
C      SPCU=SUM OF POTENTIAL CONSUMPTIVE USE
C      SRTF=SURFACE RETURN FLOW
C      SSC=ACCUMULATED SNOW PACK VOLUME FROM CROPLAND
C      SSIC=SUM OF SURFACE IN CHANNEL
C      SSW=ACCUMULATED SNOW PACK VOLUME ON FLOOD PLAIN
C      STW=AMOUNT OF STORAGE IN ANY LAG BOX OF INTERFLOW
C      SUB=SUBLIMATION
C      SWLK=COEFFICIENT TO DETERMINE THE AMOUNT OF SURFACE
C           WATER EACH MONTH PASS THRU. WETLAND
C      SWL=SURFACE DIVERSION TO WETLANDS
C      SWLCU=SUM OF WET LANDS CONSUMPTIVE USE
C      TIF=UNMEASURED TRIBUTARY INFLOW
C      TOF=TOTAL OUTFLOW (BOTH SURFACE AND SUBSURFACE)
C      TSRZ=TOTAL SUPPLY AVAILABLE TO ROOT ZONE
C      TSWL=TOTAL SUPPLY AVAILABLE TO WETLAND
C      USW=MANAGEABLE SURFACE WATER
C      VW=EFFECTIVE WIDTH OF FLOODPLAIN
C      WGSC=RESERVOIR EVAPORATION (CALCULATE FROM RESERVOIR)
C      WLAGW=WET LANDADDITION TO GROUND WATER
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C       WLCU=WETLAND CONSUMPTIVE USE PER CROP
C       WLCUU=WET LAND CONSUMPTIVE USE UNIT(PER ACRE)PER CROP
C       WLDEF=WETLAND DEFICIT CONSUMPTIVE USE
C       WLSM=MONTHLY FLOOD PLAINS SOIL MOISTURE STORAGE
C       ZB=ELEVATION OF RIVER BED FROM DATUM
C       ZGW=VELEVATION OF G.W. TABLE AT THE END OF THE MONTH
C       ZINT=INITIAL GROUNDWATER ELEVATION
C       ZRIV=ELEVATION OF WATER SURFACE IN CHANNEL FROM DATUM
C       ZS=STAGE OF WATER IN CHANNEL
        STOP
        END
```