THE UNIVERSITY OF IDAHO

College of Engineering
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SYSTEMS ANALYSIS OF IRRIGATION WATER MANAGEMENT IN EASTERN IDAHO

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ABSTRACT

A water management study to include a complete water budget of the irrigated area of the Snake River fan in eastern Idaho was initiated in May 1970. The study was initiated to develop alternate management solutions to the increasing high water table problem causing inconvenience and financial hardships to local residents and to develop methods of solving regional groundwater problems. Water levels in wells raise as much as 40 feet during the irrigation season.

A mathematical model of the gravel aquifer was developed utilizing alternating direction implicit procedures for finite difference solutions to the basic flow equations. Data on water table fluctuation, soils, crop distribution, irrigation diversions, distribution system losses and wastes evapotranspiration, and irrigation practices were obtained for input to the model.

A dense network of canals with seepage rates averaging 3.5 cubic feet per square foot per day, irrigated soils with high infiltration rates, and in some cases inefficient irrigation practices contribute to diversions for irrigation significantly in excess of the state average. In 1970 the net diversion from the Snake River was 16.5 acre feet per irrigated acre and the net irrigation application was 9.6 acre feet per acre for the entire irrigation season.

Continuing studies are underway to evaluate the response of the aquifer due to changes in inputs caused by canal lining or consolidation, drainage systems, and changes in water management procedures.

BROCKWAY, C. E.; BONDURANT, J. A.; and WORSTELL, R. V.

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DESCRIPTORS *Groundwater movement/ *Water management/ *Surface groundwater relationship/ *Water level fluctuations/ Alluvial aquifers/ Digital computers/ Model studies/ *Idaho

IDENTIFIERS Snake River fan/ Groundwater hydrology

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ILLUSTRATIONS

INTRODUCTION

In compliance with the work outline contained in the recent contract between the Idaho Department of Water Administration and the University of Idaho and in cooperation with the Agricultural Research Service, USDA, the research study on water use was begun in the Rigby-Ririe area of the upper Snake River Basin about May 1, 1970. Concern for the high water table problems being experienced in this area resulted in the formation within Jefferson County of a sub-water committee to investigate possible causes and solutions to the problem. This committee has been very cooperative with the University and the Agricultural Research Service in formulating procedures for data collection and in securing some field data. The County Commissioners of Jefferson County also have been cooperative and have supplied at the county court house an office for the full-time field man presently working in the area. Meetings have been held with the Jefferson County Commissioners and with the members of the Great Feeder Canal Board under whose jurisdiction a majority of the irrigation water is delivered to this area. Good cooperation has been received from the local farmers in the area and from the government agencies involved.

OBJECTIVES

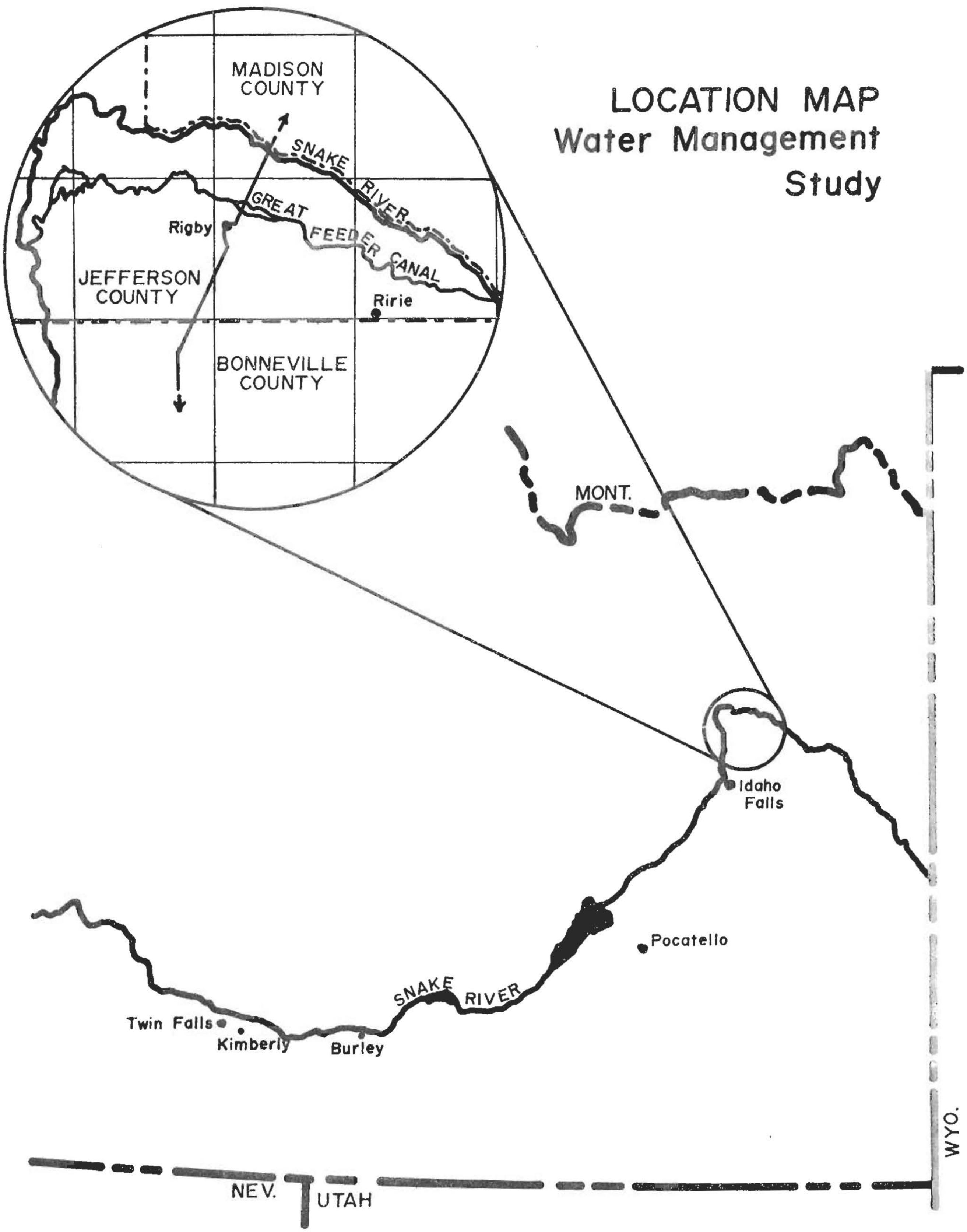
Recognizing that the problem of high groundwater tables and drainage that exists in the Rigby-Ririe area is typical also of other areas in the State of Idaho and because of the known high rates of irrigation diversions to this area, this project area affords an excellent opportunity to study various aspects of water management in irrigation distribution systems.

Therefore, the objectives of this study were 1) to develop procedures for analyzing regional water management problems 2) to develop and evaluate alternate management solutions for water table control, 3) to develop procedures for scheduling irrigation water deliveries to multiple canal companies and districts.

STUDY AREA

The water management study area as shown in Figure 1 is located in Jefferson and Bonneville counties in Townships 3, 4, and 5N and Ranges 37 through 40E of the Boise Meridian. The area selected for study comprises approximately 100,500 acres. The city of Rigby, Idaho lies in approximately the center of the study area and is the county seat of Jefferson County. Other communites in the area are Lewisville, in the western part of the area; Menan and Lorenzo in the northern part of the area; and the city of Ririe in the eastern part. This area which is an old alluvial fan from the Snake River is served by an irrigation system which was developed in the late 1800's by private and cooperative groups. A former channel of the Snake River runs east and west through the area and is used as a canal for the greater part of its length. This canal, referred to as the Great Feeder Canal, delivers water to some twenty smaller canals each one operated by a separate and independent canal company or irrigation district. The lands served by canals from the Great Feeder system and other canals diverting directly out of the Snake River have some of the earliest water rights in the upper Snake River Basin. As a result of these early water rights, water for irrigation has generally not been in scarce supply. With the construction of the Palisades Dam and reservoir in 1954 by the U. S. Bureau of Reclamation new storage rights purchased by the individual canal companies have firmed up the irrigation water supply so that a shortage of water is not likely to occur.

FIGURE 1


LOCATION MAP
Water Management
Study
MADISON
COUNTY
SNAKE
RIVER
GREAT
FEEDER
CANAL
Rigby
JEFFERSON
COUNTY
Ririe
BONNEVILLE
COUNTY
MONT.
Idaho
Falls
Pocatello
SNAKE
RIVER
Twin Falls
Kimberly
Burley
NEV.
UTAH
WYO.

The soils of the area are generally quite coarse, varying in texture from east to west along the alluvial fan. The material from which the irrigation canals are excavated is generally rocky and quite permeable especially in the upper areas of the fan. Diversions from the individual canals to farm ditches are seldom measured; however on many of the farm turnouts there are or have been meter gates or other measuring devices. It appears that at this time these devices are not being used for water measurement.

Crops grown in the area are alfalfa, small grains, potatoes, and pasture. The size of individual farms is lower than the average for the state and it is estimated that some 30% of the farm owners are part-time farmers and supplement their income with non-farm work. Border irrigation is practiced quite extensively with large inflow streams being used. The canals and laterals of the delivery systems are generally checked up as high as possible to allow for maximum farm diversions.

WATER SUPPLY

All of the irrigated lands in the study area are served from the Snake River with water rights dating as early as June 1880. The majority of the area is served by irrigation canals diverting from the Great Feeder Canal which serves as a by-pass for the Snake River main stream and generally runs continuously. Management of deliveries to the smaller independent canals is the responsibility of a cooperative group called the Great Feeder Board.

Historical diversions to the area are recorded in the reports of the watermaster for Water District 36 of the State of Idaho commencing in 1919 through the present. Some canals serve lands in the study area as well as land south of the area. A list of canals diverting from the Snake River and Great Feeder is contained in Appendix 1. Figure 2 shows the annual diversions for all canals for the period 1919 through 1970 and a mass curve of accumulated discharges for the same period. The area irrigated under these canals, as indicated in the District 36 records, has not increased significantly over the period so that the trend of increase in total diversions is indicative of the trend in total diversion per acre. Several increases in slope of the mass curve can be seen after dry periods such as 1931-1935 and also after the Palisades Reservoir became operational.

Total diversions per acre for the period 1 May to 30 September have increased over the period and were 10.2 af/acre in 1969. On some canals, diversions were made in October and November which are not recorded in District 36 records.

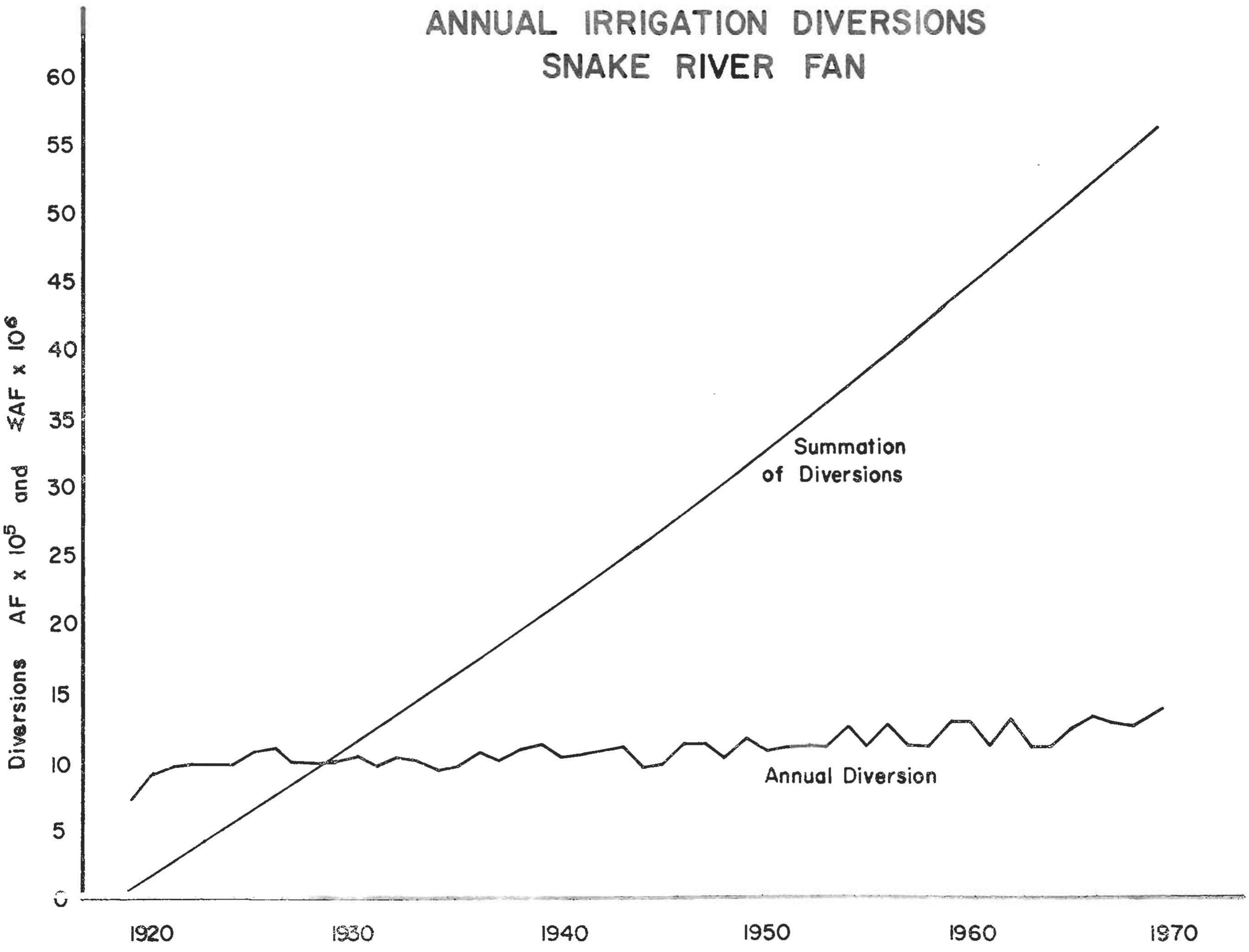
CLIMATE

The Rigby-Ririe area of Jefferson County lies in the climatological area known as the Upper Snake River Plains with moderately warm summers and rather severe winters. Temperatures average about 68°F in July and 17°F in January and 0°F temperatures or lower generally occur for at least 16 days each year.

The growing season averages 123 days in duration and the growing degree days above 40°F average 3710 degree days.

Precipitation averages 8.7 inches with 25% occurring in May and June and sunshine averages from 80 to 85% of possible in July-September. Average windspeeds, generally from the south-southwest range from 10-15 miles per hour with high winds of 40-45 miles per hour occurring most often in April.

FIGURE 2


ANNUAL IRRIGATION DIVERSIONS
SNAKE RIVER FAN
Diversions AF x 10^5 and ΣAF x 10^6
0
5
10
15
20
25
30
35
40
45
50
55
60
1920
1930
1940
1950
1960
1970
Summation of Diversions
Annual Diversion

SOILS

Agricultural soils of the Snake River Fan are dominated by medium texture soils as found on fans and stream bottom lands. This soil group is identified as Group A in a recent soil survey by the U. S. Department of Agriculture Soil Conservation Service. Approximate locations of the soil association in the study area are shown in Figure 3.

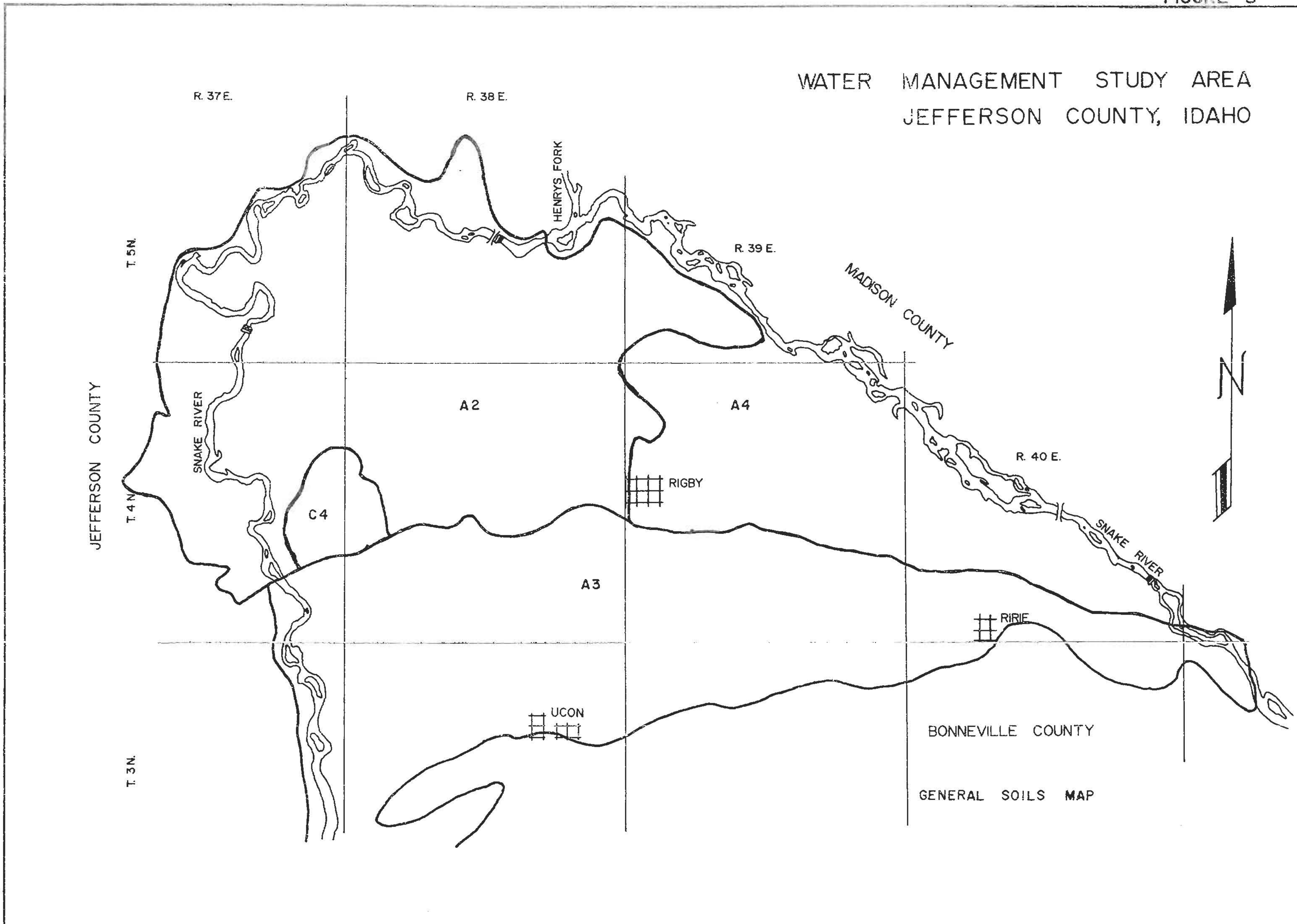
The A2 association primarily in the lower elevations of the northwest section of the fan comprises some of the better crop land and consists of silt and clay loams of 40-60 inches depth underlain by sand and gravel. The available water holding capacity ranges from 3.5 to 13 inches and averages about 10 inches. These soils are moderately well drained and are presently utilized as cropland.

In the southern part of the study area and extending into Bonneville County the soils are primarily of the A3 association consisting of the Bock and Bannock loam series. These soils are well drained with water holding capacities from 4 to 10 inches and depths of 20-60 inches over sand and gravel. In some areas top soils contain from 0 to 50 percent gravels.

The northeast part of the study area just south of the Snake River is classified as soil group A4 consisting primarily of the Blackfoot silt loam. These soils are well drained with depths generally from 20 to 60 inches above sand and gravel however one soil comprising about 15 percent of the area is very shallow with depths of 5 to 20 inches. Most of the soils are cropped with the gravelly soils being used for pasture production.

A soil group C4 overlies the Lewisville Knolls area and is presently used only for range and wildlife. Water holding capacities are low, 1.0 to 6.5 inches, and depths are 10 to 40 inches above basalt bedrock.

FIGURE 3


WATER MANAGEMENT STUDY AREA
JEFFERSON COUNTY, IDAHO
R. 37 E.
R. 38 E.
R. 39 E.
R. 40 E.
T. 5 N.
T. 4 N.
T. 3 N.
JEFFERSON COUNTY
MADISON COUNTY
BONNEVILLE COUNTY
HENRYS FORK
SNAKE RIVER
SNAKE RIVER
A2
A4
A3
C4
RIGBY
RIRIE
UCON
N
GENERAL SOILS MAP

All of the soils with the exception of the C4 group are mainly of Class II or III capability for irrigated agriculture.

CROPS

Crop distribution throughout the study area is nearly uniform and U. S. Bureau of Reclamation reports for 1969 from irrigation districts comprising about 32,600 acres indicate the following distribution.

Mixed Grains	31.2%
Alfalfa hay	27.6%
Irrigated Pasture	7.3%
Potatoes	31.4%
Other	2.5%

IRRIGATION PRACTICES

Border irrigation is used extensively on grains, alfalfa and pasture. Large stream sizes are prevalent with turnouts from the canals regulated in most cases by individual farmers. Large siphon tubes are used for border irrigation and overnight sets are not uncommon.

Irrigation practice on three potato fields and two bordered grain fields was evaluated in 1970. Test results show that intake rates are very high. Border irrigation of grains resulted in 12 to 15 inches of water being applied to irrigate a 1300 ft. run. Many fields are longer than this and streams used were as much as could be held in the border. Overnite irrigation with reduced stream size can result in almost twice this application while the soil profile will hold only 5 inches of water.

Furrow irrigation of potatoes was about 50% efficient for a 2" irrigation on 1000 ft. furrows early in the season where the wheel compacted furrow was used. Use of non-compacted rows early in the season gave about 20% efficiency.

Later in the season the vines fall into the rows and intake rates increase. Stream sizes used ranged from 10 to 80 gpm. Wheel compaction at the right soil moisture can be very effective in reducing the intake rate of these soils. Nearly all fields could benefit from more leveling and the high intake rates measured indicate that this area would benefit from sprinkler irrigation.

The water master's records and spot field checking reveal that most canal companies in the study area are diverting at a rate greater than decreed rights. This occurs about one-half of the irrigation season. Canal management by the watermasters is lax. On most canals diversions are made at will by the farmers and canal check dams are operated by the farmer instead of the ditch rider. The prevailing attitude seems to be that the ditch rider's job is to keep the canal full regardless of what water rights exist.

SYSTEM SIMULATION

Modeling

In order to efficiently determine and evaluate the alternative solutions for relieving the high groundwater table, a method of predicting the response of the aquifer to varying degrees of change in the input and output is necessary. Analytical solutions to the basic flow equations are not applicable because of the complexity of the hydrogeologic system, varying boundary conditions and high degree of simplification needed to secure a solution. Analog models of the resistance-capacitance type would suffice. However, construction of an analog is costly and the size and flexibility required for this study would be difficult to achieve.

The availability of large digital computers and new finite difference techniques for solving the flow equations make a digital model most feasible. The General Electric time-share unit in Los Angeles is available through the terminal at the Snake River Research Center and access is available to the large IBM 360-75 system of the Atomic Energy Commission in Idaho Falls.

The model being designed describes the response of the aquifer due to a wide range of conditions. It is general enough to be applied to other aquifers and areas and will accommodate non-homogenous and anisotropic aquifers. All boundary conditions normally encountered can be handled. Inputs to the modeled area include precipitation, canal seepage, irrigation application, river losses, or drainage well inputs. Output includes crop evapotranspiration, pumped well discharges, natural spring discharges and aquifer leakage.

Mathematical Theory

The basic equation for non-steady flow in an unconfined aquifer when we assume water as an ideal incompressible fluid is:

$$\frac{\partial}{\partial x}\left(K_{(x,y,z)}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{(x,y,z)}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{(x,y,z)}\frac{\partial h}{\partial z}\right)=\frac{S}{b}\frac{\partial h}{\partial t}+\frac{W}{b}(x,y,z,t) \tag{1}$$

where K = hydraulic conductivity L/T

h = piezometric head L

S = storage coefficient dimensionless

b = saturated aquifer thickness L

W = volume flux per unit area L/T

Since b is variable with place and time we can write:

$$T_{(x,y,z,t)} = b\,K_{(x,y,z)}$$

where $T_{(x,y,z,t)}$ = aquifer transmissibility

and:

$$\frac{\partial}{\partial x}\left(T_{(x,y,z,t)}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_{(x,y,z,t)}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(T_{(x,y,z,t)}\frac{\partial h}{\partial z}\right)=S\frac{\partial h}{\partial t}+W_{(x,y,z,t)} \tag{2}$$

This general equation can be reduced to a more simple approximate equation which is easier to solve mathematically if we assume that vertical velocities in the aquifer are small compared to horizontal velocities

This means that $\frac{\partial h}{\partial z}$ can be disregarded with respect to $\frac{\partial h}{\partial x}$ and $\frac{\partial h}{\partial y}$ and implies that the head can be considered to be constant over the height of aquifer. This is actually the Dupuit-Forchheimer assumption which is a valid approximation if the gradient of the water table is small. If the drawdown does not change significantly in relation to the saturated thickness of the aquifer it is possible to consider $T_{(x,y,t)}$ constant after computing an initial T as a starting value.

If these assumptions are valid, equation (2) reduces to:

$$\frac{\partial}{\partial x} T_{(x,y)} \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} T_{(x,y)} \frac{\partial h}{\partial y} = S \frac{\partial h}{\partial t} + W_{(x,y,t)}. \qquad (3)$$

This equation can be solved by using a finite difference scheme. If a rectangular grid is superimposed on a plan view of the aquifer the equation, utilizing the transmissibility half-way between two grid points, leads to:

$$\frac{T_{xi+\frac{1}{2},j}}{(\Delta x)^2}\left(h_{i+1,j,k} - h_{i,j,k}\right) + \frac{T_{xi-\frac{1}{2},j}}{(\Delta x)^2}\left(h_{i-1,j,k} - h_{i,j,k}\right)$$

$$+ \frac{T_{y,i,j+\frac{1}{2}}}{(\Delta y)^2}\left(h_{i,j+1,k} - h_{i,j,k}\right) + \frac{T_{y,i,j+\frac{1}{2}}}{(\Delta y)^2}\left(h_{i,j-1,k} - h_{i,j,k}\right)$$

$$= \frac{S}{\Delta t}\left(h_{i,j,k} - h_{i,j,k-1}\right) + W_{(i,j,k)}$$

where, i denotes x direction

j denotes y direction

k denotes time dimension

In the finite difference model being designed it is possible to change the value of T at each node after each time step thereby modeling the real situation more closely. For an unconfined aquifer

$$T_{i,j,k} = T_{i,j,k-1}\, b_{i,j,k} / b_{i,j,k-1}$$

and for a confined aquifer T is held constant.

A technique developed by Peaceman and Rachford [1] and used by Pinder,[2] termed the alternating direction implicit (ADI) procedure, enhances the convergence of the solution to the set of equations and allows more flexibility in the selection of time steps to be used.

Sources

The source term, $W(x,y,t)$, can be written as follows:

$$W(x,y,t) = -Q_I(x,y,t) - Q_S(x,y,t) - P_E(x,y,t) + E(x,y,t) + \frac{\partial \bar{\theta}}{\partial t} Z_t + P_U(x,y,t) + Q_L(x,y,t)$$

where: Q_I = input due to irrigation at each node during the time increment (K-1) to K. L/T

Q_S = input due to canal seepage at each node for time increment (K-1) to K. L/T

P_E = precipitation L/T.

E = evapotranspiration L/T.

$\bar{\theta}$ = avg. water content of soil in feet per foot of soil profile.

Z = depth of soil profile

P_U = output or input due to a well at each node for time increment K-1 to K. L/T

Q_L = input or output due to a leaky aquifer. L/T

The canal seepage term Q_S can be expressed as

$$Q_S(x,y,t) = A_S(x,y,t) \; I_S(x,y,t)$$

where: $A_S(x,y,t)$ = total wetted area of canal cross section at time t.

$I_S(x,y,t)$ = seepage rate in cubic feet per square foot per day at time t.

Since the normal operating procedure for canals in the study area is to maintain water levels as near maximum as possible the change in wetted area with time is small and A_S becomes a function of x and y only. Functional relationships between the canal seepage rate and depth to water table require knowledge of the vertical hydraulic conductivity in the aquifer and would be difficult to determine. Since little data is available on K values and several measurements of I_S in canals throughout the area have been made, $I_{S(i,j)}$ is read in as an array and the values changed with time if necessary. Discharge from the aquifer into surface channels can be treated as negative canal seepage.

Pumping, $P_U(x,y,t)$, precipitation $P_E(x,y,t)$, evapotranspiration E (x,y,t) and irrigation $Q_I(x,y,t)$ are computed as a volume per mesh-surface and per unit of time for each grid point for each time. The term $\frac{\partial\bar{\theta}}{\partial t}$ Z_t may or may not be significant depending on the value of Z_t. Values for $\bar{\theta}$ at the beginning of the irrigation season (t = 0), can be estimated or measured. During the irrigation season $\bar{\theta}$ will increase to a certain value around which it alternates, depending on irrigation practices (Figure 4).

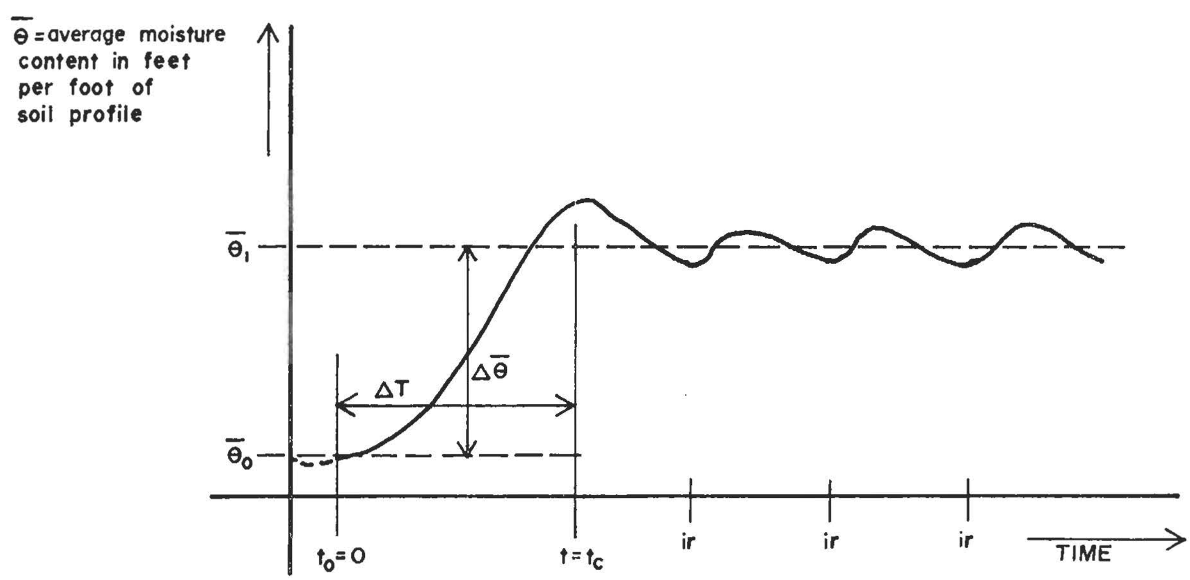


Figure 4 Simplified Soil Moisture Variation

At some time, $t = t_c$, the term $\frac{\partial \theta}{\partial t}$ Z_t becomes insignificant if the fluctuations of θ about the average moisture content, θ_e, are not large. $\Delta T = t_c - t_o$ is a function of θ_o, porosity, Z_t, and the rate of water supply. If Z_t is small, ΔT will be small and the change in storage may be neglected. However, if Z_t is large this term could have a significant damping effect on the rise of the water table and therefore influence the time response of the water table in the region.

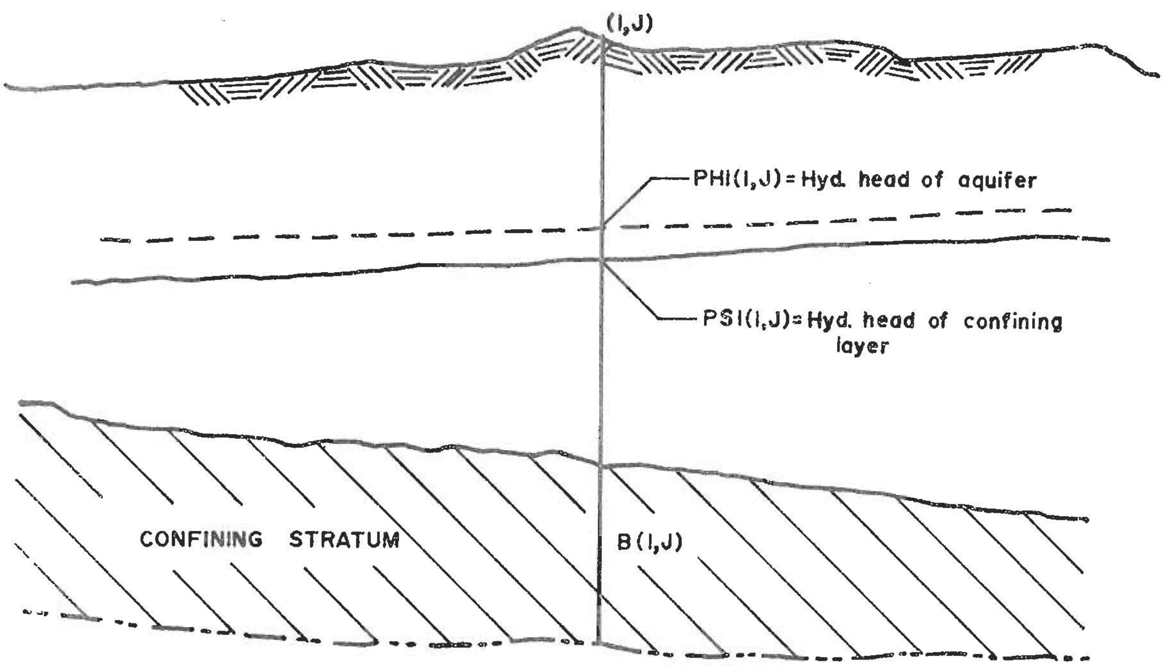


Figure 5. Schematic Diagram of Leaky Aquifer

If input to or output from an unconfined aquifer from underlying strata is constant with time at each node then Q_L for each node can be read in as an array. If leakage is variable and dependent on the difference of head in the confining layer and aquifer the problem becomes more complex. This leaky aquifer situation is depicted in Figure 5. Because of the large area and scarcity of deep wells it is not possible to measure the head in the confining stratum at each node. However, depending on the geology of the area it may be possible to assume that the head in the confining layer is constant in time for all nodes. Variation in aquifer head then causes variation in leakage, and the constant leakage term, Q_L, can be replaced by:

$$QVA\ (i,j) = \frac{K_v}{B}\ (i,j) \left(PSI\ (i,j) - PHI\ (i,j) \right)$$

where $\frac{K_v}{B}$ = vertical hydraulic impedance of the confining layer.

PSI (i,j) = head in the confining layer at each node.

PHI (i,j) = aquifer head

PSI (i,j) are read in as constants for each node, while PHI (i,j) the hydraulic head in the aquifer changes with each time step. QVA (i,j) is calculated each time step.

Boundary Conditions

The two most common boundary conditions are the impermeable boundary $\frac{\partial h}{\partial n} = 0$ and the constant head $(h_{i,j,k} = C)$ condition. Along the southeast boundary of the study area in the vicinity of Ririe the impermeable boundary condition is applicable and can be described by letting T (i,j) equal zero at nodes just outside the boundary. The northeast boundary which is the Snake River is a constant head boundary with the head dictated by the river stage. Boundary conditions along the western edge and the western part of the south boundary are either impermeable or constant head conditions. Flow occurs westward under the basalt formation known as the Lewisville Knolls and connects apparently with the general water table in the Snake Plain aquifer. Some flow apparently occurs southwestward across the southern boundary as indicated by the groundwater contours measured in 1970.

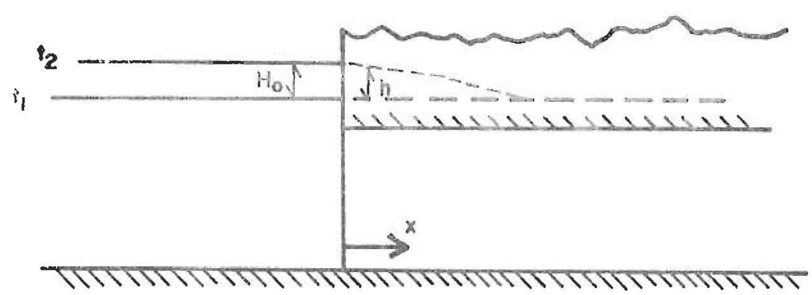
No-flow and constant head boundaries can be handled quite easily; however, when flow occurs across boundaries in which the head at the boundary is changing then some function for defining the head becomes necessary. Several possible alternatives to this boundary problem were considered.

One solution is to write $h_{(boundary)}$ as a function of time. Historical records of the change in h throughout the year can be approximated with a harmonic function. The program can then be run for the preceding years in which the computer must reproduce the historic values of the groundwater levels in the remainder of the aquifer. If computed and measured historical levels do not agree the K values within the aquifer may be adjusted until a satisfactory fit of computed water table elevations with measured values is obtained. This method allows the adjustment and refinement of variables using historical data. However, if major changes in hydraulic activities are made (such as setting up a domestic well field or change in irrigation practices), the function which defines the hydraulic head at the boundary becomes invalid.

There are some other approximations available. In this particular case flow occurs generally from northeast to southwest across the unknown boundary. Across the boundary the unconfined character of the flow apparently changes into a confined character which can be described easily in the mathematical model. The changes in hydraulic head of the unconfined aquifer migrate through the confined aquifer and can be described by:

$$h/H_o = \operatorname{erfc}\left(x/2\sqrt{Tt/S}\right)$$

A problem similar to this is encountered in bank storage calculations, as shown in the accompanying figure,



where x = distance from boundary.

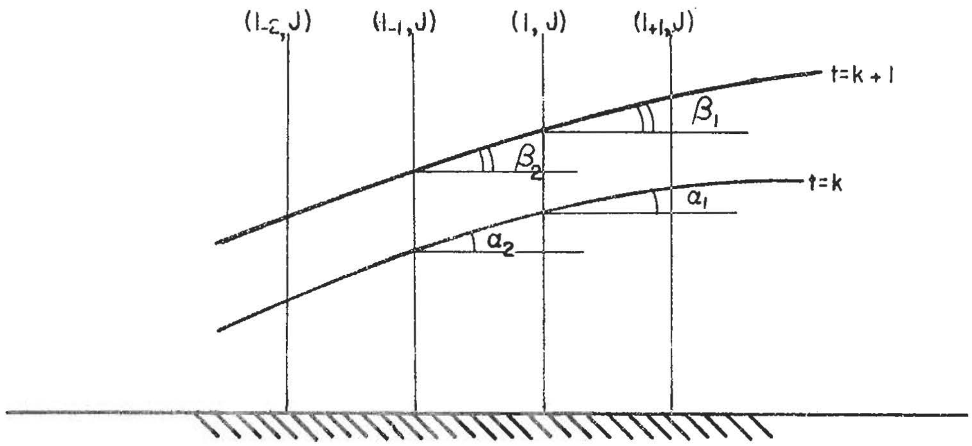
T = transmissibility of the confined strata

S = storage coefficient of the confined strata

erfc = complementary error function.

This equation indicates that at some distance in the confined aquifer the influence of the initial head, H_o, is negligible. If the boundary is moved to or beyond that specific point this boundary can be described as a constant head boundary.

A third possibility exists for the boundary in the southwest direction. In the following figure, $h_{i,j}$ is the boundary node.



The new hydraulic head is calculated in a system of tridiagonal equations in which the boundary equations have only two unknowns. In this case, by cutting off the aquifer at point i,j three unknowns remain because nothing is known about node point $h_{i-1,j}$. To eliminate one of the unknowns a means must be found to express $h_{i-1,j,k}$ in terms of $h_{i,j,k}$ and $h_{i+1,j,k}$. A solution is to assume that the change in hydraulic head per timestep is not abrupt in the vicinity of these special boundary points, or that a gradual change in head occurs. This assumption is valid if no major hydraulic activities take place close to those boundary points.

Then: $\frac{\alpha_1}{\alpha_2} = \frac{\beta_1}{\beta_2}$ ratios of average hydraulic slope close to boundary points

where α_1 and α_2 are the slopes of the water table from the previous time step.

and $h_{i-1,j,k} = h_{i,j,k} - \beta_2 x = h_{i,j,k} - \frac{\alpha_2}{\alpha_1}\left(h_{i+1,j,k} - h_{i,j,k}\right)$

With this assumption, then $h_{i-1,j,k}$ is defined for the initial time step and the system of equations can be solved. For subsequent time steps $h_{i-1,j,k}$ (the "outside" boundary point) could be calculated with this "ratio" technique using $\frac{\alpha_2}{\alpha_1}$ but since the character of the hydraulic slope has more resemblance to a quadratic function, $h_{i-1,j,k}$ can be calculated with a 2nd degree polonomial which fits $h_{i,j,k}$ $h_{i+1,j,k}$ and $h_{i+2,j,k}$. In this way the outside boundary point $h_{i-1,j,k}$ is forced to "behave" in the same way as points inside the boundary and close to this specific node point. If no major hydraulic activities close to this boundary condition occur, this is a justified approach and, because of the technique used, the solution will be stable. This treatment of the boundary condition proved valid in one test case, however thorough investigation of the restraints and possibilities will be made.

The model is capable of accommodating variable number and spacing of node points and time increments. The computer calculates an array of water table elevations for each grid point for each time step so that the response of the aquifer can be monitored throughout the season. These arrays are read out on magnetic tape and are then coupled to an existing contour plotting program which plots water table contours on hard copy and/or produces a movie film with one frame for each time step.

For the Snake River fan area, a node spacing of one mile and a 25 by 20 mile grid is being used. A time step of two weeks during the period May - November and four weeks during the winter months should be sufficient to predict the water table response.

DATA COLLECTION

In order to properly calibrate the mathematical model a large amount of field data is necessary. A continuous data collection program was begun in May 1970 in the area. Cooperating local residents have greatly assisted in the data collection program.

Geology

Available well logs from the Department of Water Administration and local residents indicate that the gravel aquifer is extensive over the fan. However, very few of the domestic wells for which logs are available are over 100 feet deep so that the depth of the gravels is not discernible over the entire fan. One exploratory well, one and one-half miles northwest of Rigby is 1008 feet deep and indicates a 300 foot depth of gravel underlain by 170 feet of clay above basalt. Basalt is encountered at shallow depths south of Ririe and fingers of basalt extend eastward from the Lewisville Knolls on the western edge of the area into the gravels.

Because of the lack of geologic information in the area, a cooperative geophysical study was undertaken in May 1971 with the U.S. Bureau of Reclamation. Electrical resistivity transects were run from east to west across the fan from the Lewisville Knolls to the Snake River. A report on this work, performed by a private group out of Colorado, is pending.

Ground Water Table Elevations

A network of some 40 wells in the area is being used to monitor changes in the groundwater table throughout the year. Figure 6 shows the locations of wells and well points being measured in the network. Water stage recorders were installed on seven of the wells in order to detect fluctuations of shorter period than the normal weekly measurements. In the vicinity of Rigby, water

FIGURE 6

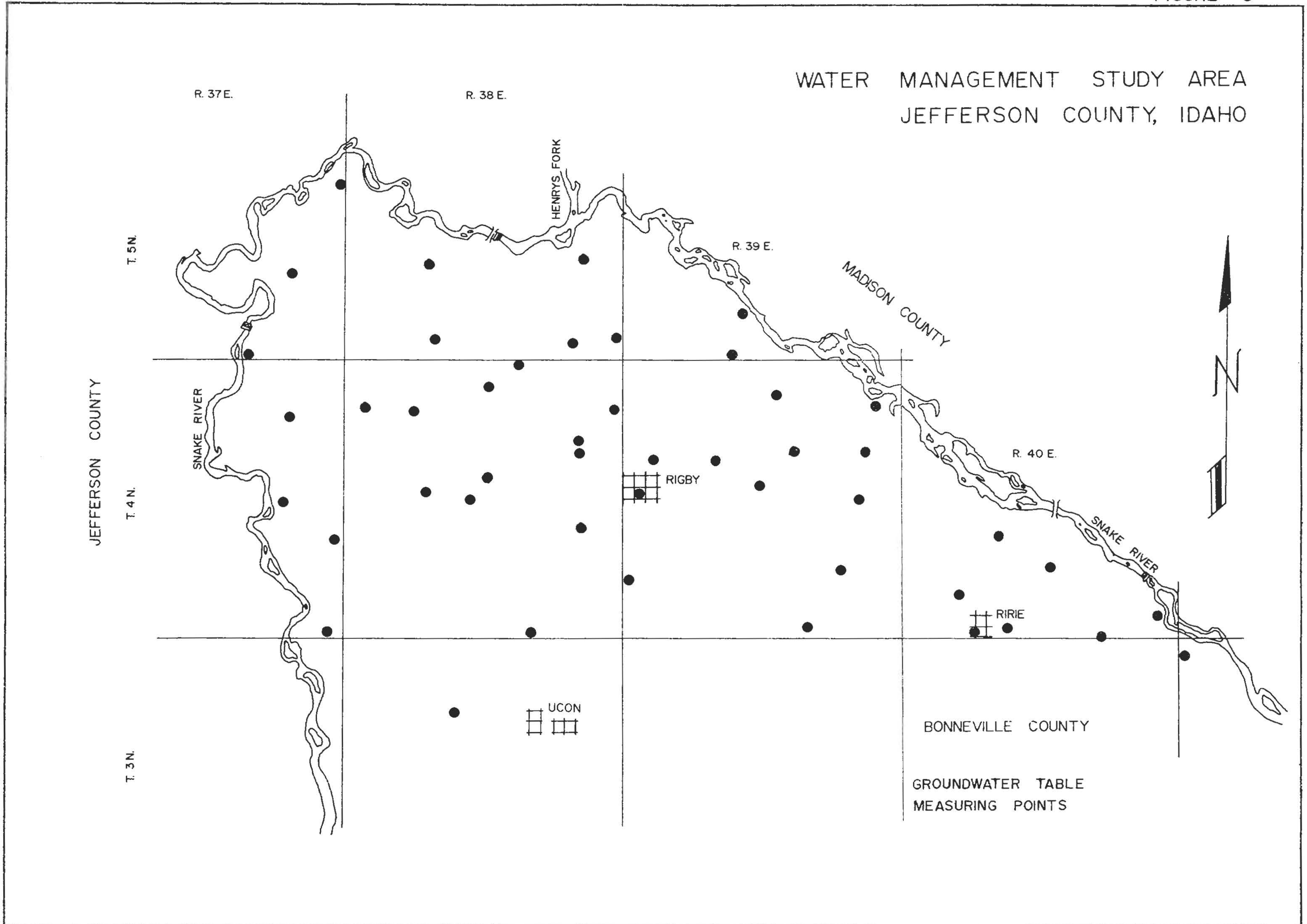

WATER MANAGEMENT STUDY AREA
JEFFERSON COUNTY, IDAHO
R. 37 E.
R. 38 E.
R. 39 E.
R. 40 E.
T. 5 N.
T. 4 N.
T. 3 N.
HENRYS FORK
MADISON COUNTY
JEFFERSON COUNTY
SNAKE RIVER
RIGBY
SNAKE RIVER
RIRIE
UCON
BONNEVILLE COUNTY
GROUNDWATER TABLE
MEASURING POINTS
N

table rises of 30 feet or more have been recorded for the period from the beginning of the irrigation season until mid July. Figure 7 shows the hydrograph of the Clark well northwest of Rigby for several seasons beginning with 1963.

Water table contours for the area indicate a general east-west water flow with a rapid increase in water table depth on the west and southwest boundaries. Figure 8 shows the water table contours interpreted from well measurements made on July 15, 1970. The flow is generally from east to west with the flow under the Snake River south of the city of Roberts being at greater depths where the gravels of the fan apparently interfinger into basalts of the Snake Plain aquifer.

Maximum groundwater table elevations usually occur in the month of August and associated problems are prevalent during August and September. Figure 9 shows the depths to the water table on August 30, 1970 as computed from the groundwater contours. The area north and west of Rigby as indicated in the figure had depths to water of five feet or less during July, August and September of 1970. The area around the city of Ririe is a local groundwater mound and some reports of damage have been received from this area.

In August 1970 a questionnaire was sent to residents of Jefferson County requesting information on any damage or problems associated with the sub-water. A total of 700 questionnaires were mailed with the cooperation of the University of Idaho Extension Service. Seventy-eight affirmative returns were received which indicated problems such as water in basements, potato cellars, flooded fields or corrals. The locations of the affirmative returns closely correlated with the high water table areas as indicated in Figure 9. Estimates of damages for 1970 amounted to nearly $24,000.

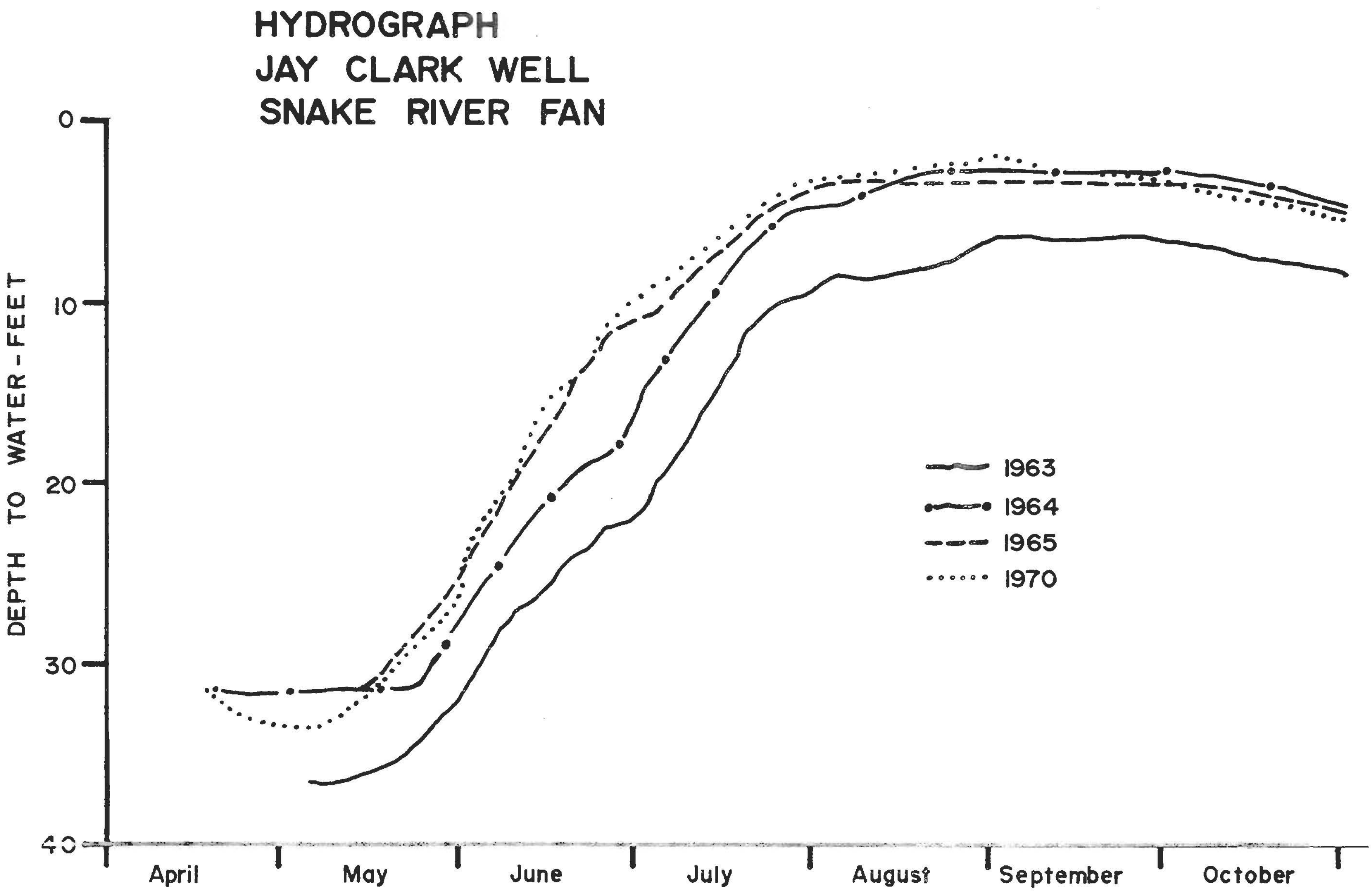

HYDROGRAPH
JAY CLARK WELL
SNAKE RIVER FAN
DEPTH TO WATER - FEET
0
10
20
30
40
April
May
June
July
August
September
October
1963
1964
1965
1970

FIGURE 8

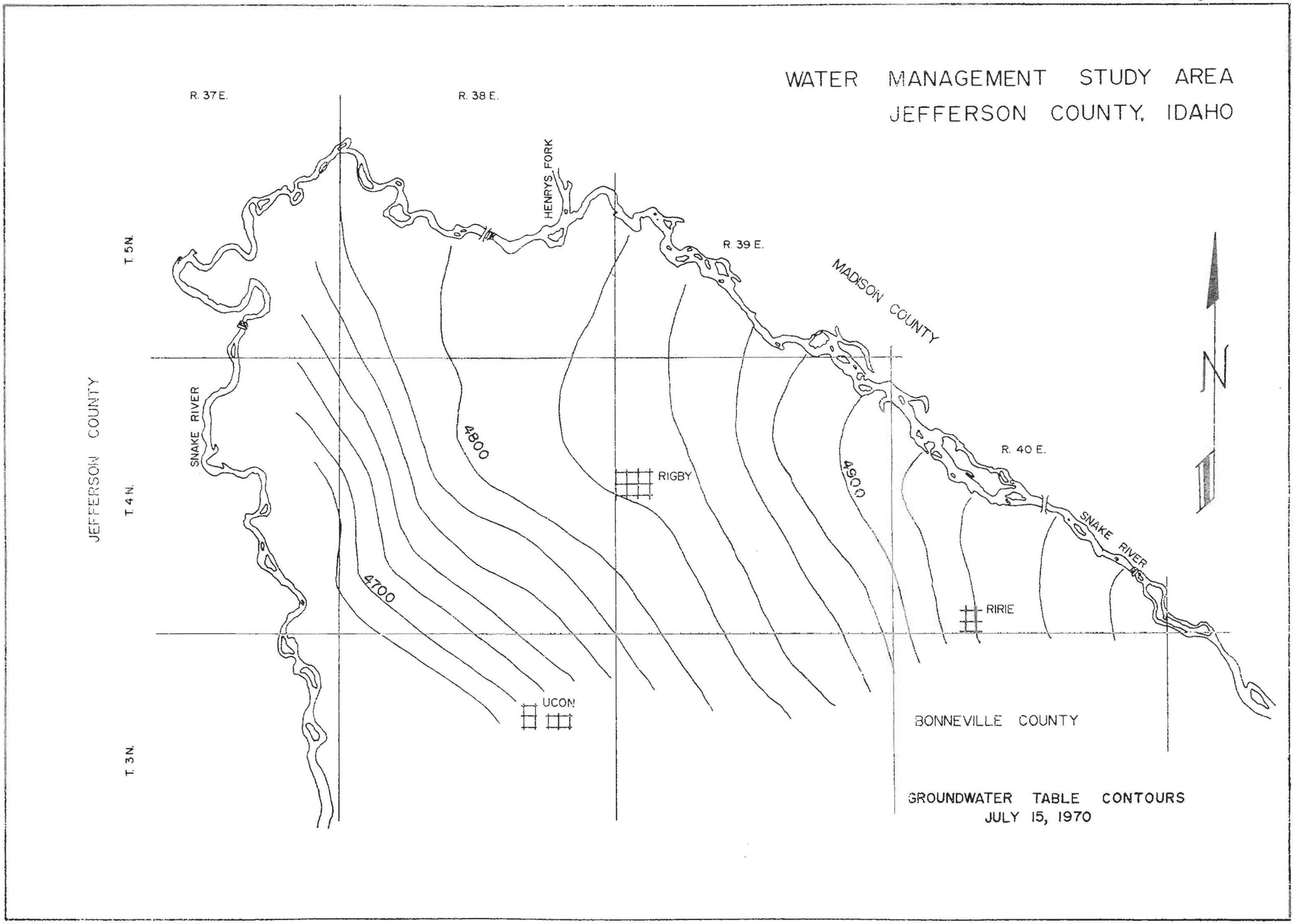
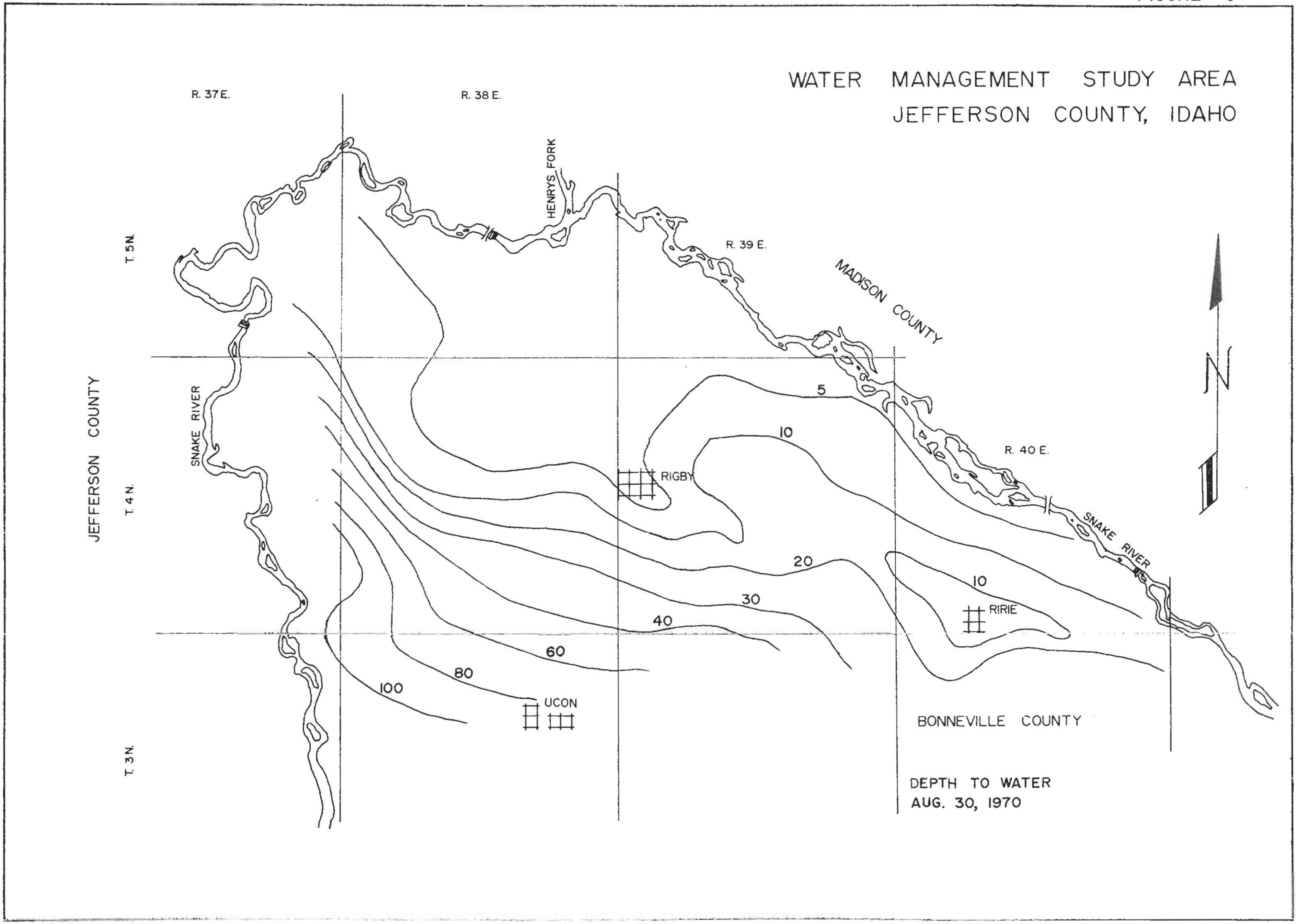

WATER MANAGEMENT STUDY AREA
JEFFERSON COUNTY, IDAHO
R. 37 E.
R. 38 E.
R. 39 E.
R. 40 E.
T. 5 N.
T. 4 N.
T. 3 N.
HENRYS FORK
MADISON COUNTY
JEFFERSON COUNTY
SNAKE RIVER
4800
4900
4700
RIGBY
RIRIE
UCON
SNAKE RIVER
N
BONNEVILLE COUNTY
GROUNDWATER TABLE CONTOURS
JULY 15, 1970

FIGURE 9



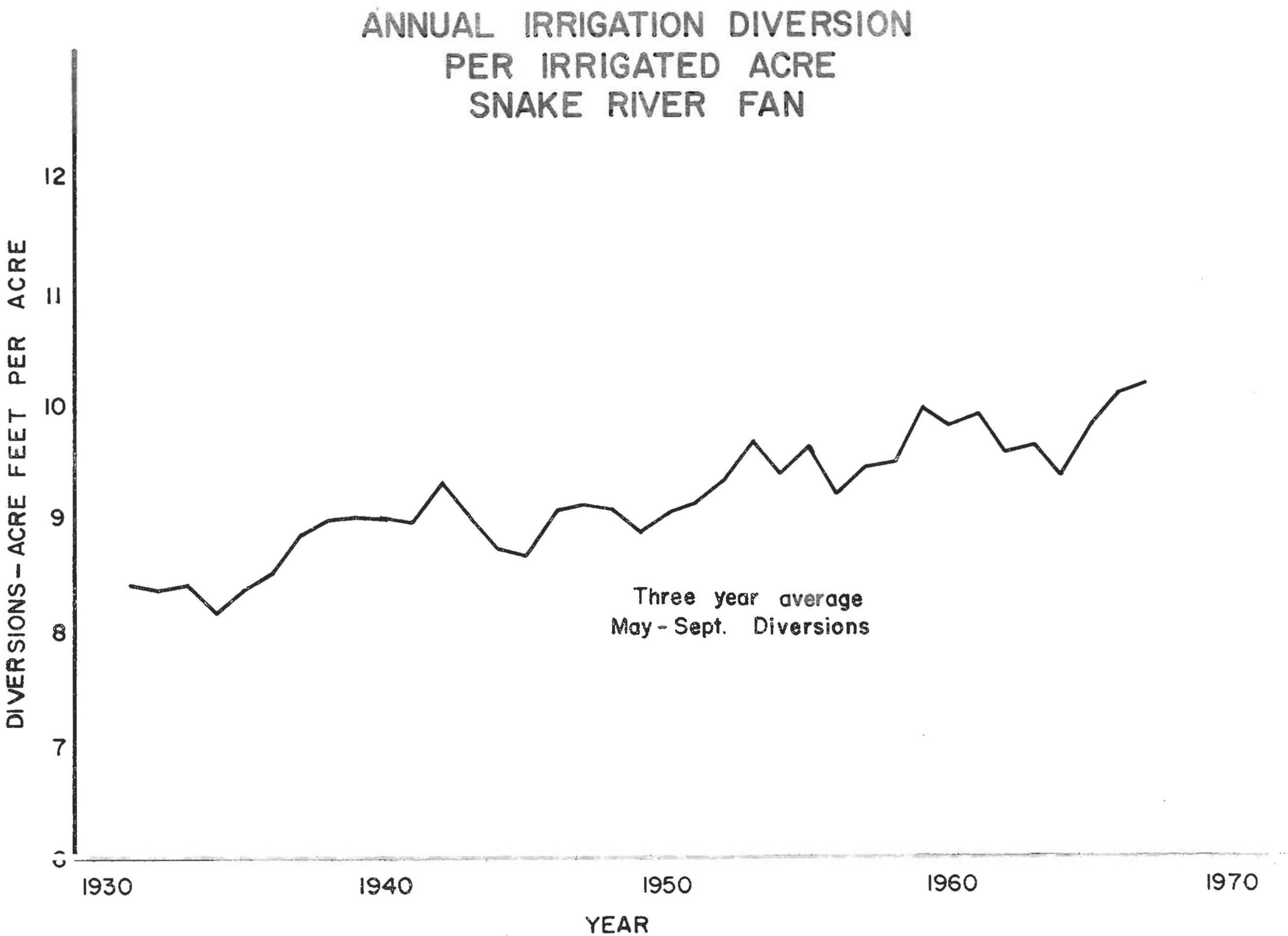
WATER MANAGEMENT STUDY AREA
JEFFERSON COUNTY, IDAHO
R. 37 E.
R. 38 E.
R. 39 E.
R. 40 E.
T. 5 N.
T. 4 N.
T. 3 N.
HENRYS FORK
MADISON COUNTY
JEFFERSON COUNTY
SNAKE RIVER
RIGBY
RIRIE
UCON
BONNEVILLE COUNTY
5
10
20
30
40
60
80
100
N
DEPTH TO WATER
AUG. 30, 1970

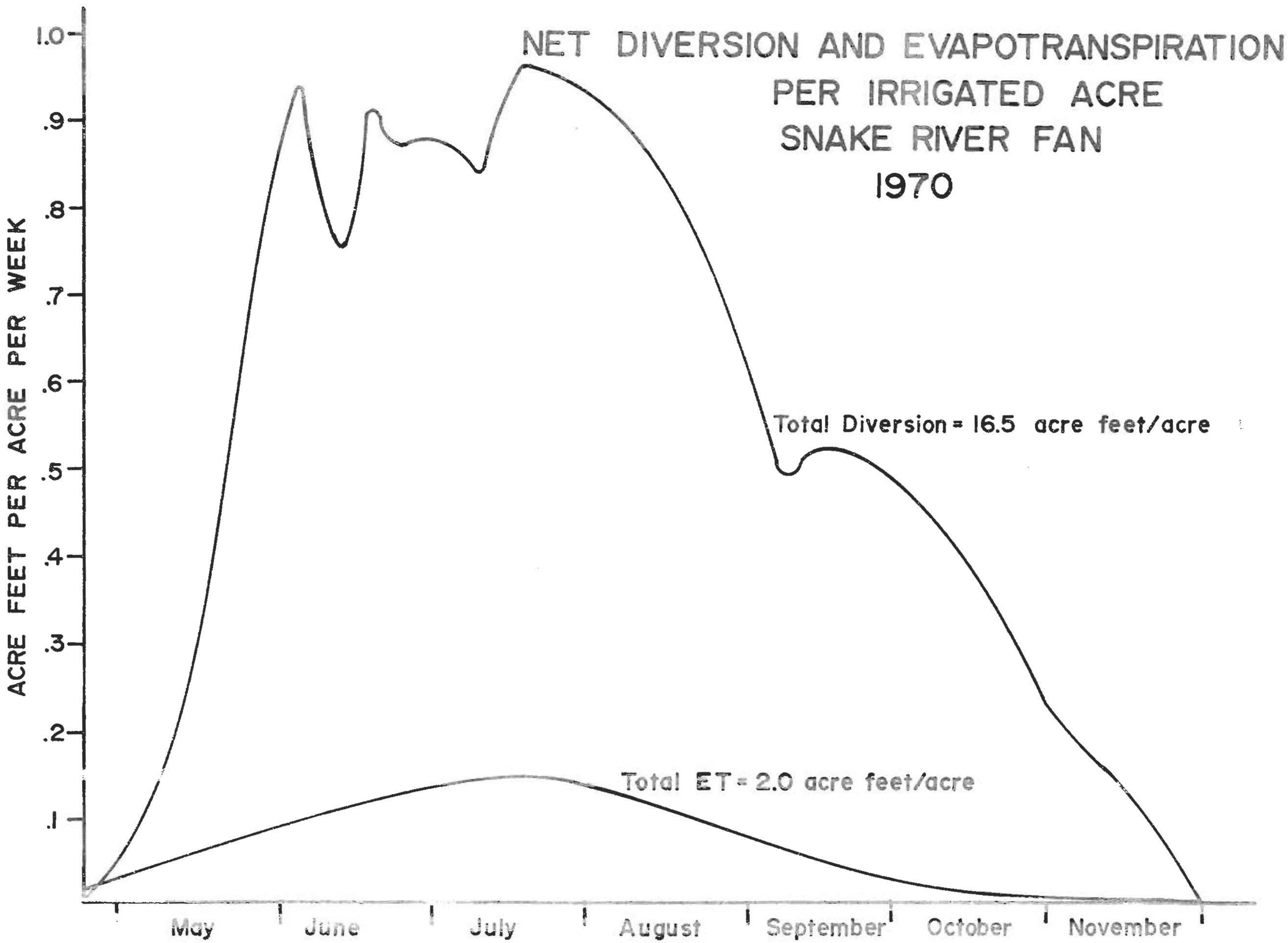
Surface Water Diversions

Irrigation diversions for the major canals in the study area for the May 1 - September 30 period are recorded in the reports of Water District 36. These measurements performed by District 36 and U.S. Geological Survey personnel are obtained primarily by periodic current metering of the canals at selected rating sections and reporting of daily staff gage readings by watermasters. No standard water measuring devices are in use on the major canals. During the 1970 season measurements were extended by University and ARS personnel past the normal September 30 cutoff date through November 30 or until all canals had been shut down for the winter. Return flows to the Snake River at the Burgess Canal spill, Long Island Slough, and Great Feeder were measured throughout the season. Water transported out of the study area to the south was measured in the Anderson, Farmers Friend, and Harrison canals.

Figure 10 shows the recorded May - September diversions per acre from the Snake River for all canals on the Snake River fan. The acre feet per acre values were computed from discharges and acreages for each irrigation district as recorded in District 36 records. An increasing trend can be observed with the 1967-69 diversions approaching 10 acre feet per acre. The seasonal distribution of net diversions for 1970 is shown in Figure 11. The net diversion is calculated as the measured diversion at the canal headgates minus all surface wastes. An irrigated acreage of 82,250 acres in the study area was determined from 1966 aerial photographs and does not include roads, canal rights of way, farmsteads and undeveloped lands within the study area. Total diversions for May - November 1970 season were 1,507,000 acre feet of which 100,000 acre feet was measured as irrigation water transported out of

FIGURE 10


ANNUAL IRRIGATION DIVERSION
PER IRRIGATED ACRE
SNAKE RIVER FAN
DIVERSIONS - ACRE FEET PER ACRE
12
11
10
9
8
7
0
1930
1940
1950
1960
1970
YEAR
Three year average
May - Sept. Diversions


NET DIVERSION AND EVAPOTRANSPIRATION
PER IRRIGATED ACRE
SNAKE RIVER FAN
1970
ACRE FEET PER ACRE PER WEEK
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
Total Diversion = 16.5 acre feet/acre
Total ET = 2.0 acre feet/acre
May
June
July
August
September
October
November

the study area and 48,200 acre feet returned to the Snake River. The total net diversion for 1970 was 16.5 acre feet per irrigated acre of which 14% was diverted after September 30.

Canal Seepage Losses

The main canals of the systems have a total water surface area of 820 acres or slightly less than 1% of the irrigated area. Seepage tests were made in 20 locations in the late summer and fall of 1970 and in 16 locations in early spring of 1971. These tests were made by inflow-outflow measurement method in reaches with little or no diversion at the time of measurement. The accuracy of any one flow measurement is probably ±5 or 10% which can lead to much variability in seepage loss measurements but the average of many loss measurements will give values that are good estimates. The average of the 1970 tests was 3.55ft/day with a range from 0.2 ft/day to 11.5 ft/day. The average of the 16 tests made in early May, 1971 was 3.28 feet/day with a range of 0.67 to 12.07 ft/day.

The spring tests had an average value that was 8% less than the average found in late summer, but the reaches tested were not the same and the channel flow depths were 1½ to 2 feet lower in the spring.

The average loss of 3.43 ft/day for all of the tests would amount to a total loss of 2810 acre ft. per day (or 1405 cfs) if it were applicable to all the main canals in the system. Assuming a 150 day irrigation season this seepage rate would involve a loss of 428,500 acre feet per season or about 28 percent of the yearly diversion. Assuming a 200 day season, which more nearly approximates the actual operating procedure, canal seepage adds 570,000 acre feet to the aquifer.

Further seepage loss determinations will be made in 1971 to improve on the accuracy of the estimates and to determine if some areas may have seepage losses that are consistently above or below the average.

Snake River Losses

Recognizing that losses in the Snake River as it flows over the fan can contribute to the groundwater table rise, an attempt was made to evaluate these losses. Stearns[3] in 1928 reported losses of from 20 cfs to 830 cfs or an average loss of 288 cfs or 3.3 percent of the flow from the measuring station at Heise to Lorenzo, a distance of about 13.8 miles. In 1970 current meter measurements were made at three times during the year during which the river was maintained at constant discharge at Palisades Dam. Discharge varied from 3340 cfs to 17,000 cfs and computed losses varied from 808 cfs to 208 cfs or an average of 408 cfs. Based on a loss of 408 cfs for a 200 day season, losses from the Snake River account for 41,600 acre feet of water added to the aquifer.

Evapotranspiration

Crop evapotranspiration for the 1970 season was calculated using the combination equation with crop coefficients based on the crop distribution for the 22,000 acres of the Burgess Canal system. Differences in crop distribution throughout the study area were not significant. Figure 11 shows the seasonal distribution of crop evapotranspiration for 1970. The total evapotranspiration for the season was 2.0 acre feet per acre or 161,900 acre feet for the study area.

SUMMARY AND CONCLUSIONS

Results of the first year's study show definitely that the Snake River fan irrigated area is in need of some system of water table control. Increasing inconvenience and financial loss to both urban and rural residents of the area is evident.

Because of the number of factors affecting the water table such as contribution from the Snake River, canal seepage, irrigation application and others, the most feasible means of studying the system is by modeling. A digital model is more easily adapted to this study than analog or analytical models. The model being developed utilizes a finite difference technique and is capable of handling any foreseeable aquifer boundary conditions. Calibration of the model with inputs and aquifer response measured in 1970 is being made.

Input and output data collection in 1970 for the model indicate the major contributions to the ground water in the area. During the 1970 irrigating season losses from the Snake River from Heise to Lorenzo were approximately 41,600 acre feet. Diversions from the Snake River for irrigation were 1,507,000 acre feet of which 100,000 acre feet was transported out of the study area and 48,200 returned to the Snake River as surface waste. The net diversion per irrigated acre was 16.5 acre feet. Canal seepage accounted for 570,000 acre feet leaving a net irrigation application of 788,800 acre feet or 9.6 acre feet per acre. Crop use was computed to be 2.0 acre feet per acre.

The net diversion and irrigation application per season in the study area are somewhat greater than the State average and farm water management could be improved. Distribution system management could also be improved with the objective of providing farm diversions in the amount of decreed rights only.

Any changes in water management which affect decreases in water application will affect the seasonal response of the water table. Changes in inputs such as this on the aquifer response will be analyzed with the model. In addition, some of the alternatives for water table control such as deep surface drain ditches, canal lining, canal consolidation, Snake River operation, and vertical drain wells will be investigated.

Implementation of any technically feasible alternatives could require financing by local residents and farmers. The economic feasibility of any corrective measures depends on the ability of the residents to finance the improvements. At present, the repayment capacity of the area is not known and any future planning will require a study to determine this potential.

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2. Pinder, G.F.
A Digital Model for Aquifer Evaluation.
U.S. Geological Survey Techniques of Water Resources Investigation Series, Book 7, Chapter C-1, 1969.

3. Stearns, H.T., Crandall, Lynn; Steward, W.G.
Geology and Groundwater Resources of the Snake River Plain in Southeastern Idaho, Water Supply Paper 774, U.S. Government Printing Office 1938.

APPENDIX

IRRIGATION CANALS ON THE SNAKE RIVER FAN*

Canal	Gross Acres Served
Riley	900
Anderson } Eagle Rock }	33,000
Farmers Friend	10,500
Enterprise	5,200
Butler Island	1,100
Harrison	13,000
Rudy	5,000
Burgess	22,000
Clark and Edwards	1,940
Lowder	1,000
East Labelle	3,000
Rigby	4,000
Dilts	580
Island	5,500
W. Labelle and Long Island	10,500
Parks and Lewisville	7,000
North Rigby	1,400
Other 9 (small canals)	1,760
	127,380

*Includes all lands served by the canals as published in reports of the Watermaster, District 36.