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Environmental Protection Technology Series

PREDICTION OF MINERAL QUALITY OF IRRIGATION RETURN FLOW
Volume I. Summary Report and Verification

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U.S. Environmental Protection Agency
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PREDICTION OF MINERAL QUALITY OF IRRIGATION RETURN FLOW

VOLUME I

SUMMARY REPORT AND VERIFICATION

by

Bureau of Reclamation
Engineering and Research Center
Denver, Colorado 80225

EPA-IAG-D4-0371

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar
Director
Robert S. Kerr Environmental
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ABSTRACT

This volume of the report outlines the purpose and scope of the return flow research and specifically explains the capabilities of the conjunctive use model for predicting the mineral quality of irrigation return flow. The purpose of the research was to develop a conjunctive use model which would (1) predict the salinity contribution from new irrigation projects and (2) predict the change in return flow salinity that would result from operational changes on existing projects.

The model developed and described herein describes the chemical quality in terms of eight ionic constituents and total dissolved solids. A nodal concept has been used to facilitate subdividing the project area along physical or hydrologic boundaries as desired. The study may be limited to 1 or as many as 20 nodes.

A description of the Vernal Field Study which describes the physical setting for the model testing is included. A narrative describing the problems encountered with the original data is included. A data collection program was initiated to fill the gaps. The model satisfactorily simulated the new 2-year data base. Tables and figures showing the computed-observed comparisons from the verification are included. Results of model operations for the Cedar Bluff and Grand Valley areas are also described.

It is concluded that the model can satisfactorily be used to simulate irrigation return flows if sufficient data are available, especially groundwater hydrology and chemistry.

This report was submitted in fulfillment of Project EPA-IAG-D4-0371 by the U.S. Bureau of Reclamation, Engineering and Research Center, under the sponsorship of the Environmental Protection Agency.

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ACKNOWLEDGMENTS

The cooperation of a number of state and federal agencies, the local water users, and two state universities is hereby acknowledged for the services they rendered in the collection of field data and the preparation of this report.

1. The full cooperation of the Environmental Protection Agency was received throughout the study period. Field installations and field work were thoroughly reviewed by EPA personnel and procedures for developing the model were periodically reviewed to provide assurance that the mathematical model would fulfill the requirements of EPA. Preparation of the report received the full guidance and support of THE EPA office at Ada, Oklahoma. Funding for the entire research study was provided by EPA.

2. A research study of this nature requires the collection of field data from operating projects and data collection is dependent on the cooperation of the water users and irrigation managers. Mr. Lawrence Siddoway, the Secretary-Manager of the Uinta Basin Conservancy District in the Vernal area, cooperated fully in the collection of field data and assisted in the selection of sites for meteorological equipment. Individual water users cooperated by allowing the installation of observation and test wells on their property.

3. The United States Geological Survey installed gaging stations to measure the inflow and outflow of water from Ashley Valley and at other locations within the Vernal study area. The USGS also drilled a test hole deep in the shale in Ashley Valley to determine if any upward movement of water through the shale could be detected. The USGS assisted in obtaining data for Bureau use that was collected on the Cedar Bluff Unit in Kansas for the Kansas State Health Department. Other water supply records of the Geological Survey were used freely in preparation of the report.

4. The National Weather Service of the National Oceanic and Atmospheric Administration provided instrumentation for the Vernal weather stations and routinely maintained the equipment during the study period. The equipment consisted of solar radiation measuring devices, evaporation ponds, rain gages, anemometers, and temperature and humidity measuring equipment.

5. The Provo, Salt Lake City, and Denver Offices of the Bureau of Reclamation were involved in conducting this reasearch study. Volume II was prepared mainly by the Central Utah Projects Office in Provo, Utah, and the remaining three volumes were prepared by

the Engineering and Research Center in Denver, Colorado. Bureau soils scientists familiar with soil and vegetation conditions in the Vernal area made the land use studies to determine the quantity and type of vegetation in the valley on both the cropped and non-cropped areas. The services of a Bureau of Reclamation lysimeter expert from Albuquerque, New Mexico, were required in designing and installing the lysimeters at Vernal. The lysimeter data were necessary to determine consumptive use from noncropped areas.

6. A concurrent research study for EPA was conducted by Utah State University in the Vernal area. The final report for this study has been published as EPA-R2-73-265 entitled "Irrigation Management for Control of Quality of Irrigation Return Flow." The advice and assistance of University representatives were obtained on such matters as lysimeter planting and consumptive use determinations.

7. Data collected by Colorado State University from the Grand Valley area were used to made the verification runs in Section VI of this volume. Those data are contained in a report entitled "Evaluation of Canal Lining for Salinity Control in Grand Valley" and is designated EPA-R2-72-047 dated October 1972.

SECTION I

CONCLUSIONS

This research was concerned with the development of procedures for predicting the mineral and nutrient quality of return flows from irrigation. Actual field conditions that typify irrigation development in the western United States were studied. In each study area, the research involved characterizing field conditions, applying computer models to predict quality of the percolating irrigation water, determining the effect of the percolating water on drainage effluent, and evaluating system changes on quality of return flow.

The percolation of water through soil in the process of irrigating crops results in very complex chemical relationships. Both the mineral and nutrient content and the quantity of return flow are difficult to predict under conditions found in irrigated agriculture.

In developing a predictive mathematical model to simulate the effect of irrigation on water quality, it was relatively simple to duplicate surface conditions. The complexity of the problem stems from not having sufficient knowledge of subsurface conditions such as soil chemistry, volume of groundwater, aquifer capacity, depth to barrier, and drainage characteristics. Variation in soil types within short horizontal distances makes the acquisition of this type of data costly, and it is not always available as needed.

This study dealt with three irrigated areas in attempting to verify the predictive conjunctive use model - the Vernal, Utah area; the Grand Valley, Colorado area; and the Cedar Bluff, Kansas area.

Adequate data were available for the Vernal area and the verification effort was minimal. Less data were available from the Cedar Bluff area with respect to the groundwater body, and the verification proved to be much more difficult. The chemistry of the return flow water is dependent to a large degree on the volume and chemistry of the subsurface water. Although the quality of the groundwater was well established, considerable adjustment of the groundwater volume was necessary in order to simulate existing conditions. This suggests that the primary requirement in the simulation process is to have a good knowledge of hydrologic conditions, including the groundwater body, and particularly to establish a hydrologic balance in the system.

SECTION II

RECOMMENDATIONS

The complexity of the salinity problem as it relates to irrigated agriculture is borne out by these studies. The need for a mathematical prediction model to assist in understanding the salinity and nutrient problem is now more clearly evident. The usefulness of the model in simulating project conditions has been demonstrated and its ability to forecast changes resulting from improved management has also been demonstrated in a limited way.

Although model development and testing have been hampered by the lack of sufficient data, confidence could be extended by the collection of additional data and testing the model under a variety of conditions. The two primary functions of the model are (1) to predict the salinity effect from new irrigation projects and (2) to predict the change in salinity that might result from operational changes on existing projects. Some further work should be undertaken, particularly on Item 2, since the results could be quickly monitored and since there is very little development of new irrigation projects underway.

Model development has demonstrated that data of good quality and quantity are the primary requirements in achieving a good simulation of irrigation project conditions. Another requirement would be a good basic knowledge of hydrologic conditions in the study area. If these elements are lacking, difficulty can be expected in simulation results.

A comparison of month-by-month observed and predicted values with the annual values in the various studies indicates that the predictions are more reliable on an annual basis than a monthly basis. Since a great many factors influence salinity levels on a monthly time frame, decisions related to salinity projections based on model studies should be limited to annual values.

SECTION III

INTRODUCTION

GENERAL

Control and alleviation of salinity in the southwestern United States require critical methods for assessing water quality impacts of present and future resource developments. Under an agreement between the Environmental Protection Agency and the Bureau of Reclamation, this research project was designed to fulfill such a need. The investigation utilized data from existing irrigation projects and focused on evaluating the effects of irrigation on the quality of return flow water. Methods have been developed to predict the effect of new irrigation projects on downstream water quality by the use of mathematical models and high-speed computers. The study started in 1969 using existing field data and a partially developed mathematical model.

PURPOSE AND SCOPE OF THE RESEARCH

After passage of the 1965 Water Quality Act, it became urgent to upgrade polluted waters and to protect clean waters. Because of the increasing salinity, particularly in the southwestern United States, it was considered advisable to examine the special problems related to salinity to see if it could be reduced or maintained at a given level. It was well understood that a certain level of salinity existed naturally from mineral weathering of soils and another portion was added by mineral springs, but the amount contributed by irrigated agriculture was uncertain and difficult to measure. The purpose of this study was to use an existing irrigation project and measure the changes resulting from irrigation and then develop a mathematical model to see if the changes could be simulated or predicted.

If goals of the Water Quality Act are to be met, existing water-use patterns will, in many cases, require change. These changes, for the most part, will need to be accommodated within the constraints imposed by water rights and water right laws. Irrigators can be expected to resist change unless impacts of the changes can be specified beforehand.

The conjunctive use model developed by this research is expected to help answer such questions as: (1) What effect would improved water-use efficiency have on the return flow water quality, (2) would the change to a higher efficiency increase or decrease salt loading, (3) what influence would development of new irrigation projects have on the salt load, (4) what effect would canal lining have on salinity, and (5) what is the effect of drainage systems on salinity? Such questions involve many complexities and cannot be answered easily. This research was needed to better define and understand the relationship between irrigated agriculture and the salt loading of streams. Of the various physical phenomena involved in developing water projects, water quality is one of the most important and least understood. One of the most complex problems involves predicting the quality of return flows from irrigated land and nonirrigated land. Water development projects encompass many diverse situations, each of which will affect water quality in different ways. These involve multiple reuse of surface water, recycling of groundwater for irrigation use, and combined surface and groundwater use. The water quality returned to the streams under these varying conditions requires a different analytical approach for each condition.

Return flows can be measured and the effects of ongoing projects assessed by well-planned hydrologic studies, but when a new land area is brought under irrigation or the water supply of an existing irrigated area is altered, predictions of impacts on water quality will be required.

In light of the conditions cited above, the stated purpose of this research effort has been to develop procedures for predicting irrigation return flow water quality and development of simulation programs for the study of water quantity and quality on a basinwide basis (6).

DESCRIPTION OF THE FIVE VOLUMES

This report on the "Prediction of Mineral Quality of Irrigation Return Flow" has been prepared in five volumes which are described briefly as follows:

Volume I

Volume I contains an overview of the research including the purpose and scope of the research, descriptions of the study areas and input data, the approach to the study, a description of the preliminary model testing with existing data, and conclusions and recommendations. The volume also contains the verification of the conjunctive use using Vernal data and results of processing the Cedar Bluff data and the Grand Valley data.

Volume II

Volume II includes a description of the Vernal field study, how the data were collected, and results of the data collection. Also described are the land classification studies; drainage; water supply and irrigation under the historical setting; and the current studies of groundwater, hydrology, canal losses, and land use wherein data were collected for verification of the model.

Volume III

Volume III includes a user's manual for the simulation submodel, the development of the mathematical relationships, and a complete computer listing of the simulation submodel. The mathematical formulas used in the model are included along with assessments of the limitations of the procedures and algorithms used in the model. The user's manual details the step-by-step procedures needed to apply the model to any situation requiring the prediction of mineral quality of return flow from irrigation. It includes flow diagrams that give a general understanding of the program rationale. Subroutines have narrative descriptions which define the functions, the arguments, and the limitations.

Volume IV

Volume IV contains the development of the data analysis package. It includes detailed data analysis subroutines which can be used to analyze data prior to input into the simulation model.

Volume V

Volume V includes a discussion of the return flow quality model. This model was developed under contracts with the University of Arizona and by Bureau of Reclamation personnel over a period of about 5 years.

The model utilizes a number of sophisticated subroutines to simulate unsaturated flow in one dimension, two-dimensional saturated flow to a tile or open channel drainage system, consumptive use of water by crops, nitrogen transformations, uptake of nitrogen by crops, solution-precipitation of lime and gypsum, ion pairing, CO_2 - Ca^{++} = HCO_3^- interactions, and ion exchange. The subroutines are interfaced to allow nonsteady and steady state predictions of salt and nitrogen movement from the soil surface to the drain.

In addition, as described in Volume V, this model can be interfaced with the conjunctive use model. Volume V also includes verification results, test runs, and complete user's manuals for this model.

RELATED STUDIES

The work done by Utah State University (1) on the Vernal Unit included detailed studies of water and salt movement on an experimental farm. They conducted a highly detailed study on a very small area aimed at identifying the nature of the salt output from the farm. This required the installation of closely spaced drains, a sprinkler irrigation system, weighing lysimeters, and making consumptive use measurements. They also investigated the practicability of controlling the salinity releases. Each drain included a measuring device and facilities for obtaining samples for water quality analysis.

The purpose of the research was to develop and field test rational models for predicting the salt and water status within the soil between the time of entry as irrigation water and the time of departure as drainage water or evaporation from the soil or transpiration by the plant. The model development resulted in a "simplified" model and a "detailed" model. The simplified model was intended to provide a tool for irrigation management. It was formulated to require a small amount of computer time and a minimum of field data as input and to allow consideration of a wide range of variation of factors affecting the quality of irrigation return flow. It was expected that the model would predict gross effects. The main purpose of the detailed model was to understand the specifics of simultaneous water and salt flow through the crop root zones. The detailed model was based more closely on known physical principles and laws governing water movement through partially saturated soils. The results of the studies indicate that control over quality of soil profile effluent will require precise control of water on the farm, particularly the depth and timing of irrigations.

Colorado State University conducted a study for the Environmental Protection Agency titled "Evaluation of Canal Lining for Salinity Control in the Grand Valley ((5). This study proposed to determine the effect of salinity management practice on conditions in the basin. The objectives were to: (1) demonstrate the feasibility of reducing salt loading in the Colorado River system by lining conveyance channels to reduce unneccesary groundwater additions and (2) extend the results of this study to evaluate the method for applicability to the problem in the Grand Valley and the Upper Colorado River basin.

The study evaluated conditions in the area prior to construction of lining and then reevaluated conditions after lining had been completed.

The plan was to collect data in order to define both water and salt flow systems. The data were collected generally from 1969 through 1971 but only the 1970-1971 water year data were considered sufficient to apply on the prediction model.

MODEL CAPABILITY

The conjunctive use model has those capabilities required to simulate simultaneously the use of water resources within a river basin from both surface resources and subsurface or groundwater resources.

These capabilities include the resource magnitude as well as its chemical quality. The chemical quality of the water resource is characterized in terms of eight inorganic ionic constituents and total dissolved salts.

The overall simulation model has as a basis a nodal concept or structure which facilitates the mathematical representation of a river basin and a simple compact manner of performing calculations, many of which are iterative in design.

A river basin can be studied as one node or as many as 20 nodes. The model is designed for a maximum of 20 nodes; however, this maximum is determined by the limitations of the computer system being used. The number of nodes used in a particular river basin study will be a decision the analyst must make on the basis of data available, the number of response points desired, and the physical features within the river basin. The node then as a common denominator can be used to represent the simplest river basin study to one that is quite complex.

The node can include the simulation of one or all of the following features:

1. Ten tributary inflows
2. Ten demands of water resources, both surface and subsurface
3. The operation of a surface reservoir
4. The operation of a power facility
5. The operation of a subsurface reservoir (aquifer)
6. The percolation of surface waters vertically through a soil profile
7. The operation of a pumping facility
8. The determination of return flows, both magnitude and quality, when given consumptive use and conveyance losses

The electronic computer application of the conjunctive use simulation model consists of 24 subroutines or functions plus the executive or main program. The FORTRAN listings included as part of Volume III for the main program, as well as the subroutines and functions, are filled with comments at pertinent points. The extensive use of these comments is meant to aid in describing the flow of the model and to provide information within the listings that would be helpful in making program modifications or conversions to other computer systems as either become necessary.

The return flow quality model provides a highly sophisticated and detailed simulation of salt and nutrient movement from the soil surface to a tile or open-channel drainage system. This model can be interfaced with the conjunctive use model to provide basinwide simulation capabilities involving more than one node.

SECTION IV

VERNAL STUDY AREA

Irrigation began in the Vernal area of Ashley Valley almost 100 years ago, and by 1900 most of the irrigable lands in the valley had been placed under production by diverting directly from Ashley Creek. The Ashley Creek drainage is on the south slope of the Uinta mountains, and, consequently, the spring runoff from snowmelt is of relatively short duration. Historically, the farmers applied as much of the heavy runoff as possible and were then subject to having practically no water in the late summer months. This condition was partially alleviated in 1962 by construction of the offstream Steinaker Reservoir to store runoff for use when Ashley Creek flows diminished. This resulted in a different method of irrigation in the valley, but the storage is still not sufficient to meet the needs of the whole valley. Evaluation of the data collected in 1971 and 1972 indicates that the same condition still persists, to a degree, in that much more water is applied in the early season than is required. Consumptive use values were computed for the area showing that deliveries exceeded requirements in May and June and were deficient later in the season. Location of the reservoir offstream is partially responsible for this condition since the lands cannot all be served directly from the reservoir. It is believed, however, that the situation could be improved if irrigation scheduling were instituted and deliveries were more in line with consumptive use requirements. This, in turn, would result in less deep percolation and theoretically less pickup of salt from the shale surface. Further description of the Vernal area is contained in Volume II, Vernal Field Study.

APPROACH

The Vernal study has been conducted in two phases. The first phase consisted of testing the mathematical model with data that existed prior to initiation of the agreement between the two agencies. The Bureau of Reclamation had collected data in the Vernal area for other purposes during the period from 1957 through 1962, and an analysis of these data indicated that they could be used for developing and testing a mathematical model. Accordingly, the data were assembled and the model tested. After a number of attempts, a successful, limited, prediction model was developed.

The results of this preliminary model testing gave indications of the kinds of data that should be collected for model verification for the second phase. The most significant gap in the existing data proved to be the lack of consumptive use values from both the natural vegetation and the farmed areas along with continuous water quality data from surface sources.

A data-gathering program was outlined that provided for installation of lysimeters, continuous conductivity recorders, additional gaging stations, observation holes, soil test holes, and weather stations. A land use survey was conducted, pumping tests were made, a shale leakage test was made, and inflow-outflow studies were made.

Data were collected for a 2-year period to again test the mathematical model. The results of testing with the new data indicated some adjustment in the model was required to attain a satisfactory prediction.

The mathematical model has been designed as a general model that would be applicable to a data set from any location in accordance with EPA requirements, and it also has capability far beyond the data input from the three projects tested - Vernal, Grand Valley, and Cedar Bluff.

The study of the Vernal area was ideal with respect to the large areas under irrigation and the relatively large increases in salinity as the water traversed the irrigated lands in the valley.

The design of the simulation model incorporated the simultaneous use of both surface and subsurface water resources and the representation of these resources in magnitude and chemical quality. The preliminary studies lumped the entire area into one gross simulation of the operational features. The results pointed up the need for breaking the area into smaller subareas in order to better define the existing conditions. These subareas were later called nodes and this resulted in the development of the nodal concept in the design of the simulation model. Additional applications of the model to the Vernal data using nodal divisions resulted in continued refinements. The nodal division points represented natural physical divisions within the Ashley Valley.

The results of the early simulation studies using the 5-year historic period also indicated that it was not possible to obtain a hydraulic balance of surface flows in any of the nodes unless an exchange mechanism was included in the simulation model to allow the surplus surface water to enter the aquifer as a lateral transfer or conversely to allow a deficit of surface water to be drawn from the aquifer. This exchange mechanism in effect becomes a "black box" approach to the uncertainties related to the disposition of the return flows.

PRELIMINARY MODEL TESTING WITH EXISTING DATA

Initial efforts to verify the model were made with data collected earlier for other project purposes, as previously indicated. The chemical data were not complete, and, in order to have monthly data, it became necessary to supply missing months by inspection or rough correlation. Consumptive use data were developed without the benefit of concurrent weather information, and, as a result, inconsistencies were found in applying both the chemical quality and consumptive use data to the model. The inconsistencies in data concerning consumptive use were dampened in the overall system by allowing the excesses and deficiencies to accumulate in the aquifer storage facilities.

All effort to obtain explicit or deterministic analyses of the chemical exchanges in the return flow waters was discarded in favor of statistical inference which measures the chemical exchanges on a probabilistic basis. It was found that the use of statistical inference enables the prediction of return flow chemistries, constituent by constituent, at about the 92.5-percent level. To obtain data for the statistical inference study, it was assumed that all waters available for diversion, with the exception of extremes, were applied to irrigation and the measured aquifer chemistries from each node (drain outflow) represented the chemistry of the return flows. Even though there was some significant difference in the distribution functions, constituent by constituent, if the distribution function obtained for the chemical constituent of highest concentration was used, all other constituents could be estimated with a simple transform with respect to the fitting parameters. This technique was justified because of the low sensitivity of those constituents of lesser concentrations. The high level of predictability, and the fact that variance was not significantly different than 1.0, produced a peculiar situation. It was found that not only had the daily sampling fluctuations been dampened by the longer time period of monthly reporting, but also, in several cases, the supposedly observed data had been obtained for missing periods by simply using the mean as the expected value. This particular manipulation would also account for the inconsistency in the distribution function for the lower concentrated constituents.

At the conclusion of the above-described analyses and with the use of statistical inference techniques, several simulations were made of the Vernal Unit using the conjunctive use model. In each of these simulations, parameters describing the allotment of inflow waters to each of the nodes were manipulated until the system was in balance hydraulically or quantitatively. The last of these simulations was one that compared predicted aquifer capacities with those as computed for the historic period 1958 through 1962. In each of the nodes, with the exception of one, a high rate of divergence existed between the aquifer capacities as observed and those that were predicted with the use of the model. The divergence was expected because the inconsistencies of consumptive use had been accumulated in the aquifer.

It should be noted from the previous discussion that no effort was made to simulate waters percolating through the soil profile. This simulation was not required because of the very low sensitivity to the overall objective as provided by this type of simulation. Also, the rate of change of chemistry in the aquifer, time period by time period, was not significant.

The above-described applications had exhausted the conceivable manipulation of parameters and existing basic data pertinent to the Vernal Unit. From these several applications, it was concluded that the total objective in studying the Vernal area with the historic time sets was satisfied. It was further concluded that the ongoing sampling format of data in the Vernal area would have to be changed to render a more meaningful predictive model. Some of the expected ramifications of the new data being collected with the changed sampling format are: (1) a lower level of predictability with the use of statistical inference because of the impact of the true sampling fluctuations, (2) a higher degree of consistency in the estimate of consumptive use, and (3) the elimination of, or at least a considerable reduction in, the divergences of the experienced and predicted aquifer capacities.

It was clear at this point that a set of statistical techniques was needed that would enable a comprehensive analysis of the consistencies of all basic data sets that might be used in further applications of the model in other project areas. The use of the data analysis techniques would eliminate many of the trial and error methods that were required in the preliminary Vernal study and would, in addition, create a more meaningful assignment of node configuration with respect to total analytical objectives. The concurrent analyses of other projects would aid in the evaluation of the mathematical and statistical techniques included as a part of the sensitivity and data analysis concept. Many of the techniques employed in the data analysis concepts are an integral part of the stochastic concept in developing larger samples from smaller historic time sets.

DESCRIPTION OF NEW INPUT DATA

The Vernal area could logically be divided into three nodes representing three natural physical divisions, so new data were collected at each of the node or division boundaries in 1971 and 1972 in order to assess changes within the nodes. This entailed collecting flow and quality data on canal flows and stream flows and computing consumptive use values for the types of vegetation contained within the nodes. An additional important factor was defining the volume and chemistry of water contained in the groundwater body. Observation holes and test holes were located throughout the area.

Periodic samples were taken from each hole and analyzed and the water levels in each hole were logged. Permeability rates were established and the water-holding capacity of the soil was determined, and, from these data, the volume of water in each node was computed. Depth to shale had previously been established by drilling the observation holes and test holes through the soil to the shale surface. The shale was considered relatively impermeable.

Previous studies indicated the salt pickup in the Vernal area had to be derived from the groundwater body since the chemistry of the outflowing water was nearly identical to that of the groundwater while the inflowing water from Ashley Creek contained a very low concentration of dissolved solids.

The quality of the groundwater differed substantially from one location to another, so the values were averaged in order to obtain an initial groundwater condition for the model study. The groundwater is very high in sulfate, the primary composition of the Mancos Shale which underlies the valley. An early attempt to model the chemistry of the outflows without considering the groundwater quality failed.

Water quality throughout the area was determined by electrical conductivity measurements combined with periodic sampling and complete analysis in the laboratory. The quantity of water in the canals and Ashley Creek was obtained from stream gaging stations with continuous recorders and from staff gages read by project personnel. Canal losses were previously determined from studies made by the Soil Conservation Service.

The Vernal area was ideally adaptable to model analysis because all the inputs and outflows were measurable to a good degree of accuracy.

A hydrologic balance was easily obtained, thereby simplifying analysis by the computer.

VERIFICATION AND TESTING WITH NEW DATA

The initial testing of the conjunctive use model with existing Vernal data pointed up the deficiencies in these data and set the stage for collection of new data during the 1971-72 period. As soon as all the new data were collected and tabulated, a new series of conjunctive use studies were initiated. A good hydrologic balance was obtained and the corresponding chemistry was used as collected in the field without any manipulation or correlation. The first computer run indicated the new data to be far superior to the existing data and that the results of the model runs would be much more reliable than the previous runs. This also leads to the premise that a model will simulate conditions only when sufficient and accurate data are obtained for verification.

Study No. 1

This study was made without the use of the internodal transfer option in transferring flows from one subsurface storage facility (aquifer) to another subsurface storage facility. Also in this study the return flows were directed to the subsurface storage facility for mixing during the same time frame. The results of this study were discarded because the aquifer in Node 3 showed small, negative, storage values for the months of March and October 1972. These negative storage values invalidated the system hydrologic balance for the period of study.

Study No. 2

This study was made using the internodal transfer option. The constraint in the use of this option is that transfers will be made only from the node immediately upstream from the node in deficit. Also, in this study, return flows were directed to the aquifer for mixing in the same time frame. The mixing of the internodal transfers were handled in a like manner.

During the period of study, a total of 1,088 acre-feet were transferred to Node 3 (103) from Node 2 (102) as internodal transfers. These transfers were required for the months of March and October 1972.

For the purpose of validating the model, two comparisons were made for this study and the subsequent Study No. 2. These comparisons were considered as the most meaningful because of the short period of study and the simplicity of the model application.

The first comparison, as shown in Table 1, is that of comparing the salt load, leaving each node as predicted by the model to the salt load observed as leaving each node. Although some months in this comparison show a large difference between the predicted and observed values, the totals and the means for the period of study are reasonably close as the summary shown below indicates:

Table 1. VERNAL SIMULATION STUDY
Predicted/Observed Salt Load Leaving Each Node
(Mg/1)

		Node 1		Node 2		Node 3	
Year	Month	Without soil column	With soil column	Without soil column	With soil column	Without soil column	With soil column
1971	Apr	335/386	335/386	825/1,082	825/1,082	1,626/2,017	1,626/2,017
	May	70/141	72/141	141/500	141/500	500/1,115	500/1,115
	Jun	43/143	43/143	223/428	225/428	528/1,178	428/1,178
	Jul	134/148	147/148	321/264	334/264	1,416/1,352	1,296/1,352
	Aug	245/174	327/174	527/363	527/363	2,895/1,918	2,684/1,918
	Sep	294/241	430/241	581/681	643/681	2,936/1,271	2,709/1,271
	Oct	188/546	234/546	792/1,022	865/1,022	1,256/1,641	1,213/1,641
	Nov	488/804	791/804	1,041/1,242	1,156/1,292	1,877/1,727	1,725/1,727
	Dec	480/880	777/880	1,047/1,242	1,145/1,242	1,940/1,831	1,758/1,831
1972	Jan	493/678	802/678	1,029/1,258	1,138/1,258	2,294/1,704	2,000/1,704
	Feb	462/830	744/830	1,090/1,189	1,200/1,189	2,595/1,704	2,161/1,704
	Mar	471/476	772/471	957/1,243	1,044/1,243	2,367/1,647	1,902/1,647
	Apr	149/268	179/268	268/573	268/573	729/2,151	672/2,151
	May	60/141	60/141	114/371	114/371	371/1,498	371/1,498
	Jun	63/135	71/135	162/442	167/442	541/1,195	524/1,195
	Jul	181/162	262/162	513/361	604/361	1,609/2,016	1,407/2,016
	Aug	296/181	526/181	812/414	1,029/414	1,938/1,652	1,789/1,652
	Sep	328/184	626/184	713/455	924/455	2,265/2,038	2,135/2,038
	Oct	452/384	943/384	803/923	1,040/923	1,597/2,011	1,620/2,011
	Total	5,232/6,897	8,141/6,897	11,959/14,053	13,389/14,053	31,180/31,666	28,520/31,666
	Mean	275/363 = 0.758	428/363 = 1.179	629/740 = 0.850	704/740 = 0.951	1,641/1,667 = 0.984	1,580/1,667 = 0.948

	Node 1 (101)	Node 2 (102)	Node 3 (103)
Totals (ppm)			
Predicted	5,232	11,959	31,180
Observed	6,987	14,053	31,666
Means (ppm)			
Predicted	275	629	1,641
Observed	363	740	1,677
Absolute differences expressed as a percent of the observed	24	15	2

The second comparison in Table 2 shows the salt load pickup in each node as predicted by the model and the salt load pickup as observed. The characterizations made for the first comparison are also valid for this comparison and a similar summary is shown below:

	Node 1 (101)	Node 2 (102)	Node 3 (103)
Totals (tons/ acre-foot)			
Predicted	4.528	6.930	23.296
Observed	6.747	9.768	23.956
Means (tons/ acre-foot)			
Predicted	0.238	0.364	1.226
Observed	0.355	0.514	1.260
Absolute differences expressed as a percent of the observed	33	29	3

Study No. 3

This study used the internodal transfer option as was used in Study No. 2. However, in this study the return flows were directed to the soil column simulation and after percolating through the soil were mixed with the waters in the subsurface storage facilities with a one-time frame lag.

The same comparisons were made for this study as were made for Study No. 2, the results of which are also shown in Tables 1 and 2. The comparison of the salt loads leaving the system is summarized as follows:

Table 2. VERNAL SIMULATION STUDY
Predicted/Observed Salt Pickup in Each Node
(tons/acre-foot)

		Node 1		Node 2		Node 3	
Year	Month	Without soil column	With soil column	Without soil column	With soil column	Without soil column	With soil column
1971	Apr	0.264/0.334	0.264/0.334	0.597/0.946	0.597/0.946	0.770/1.271	0.740/1.271
	May	0.007/0.103	0.010/0.103	0.000/0.488	0.000/0.488	0.000/0.837	0.000/0.837
	Jun	0.000/0.136	0.000/0.136	0.109/0.388	0.112/0.388	0.000/1.019	0.000/1.019
	Jul	0.072/0.091	0.089/0.091	0.235/0.157	0.250/0.157	1.567/1.480	1.405/1.480
	Aug	0.201/0.105	0.314/0.105	0.481/0.257	0.544/0.257	3.444/2.115	3.157/2.115
	Sep	0.280/0.208	0.465/0.280	0.462/0.599	0.547/0.599	3.066/0.802	2.758/0.802
	Oct	0.074/0.562	0.136/0.562	0.334/0.646	0.433/0.646	0.318/0.842	0.261/0.842
	Nov	0.513/0.942	0.925/0.942	0.332/0.596	0.479/0.596	0.864/0.660	0.657/0.660
	Dec	0.450/0.992	0.852/0.992	0.228/0.493	0.361/0.493	0.950/0.801	0.702/0.801
1972	Jan	0.489/0.740	0.909/0.740	0.477/0.789	0.626/0.789	1.409/0.607	1.009/0.607
	Feb	0.446/0.947	0.831/0.947	0.354/0.488	0.504/0.488	1.913/0.701	1.322/0.701
	Mar	0.444/0.437	0.846/0.437	0.660/1.049	0.779/1.049	1.529/0.580	0.897/0.550
	Apr	0.071/0.232	0.112/0.232	0.000/0.415	0.000/0.415	0.213/2.147	0.136/2.147
	May	0.017/0.091	0.017/0.091	0.000/0.350	0.000/0.350	0.000/1.533	0.000/1.533
	Jun	0.014/0.112	0.025/0.112	0.037/0.418	0.044/0.418	0.134/1.024	0.112/1.024
	Jul	0.141/0.115	0.251/0.115	0.478/0.272	0.602/0.272	1.698/2.251	1.422/2.251
	Aug	0.284/0.128	0.597/0.218	0.858/0.317	1.152/0.317	2.072/1.684	1.870/1.684
	Sep	0.327/0.131	0.732/0.131	0.718/0.367	1.006/0.367	2.463/2.153	2.286/2.153
	Oct	0.434/0.341	1.102/0.341	0.570/0.733	0.892/0.733	0.916/1.479	0.947/1.479
	Total	4.528/6.747	8.477/6.747	6.930/9.768	8.931/9.768	23.296/23.956	19.681/23.956
	Mean	0.238/0.355= 0.670	0.446/0.355 = 1.256	0.364/0.514 = 0.708	0.470/0.514 = 0.914	1.226/1.260 = 0.973	1.035/1.260 = 0.821

	Node 1 (101)	Node 2 (102)	Node 3 (103)
Total (ppm)			
Predicted	8,141	13,474	28,520
Observed	6,897	14,503	31,666
Means (ppm)			
Predicted	426	709	1,501
Observed	363	739	1,667
Absolute differences expressed as a percent of the observed	17	4	10

The comparison of the salt pickup in each node is also summarized as follows:

	Node 1 (101)	Node 2 (102)	Node 3 (103)
Totals tons/ acre-foot)			
Predicted	8.477	8.931	19.681
Observed	6.747	9.768	23.956
Means (tons/ acre-foot)			
Predicted	0.446	0.470	1.035
Observed	0.355	0.514	1.260
Absolute differences expressed as a percent of the observed	26	9	18

Figures 1-3 are graphic presentations of the predicted versus observed quality of outflow from each node from Study No. 3.

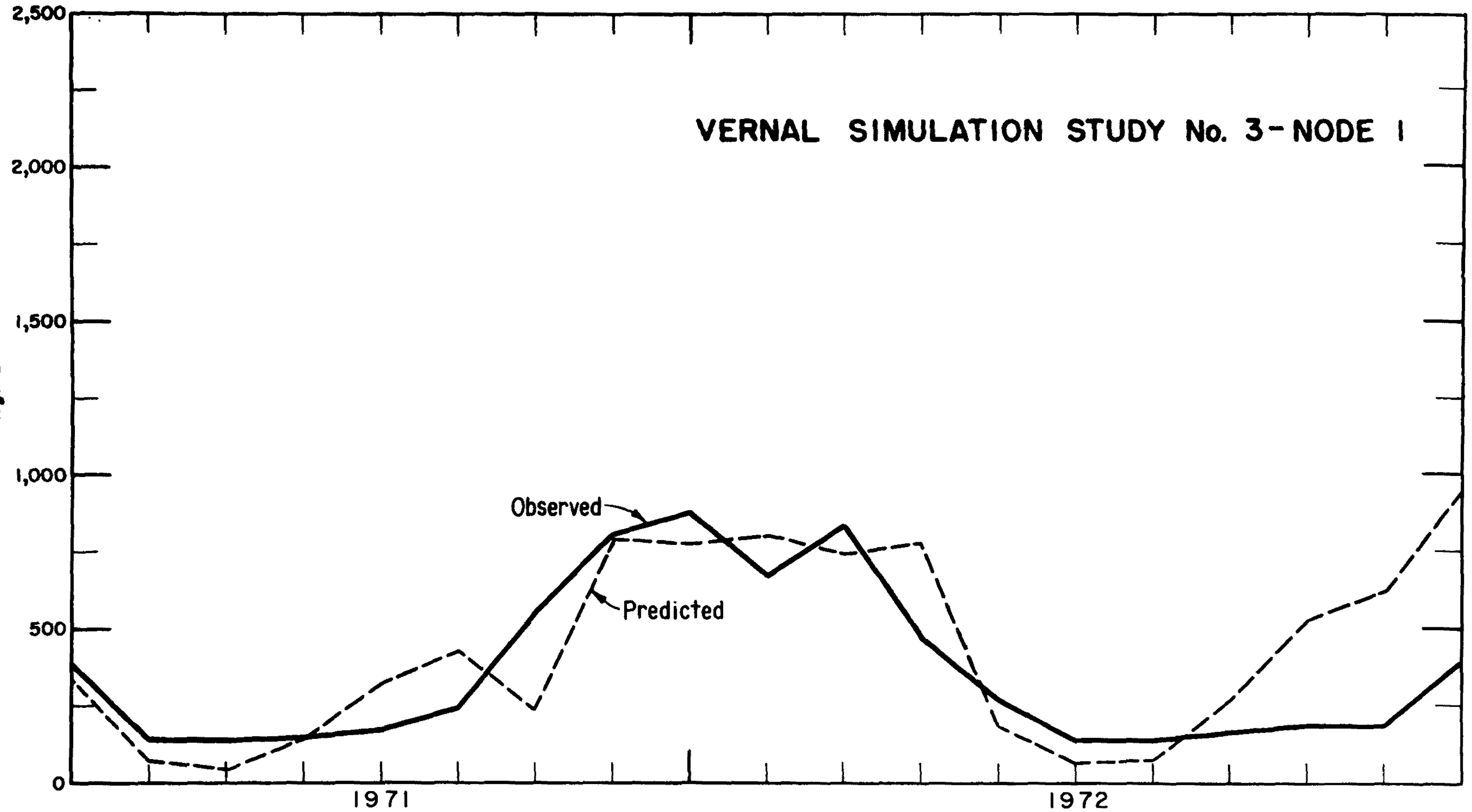

Figure 1. Vernal simulation study no. 3, node 1.

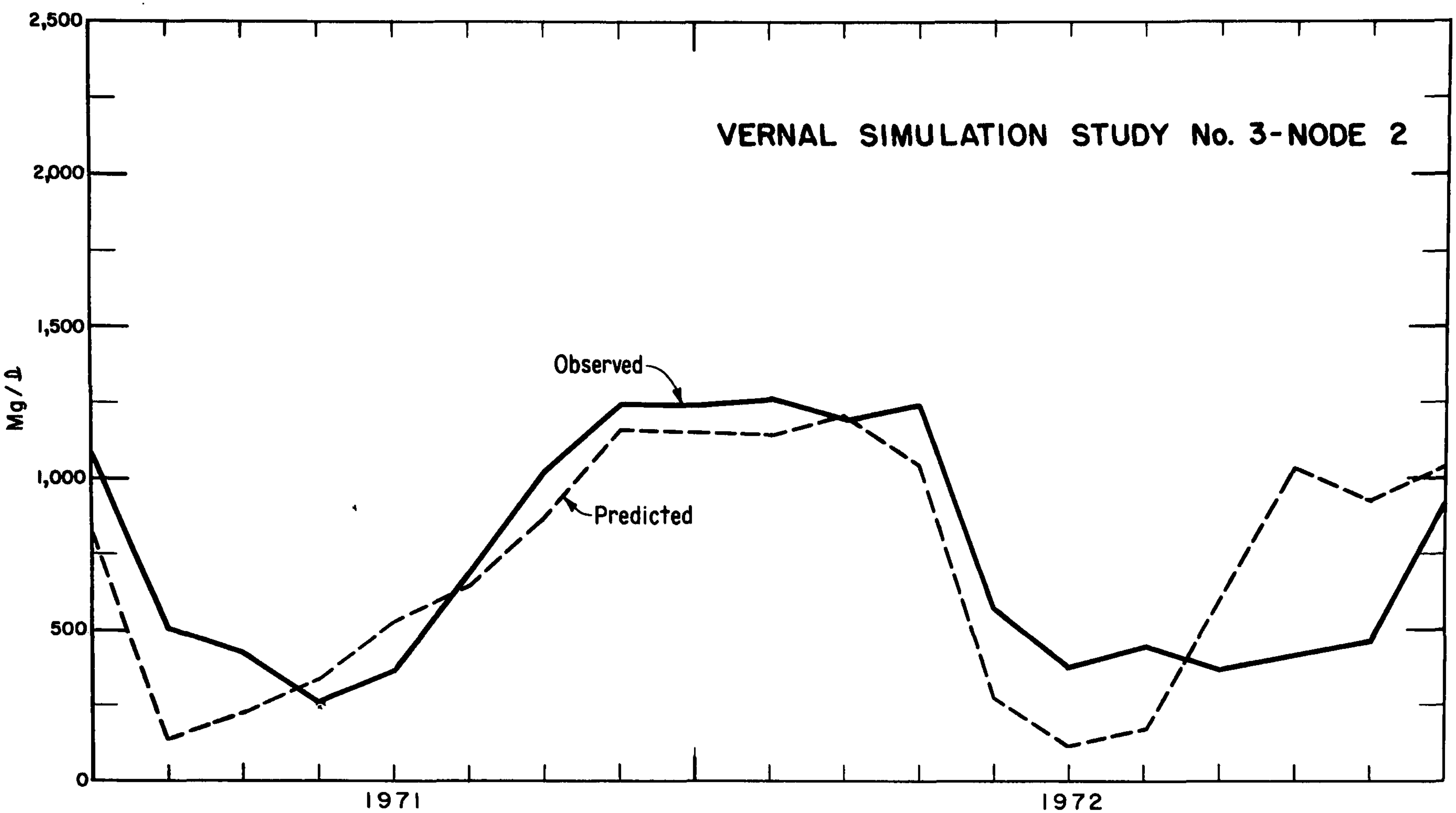

Figure 2. Vernal simulation study no. 3, node 2.

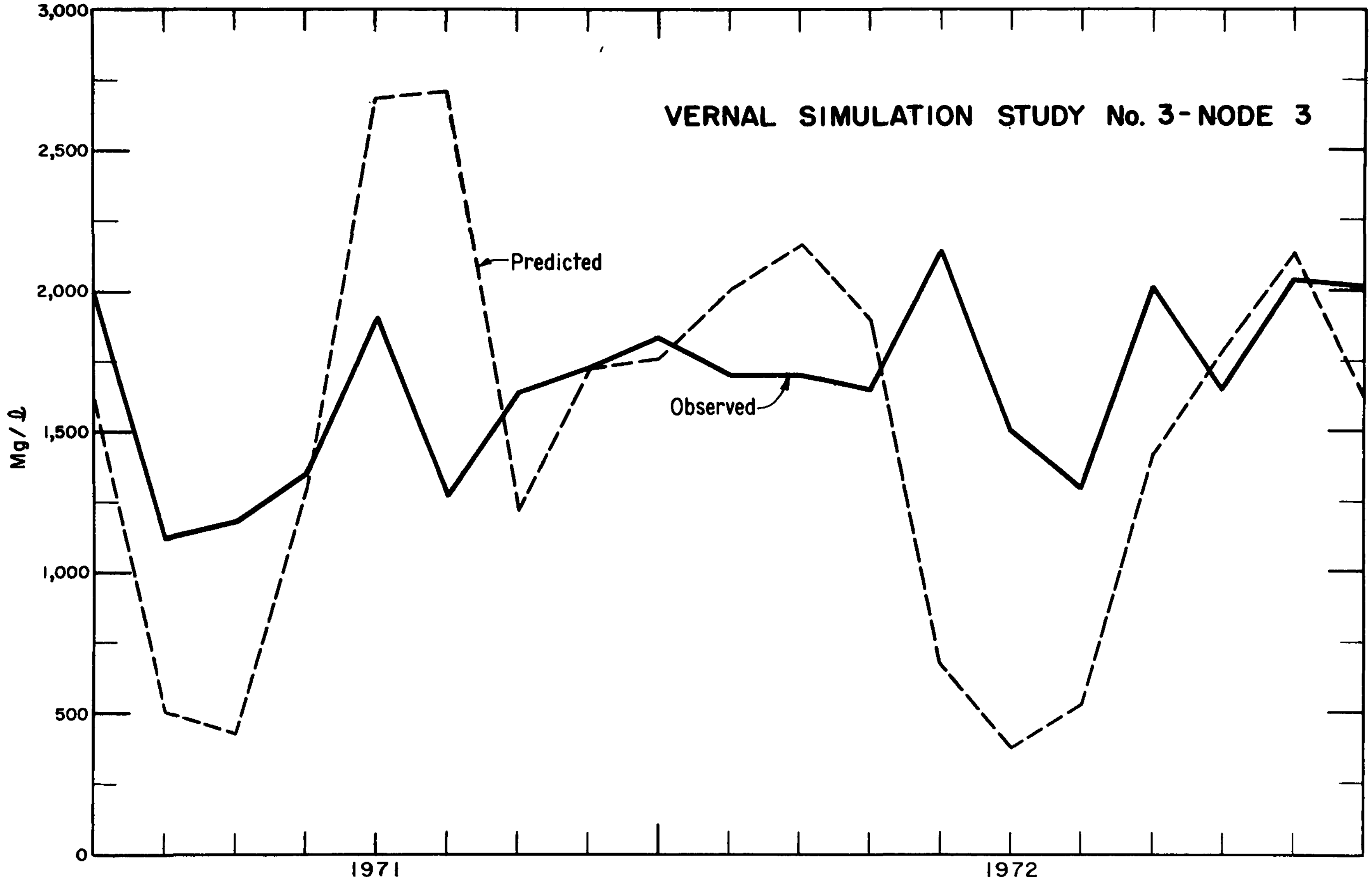

Figure 3. Vernal simulation study no. 3, node 3.

SAMPLE OF VERNAL SIMULATION RUNS

Nos. 1, 2, and 3

NODE NUMBER = 101 MONTH OF MAY YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	18160	22	4	2	0	17	37	0	0	65	0.089
FEEDER CANAL TO STEINECKER RESERVOIR	4800	22	4	2	0	17	37	0	0	65	0.089
INFLOW FROM STEINECKER RESERVOIR	1324	38	10	6	1	59	53	0	0	143	0.195
DIVERSION TO SUPPLY IRRIGATED AREA	3430	23	5	2	0	21	38	0	0	72	0.099
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	1508	22	4	2	0	17	37	0	0	65	0.089
UPPER CANAL OUTFLOW GAGE NO. 2	4264	23	2	2	1	13	33	0	0	58	0.080
CENTRAL CANAL OUTFLOW GAGE NO. 1	2014	26	5	1	1	16	43	0	0	73	0.100
SERVICE CANAL OUTFLOW GAGE NO. 245	984	38	10	6	1	59	53	0	0	143	0.195
ASHLEY CREEK OUTFLOW GAGE NO. 11	1115	142	63	34	23	314	200	0	0	678	0.922
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	24086	126	82	61	20	272	285	0	0	707	0.962
RETURN FLOW FROM IRRIGATION	687	117	27	13	0	107	192	0	0	362	0.494
TRANSFER OF FLOW FROM RIVER TO AQUIFER	1369	23	5	2	0	21	38	0	0	72	0.099
INFLOW TO AQUIFER FROM RIVER	1369	23	5	2	0	21	38	0	0	72	0.099
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	9885	38	10	6	3	53	56	0	0	141	0.192
PREDICTED OUTFLOW FROM THIS NODE	9885	23	5	2	0	21	38	0	0	72	0.099
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	15	5	3	3	31	17	0	0	68	0.093
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	16	5	3	3	35	19	0	0	75	0.103
PREDICTED CHANGE	0	1	0	0	0	3	1	0	0	6	0.010

NODE NUMBER = 102 MONTH OF MAY YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	9885	38	10	6	3	53	56	0	0	141	0.192
DIVERSION TO SUPPLY IRRIGATED AREA	2810	38	10	6	3	53	56	0	0	141	0.192
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	645	18	3	1	0	13	30	0	0	53	0.073
UPPER CANAL OUTFLOW GAGE NO. 10	2624	27	6	1	0	16	48	0	0	76	0.105
CENTRAL CANAL OUTFLOW GAGE NO. 6	452	119	47	19	6	377	78	0	0	608	0.827
SERVICE CANAL OUTFLOW GAGE NO. 5	416	55	21	6	4	51	108	0	0	193	0.263
ASHLEY CREEK OUTFLOW GAGE NO. 8	2655	155	98	58	18	665	120	0	0	1056	1.437
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	19272	226	99	26	11	695	173	0	0	1146	1.559
RETURN FLOW FROM IRRIGATION	422	257	72	40	24	354	377	0	0	939	1.278
TRANSFER OF FLOW FROM RIVER TO AQUIFER	283	38	10	6	3	53	56	0	0	141	0.192
INFLOW TO AQUIFER FROM RIVER	283	38	10	6	3	53	56	0	0	141	0.192
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	6792	84	45	25	7	296	80	0	0	500	0.680
PREDICTED OUTFLOW FROM THIS NODE	6792	38	10	6	3	53	56	0	0	141	0.192
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	45	34	19	4	242	24	0	0	358	0.488
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	45	34	19	4	242	24	0	0	358	0.488
PREDICTED CHANGE	0	0	-0	-0	0	0	0	0	0	0	0.000

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT NUMBER OF NODES = 3 PAGE NO. 6

NODE NUMBER = 103 MONTH OF MAY YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	6792	84	45	25	7	296	80	0	0	500	0.680
DIVERSION TO SUPPLY IRRIGATED AREA	3630	84	45	25	7	296	80	0	0	500	0.680
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	332	28	6	1	1	16	48	0	0	79	0.108
OUTFLOW AT USGS GAGE NO. 2	204	238	110	95	15	849	209	0	0	1414	1.924
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	2230	214	101	72	30	730	185	0	0	1242	1.689
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	5702	603	220	41	16	2044	209	0	0	3031	4.123
RETURN FLOW FROM IRRIGATION	362	847	458	255	79	2969	810	0	0	5014	6.820
TRANSFER OF FLOW FROM RIVER TO AQUIFER	396	84	45	25	7	296	80	0	0	500	0.680
INFLOW TO AQUIFER TO RIVER	396	84	45	25	7	296	80	0	0	500	0.680
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	2766	194	90	65	25	653	171	0	0	1115	1.517
PREDICTED OUTFLOW FROM THIS NODE	2766	84	45	25	7	296	80	0	0	500	0.680
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	109	45	40	17	357	90	0	0	615	0.837
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	109	45	40	17	357	90	0	0	615	0.837
PREDICTED CHANGE	0	0	-0	0	0	0	-0	0	0	0	0.000
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	172	85	63	25	635	133	0	0	1049	1.427
PREDICTED CHANGE	0	62	40	23	7	278	43	0	0	434	0.591

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT   NUMBER OF NODES = 3   PAGE NO. 7

NODE NUMBER = 101   MONTH OF JUN   YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	37970	14	3	2	1	10	23	0	0	43	0.059
FEEDER CANAL TO STEINECKER RESERVOIR	4690	14	3	2	1	10	23	0	0	43	0.059
INFLOW FROM STEINECKER RESERVOIR	0	0	0	0	0	0	0	0	0	0	0.000
DIVERSION TO SUPPLY IRRIGATED AREA	6565	14	3	2	1	10	23	0	0	43	0.059
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	4171	14	3	2	1	10	23	0	0	43	0.059
UPPER CANAL OUTFLOW GAGE NO. 2	7639	15	2	0	0	10	21	0	0	39	0.054
CENTRAL CANAL OUTFLOW GAGE NO. 1	4268	24	2	2	1	11	36	0	0	60	0.082
SERVICE CANAL OUTFLOW GAGE NO. 245	0	0	0	0	0	0	0	0	0	0	0.000
ASHLEY CREEK OUTFLOW GAGE NO. 11	6440	79	33	24	8	182	113	0	0	386	0.525
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	26142	120	77	57	19	254	270	0	0	664	0.904
RETURN FLOW FROM IRRIGATION	1311	70	15	10	8	52	117	0	0	216	0.295
TRANSFER OF FLOW FROM RIVER TO AQUIFER	4227	14	3	2	1	10	23	0	0	43	0.059
INFLOW TO AQUIFER FROM RIVER	4227	14	3	2	1	10	23	0	0	43	0.059
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	22488	35	11	7	3	60	51	0	0	143	0.195
PREDICTED OUTFLOW FROM THIS NODE	22488	14	3	2	1	10	23	0	0	43	0.059
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	21	8	5	1	49	27	0	0	100	0.136
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	21	8	5	1	49	27	0	0	100	0.136
PREDICTED CHANGE	0	0	0	-0	-0	-0	0	0	0	-0	-0.000

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT   NUMBER OF NODES = 3   PAGE NO. 8

NODE NUMBER = 102   MONTH OF JUN   YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	22488	35	11	7	3	60	51	0	0	143	0.195
DIVERSION TO SUPPLY IRRIGATED AREA	5460	35	11	7	3	60	51	0	0	143	0.195
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	2621	18	2	0	1	13	25	0	0	48	0.066
UPPER CANAL OUTFLOW GAGE NO. 10	4504	19	2	1	0	10	29	0	0	48	0.065
CENTRAL CANAL OUTFLOW GAGE NO. 6	632	126	43	16	7	326	108	0	0	574	0.782
SERVICE CANAL OUTFLOW GAGE NO. 5	0	0	0	0	0	0	0	0	0	0	0.000
ASHLEY CREEK OUTFLOW GAGE NO. 8	10780	118	58	38	11	384	121	0	0	672	0.914
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	19977	224	97	26	11	679	176	0	0	1127	1.533
RETURN FLOW FROM IRRIGATION	822	234	75	53	20	399	339	0	0	953	1.297
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1509	224	97	26	11	679	176	0	0	1127	1.533
INFLOW TO RIVER FROM AQUIFER	1509	224	97	26	11	679	176	0	0	1127	1.533
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	18537	80	36	23	7	239	85	0	0	428	0.583
PREDICTED OUTFLOW FROM THIS NODE	18537	50	18	9	3	110	61	0	0	223	0.304
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	29	17	13	3	128	23	0	0	205	0.279
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	45	24	15	3	179	33	0	0	285	0.388
PREDICTED CHANGE	0	15	7	1	0	50	10	0	0	80	0.109

NODE NUMBER = 103 MONTH OF JUN YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	18537	80	36	23	7	239	85	0	0	428	0.583
DIVERSION TO SUPPLY IRRIGATED AREA	6800	80	36	23	7	239	85	0	0	428	0.583
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	696	19	2	1	0	10	29	0	0	48	0.065
OUTFLOW AT USGS GAGE NO. 2	212	197	69	68	11	604	168	0	0	1035	1.409
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	10280	216	107	59	19	771	167	0	0	1258	1.711
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	6460	585	223	52	19	1989	235	0	0	2987	4.063
RETURN FLOW FROM IRRIGATION	684	800	361	231	70	2378	846	0	0	4264	5.800
TRANSFER OF FLOW FROM RIVER TO AQUIFER	549	80	36	23	7	239	85	0	0	428	0.583
INFLOW TO AQUIFER TO RIVER	549	80	36	23	7	239	85	0	0	428	0.583
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	11188	203	99	56	17	721	159	0	0	1178	1.603
PREDICTED OUTFLOW FROM THIS NODE	11188	80	36	23	7	239	85	0	0	428	0.583
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	123	63	33	10	482	74	0	0	749	1.019
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	123	63	33	10	482	74	0	0	749	1.019
PREDICTED CHANGE	0	-0	-0	0	0	0	0	0	0	-0	-0.000
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	189	96	54	16	710	135	0	0	1135	1.544
PREDICTED CHANGE	0	66	33	21	5	228	61	0	0	385	0.525

NODE NUMBER = 101 MONTH OF JUL YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	10730	1	0	0	0	2	1	0	0	5	0.007
FEEDER CANAL TO STEINECKER RESERVOIR	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW FROM STEINECKER RESERVOIR	7952	38	10	6	4	50	56	0	0	138	0.188
DIVERSION TO SUPPLY IRRIGATED AREA	6870	17	4	2	1	22	25	0	0	61	0.084
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	2490	30	7	2	0	19	55	0	0	88	0.120
UPPER CANAL OUTFLOW GAGE NO. 2	2858	29	6	1	0	17	50	0	0	80	0.109
CENTRAL CANAL OUTFLOW GAGE NO. 1	434	50	19	4	2	53	94	0	0	177	0.242
SERVICE CANAL OUTFLOW GAGE NO. 245	6224	38	10	6	4	50	56	0	0	138	0.188
ASHLEY CREEK OUTFLOW GAGE NO. 11	735	135	64	44	18	336	192	0	0	695	0.946
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	31680	104	64	48	16	213	231	0	0	563	0.766
RETURN FLOW FROM IRRIGATION	1371	85	23	14	9	114	125	0	0	309	0.421
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	929	104	64	48	16	213	231	0	0	563	0.766
INFLOW TO RIVER FROM AQUIFER	929	104	64	48	16	213	231	0	0	563	0.766
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	12741	40	12	6	3	53	63	0	0	148	0.203
PREDICTED OUTFLOW FROM THIS NODE	12741	23	9	6	2	36	40	0	0	98	0.134
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	17	3	0	0	16	23	-0	0	50	0.069
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	39	11	6	3	51	62	0	0	143	0.195
PREDICTED CHANGE	0	22	8	6	2	34	38	0	0	93	0.127

NODE NUMBER = 102   MONTH OF JUL   YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	12741	40	12	6	3	53	63	0	0	148	0.203
DIVERSION TO SUPPLY IRRIGATED AREA	5730	40	12	6	3	53	63	0	0	148	0.203
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSEPVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	1392	27	6	1	1	14	49	0	0	76	0.104
UPPER CANAL OUTFLOW GAGE NO. 10	1057	30	6	2	1	14	54	0	0	82	0.112
CENTRAL CANAL OUTFLOW GAGE NO. 6	352	76	27	9	5	171	82	0	0	332	0.452
SERVICE CANAL OUTFLOW GAGE NO. 5	4564	50	19	4	2	53	94	0	0	177	0.242
ASHLEY CREEK OUTFLOW GAGE NO. 8	1160	180	79	51	14	564	168	0	0	975	1.326
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	19290	224	96	27	12	668	182	0	0	1120	1.524
RETURN FLOW FROM IRRIGATION	856	272	83	44	23	358	428	0	0	996	1.356
TRANSFER OF FLOW FPOM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1514	224	96	27	12	668	182	0	0	1120	1.524
INFLOW TO RIVER FROM AQUIFER	1514	224	96	27	12	668	182	0	0	1120	1.524
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	8525	62	24	10	4	116	91	0	0	264	0.359
PREDICTED OUTFLOW FROM THIS NODE	8525	73	27	10	5	162	85	0	0	321	0.437
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-10	-2	-0	-0	-46	6	0	0	-57	-0.078
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	22	12	3	0	63	27	0	0	115	0.157
PREDICTED CHANGE	0	32	14	3	1	109	21	0	0	172	0.235

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT NUMBER OF NODES = 3 PAGE NO. 12

NODE NUMBER = 103 MONTH OF JUL YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	8525	62	24	10	4	116	91	0	0	264	0.359
DIVERSION TO SUPPLY IRRIGATED AREA	7110	62	24	10	4	116	91	0	0	264	0.359
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	493	29	6	2	0	14	54	0	0	80	0.110
OUTFLOW AT USGS GAGE NO. 2	257	216	137	139	19	1134	120	0	0	1707	2.322
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	1750	207	140	123	27	1108	102	0	0	1658	2.255
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	7693	568	222	66	23	1898	279	0	0	2918	3.969
RETURN FLOW FROM IRRIGATION	709	630	245	102	41	1169	917	0	0	2649	3.603
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1085	568	222	66	23	1898	279	0	0	2918	3.969
INFLOW TO RIVER FROM AQUIFER	1085	568	222	66	23	1898	279	0	0	2918	3.969
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	2500	173	113	101	21	895	95	0	0	1352	1.839
PREDICTED OUTFLOW FROM THIS NODE	2500	282	110	34	12	890	172	0	0	1416	1.926
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-108	3	66	8	5	-77	0	0	-64	-0.087
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	110	89	90	16	778	3	0	0	1087	1.480
PREDICTED CHANGE	0	219	85	24	8	773	81	0	0	1152	1.567
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	171	113	100	21	892	93	0	0	1346	1.832
PREDICTED CHANGE	0	280	109	34	12	887	170	0	0	1410	1.919

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT NUMBER OF NODES = 3 PAGE NO. 10

NODE NUMBER = 101 MONTH OF JUL YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	10730	32	5	2	0	11	58	0	0	81	0.111
FEEDER CANAL TO STEINECKER RESERVOIR	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW FROM STEINECKER RESERVOIR	7952	38	10	6	4	50	56	0	0	138	0.188
DIVERSION TO SUPPLY IRRIGATED AREA	6870	35	7	4	2	27	57	0	0	105	0.144
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	2490	30	7	2	0	19	55	0	0	88	0.120
UPPER CANAL OUTFLOW GAGE NO. 2	2858	29	6	1	0	17	50	0	0	80	0.109
CENTRAL CANAL OUTFLOW GAGE NO. 1	434	50	19	4	2	53	94	0	0	177	0.242
SERVICE CANAL OUTFLOW GAGE NO. 245	6224	38	10	6	4	50	56	0	0	138	0.188
ASHLEY CREEK OUTFLOW GAGE NO. 11	735	135	64	44	18	336	132	0	0	695	0.946
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	36480	93	57	42	14	188	205	0	0	498	0.678
RETURN FLOW FROM IRRIGATION	1371	175	39	20	11	139	289	0	0	530	0.721
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	929	93	57	42	14	188	205	0	0	498	0.678
INFLOW TO RIVER FROM AQUIFER	929	93	57	42	14	188	205	0	0	498	0.678
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	12741	40	12	6	3	53	63	0	0	148	0.203
PREDICTED OUTFLOW FROM THIS NODE	12741	39	11	6	3	39	68	0	0	134	0.183
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	1	1	-0	0	14	-4	-0	0	14	0.020
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	8	6	4	2	42	5	0	0	67	0.091
PREDICTED CHANGE	0	6	5	4	2	28	9	0	0	52	0.072

NODE NUMBER = 102 MONTH OF JUL YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	12741	40	12	6	3	53	63	0	0	148	0.203
DIVERSION TO SUPPLY IRRIGATED AREA	5730	40	12	6	3	53	63	0	0	148	0.203
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	1392	27	6	1	1	14	49	0	0	76	0.104
UPPER CANAL OUTFLOW GAGE NO. 10	1057	30	6	2	1	14	54	0	0	82	0.112
CENTRAL CANAL OUTFLOW GAGE NO. 6	352	76	27	9	5	171	82	0	0	332	0.452
SERVICE CANAL OUTFLOW GAGE NO. 5	4564	50	19	4	2	53	94	0	0	177	0.242
ASHLEY CREEK OUTFLOW GAGE NO. 8	1160	180	79	51	14	564	168	0	0	975	1.326
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	19290	224	96	27	12	668	182	0	0	1120	1.524
RETURN FLOW FROM IRRIGATION	856	272	83	44	23	359	428	0	0	996	1.356
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1514	224	96	27	12	668	182	0	0	1120	1.524
INFLOW TO RIVER FROM AQUIFER	1514	224	96	27	12	668	182	0	0	1120	1.524
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	8525	62	24	10	4	116	91	0	0	264	0.359
PREDICTED OUTFLOW FROM THIS NODE	8525	73	27	10	5	162	85	0	0	321	0.437
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-10	-2	-0	-0	-46	6	0	0	-57	-0.078
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	22	12	3	0	63	27	0	0	115	0.157
PREDICTED CHANGE	0	32	14	3	1	109	21	0	0	172	0.235

NODE NUMBER = 103 MONTH OF JUL YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	8525	62	24	10	4	116	91	0	0	264	0.359
DIVERSION TO SUPPLY IRRIGATED AREA	7110	62	24	10	4	116	91	0	0	264	0.359
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	493	29	6	2	0	14	54	0	0	80	0.110
OUTFLOW AT USGS GAGE NO. 2	257	215	137	139	19	1134	120	0	0	1707	2.322
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	1750	207	140	123	27	1108	102	0	0	1658	2.255
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	7693	568	222	66	23	1898	279	0	0	2918	3.969
RETURN FLOW FROM IRRIGATION	709	530	245	102	41	1169	917	0	0	2649	3.603
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1085	568	222	66	23	1898	279	0	0	2918	3.969
INFLOW TO RIVER FROM AQUIFER	1085	568	222	66	23	1898	279	0	0	2918	3.969
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	2500	173	113	101	21	895	95	0	0	1352	1.839
PREDICTED OUTFLOW FROM THIS NODE	2500	282	110	34	12	890	172	0	0	1416	1.926
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-108	3	66	8	5	-77	0	0	-64	-0.087
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	110	89	90	16	778	3	0	0	1087	1.480
PREDICTED CHANGE	0	219	85	24	8	773	81	0	0	1152	1.567
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	140	107	99	20	884	36	0	0	1270	1.728
PREDICTED CHANGE	0	249	104	32	11	879	114	0	0	1334	1.815

NODE NUMBER = 101 MONTH OF AUG YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	4980	31	9	1	0	27	53	0	0	97	0.132
FEEDER CANAL TO STEINECKER RESERVOIR	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW FROM STEINECKER RESERVOIR	6030	32	9	5	2	35	54	0	0	113	0.154
DIVERSION TO SUPPLY IRRIGATED AREA	6070	32	9	3	1	32	54	0	0	105	0.144
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	667	31	11	2	1	35	56	0	0	110	0.150
UPPER CANAL OUTFLOW GAGE NO. 2	1664	35	8	2	1	24	59	0	0	102	0.139
CENTRAL CANAL OUTFLOW GAGE NO. 1	142	63	27	7	6	62	129	0	0	232	0.316
SERVICE CANAL OUTFLOW GAGE NO. 245	4558	32	9	5	2	35	54	0	0	113	0.154
ASHLEY CREEK OUTFLOW GAGE NO. 11	610	170	62	58	14	491	165	0	0	890	1.197
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	36922	96	56	41	14	186	208	0	0	499	0.679
RETURN FLOW FROM IRRIGATION	1221	159	45	18	9	159	268	0	0	526	0.716
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	2701	96	56	41	14	186	208	0	0	499	0.679
INFLOW TO RIVER FROM AQUIFER	2701	95	56	41	14	186	208	0	0	499	0.679
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	7641	44	14	8	3	70	66	0	0	174	0.237
PREDICTED OUTFLOW FROM THIS NODE	7641	54	25	16	6	86	108	0	0	245	0.333
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-10	-11	-8	-2	-16	-42	-0	0	-70	-0.096
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	13	4	7	2	42	12	0	0	76	0.105
PREDICTED CHANGE	0	23	16	15	5	58	55	0	0	147	0.201

NODE NUMBER = 102 MONTH OF AUG YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	7641	44	14	8	3	70	66	0	0	174	0.237
DIVERSION TO SUPPLY IRRIGATED AREA	4935	44	14	8	3	70	66	0	0	174	0.237
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	288	31	8	1	1	23	55	0	0	95	0.129
UPPER CANAL OUTFLOW GAGE NO. 10	700	31	9	1	0	23	58	0	0	95	0.130
CENTRAL CANAL OUTFLOW GAGE NO. 6	212	102	35	17	6	265	94	0	0	475	0.646
SERVICE CANAL OUTFLOW GAGE NO. 5	2194	39	9	5	2	47	60	0	0	135	0.184
ASHLEY CREEK OUTFLOW GAGE NO. 8	860	184	101	67	18	806	94	0	0	1225	1.667
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	18632	226	96	28	12	655	193	0	0	1115	1.517
RETURN FLOW FROM IRRIGATION	749	298	93	57	22	466	440	0	0	1158	1.576
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1598	226	96	28	12	655	193	0	0	1115	1.517
INFLOW TO RIVER FROM AQUIFER	1598	226	96	28	12	655	193	0	0	1115	1.517
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	4254	70	29	17	5	205	68	0	0	363	0.494
PREDICTED OUTFLOW FROM THIS NODE	4254	113	44	16	6	289	113	0	0	527	0.718
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-42	-15	1	-1	-83	-45	0	0	-164	-0.224
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	25	15	9	1	135	2	0	0	189	0.257
PREDICTED CHANGE	0	68	30	7	3	219	47	0	0	353	0.481

NODE NUMBER = 103 MONTH OF AUG YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	4254	70	29	17	5	206	68	0	0	363	0.494
DIVERSION TO SUPPLY IRRIGATED AREA	4254	70	29	17	5	206	68	0	0	363	0.494
SHORTAGE FROM THE IDEAL DEMAND	2046										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	89	32	9	1	1	23	58	0	0	97	0.132
OUTFLOW AT USGS GAGE NO. 2	365	322	152	141	24	1288	218	0	0	2038	2.773
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	960	259	167	168	33	1335	157	0	0	2041	2.777
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	7317	573	224	69	25	1837	333	0	0	2895	3.938
RETURN FLOW FROM IRRIGATION	425	702	296	178	53	2060	683	0	0	3633	4.941
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1414	573	224	69	25	1837	333	0	0	2895	3.938
INFLOW TO RIVER FROM AQUIFER	1414	573	224	69	25	1837	333	0	0	2895	3.938
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	1414	260	153	150	29	1240	167	0	0	1918	2.609
PREDICTED OUTFLOW FROM THIS NODE	1414	573	224	69	25	1937	333	0	0	2895	3.938
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-312	-70	81	4	-596	-165	0	0	-977	-1.329
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	190	124	133	23	1034	98	0	0	1555	2.115
PREDICTED CHANGE	0	503	194	51	19	1631	264	0	0	2532	3.444
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	229	144	149	28	1212	113	0	0	1821	2.477
PREDICTED CHANGE	0	542	214	67	24	1809	279	0	0	2798	3.806

NODE NUMBER = 101 MONTH OF SEP YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	3750	30	7	2	0	19	55	0	0	88	0.120
FEEDER CANAL TO STEINECKER RESERVOIR	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW FROM STEINECKER RESERVOIR	1705	38	10	6	1	59	53	0	0	143	0.195
DIVERSION TO SUPPLY IRRIGATED AREA	3154	33	8	3	1	31	54	0	0	105	0.143
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	449	39	10	2	1	31	67	0	0	119	0.163
UPPER CANAL OUTFLOW GAGE NO. 2	1674	31	9	1	0	23	58	0	0	96	0.131
CENTRAL CANAL OUTFLOW GAGE NO. 1	120	62	25	6	4	60	123	0	0	222	0.302
SERVICE CANAL OUTFLOW GAGE NO. 245	1269	38	10	6	1	59	53	0	0	143	0.195
ASHLEY CREEK OUTFLOW GAGE NO. 11	900	121	58	48	10	414	119	0	0	712	0.969
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	35442	98	56	40	14	185	210	0	0	500	0.680
RETURN FLOW FROM IRRIGATION	622	168	43	17	5	161	275	0	0	534	0.727
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	2111	98	56	40	14	185	210	0	0	500	0.680
INFLOW TO RIVER FROM AQUIFER	2111	98	56	40	14	185	210	0	0	500	0.680
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	4412	53	20	12	3	115	72	0	0	241	0.328
PREDICTED OUTFLOW FROM THIS NODE	4412	64	31	21	7	105	129	0	0	294	0.400
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-10	-10	-8	-3	10	-57	-0	0	-53	-0.072
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	22	12	10	2	96	16	0	0	153	0.208
PREDICTED CHANGE	0	33	23	19	6	86	74	0	0	206	0.280

NODE NUMBER = 102 MONTH OF SEP YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	4412	53	20	12	3	115	72	0	0	241	0.328
DIVERSION TO SUPPLY IRRIGATED AREA	2591	53	20	12	3	115	72	0	0	241	0.328
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	135	32	7	0	1	13	55	0	0	87	0.119
UPPER CANAL OUTFLOW GAGE NO. 10	875	31	9	1	0	23	57	0	0	95	0.130
CENTRAL CANAL OUTFLOW GAGE NO. 6	214	119	47	19	6	377	78	0	0	608	0.827
SERVICE CANAL OUTFLOW GAGE NO. 5	61	30	14	6	2	48	58	0	0	132	0.180
ASHLEY CREEK OUTFLOW GAGE NO. 8	1690	187	88	61	19	615	178	0	0	1062	1.445
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	17783	229	95	29	12	647	202	0	0	1117	1.519
RETURN FLOW FROM IRRIGATION	339	357	135	84	22	763	479	0	0	1607	2.186
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1154	229	95	29	12	647	202	0	0	1117	1.519
INFLOW TO RIVER FROM AQUIFER	1154	229	95	29	12	647	202	0	0	1117	1.519
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	2975	126	57	37	12	385	127	0	0	681	0.927
PREDICTED OUTFLOW FROM THIS NODE	2975	121	49	19	7	321	122	0	0	581	0.790
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	4	7	17	4	63	4	0	0	100	0.137
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	72	36	24	8	270	55	0	0	440	0.599
PREDICTED CHANGE	0	68	29	6	3	206	50	0	0	339	0.462

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NODE NUMBER = 103 MONTH OF SEP YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	2975	126	57	37	12	385	127	0	0	681	0.927
DIVERSION TO SUPPLY IRRIGATED AREA	2975	126	57	37	12	385	127	0	0	681	0.927
SHORTAGE FROM THE IDEAL DEMAND	345										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	128	31	9	1	0	23	57	0	0	95	0.130
OUTFLOW AT USGS GAGE NO. 2	104	273	102	92	15	912	201	0	0	1497	2.036
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	1710	248	105	64	19	811	193	0	0	1345	1.830
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	6328	580	228	75	26	1849	352	0	0	2936	3.994
RETURN FLOW FROM IRRIGATION	297	1263	571	370	120	3855	1275	0	0	6818	9.274
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1942	580	228	75	26	1849	352	0	0	2936	3.994
INFLOW TO RIVER FROM AQUIFER	1942	580	228	75	26	1849	352	0	0	2936	3.994
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	1942	235	99	61	17	764	184	0	0	1271	1.729
PREDICTED OUTFLOW FROM THIS NODE	1942	580	228	75	26	1849	352	0	0	2936	3.994
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-344	-129	-13	-8	1084	-167	0	0	-1665	-2.265
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	109	41	24	5	379	57	0	0	599	0.802
PREDICTED CHANGE	0	454	170	38	14	1464	224	0	0	2254	3.066
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	204	91	59	17	745	129	0	0	1183	1.609
PREDICTED CHANGE	0	549	220	73	25	1830	297	0	0	2848	3.874

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NODE NUMBER = 101 MONTH OF APR YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	1379	38	12	3	1	36	58	20	0	141	0.192
FEEDER CANAL TO STEINECKER RESERVOIR	400	35	12	3	1	36	58	20	0	141	0.192
INFLOW FROM STEINECKER RESERVOIR	653	42	12	6	2	60	62	0	0	155	0.211
DIVERSION TO SUPPLY IRRIGATED AREA	726	40	12	4	1	46	60	12	0	146	0.200
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	0	0	0	0	0	0	0	0	0	0	0.000
UPPER CANAL OUTFLOW GAGE NO. 2	460	33	9	6	2	48	50	0	0	125	0.170
CENTRAL CANAL OUTFLOW GAGE NO. 1	156	62	25	6	4	60	123	0	0	222	0.302
SERVICE CANAL OUTFLOW GAGE NO. 245	440	41	12	6	2	158	0	0	0	222	0.302
ASHLEY CREEK OUTFLOW GAGE NO. 11	309	194	82	76	21	653	151	0	0	1094	1.488
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	24400	125	82	62	20	272	285	0	0	706	0.961
IRRIGATION RETURN FLOW TO SOIL COLUMN	145	200	60	23	8	231	300	60	0	735	1.000
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	459	125	82	62	20	272	285	0	0	706	0.961
INFLOW TO RIVER FROM AQUIFER	459	125	82	62	20	272	285	0	0	706	0.961
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	1365	73	28	22	7	222	65	0	0	386	0.526
PREDICTED OUTFLOW FROM THIS NODE	1365	68	35	24	8	122	135	8	0	335	0.456
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	4	-7	-1	-1	100	-70	-8	0	51	0.070
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	35	16	19	5	185	7	-20	0	245	0.334
PREDICTED CHANGE	0	30	23	20	7	85	77	-12	0	193	0.264

NODE NUMBER = 102 MONTH OF APR YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	1365	73	28	22	7	222	65	0	0	386	0.526
DIVERSION TO SUPPLY IRRIGATED AREA	634	73	28	22	7	222	65	0	0	386	0.526
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	0	0	0	0	0	0	0	0	0	0	0.000
UPPER CANAL OUTFLOW GAGE NO. 10	307	37	11	3	1	37	64	0	0	123	0.168
CENTRAL CANAL OUTFLOW GAGE NO. 6	160	206	98	33	12	683	154	0	0	1115	1.517
SERVICE CANAL OUTFLOW GAGE NO. 5	117	50	19	4	2	53	94	0	0	177	0.242
ASHLEY CREEK OUTFLOW GAGE NO. 8	1170	250	115	74	23	855	202	0	0	1420	1.932
42 **SUBSURFACE OPERATIONS AND FLOW TRANSFERS**											
AQUIFER CONDITIONS OF LAST TIME FRAME	20200	224	98	25	11	692	172	0	0	1139	1.550
IRRIGATION RETURN FLOW TO SOIL COLUMN	95	490	191	149	47	1483	437	0	0	2582	3.512
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1023	224	98	25	11	692	172	0	0	1139	1.550
INFLOW TO RIVER FROM AQUIFER	1023	224	98	25	11	692	172	0	0	1139	1.550
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	1754	195	89	53	16	643	166	0	0	1082	1.473
PREDICTED OUTFLOW FROM THIS NODE	1754	161	69	24	9	496	127	0	0	825	1.123
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	34	19	28	7	147	38	0	0	257	0.350
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	122	60	30	9	421	101	0	0	695	0.946
PREDICTED CHANGE	0	88	40	2	2	273	62	0	0	438	0.597

NODE NUMBER = 103   MONTH OF APR   YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	1754	196	89	53	16	643	166	0	0	1082	1.473
DIVERSION TO SUPPLY IRRIGATED AREA	802	196	89	53	16	643	166	0	0	1082	1.473
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	0	0	0	0	0	0	0	0	0	0	0.000
OUTFLOW AT USGS GAGE NO. 2	0	0	0	0	0	0	0	0	0	0	0.000
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	1350	278	162	152	35	1301	174	0	0	2017	2.744
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	6020	585	211	34	14	1986	190	0	0	2927	3.982
IRRIGATION RETURN FLOW TO SOIL COLUMN	80	1966	894	534	170	6454	1671	0	0	10855	14.763
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	398	585	211	34	14	1986	190	0	0	2927	3.982
INFLOW TO RIVER FROM AQUIFER	398	585	211	34	14	1986	190	0	0	2927	3.982
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	1350	278	162	152	35	1301	174	0	0	2017	2.744
PREDICTED OUTFLOW FROM THIS NODE	1350	310	125	47	16	1039	173	0	0	1626	2.212
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	-32	37	104	19	261	0	0	0	390	0.531
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	82	73	99	18	657	7	0	0	934	1.271
PREDICTED CHANGE	0	114	36	-5	-0	395	7	0	0	543	0.740
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	240	150	149	34	1264	116	-20	0	1876	2.552
PREDICTED CHANGE	0	272	113	44	15	1002	115	-20	0	1485	2.020

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NODE NUMBER = 101 MONTH OF MAY YEAR 1971

OPERATIONAL SEQUENCE OF SURFACE FACILITIES

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
ASHLEY CREEK AT HEAD OF SYSTEM	18160	22	4	2	0	17	37	0	0	65	0.089
FEEDER CANAL TO STEINECKER RESERVOIR	4800	22	4	2	0	17	37	0	0	65	0.089
INFLOW FROM STEINECKER RESERVOIR	1324	35	10	6	1	59	53	0	0	143	0.195
DIVERSION TO SUPPLY IRRIGATED AREA	3430	23	5	2	0	21	38	0	0	72	0.099
SHORTAGE FROM THE IDEAL DEMAND	0										

OBSERVED OUTFLOWS FROM NODE

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
HIGHLINE CANAL OUTFLOW GAGE NO. 3	1508	22	4	2	0	17	37	0	0	65	0.089
UPPER CANAL OUTFLOW GAGE NO. 2	4264	23	2	2	1	13	33	0	0	58	0.080
CENTRAL CANAL OUTFLOW GAGE NO. 1	2014	26	5	1	1	16	43	0	0	73	0.100
SERVICE CANAL OUTFLOW GAGE NO. 245	934	38	10	6	1	59	53	0	0	143	0.195
ASHLEY CREEK OUTFLOW GAGE NO. 11	1115	142	63	34	23	314	200	0	0	678	0.922

SUBSURFACE OPERATIONS AND FLOW TRANSFERS

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
AQUIFER CONDITIONS OF LAST TIME FRAME	24086	127	82	62	20	278	284	0	0	714	0.972
IRRIGATION RETURN FLOW TO SOIL COLUMN	687	117	27	13	0	107	192	0	0	362	0.494
TRANSFER OF FLOW FROM RIVER TO AQUIFER	1369	23	5	2	0	21	38	0	0	72	0.099
INFLOW TO AQUIFER FROM RIVER	1369	23	5	2	0	21	38	0	0	72	0.099
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000

COMPARISON INDEX

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
TOTAL OBSERVED OUTFLOWS FROM NODE	9885	38	10	6	3	53	56	0	0	141	0.192
PREDICTED OUTFLOW FROM THIS NODE	9885	23	5	2	0	21	38	0	0	72	0.099
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	15	5	3	3	31	17	0	0	68	0.093

CHEMICAL CHANGES IN NODE

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OBSERVED CHANGE	0	16	5	3	3	35	19	0	0	75	0.103
PREDICTED CHANGE	0	1	0	0	0	3	1	0	0	6	0.010

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NODE NUMBER = 102 MONTH OF MAY YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	9885	38	10	6	3	53	56	0	0	141	0.192
DIVERSION TO SUPPLY IRRIGATED AREA	2810	38	10	6	3	53	56	0	0	141	0.192
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	645	18	3	1	0	13	30	0	0	53	0.073
UPPER CANAL OUTFLOW GAGE NO. 10	2624	27	6	1	0	16	48	0	0	76	0.105
CENTRAL CANAL OUTFLOW GAGE NO. 6	452	119	47	19	6	377	78	0	0	608	0.827
SERVICE CANAL OUTFLOW GAGE NO. 5	416	55	21	6	4	51	108	0	0	193	0.263
ASHLEY CREEK OUTFLOW GAGE NO. 8	2655	155	38	58	18	665	120	0	0	1056	1.437
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	19272	225	99	26	11	696	172	0	0	1144	1.556
IRRIGATION RETURN FLOW TO SOIL COLUMN	422	257	72	40	24	354	377	0	0	939	1.278
TRANSFER OF FLOW FROM RIVER TO AQUIFER	283	38	10	6	3	53	56	0	0	141	0.192
INFLOW TO AQUIFER FROM RIVER	283	38	10	6	3	53	56	0	0	141	0.192
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	6792	84	45	25	7	296	60	0	0	500	0.680
PREDICTED OUTFLOW FROM THIS NODE	6792	38	10	6	3	53	56	0	0	141	0.192
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	45	34	19	4	242	24	0	0	358	0.488
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	45	34	19	4	242	24	0	0	358	0.488
PREDICTED CHANGE	0	0	-0	-0	0	0	0	0	0	0	0.000

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT . NUMBER OF NODES = 3 PAGE NO. 6

NODE NUMBER = 103 MONTH OF MAY YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	6792	84	45	25	7	296	80	0	0	500	0.680
DIVERSION TO SUPPLY IRRIGATED AREA	3630	84	45	25	7	296	80	0	0	500	0.680
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	332	28	6	1	1	16	48	0	0	79	0.108
OUTFLOW AT USGS GAGE NO. 2	204	238	110	95	15	849	209	0	0	1414	1.924
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	2230	214	101	72	30	730	185	0	0	1242	1.689
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	5702	582	212	36	15	1987	189	0	0	2929	3.984
IRRIGATION RETURN FLOW TO SOIL COLUMN	362	847	458	255	79	2969	810	0	0	5014	6.820
TRANSFER OF FLOW FROM RIVER TO AQUIFER	396	84	45	25	7	296	80	0	0	500	0.680
INFLOW TO AQUIFER FROM RIVER	396	84	45	25	7	296	80	0	0	500	0.680
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	2766	194	90	65	25	653	171	0	0	1115	1.517
PREDICTED OUTFLOW FROM THIS NODE	2766	84	45	25	7	296	80	0	0	500	0.680
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	109	45	40	17	357	90	0	0	615	0.837
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	109	45	40	17	357	90	0	0	615	0.837
PREDICTED CHANGE	0	0	-0	0	0	0	-0	0	0	0	0.000
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	172	85	63	25	635	133	0	0	1049	1.427
PREDICTED CHANGE	0	62	40	23	7	278	43	0	0	434	0.591

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT NUMBER OF NODES = 3 PAGE NO. 7

NODE NUMBER = 101 MONTH OF JUN YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
ASHLEY CREEK AT HEAD OF SYSTEM	37970	14	3	2	1	10	23	0	0	43	0.059
FEEDER CANAL TO STEINECKER RESERVOIR	4690	14	3	2	1	10	23	0	0	43	0.059
INFLOW FROM STEINECKER RESERVOIR	0	0	0	0	0	0	0	0	0	0	0.000
DIVERSION TO SUPPLY IRRIGATED AREA	6565	14	3	2	1	10	23	0	0	43	0.059
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 3	4171	14	3	2	1	10	23	0	0	43	0.059
UPPER CANAL OUTFLOW GAGE NO. 2	7609	15	2	0	0	10	21	0	0	39	0.054
CENTRAL CANAL OUTFLOW GAGE NO. 1	4268	24	2	2	1	11	36	0	0	60	0.082
SERVICE CANAL OUTFLOW GAGE NO. 245	0	0	0	0	0	0	0	0	0	0	0.000
ASHLEY CREEK OUTFLOW GAGE NO. 11	6440	79	33	24	8	182	113	0	0	386	0.525
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	26142	130	79	58	19	293	267	0	0	714	0.972
IRRIGATION RETURN FLOW TO SOIL COLUMN	1311	70	15	10	8	52	117	0	0	216	0.295
TRANSFER OF FLOW FROM RIVER TO AQUIFER	4227	14	3	2	1	10	23	0	0	43	0.059
INFLOW TO AQUIFER FROM RIVER	4227	14	3	2	1	10	23	0	0	43	0.059
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	22488	35	11	7	3	60	51	0	0	143	0.195
PREDICTED OUTFLOW FROM THIS NODE	22488	14	3	2	1	10	23	0	0	43	0.059
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	21	8	5	1	49	27	0	0	100	0.136
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	21	8	5	1	49	27	0	0	100	0.136
PREDICTED CHANGE	0	0	0	-0	-0	-0	0	0	0	-0	-0.000

RESEARCH IN CONJUNCTIVE USE STUDY FOR THE VERNAL PROJECT   NUMBER OF NODES = 3

NODE NUMBER = 102   MONTH OF JUN   YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL SALTS PPM	TOTAL SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	22488	35	11	7	3	60	51	0	0	143	0.195
DIVERSION TO SUPPLY IRRIGATED AREA	5460	35	11	7	3	60	51	0	0	143	0.195
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
HIGHLINE CANAL OUTFLOW GAGE NO. 4	2621	18	2	0	1	13	25	0	0	48	0.066
UPPER CANAL OUTFLOW GAGE NO. 10	4504	19	2	1	0	10	29	0	0	48	0.065
CENTRAL CANAL OUTFLOW GAGE NO. 6	632	126	43	16	7	326	108	0	0	574	0.782
SERVICE CANAL OUTFLOW GAGE NO. 5	0	0	0	0	0	0	0	0	0	0	0.000
ASHLEY CREEK OUTFLOW GAGE NO. 8	10780	118	58	38	11	384	121	0	0	672	0.914
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	19977	227	98	25	11	703	168	0	0	1151	1.567
IRRIGATION RETURN FLOW TO SOIL COLUMN	822	234	75	53	20	399	339	0	0	953	1.297
TRANSFER OF FLOW FROM RIVER TO AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO AQUIFER FROM RIVER	0	0	0	0	0	0	0	0	0	0	0.000
TRANSFER OF FLOW FROM AQUIFER TO RIVER	1509	227	98	25	11	703	168	0	0	1151	1.567
INFLOW TO RIVER FROM AQUIFER	1509	227	98	25	11	703	168	0	0	1151	1.567
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	18537	80	36	23	7	239	85	0	0	428	0.583
PREDICTED OUTFLOW FROM THIS NODE	18537	50	18	9	3	112	60	0	0	225	0.307
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	29	17	13	3	126	24	0	0	203	0.277
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	45	24	15	3	179	33	0	0	285	0.388
PREDICTED CHANGE	0	15	7	1	0	52	9	0	0	82	0.112

NODE NUMBER = 103 MONTH OF JUN YEAR 1971

	VOLUME ACRE FEET	CA PPM	MG PPM	NA PPM	CL PPM	SO4 PPM	HCO3 PPM	CO3 PPM	NO3 PPM	TOTAL PPM	SALTS TONS/AF
OPERATIONAL SEQUENCE OF SURFACE FACILITIES											
OBSERVED INFLOW AT HEAD OF NODE	18537	80	36	23	7	239	85	0	0	428	0.583
DIVERSION TO SUPPLY IRRIGATED AREA	6800	80	36	23	7	239	85	0	0	428	0.583
SHORTAGE FROM THE IDEAL DEMAND	0										
OBSERVED OUTFLOWS FROM NODE											
OUTFLOW AT USGS GAGE NO. 1	696	19	2	1	0	10	29	0	0	48	0.065
OUTFLOW AT USGS GAGE NO. 2	212	197	59	68	11	604	168	0	0	1035	1.409
ASHLEY CREEK OUTFLOW AT JENSEN, UTAH	10280	216	107	59	19	771	167	0	0	1258	1.711
SUBSURFACE OPERATIONS AND FLOW TRANSFERS											
AQUIFER CONDITIONS OF LAST TIME FRAME	6460	541	204	44	18	1889	177	0	0	2787	3.792
IRRIGATION RETURN FLOW TO SOIL COLUMN	684	800	361	231	70	2378	846	0	0	4264	5.800
TRANSFER OF FLOW FROM RIVER TO AQUIFER	549	80	36	23	7	239	85	0	0	428	0.583
INFLOW TO AQUIFER FROM RIVER	549	80	36	23	7	239	85	0	0	428	0.583
TRANSFER OF FLOW FROM AQUIFER TO RIVER	0	0	0	0	0	0	0	0	0	0	0.000
INFLOW TO RIVER FROM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
INTERNODAL TRANS FROM UPSTREAM AQUIFER	0	0	0	0	0	0	0	0	0	0	0.000
COMPARISON INDEX											
TOTAL OBSERVED OUTFLOWS FROM NODE	11188	203	99	56	17	721	159	0	0	1178	1.603
PREDICTED OUTFLOW FROM THIS NODE	11188	80	36	23	7	239	85	0	0	428	0.583
SIMPLE DIFFERENCE (OBSERVED - PREDICTED)	0	123	63	33	10	482	74	0	0	749	1.019
CHEMICAL CHANGES IN NODE											
OBSERVED CHANGE	0	123	63	33	10	482	74	0	0	749	1.019
PREDICTED CHANGE	0	-0	-0	0	0	0	0	0	0	-0	-0.000
CHEMICAL CHANGES IN SYSTEM											
OBSERVED CHANGE	0	189	96	54	16	710	135	0	0	1135	1.544
PREDICTED CHANGE	0	66	33	21	5	228	61	0	0	385	0.525

SECTION V

CEDAR BLUFF STUDY AREA

DESCRIPTION OF AREA

The Cedar Bluff Irrigation District is located north of the Smoky Hill River and downstream from Cedar Bluff Dam, which is approximately 13 miles southwest of Ellis in west central Kansas. The district includes about 6,600 irrigable acres in Ellis and Trego Counties.

The irrigated lands are located on a loess-covered terrace at an elevation of 25 to 60 feet above the level of the flood plain and 60 to 120 feet below the level of the surrounding rolling uplands.

Terrace deposits, up to 70 feet thick, overlap and fill channels eroded in relatively impermeable shale and limestone. The permeability of the unconsolidated sediments over most of the area is adequate to permit deep percolation of rainfall and irrigation water.

The chemical composition of the natural groundwater is determined chiefly by the soluble minerals in the soil and rock. Calcium derived from the dissolution of limestone and gypsum is the predominant cation in nearly all well waters. Bicarbonate from limestone and sulfate from gypsum are the predominant anions.

Precipitation while not a factor in the Vernal study is a very important part of consumptive use at Cedar Bluff and amounts to almost 23 inches a year. The rainfall is sufficient to cause dilution of surface and groundwaters.

INPUT DATA

The data used for the Cedar Bluff study were collected by the Environmental Health Services of the Kansas State Department of Health, the U.S. Geological Survey, the U.S. Bureau of Reclamation, and other agencies. In 1964 these agencies began collecting data to evaluate the progressive effects of irrigation on the chemical quality of ground and surface water in and adjacent to the newly established Cedar Bluff Irrigation District. The data include records of measurement of rainfall, water levels, water discharge, chemical analysis of groundwater, surface water, and soil. Data were collected on pesticides and sediment but were not used in this study. The data collected generally cover the period 1966-71 so the study period selected was 1966 through 1970. More than 100 observation wells were installed in and adjacent to the irrigation district by the various agencies.

Chemical analysis and runoff at the two principal stations above and below the Cedar Bluff area were obtained from the U.S. Geological Survey water supply papers (2, 3, 4) for the 5-year period. Data for the soil column were obtained from Bureau of Reclamation records.

Examination of the chemical analyses of water from the observation wells revealed a wide variation in the chemical quality from well to well and at different times in some wells.

VERIFICATION AND TESTING

Prior to making the first model test of the Cedar Bluff data, several assumptions were required to fill voids in the available information. They were:

1. The volume of the groundwater aquifer was not defined and an initial assumption of 15,000 acre-feet was made.

2. The total surface area between the two gaging stations is 220 square miles, and it was assumed that precipitation percolation from the entire area would contribute to the aquifer.

3. One soil sample chemistry analysis was available, and it was assumed that it was representative of the entire area.

The initial trial indicated the fallacy of Assumption No. 2. The growth in the aquifer volume was so great that the model run failed after processing a few months of data. The catchment area was arbitrarily reduced to a size which kept the aquifer volume at the end of the 5-year analysis at approximately the initial level.

Model Study No. 1

The conjunctive use model was used to process the 5 years of data using the original Assumptions No. 1 and 3 and the revised precipitation catchment area. All irrigation and precipitation infiltration greater than the consumptive needs of the vegetation were passed through the soil profile, and the effluent was mixed with the aquifer water. Transfers were then made from the aquifer to the river to make up the difference between measured system inflows and outflows.

Figure 4 contains plots of the observed water quality at the outflow gage versus the quality predicted by Study No. 1. It is obvious that the assumptions of aquifer size and/or soil chemistry are not valid.

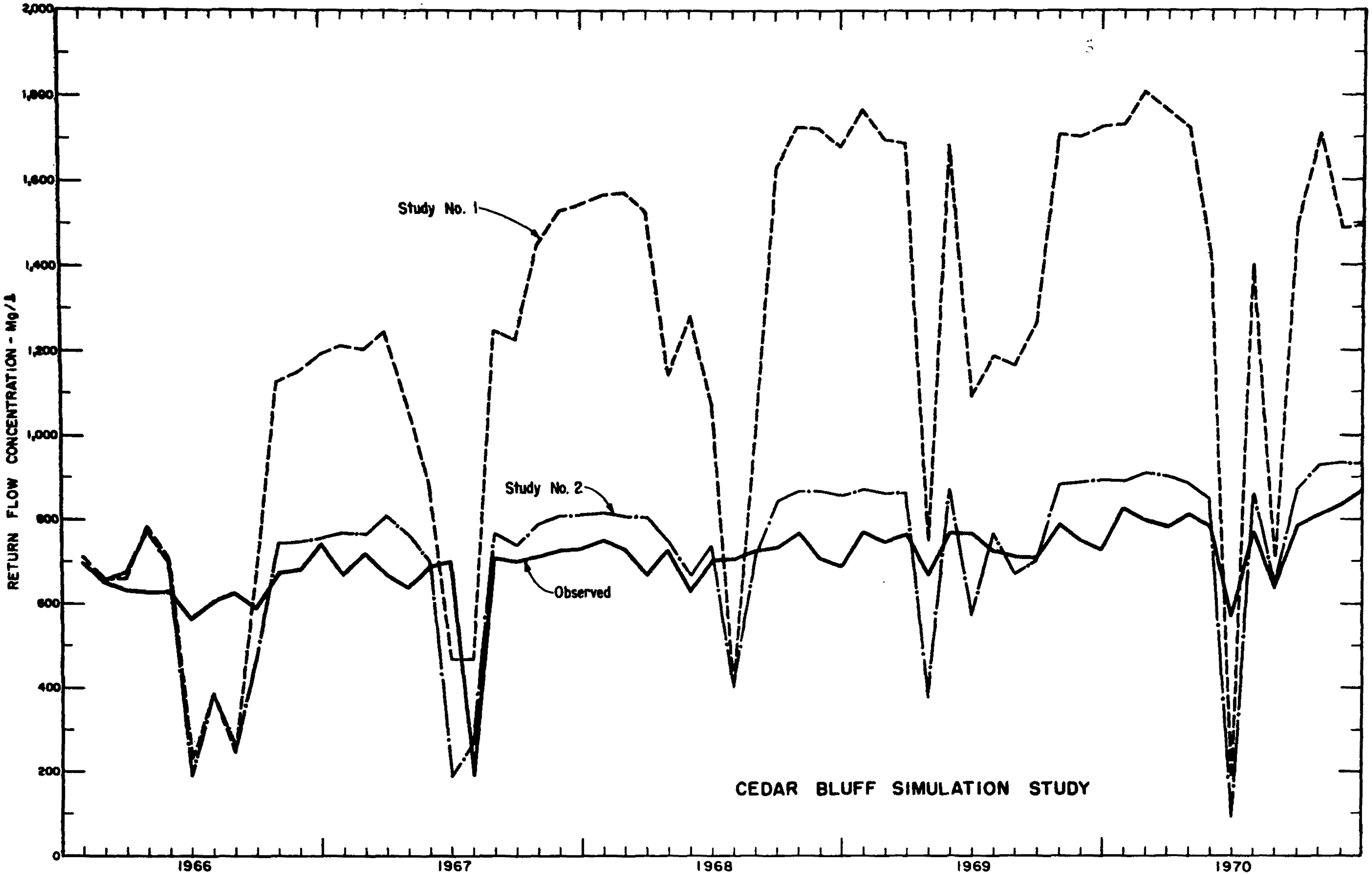

Figure 4. Cedar Bluff simulation study.

Model Study No. 2

A new assumption as to aquifer size was made and the 5-year data base was processed again. A total aquifer volume of 215,000 acre-feet was used for this study. The soil profile return flow option was again used in this study.

The results of this study are also plotted on Figure 4. Although these results show better agreement than Study No. 1, they do not necessarily verify the model operation. The quality of outflow water from the system has very little variation with time, although a slight deterioration trend in quality is noted over the 5-year period. This same trend is apparent in the water discharged to the river from the reservoir, however, and the large aquifer volume has the effect of a large damper by releasing relatively constant quality water to make up the river outflow.

Model Study No. 3

This study is identical to No. 2, except the percolating return flow was not adjusted for salt pickup from the soil profile. The results of this study are very similar to Study No. 2 and are not plotted on Figure 4.

The Cedar Bluff analyses do not serve as adequate verification of the model due to the gross assumptions made during the study process. Additional data concerning the nature of the aquifer and the soil chemistry are believed to be available and should be pursued if further model verification is desired.

SECTION VI

GRAND VALLEY STUDY AREA

DESCRIPTION OF THE AREA

The Grand Valley of Colorado is near the western edge of Mesa County. Grand Junction, the largest city in Colorado west of the Continental Divide, is located in the Valley. The Valley covers an area of about 122,000 acres. The Valley was carved in the Mancos Shale formation (a high salt bearing marine shale) by the Colorado River and its tributaries and for the most part is surrounded by steep, rough terrain. Deep canyons flank the valley to the southwest; a sharp escarpment known as the Book Cliffs rises above it to the north and northeast; foot slopes of the Grand Mesa lie to the east; and rough, broken and steep, hilly land that borders high terraces or mesas lies to the south. Within the Valley, the irrigated lands have developed on recent alluvial plains consisting of broad coalescing alluvial fans and on older and higher alluvial fans, terraces, and mesas. Other lands in this arid setting, where rainfall averages only about 9 inches per year, include the stream flood plains and rough broken land occurring as terrace escarpments, high knobs, and remnants of former mesas.

A total of about 76,000 acres is served water by various irrigation entities with approximately 42,000 acres under Federal projects. Major crops produced in the valley are corn, sugar beets, small grains, alfalfa, and various orchard crops. Most of the salts contributed from irrigated areas are thought to be leached from the soil and underlying Mancos Shale and washed into the river by deep percolation and water delivery system losses.

Mancos Shale is a very thick sequence of drab gray fissile shale that lies between the underlying Dakota sandstone and the overlying Mesa Verde formation. The thickness of the shale usually varies between 3,000 and 5,000 feet. Due to this great thickness and its easy erodibility, the shale forms most of the large valleys of western Colorado and eastern Utah. It is of marine origin and contains marine fossils at many locations. Geologic studies suggest that the shale was deposited as mud in the shallow water of a very extensive late Cretaceous sea and that the region was gradually subsiding which emplains the great thickness of the formation. Because of its marine origin, the shale contains a high percentage of salts; the high salt content is borne out by the many white patches of alkali on both irrigated and nonirrigated surfaces. The type of salts present in the shale are mostly calcium sulfate with smaller amounts of sodium chloride, sodium sulfate, and magnesium sulfate. The evidence that calcium sulfate is the most common salt is verified by the existence of the mineral gypsum commonly found in crystal form in open joints and fractures of the Mancos Shale.

Due to the compactness of the clay and silt particles making up the shale, the formation is not considered as water bearing at depth. However, the weathered zone near the surface does transmit small quantities of water along joints, fractures, and open bedding planes. This zone is the area from which percolating water, often originating from irrigation of croplands, dissolves out salts present in the shale.

A gravel and cobble layer also has been found under some of the irrigated areas in the Grand Valley and is believed to serve as an aquifer for groundwater. Previous studies have identified areas where the groundwater has an upward pressure gradient in the cobble aquifer due to the confining effect of the Mancos Shale beneath and the tight clay soil above. This situation is believed to be responsible for some areas of high water tables. The gravel and cobble layer may be ancient stream deposits from the Colorado River and may not be continuous throughout the Valley.

The area selected for study by Colorado State University is comprised of about 4,600 acres. As stated by the University, the area was selected for its accessibility in isolating most of the important hydrologic parameter but had the important advantage that it allowed five irrigation companies to participate in one unit. The principle effort was to gather preconstruction data from the 4,600-acre area, install canal and lateral lining, and finally collect post-construction data to determine if lining had any effect in reducing salinity. The University acknowledged some difficulty in collecting data from the area since it could not be isolated from other parts of the Grand Valley irrigated areas.

DESCRIPTION OF INPUT DATA

The data collected by Colorado State University (5) consisted of miscellaneous measurements of canal and lateral water quantity and quality. The University personnel also installed flumes on the drains to measure the drainage properties. Piezometers and observation wells were installed to log the depth to groundwater and to obtain samples of the groundwater for salinity analyses. Seepage measurements were also made on the canals and laterals. Water year 1971 was used for this analysis.

The groundwater data indicated large variations in total dissolved solids both with time and location within the study area. Canal and drain measurements were more consistent; however, they were not available at regular intervals throughout the study period and were extrapolated to cover the period. No measurements were available of Colorado River flow upstream and downstream from the test area; therefore, the quantity and quality of subsurface outflows were estimated from hydraulic conductivity measurements and sample analyses from the observation wells.

VERIFICATION AND TESTING

Study No. 1

The outflow from the Grand Valley test area is comprised of (1) the discharge in the drains which is mainly surface runoff with some groundwater interception and (2) subsurface groundwater flow to the river. Both these discharges must be simulated for model verification.

For Study No. 1, an aquifer volume of 12,000 acre-feet was assumed to underlie the study area. Figure 5 is a plot of the model simulation for the period October 1970-September 1971.

More data would be required for verification of the model in the Grand Valley test area. Definition of the size of aquifer, the relation of the groundwater underlying the test area to the total aquifer, the measurement of subsurface outflows, and more frequent collection of quality data are minimal requirements for additional data for this purpose.

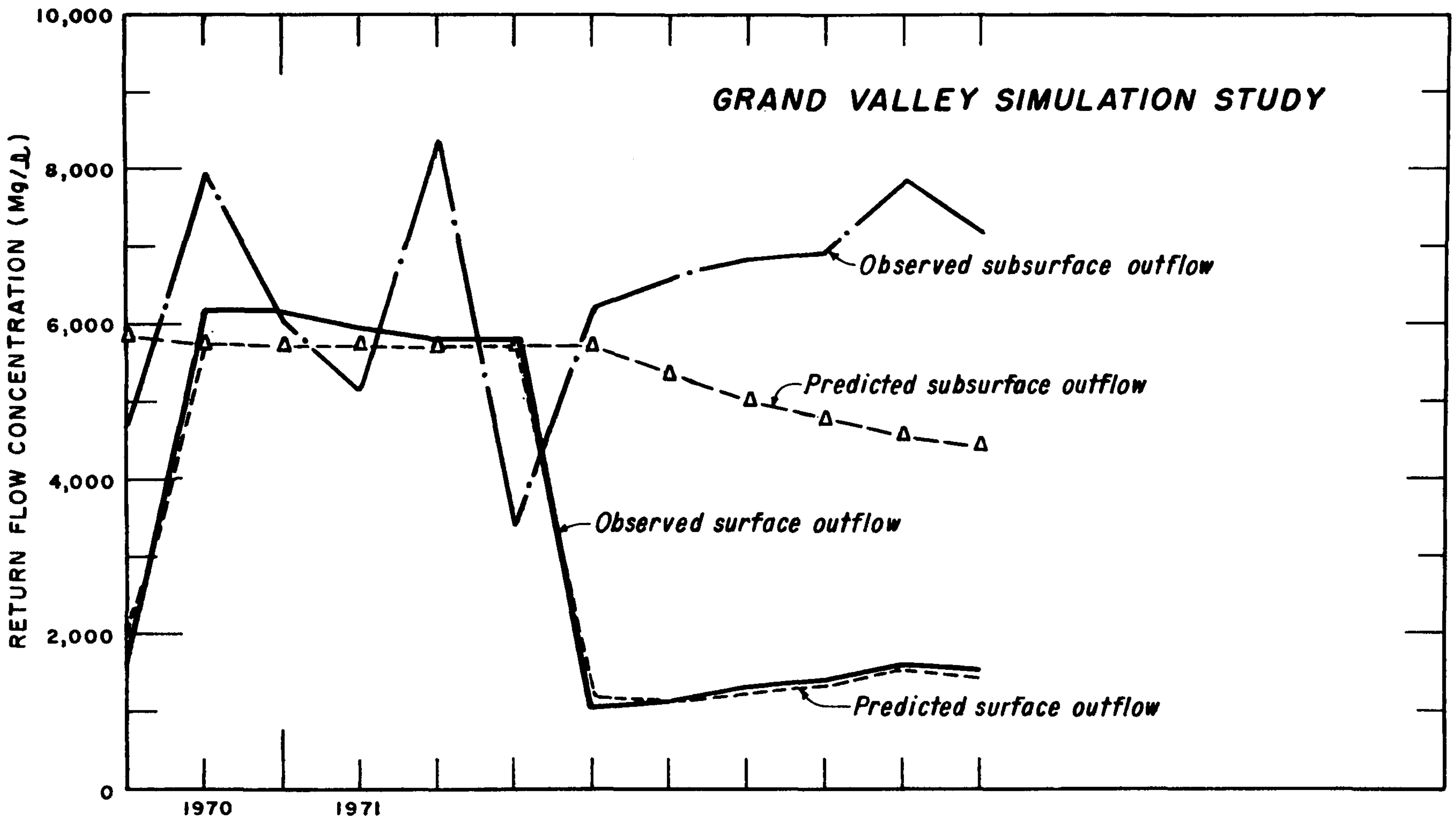

Figure 5. Grand Valley simulation study.

SECTION VII

REFERENCES

1. King, Larry G., and R. John Hanks. "Irrigation Management for Control of Quality of Irrigation Return Flow." EPA-R2-73-265, Office of Research and Monitoring, U.S Environmental Protection Agency, Washington, D.C. 307 pp. (1973)

2. Leonard, Robert B. "Effect of Irrigation on the Chemical Quality of Low Streamflow Adjacent to Cedar Bluff Irrigation District, Kansas." Kansas State Department of Health - Environmental Health Services, Topeka, Kansas. 17 pp. (1968)

3. Leonard, Robert B. "Variations in the Chemical Quality of Ground Water Beneath an Irrigated Field, Cedar Bluff Irrigation District, Kansas." Kansas State Department of Health - Environmental Health Services, Topeka, Kansas. 20 pp. (169)

4. Leonard, Robert B. and Gerald A. Stoltenberg. "Compilation of Data for Water Quality Investigation, Cedar Bluff Irrigation District, Kansas." Kansas State Department of Health - Division of Environmental Health, Topeka, Kansas. 158 pp. (1972)

5. Skogerboe, Gaylord V., and Wynn R. Walkerk. "Evaluation of Canal Lining for Salinity Control in Grand Valley." EPA-R2-72-047, Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington D.C. 199 pp. (1972)

6. U.S. Department of the Interior, Bureau of Reclamation and Federal Water Pollution Control Administration. "A Joint Research Proposal on the Prediction of Mineral Quality of Return Flow Water from Irrigated Land." Office of the Chief Engineer, Denver, Colorado. 44 pp. plus Appendices (1968)

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16. ABSTRACT

The development and evaluation of modeling capability to simulate and predict the effects of irrigation on the quality of return flows are documented in the five volumes of this report. The report contains two different modeling packages which represent different levels of detail and sophistication. Volumes I, II, and IV pertain to the model package given in Volume III. Volume V contains the more sophisticated model. User's manuals are included in Volumes III and V.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Mathematical Model, digital simulation, scheduling, Irrigated land, Evapotranspiration, Agriculture, Agronomy, water pollution, water loss	Irrigation Return Flow	02 C/D

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